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Abstract

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Abstracts

Emerging Technologies: Communications, Microelectronics, Optoelectronics, Sensors

Emerging Technologies Services provides researchers and industry representatives in the high-tech sector with an opportunity to discuss new and exciting developments in all areas of high technology. Since 2006, our annual conferences provide companies and academic institutions with an international stage for showcasing their technology, innovations, products and services. Our participants come from around the world and represent every segment of high-tech, from VLSI to green energy to wireless communications to photonics. Together, we create a stimulating common ground for exploring collaborations and encouraging discussions on emerging technologies. This book presents the abstracts submitted for talks at the 2016 ETCMOS conference in Montreal, Canada, May 25–27, 2016.

The ETCMOS conferences are held annually, and we sincerely hope to see you at the next one.

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Track P: Plenary

Session P1: Plenary I

Chair 1: Federico Rosei, INRS (rosei@emt.inrs.ca)

David Cumming, University of Glasgow (David.Cumming.2@glasgow.ac.uk)

Biological and Chemical Sensing Using CMOS Technologies
CMOS is at the heart of modern computing and communications technology. However, it is possible to think of the technology for making CMOS microelectronics

as a material system with far more diverse possibilities. In this talk I will present results on the hybridisation of CMOS and nanotechnology for a range of sensor applications. These will include ion sensing for chemical and biological imaging and the all electronic next generation sequencing system. I will then explore the possibilities for hyperspectral and terahertz imaging based on the integration plasmonics and metatmaterial structures on CMOS.

Wojciech Knap, University of Montpellier (knap.wojciech@gmail.com)

Terahertz Imaging with Nanometer Field Effect Transistors-from Basic Physics to First Fast Terahertz Scanners

An overview of main results concerning THz detection related to plasma nonlinearities in nanometer field effect transistors is presented. In particular nonlinearity and dynamic range of these detectors are discussed. We present also results on THz detection by Graphene field effect transistors. As a conclusion, we will show one of the first real world application of the FET THz detectors: a demonstrator of the imager developed for fast postal security imaging.

Donhee Ham, Harvard University (donhee@seas.harvard.edu)

CMOS Biotechnology

This talk will discuss three separate topics, with the common theme of using CMOS chips for biotechnological applications. First, NMR spectroscopy is a paramount analytical tool available in biology and medicine with its power to elucidate structure & function of biomolecules at atomic resolution. I will discuss biomolecular NMR exploiting CMOS chips for high throughput structural biology and pharmaceutical screening. Second, I will discuss our CMOS-nano-bio intracellular interface array and its neurotechnology and cardio-technology applications. This work is collaboration with Professor Hongkun Park of Harvard Chemistry and of Harvard Physics. Finally, I will discuss our CMOS as well as 2D material based electrochemical field effect transistors to detect biomolecules for molecular diagnostic applications.

Mina Rais-Zadeh, University of Michigan (minar@umich.edu)

Gallium Nitride MEMS and Microsystems

Gallium nitride (GaN), in contrast to other commonly used piezoceramics, is a semiconductor that exhibits piezoresistive in addition to piezoelectric effects. Although neither the static piezoresistive nor the piezoelectric response of GaN is particularly large, the combined piezoelectric and piezoresistive effects – the piezoresponse – of GaN is significant. This property of GaN can be utilized to implement micromechanical resonators with unique structures having combinatory transduction mechanisms. In this talk I go over the design and implementation of the highest-quality factor (Q) of $>$13,000, highest-frequency of $>$ 8 GHz, as well as the highest-performance GaN micromechanical resonators with the highest measured frequency $\times$ Q values of $\sim 10^{13}$, which all utilize the large piezoresponse of GaN. In addition, I cover recent advances in implementation of resonant high electron mobility transistors (HEMTs) with unprecedented acoustic properties that make use of the stress-sensitivity of the two dimensional electron gas (2DEG) present at an AlGaN/GaN interface.

Session P2: Plenary II

Chair 1: Abdelkader Souifi, INL-CNRS 5270 (abdelkader.souifi@insa-lyon.fr)

Orly Yadid-Pecht, University of Calgary (Orly.Yadid-Pecht@ucalgary.ca)

Compact Smart Sensing Devices

The advances of CMOS technology in the past decades have paved the way for smart sensing devices. Current CMOS based imagers have remarkable performance and are available for utilization in fully integrated compact sensing systems.

A high sensitivity, wide dynamic range image sensor is the basis for several compact sensing devices described herein. Custom optical filter coatings are designed to serve different substances detection. The first is a system detecting Calcium, enabling a portable, low cost system for neuron monitoring. The different parameters affecting the filter fabrication process are explained. We follow up with additional filter coatings suitable for other applications. One, for water quality monitoring, is based on chlorophyll detection. Another, serving the same purpose, is for color dissolved organic matter (CDOM) detection. An optical based pH detection system is also described and further developments in process are reviewed.

Eli Yablonovitch, University of California, Berkeley (eliy@eecs.berkeley.edu)

What Does the Clock Speed of My Computer Have to do With the Fundamental Constants of Nature, $\hbar$, c, q, m?

What limits speed? It could be the clock speed of a computer, or the speed with which we can detect a single electric charge, or we could ask the same question of many other high speed functions. One view is that the greater the resources poured into the effort; capital equipment, manpower, energy, etc., the greater the speed. The other view is that there is a fundamental speed limit that is controlled by the fundamental constants of nature, $\hbar$, c, q, m. In this talk, the clock speed of today's computers will be deduced from physics.

Jeff Bokor, University of California, Berkeley (jbokor@eecs.berkeley.edu)

Bottom-up Graphene Nanoribbon Field-Effect Transistors

Recently developed processes have enabled bottom-up chemical synthesis of graphene nanoribbons (GNRs) with precise atomic structure. These GNRs are ideal candidates for electronic devices because of their uniformity, extremely narrow width below 1 nm, atomically perfect edge structure, and desirable electronic properties. Here, we demonstrate nanoscale chemically synthesized GNR field-effect transistors, and compare results using various atomically precise ribbons with different widths.

Klaus Kern, Max Planck Institute for Solid State Research (k.kern@fkf.mpg.de)

How Much Room is Left at the Bottom?

Richard Feynman's imagination of the "small world" expressed in his famous 1959 lecture has had an important impact on the development of nanoscience and nanotechnology. In this lecture I will discuss how much of his visions and promises have become true and what challenges are left.

Session P3: Plenary III

Chair 1: André Ivanov, University of British Columbia (ivanov@ece.ubc.ca)

Sorin Marcovici, SXN International LLC (s.marcovici@verizon.net)

X-Ray Medical Imaging: Present and Future

For more than seventy years after Wilhelm Roentgen discovered the x-rays, x-ray imaging was limited to producing two-dimensional images on radiographic film or plates. It took the advances in digital computers and the genius of Sir Godfrey Hounsfield to bring to the fore the ability to combine 2D x-ray images taken at various angles into a Computed Tomography imaging method that revolutionized for good medical imaging.

Digital x-ray medical instrumentation has become, in the hands of radiologists, a very powerful tool in advancing diagnostics capabilities, devising new treatments and improving outcomes and, at the same time, reducing hospitalizations and costs.

The paper will refresh our memories on the extraordinary advances x-ray based medical imaging has made during last forty years and will anticipate its upcoming applications as an irreplaceable tool for radiology, cardiology, oncology, surgery, orthopedics and pathology.

Jun Ohta, NAIST (ohta@ms.naist.jp)

Implantable Micro-Optoelectronic Devices

This talk presents recent progress of implantable micro-optoelectronic devices for biomedical applications. Retinal prosthesis and brain imaging devices as examples of implantable micro-optoelectronic devices are presented.

Dmitri Strukov, University of California, Santa Barbara (strukov@gmail.com)

Neuromorphic Engineering with Emerging Memory Devices

Synapses, the most numerous elements of neural networks, are memory devices. Similarly to traditional memory applications, device density is one of the most essential metrics for large-scale artificial neural networks. This application, however, imposes a number of additional requirements, such as the continuous change of the memory state, so that novel engineering approaches are required. In my talk, I will discuss my group's recent efforts at addressing these needs. I will start by reviewing hybrid CMOS/nanodevice circuits, in particular of CMOL variety, which were conceived to address major challenges of artificial neural network hardware implementations. I will then discuss the recent progress towards demonstration of such circuits, focusing on the experimental and theoretical results for networks based on memristive metal oxide devices and on redesigned commercial NOR memory.

Michelle Simmons, University of New South Wales
(michelle.simmons@unsw.edu.au)

The Future of Computing in Silicon

Down-scaling has been the leading paradigm of the semiconductor industry since the invention of the first transistor in 1947. However miniaturization will soon reach the ultimate limit, set by the discreteness of matter, leading to intensified research in alternative approaches for creating logic devices. This talk will discuss the development of a radical new technology for creating atomic-scale devices which is opening a new frontier of research in electronics globally. We will introduce single atom transistors where we can measure both the charge and spin of individual dopants with unique capabilities in controlling the quantum world. To this end, we will discuss how we are now demonstrating atom by atom, the best way to build a quantum computer-a new type of computer that exploits the laws of physics at very small dimensions in order to provide a predicted exponential speed up in computational processing power.

Track A: Devices, Circuits and Systems

Session A1: Circuits and Systems

Chair 1: Tomasz Wojcicki, Sidense (tomasz@sidense.com)

Lanny Lewyn, Lewyn Consulting (lanny@pacbell.net)

Paradigm Changes for Analog CMOS Circuit and Physical Design in Technologies Beyond 10nm

At CMOS technology nodes beyond 10nm, analog IC design constraints become more severe. Supply voltage drops closer to the V_{DSsat} "Power Wall." FinFET, the main-stream technology from 15 to 10nm encounters more difficulty with gate control of the source-channel barrier, resulting in increased G_{DS} and reduced subthreshold I_dV_g slopes. NanowireFET has been proposed for better source-channel control, but manufacturing costs are projected to be higher than for FinFET. Yet, NanowireFET offers some significant advantages for high performance analog, including high-res, low-power, high-speed, ADC applications. Paradigm changes for analog CMOS circuit and physical design in technologies beyond 10nm will be explored.

Xuan Zeng, Fudan University (xzeng@fudan.edu.cn)

Automatic Synthesis and Technology Migration of Analog Integrated Circuits

As integrated circuit process technology continues to shrink down to the nanometer scale, analog integrated circuit design becomes a bottleneck of System-on-Chip design due to its relative high cost and low efficiency. In this talk, we propose to develop an automatic design methodology for sizing and technology migration of analog integrated circuits. The novel algorithms proposed here are based on the multi-starting-points programming and compressive sensing based modeling. Firstly, we propose to develop a highly accurate and parallel multi-starting-programming method based on SPICE simulation and local models to solve the analog circuit sizing problem with very low computational cost. Secondly, a local modeling method based on compressive sensing theory is developed to set up the models at different local regions with high accuracy. Thirdly, a multi-level optimization method is proposed by combining the multi-starting-points algorithm and behavioral modeling to carry on the massive computation tasks assigned by the large scale high performance analog circuits. A phase-locked loop circuit is employed to demonstrate the efficiency and qualified design of the proposed methodology compared with the existing approaches.

Rob McKenzie, University of Toronto (mckenzie@vrg.utoronto.ca)
with W. Tung Ng

Class D Audio Amplifiers-Comparison of Modulation Schemes using GaN and Silicon Output Stages

In this presentation, we will examine the performance of Digital Class D audio amplifiers using Pulse Width Modulation (PWM) and Pulse Density Modulation (PDM). These modulations scheme produce different pulse widths and repetition rates for 24-bit Hi-Res audio input. When connected to either a silicon or GaN full bridge output stage with appropriate deadtimes, significant differences in THD+N, CEMI and power efficiency performances. Experimental results for power level up to 40W will be presented to verify the advantages of PDM and GaN output stage.

Fei Yuan, Ryerson University (fyuan@ryerson.ca)

Adaptive Decision Feedback Equalizer for Serial Links with Reflection-Induced Sparse Post Cursors

Lawrence Clark, Arizona State University (Lawrence.Clark@asu.edu)

A Predictive 7-nm PDK

We describe a 7-nm predictive process design kit (PDK) called the Arizona State University 7-nm (ASAP7) PDK, developed in collaboration with ARM Ltd. for academic use. The PDK is realistic, based on current assumptions for the 7-nm technology node and is not tied to a specific foundry. The PDK assumes EUV lithography for key layers, based on EUV lithography's present near cost-effectiveness and the resulting simpler layout rules. Non-EUV layers assume appropriate multiple patterning schemes, i.e., self-aligned quad patterning, self-aligned dual patterning or litho-etch litho-etch, based on 193-nm optical immersion lithography. A high density low-power standard cell architecture, developed using design/technology co-optimization (DTCO), as well as example SRAM cells and resulting designs will be presented. The PDK transistor electrical assumptions, corners, and design rules, will be described. The PDK supports Cadence design entry and uses Calibre for extraction.

Woogeun Rhee, Tsinghua University (wrhee@mail.tsinghua.edu.cn)

Digital-Intensive Clock Generation and Modulation with Hybrid FIR-Filtering Technique

Session A2: Computing and Memories

Chair 1: André Ivanov, University of British Columbia (ivanov@ece.ubc.ca)

Swaroop Ghosh, University of South Florida (sghosh@cse.usf.edu)

Spintronics and Security: Prospects, Vulnerabilities, Attack Models and Preventions

The experimental demonstration of current driven Spin-Transfer-Torque (STT) for switching magnets and push Domain Walls (DWs) in magnetic nanowires have opened up new avenues for spintronic computations. These devices have shown great promise for logic and memory applications due to superio energy-efficiency and non-volatility. It has been noted that the nonlinear dynamics of DWs in the physical magnetic system is an untapped source of entropy that can be leveraged for hardware security. The inherent noise, spatial and temporal randomness in the magnetic system can be employed in conjunction with microscopic and macroscopic properties to realize novel hardware security primitives. Due to simplicity of integration the spintronic circuits can be an add-on to the Silicon substrate and complement the existing CMOS based security and trust infrastructures. This talk will cover the prospects of spintronics in hardware security by exploring the security specific properties and novel security primitives realized using spintronic building blocks. As spintronic elements are entering the mainstream computing platforms they are exposed to emerging attacks that were infeasible before. This paper covers the security vulnerabilities, security and privacy attack models and possible countermeasure to enable safe computing environment using spintronics.

Gregory Snider, University of Notre Dame (snider.7@nd.edu)

The Landauer Principle and Adiabatic Computation

Is there a minimum energy required to compute a bit of information? Does the choice of state variable used to represent information affect the energy dissipated in computation? These questions have more than mere academic importance, as evidenced by the heat produced by modern laptop computers. In CMOS logic the energy used to represent the bit of information is dissipated to heat at each logic transition. This is very wasteful of energy and does not scale well as devices shrink to nanoscale dimensions.

How low can dissipation be pushed? This presentation will examine the fundamental issues involved in computation, including the Landauer Principle and the use of charge as a state variable. Using the results of the Landauer Principle, one can employ reversible logic and energy recovery using adiabatic logic to achieve low dissipation, but when does it make sense to use such approaches?

This presentation will examine these issues and their implications for the future of computation. The design of a reversible, adiabatic CMOS microprocessor will be presented as a proof of concept. Quantum-dot cellular automata (QCA) will be examined as a beyond-CMOS paradigm that maps well onto reversible adiabatic logic.

Kirk Bevan, McGill University (kirk.bevan@mcgill.ca)

Connecting Quantum Transport to Electrochemistry

In this work we present a theoretical connection between the Landauer picture utilized in quantum transport and the Gerischer picture utilized in electrochemistry. A comprehensive analysis of the single-particle picture and total energy picture in electrochemistry is presented, followed by derivation of electron transfer rates utilizing the nonequilibrium Green's function formalism. Correlations are also made with the Marcus-Hush theoretical approach more often utilized in electrochemistry. The analysis is limited to tunneling (also called outer-sphere) electrochemical reactions. In general, it is expected that this work will serve to further bridge the diverse condensed matter and chemistry foundations inherent to interfacial electrochemistry. Applications to device design will also be discussed.

Jayasimha Atulasimha, Virginia Commonwealth University
(jatulasimha@vcu.edu) with M.M. Al-Rashid, H. Ahmad, D. Bhattacharya,
A.K. Biswas, N. D'Souza, V.G. Sampath and S. Bandyopadhyay

Low Power Straintronic Nanomagnetic Boolean and Non-Boolean Computing: Devices Robust to Thermal Noise and Experimental Results

Our groups proposed and theoretically showed that strain clocked nanomagnetic memory devices, universal logic gates and information propagation could be implemented with ~1 aJ/bit of energy dissipation (potentially 2–3 orders of magnitude more energy efficient than CMOS devices) at clock rates ~1 GHz. However, we also showed that such nanomagnetic memory and logic devices are extremely error prone in the presence of thermal noise at room temperature.

This talk will discuss our recent work on strain clocked Boolean memory and logic devices that are resilient to thermal noise at room temperature and non-Boolean computing devices that are inherently fault tolerant.

We will also discuss experimental demonstration of strain clocked nanomagnetic logic in Co nanomagnets patterned on a PMN-PT substrate using e-beam lithography and the reliability issues arising from the relatively low magnetoelastic coupling in Ni and Co. Furthermore, benefits and challenges in using iron-gallium (FeGa) alloys that have higher magnetoelastic coupling, in fabricating nanomagnetic devices will be discussed. Finally, intriguing experiments that demonstrate that a surface acoustic wave (SAW) can drive a single domain nanomagnet into a non-volatile vortex state, backed with rigorous micromagnetic simulations of stress induced incoherent magnetization dynamics will be presented.

This talk will conclude with our assessment of future research needed to address some of the materials and device challenges that must be overcome to make this extremely low energy nanomagnetic switching paradigm viable for practical Boolean and non-Boolean computing devices.

Sayeef Salahuddin, University of California, Berkeley (sayeef@berkeley.edu)

Controlled Phase Transition for Next-Generation Computing

Phase transition materials have long been investigated for fundamental physics and also for potential application in electronics. In this presentation, I shall discuss how a controlled phase transition can lead to fundamentally new switching devices that has significantly less energy dissipation compared to the state of the art. In particular, I shall talk about the state of negative capacitance that can be achieved in certain material systems with stored energy of phase transition. Our recent experiments with ferroelectric materials have shown that such a state of negative capacitance can actually be achieved. I shall also describe our very recent results where such negative capacitance, when combined with conventional transistors, lead to effects that was long believed to be impossible. Finally, I shall discuss how these effects can usher in a new era of energy efficient electronics.

Jerry M. Chow, Thomas J. Watson Research Center (chowmj@us.ibm.com)

Taking Superconducting Qubits to the Next Generation

Fault tolerant quantum computing is possible by employing quantum error correction techniques. In this talk I will describe an implementation of various small quantum codes using lithographically defined superconducting qubits in latticed arrangements. These codes explore a new area of quantum information processing, including the detection of full quantum errors and the encoding of a logical qubit. Our experiments require highly coherent qubits, high quality quantum operations implementing the detecting circuit, and high quality independent qubit measurements. Looking beyond further, there remains both theoretical and experimental control hurdles which must be overcome to build verifiably reliable quantum networks of qubits. I will present some experiments which point towards these important questions and give proposals for future integration capability, measurement integration, and scalable control architectures. The focus will be on a variety of questions which will increasingly become important as the field moves towards a larger network of qubits.

Brandur Thorgrimsson, University of Wisconsin-Madison (thorgrimsson@wisc.edu) with Dohun Kim, C. B. Simmons, Ryan H. Foote, D. E. Savage, M. G. Lagally, Mark Friesen, S. N. Coppersmith and M. A. Eriksson.

Increasing the Coherence Time of a Quantum Dot Hybrid Qubit

Quantum bits (qubits) are the building blocks of quantum computers, which offer the potential to solve certain problems more rapidly than their classical counterparts. An important goal is to identify qubits that can be rapidly manipulated with long coherence times–two goals that are difficult to achieve simultaneously.

In this talk I describe the “quantum dot hybrid qubit,” which consists of three electrons in a double quantum dot. I will describe how the presence of three electrons on two neighboring sites enables very rapid manipulation of this qubit with high fidelity. This qubit has internal multi-level structure with the ground and excited energy levels coupled with spin conserving tunneling matrix elements. I will describe theoretical calculations showing how choosing these parameters correctly leads to less sensitivity to charge noise, thereby extending quantum coherence. I conclude by presenting experimental data that demonstrates extended coherence in the lab by controlling inter-dot tunnel coupling.

This work was supported in part by ARO (W911NF-12-0607) and NSF (DMR-1206915 and PHY-1104660). Development and maintenance of the growth facilities used for fabricating samples is supported by DOE (DE-FG02-03ER46028). This research utilized NSF-supported shared facilities at the University of Wisconsin-Madison. Work performed in collaboration with Dohun Kim, C. B. Simmons, Ryan H. Foote, D. E. Savage, M. G. Lagally, Mark Friesen, S. N. Coppersmith, and M. A. Eriksson.

Leonel Sousa, INESC-ID (las@inesc-id.pt)

Towards Asymmetric Post-Quantum Embedded Encryption

More and more transactions are taking place over unreliable connections. For instance, many public wireless networks employ no encryption. Contrastingly, as a large part of our lives depends on this type of communication, data security is becoming increasingly important. Fortunately, cryptography enables the safe exchange of information, and asymmetric cryptography, in particular, provides key distribution, secrecy, and the generation and verification of digital signatures.

The first practical asymmetric encryption and signature scheme, Rivest-Shamir-Adleman (RSA), was proposed in 1977, and continues to be the most used asymmetric cryptosystem to this day. However, due to the massive use of embedded devices, and an increasing demand for communication security, Elliptic Curve Cryptography (ECC) arose as a promising alternative to RSA. However, should quantum computing become viable, these classical approaches to asymmetric cryptography will be broken, and consequently the needed services provided by them. Towards preventing this, alternative cryptographic systems, such as Lattice-based Cryptography (LBC), have been proposed.

Embedded systems often have low-power consumption, and small dimensions, at the cost of limited processing resources. In a wide range of applications, such as health monitoring, and surveillance, several embedded systems need to stay connected, and data has to be protected. However, due to the constrained resources of such devices, designing and implementing cryptosystems is not trivial.

In this talk, ECC and RSA will be analysed, and several algorithmic improvements, as well as implementations techniques for embedded systems will be addressed, both considering embedded multicore programmable processors and hardware accelerators. Since quantum computing may become a reality in the next decades, this talk is also focused on LBC. It will be discussed the efficiency, usability and implementation aspects of LBC.

Gyorgy Csaba, University of Notre Dame (gcsaba@nd.edu)

Computing with Nanomagnets and Magnetic Excitations

Nanomagnetic devices are among the most promising "beyond-Moore" technologies, with many potential benefits. Nanomagnet Logic (NML) offers low power dissipation and non-volatile logic operations in Boolean logic circuits and my talk will outline recent developments in NML research.

Most of my presentation will focus on a novel application area for nanomagnetic devices, showing that magnetic excitations (spin-waves) are promising candidates for non-Boolean computing functions. In particular, the talk will demonstrate that using spin-wave interference, one can design special-purpose computing blocks (hardware accelerators) that may make many data-processing tasks much more energy efficient. Spin-wave devices replicate the computing functions of optical computers and they can efficiently perform linear operations, such as Fourier transform, filtering and spectral analysis; these operations are omnipresent in many processing tasks. Spin-wave based devices can be integrated with modern integrated circuits, due to their matching size scales and operating frequency. This makes them promising as ultra-efficient co-processor blocks in future integrated circuits.

Thomas Windbacher, Technische Universität Wien
(windbacher@iue.tuwien.ac.at) with A. Makarov, V. Sverdlov and
S. Selberherr

Novel Magnetic Devices for Memory and Non-Volatile Computing Applications

The introduction of non-volatile memory elements in the proximity of the CMOS devices helps to reduce the overall power dissipation and the interconnection delay significantly. In addition, logic gates can be built by combining two non-volatile memory cells or by specially designing non-volatile logic devices on which a part of the computation can be performed. Several examples of such logic-in-memory concepts at device, circuit, and logic design level will be presented. It will also be demonstrated how magnetic devices like magnetic tunnel junctions, magnetic non-volatile flip flops, and spin transfer torque majority gates can be exploited for building functionally complete non-volatile computing environments.

Lauren Guckert, University of Texas at Austin (lguckert@gmail.com) with E. Swartzlander

Implementing Adders with Memristors

This work presents improved implementations of memristor-based adders. Ripple carry adders, carry-select adders, carry lookahead adders, and conditional sum adders are implemented using three approaches: the IMPLY operation, hybrid-CMOS memristor gates, and threshold gates. The designs are optimized by performing parallel operations, leveraging computational redundancies, and recognizing Boolean simplifications. Each of the adders is analyzed in terms of delay and area and compared against the other designs as well as CMOS. All of the proposed designs improve upon their baseline counterparts in both of these metrics. Many of the designs also outperform the CMOS implementations of the adders.

Shimeng Yu, Arizona State University (Shimeng.Yu@asu.edu)

Neuro-Inspired Computing Using Resistive Memories

The crossbar array architecture with resistive memories is attractive for the efficient implementation of weighted sum and/or weight update in the neuro-inspired learning algorithms. This talk will present the state-of-the-art synaptic device characteristics of resistive memories, and discuss circuit/architecture-level design challenges on scaling up the array size due to non-ideal device properties and array parasitics for large-scale neuromorphic computing system. Specifically, we will discuss the recent progresses on the following research topics: 1) a programing protocol to tune the synaptic weights to an arbitrary level for offline training. 2) an experimental demonstration of >200 levels synaptic weights for online training with a fully parallel write/read scheme for speed-up; 3) a device-algorithm co-design methodology to study the impact of non-ideal synaptic device behaviors on the learning accuracy of MNIST handwritten dataset using sparse coding algorithm, and circuit-level strategies to mitigate these non-ideal effects; 4) the design space exploration of the synaptic crossbar array using a custom designed circuit-level macro simulator, and the proposed architectural partitions for efficiently mapping a large matrix into multiple arrays; 5) our recent tape-out of a 128×128 neuro crossbar array with monolithic integration of resistive memories on top of the CMOS peripheral circuits.

Wei Lu, University of Michigan (wluee@umich.edu)

Memristor Networks for Neuromorphic and Arithmetic Computing

Memristors are two-terminal devices whose physical properties (e.g. resistance) are determined by an internal state variable and are controlled by the history of external stimulation. Crossbars based on memristors have now been extensively studied for memory and computing applications. In this talk, I will discuss our efforts on the developments of memristor crossbar arrays and how efficient neuromorphic computing and arithmetic computing systems can be implemented in these networks. In neuromorphic computing, the memristor networks can efficiently extract features from high-dimensional input data and create sparse reconstructions. In arithmetic computing, the memristor arrays can perform function storage and computation simultaneously and potentially lead to efficient in-memory computing platforms.

Session A3: Devices, Circuits and Systems

Chair 1: Maciej Ogorzalek, Uniwersytet Jagiellonski Krakow (maciej.ogorzalek@uj.edu.pl)

Hassan Maher, Université de Sherbrooke (hassan.maher@Usherbrooke.ca)

GaN-HEMT Devices for High-Power Applications

For high power application, different types of semiconductor materials are answering the market demands. Among these materials, Gallium Nitride (GaN) is one of the more promising ones, thanks to its wide gap and high electron velocity. Having these two key parameters within the same device will allow it to drive high power density with high switching frequency, which is the major requirement of several applications in this field. In this presentation I will describe the fabrication technology for high power device based on GaN material. I will also present state-of-the-art results that were recently obtained at University of Sherbrooke.

Pierre-Emmanuel Gaillardon, University of Utah (pierre-emmanuel.gaillardon@utah.edu)

Towards Functionality-Enhanced Devices: Controlling the Modes of Operation in Three-Independent-Gate Transistors

In this talk, we introduce Three-Independent-Gate Field-Effect Transistors (TIGFETs). Thanks to the additional gate terminals, the device exhibits additional functionalities that are relevant for creating better circuits. In particular, we present the different modes of operation achievable with TIGFETs and report results on fabricated devices including: (i) the dynamic reconfiguration of the device polarity; (ii) the dynamic control of the threshold voltage; and (iii) the dynamic control of the subthreshold slope.

Hoi Lee, University of Texas at Dallas (hoilee@utdallas.edu)

Enabling High-Performance High-Voltage Power Conversion Integrated Circuits for Energy-Efficient Systems

Nowadays, high-voltage power conversion integrated circuits have found wide applications in automotive systems, industrial and telecom systems, and renewable energy systems. Innovation in the high-voltage power converter design through miniaturization is important as it can lead to significant system cost reduction. However, state-of-the-art high-voltage power converters typically require the use of large-value bulky passive components due to the limitation of low-frequency operation. In this talk, we will first examine different power losses of state-of-the-art high-voltage power converters and explore high-frequency zero-voltage switching technique for improving the converter power efficiency and reducing required values of passive components. We will then discuss both closed-loop automatic dead-time control and high-speed level shifting technique in high-voltage on-chip gate drivers to enable high-frequency reliable zero-voltage switching in high-voltage power converters. With above techniques, the designs of a high-voltage DC-DC based dimmable LED driver with a CMOS power train will finally be presented as a design example.

Marc Riedel, University of Minnesota (mriedel@umn.edu)

Polysynchronous Stochastic Circuits

Clock distribution networks (CDNs) are costly in high-performance ASICs. This talk proposes a new approach: splitting clock domains at a very fine level, down to the level of a handful of gates. Each domain is synchronized with an inexpensive clock signal, generated locally with inverter rings. This is possible by adopting the paradigm of stochastic computation, where signal values are encoded as random bit streams. The design method is illustrated with the synthesis of circuits for applications in signal and image processing.

Ricardo Reis, Universidade Federal do Rio Grande do Sul (reis@inf.ufrgs.br)

Visualization Tools

This talk will show how we can use visualization tools to see how well our EDA tools and algorithms are running. For example, we use visualization tools to see how to improve our algorithms and tools for placement and routing.

Giovanni Beltrame, École Polytechnique de Montréal
(giovanni.beltrame@polymtl.ca)

Microprocessor Thermal Modelling and Validation

Modern integrated circuits generate very high heat fluxes that can lead to a high temperature, degrading the performance and reducing the life time of the device. Thermal simulation is used to prevent this kind of issues, and many models were introduced in recent years. However, their validation is challenging: it is either based on established simulators (with reduced accuracy), or requires to produce a specific test chip with several thermal sensors. We present a thermal modelling approach with an associated methodology and measurement setup that uses existing commercial processors to validate thermal models. We use infrared thermography and a low-cost thermoelectric cooling, avoiding the issues of mineral oil setups. We show how our approach can be used to create validated models for two thermal simulators (our own approach, and a commercial tool).

Session A4: Sensors and Imaging

Chair 1: Chair to be Announced

Catherine Dehollain, École Polytechnique Fédérale de Lausanne
(catherine.dehollain@epfl.ch)

Remote Power and Data Communication for Biomedical Sensors and RFIDs
Remotely powered systems are used in a lot of applications and in particular in the medical and telecoms fields. The main principle of remote powering is to get energy by magnetic, electro-magnetic or electro-acoustic coupling between the sensor node and the base station. Each scenario of use implies a custom-design solution due to the fact that the distance of operation between the sensor node and the base station as well as the maximum targeted volume of the sensor node and its power consumption dictate the choice of the frequency for remote powering and for data communication. Moreover, one single frequency approach for which the same frequency is used for remote powering and data transmission has to be compared to a two frequency solution by taking into account the data rate for data communication as well as the power consumption of the sensor node. All these different aspects are discussed in this talk by starting from a system level approach down to the transistor implementation including the design of the antennas.

Mohammad Reza Aziziyan, Université de Sherbrooke
(mohammad.reza.aziziyan@usherbrooke.ca) with J. Dubowski

Manipulating Electric Charge of Bacteria for Enhanced Biosensing with GaAs/AlGaAs Biochips
Biosensing based on photoluminescence of GaAs/AlGaAs heterostructures has recently emerged in bacteriological assessment of aqueous environment, in response to the need of a rapid and economical method of testing water quality. This technique relies on the impact of electric charge of bacteria on semiconductor photocorrosion process. We have investigated decoration of bacteria with negatively charged molecules, e.g., sodium dodecyl sulfate, expecting that this would increase zeta potential of bacteria and, consequently, lead to an increased sensitivity of detection. In this talk, I will discuss the results of a related research addressing detection of Legionella pneumophila in phosphate buffered saline solution.

Jean-Pierre Cloarec, Centre National de la Recherche Scientifique (jcloarec@ec-lyon.fr) with S. Ansanay-Alex, Y. Chevolot, E. Laurenceau, F. Palazon, J-F. Bryche, G. Barbillon, B. Bartenlian, R. Gillibert, R. Yasukuni, M. Lamy de Lachapelle, A. Olivero, M. Sarkar, M. Besbes, J. Moreau and M. Canva

Combining Surface Nanostructuration and Surface Chemistry at the Submicronic Scale: Towards a Bimodal SPRI/SERS Biosensor

A multimodal biosensor provides several complementary information enabling to better interpret the nature of the samples to analyze. We develop a biosensor simultaneously allowing two transduction methods on a same sample: 1) Surface Plasmon Resonance Imaging and 2) Surface Enhanced Raman Spectroscopy. Nucleic acid targets were used as a first biomolecular model to assess nanostructured samples, compatible with both SPRI and SERS analysis. Surface chemistry at the nanoscale is envisioned to improve inferior limits of detection of such biosensor, by allowing specific capture of molecular targets onto the nanotransduction zones, while repelling targets on the other parts of the transducers. We will show how such surface chemistry has been implemented for preparing future ultrasensitive biosensors.

Madhu Bhaskaran, RMIT University (madhu.bhaskaran@rmit.edu.au) with P. Gutruf, S. Walia, E. Zeller, H. Nili and S. Sriram

Zinc Oxide Thin Film Stretchable Electronics and Sensors

Fully transparent and stretchable electronic substrates that incorporate functional materials are the precursors to realising next generation devices with sensing, self-powering and portable functionalities. Furthermore, stretchable electronics offer a distinct advantage by organically conforming to irregular surfaces, this enables a new class of electronics that seamlessly integrates with the human body. Fully stretchable electronics pose a challenge for material science and micro fabrication to create devices with the ability to operate impeccably under various mechanically-stressed states.

Here, we introduce a distinctive micro-tectonic effect to enable oxygen-deficient, nano-patterned zinc oxide (ZnO) thin films on an elastomeric substrate to realize large area, stretchable, transparent, and ultra-portable sensors. We harness the unique surface structure to create stretchable gas and ultra-violet light sensors, both of which outperform their rigid counterparts under room temperature conditions. The sensors show a high sensitivity to flammable and toxic gases as well as radiation in the UV-A and UV-B band. We characterise the device performance in un-deformed and strained states using customised *in situ* techniques. We demonstrate full functionality under strain as well as an increased sensitivity through micro-tectonic surfaces by comparison to their rigid counterparts. Additionally we show excellent control over dimensions by embedding nanometre ZnO features in an elastomeric matrix which function as tunable diffraction gratings, capable of sensing displacements with nanometre accuracy.

Hua Wang, Georgia Tech (hua.wang@ece.gatech.edu) with J.S. Park and T. Chi

A Multi-Modality CMOS Sensor Array for Cell-Based Assay and Drug Screening

We present the world-first 4-modality pixelated CMOS sensor array for cellular assay and drug screening with no special post processing. Implemented in a standard 130nm CMOS process, the array has 144 tri-modality pixels (voltage, impedance, optical shadow sensing) with circuit sharing and 9 temperature sensors for joint-modality holistic cellular characterizations. On-chip mouse neurons show concurrent optical and impedance multi-modality imaging for cell localization and cell-CMOS surface attachment monitoring. Human cardiomyocytes demonstrate cardiac drug detection by joint-modality cellular potential and impedance detection.

Maryam Tabrizan, McGill University (maryam.tabrizian@mcgill.ca) with S. Filion-Côté, F. Melaine and A.G. Kirk

Monitoring of Bacterial Cells Growth Using a Custom-Made Surface Plasmon Resonance Biosensor

Bacterial viability, growth and subsequent biofilm formation is one of the main safety concerns in health centres and hospitals. Colony Forming Units (CFU) is the gold standard to estimate the number of viable bacteria on fungal cells on a sample. However, this method is lengthy and time consuming. Surface plasmon resonance (SPR) biosensors have emerged as an effective tool to monitor molecular and viral interactions non-invasively and in real-time as well as cellular activities for both mammalian and bacterial cells. The aim of this work is to develop a user-friendly platform allowing us to monitor bacterial cells activity and their response to various detergents using a custom-made surface plasmon resonance biosensor that measures complex refractive indices in real-time. As a proof-of-concept, we first demonstrated the real-time monitoring of liposomes (500 nanometers or 2 micrometers) attachment as a model mimicking bacterial cell membrane on the gold surface of our SPR instrument. The results showed the difference in kinetics for particles of different sizes. The response was much faster with the smaller liposomes as they diffuse more quickly to the surface than the larger liposomes. Additionally, the smaller liposomes cover more surface than the larger ones hence the greater change in refractive index measured at the surface. Finally, the larger concentration also results in a larger number of liposomes and therefore a greater coverage. This finding was used to prepare the protocol for the bacterial cell attachment on the gold surface and the formation of biofilm through controlling the time of incubation and flow rates. The next study will consist in assessing bacterial viability and removing bacterial biofilm in response to various antibacterial reagents.

Guido Faglia, Università degli Studi di Brescia (guido.faglia@unibs.it) with C.Baratto, F. Rigoni, N. Cattabiani, M. Donarelli and E. Comini

Metal Oxide Chemical Sensing Applications of Plasmon Resonances

By using localized surface plasmons to generate hot carriers in noble metal nanostructures supported on metal oxide nanowires, visible light can produce–in addition to plasmonic heating–energetic hot electrons (or holes) which may drive chemical reactions on the supporting semiconductor. Here we will discuss how hot electrons could boost metal oxide nanowires based chemical gas sensing.

Takakuni Douseki, Ritsumeikan University (douse@se.ritsumei.ac.jp)

Self-Powered Wireless Sensors with Electromagnetic and Piezoelectric Energy Harvesting from Human Motion

A self-powered wireless sensor is one of application with micro-scale energy harvesting that makes use of energy from human motion. We describe two self-powered sensor applications with an electromagnetic energy harvester: a bicycle speed recorder with hub dynamo and STT-MRAM, and a wireless digital tachometer for measuring spin of yo-yo. We also describe wireless electronic drums as wireless self-powered sensor application with a piezoelectric energy harvester. These applications utilize energy harvesters as both a power source and a sensor.

Laurent Francis, Université Catholique de Louvain (laurent.francis@uclouvain.be) with N. André, P. Gérard, Z. Ali, F. Udrea and D. Flandre

Impact of Radiations on CMOS-MEMS Sensors and a Mitigation Technique

High doses of ionizing radiations are detrimental to the performances of most common solid-state devices. To prevent the devices degradation, different radiation hardening techniques are already available that rely on a restricted selection of materials, on specific fabrication processes, on improved designs, on predictive models, or on dedicated packaging. In this work, we present a low-power and *in situ* mitigation technique for CMOS sensing and interfacing components based on MEMS Silicon-On-Insulator (SOI) micro-hotplates. The basic operating principle consists in the annealing of CMOS components integrated on a membrane during or after their irradiation in order to restore similar sensing characteristics over time. The SOI technology allows co-integration with analog integrated circuits and operation at elevated environmental temperatures up to 300°C, while the low thermal inertia of the membrane is used for rapid thermal cycling in the ms-range up to 700°C with mW-range electrical power.

Experimental results are reported for the electrical tests on thermodiodes, n- and p-MOS integrated to micro-hotplates after their irradiation by 23 MeV fast neutrons with total doses about 3 kGy and with short-pulsed annealing for their recovery. The demonstrated resistance to intensive radiations can extend their use in nuclear environments.

Val O'Shea, University of Glasgow (val.o'shea@glasgow.ac.uk)

Energy Sensitive Radiation Imaging Detectors-Motivation and Applications

The progress of microelectronic technology has enabled a radical increase in the functional capability of radiation imaging detectors over the past decade. Classical imaging technologies have largely been surpassed by solid-state imagers using CMOS circuits to implement ever more complex functionality. This article will describe the development and perspectives for hybrid pixel radiation detectors using examples from the Medipix family of readout circuits. Several applications that make use of the enabling features of this type of technology will be described in the areas of material characterisation, dosimetry and spectroscopic X-ray imaging.

Prabal Dutta, University of Michigan (prabal@eecs.umich.edu)

Realizing Smart Dust Vision

Session A5: Memories

Chair 1: Kirk Bevan, McGill University (kirk.bevan@mcgill.ca)

Jean-Philippe Noel, CEA-LETI (noeljp85@gmail.com) with B. Giraud

Smart Memory Solutions for IoT Oriented Circuit Design

Advanced CMOS nodes and embedded Non-Volatile (NV) memory solutions pave the way to normally-off instantly-on energy efficient chips. These hybrid chips could be a real opportunity for IoT market. This presentation will focus on our research works related to hybrid CMOS/ReRAM circuits. The aim of this work is to bring non-volatility in CMOS memory circuits for local storage, to optimize the speed of data transfer and the energy efficiency. Memory circuits like NV-Flip-flop as well as NV-SRAM, NV-RAM and crossbar architecture will be detailed. Integration of these circuits in MCU will be discussed.

Leo Bonato, Technischen Universität Berlin (leo.bonato@tu-berlin.de)

Quantum Dot-Based Flash Memories: The Holy Grail at Sunrise?

Solid state memory technology is fundamentally divided into volatile memories (e.g. DRAMs, allowing for fast data access but unable to store data for periods of time longer than a few ms), and non-volatile memories (e.g. Flash, allowing to store data for times >10 years but requiring ms to write or erase data). The hybridisation of both types, bringing together their advantages (i.e. long storage times; short write, read and erase times) has been referred to as the “Holy Grail” of solid state memory devices. This “Holy Grail” would offer unique functionalities, and could ensure future progress of memory development after the exhaustion of Moore’s law. The feasibility of our QD-Flash concept and its fast write and erase times have been previously demonstrated. On the other hand, the goal of non-volatility (i.e. storage time > 10 years) has not been achieved yet, 230 s being the best result reported to date. Here we report on extending the storage time of holes in GaSb QDs embedded in a GaP matrix, achieving 4 days at room temperature.

Gregory Di Pendina, CEA (Gregory.DiPendina@cea.fr) with E. Zianbetov, J. Lopes, L. Torres and E. Beigné

MRAM-Based Non-Volatile FD-SOI Technology, from Ultra-Low Power to Space Applications using Asynchronous Design

Magnetic Random Access Memory (MRAM), using Magnetic Tunnel Junction (MTJ) as the basis element, is nowadays well known in the emerging non-volatile memory (NMV) community. Lots of research efforts are done in both academic and industrial worlds. Its specific features such as fast writing and reading capabilities compared to other NVM, its low power consumption and advanced CMOS process compatibility, its scalability down to 20–40 nm, its high endurance and its intrinsic immunity to radiations attracts lots of research groups worldwide. In the same way, Fully Depleted Silicon On Insulator (FD-SOI) fabrication process is well known for potentially being a breakthrough in terms of Application Specific Integrated Circuit (ASIC) power consumption on very advanced process nodes, ranging from 28nm to 10nm. Such a process is latch-up free, offers the possibility to boost the speed performance or drastically reduce the leakage power using body biasing, and is more robust against radiation effects than a standard bulk CMOS process. Finally, in opposition to standard synchronous ASICs, clock-less or asynchronous ASICs are well known for being much more efficient in terms of power consumption since there is no clock that consumes the majority of the dynamic power, even when the circuit is in a standby mode. They are also Quasi Delay Insensitive (QDI) meaning asynchronous ASICs are extremely robust against process variations. As a consequence, this paper presents our work that consists in combining these three microelectronics features to address: i) Ultra-Low power ASIC design for Internet of Things (IoT) applications; ii) Radiation hardened ASIC for space applications. In the case of i) we demonstrated that our circuit can compute at 160mV in CMOS mode and 650 mV in non-volatile mode giving a gain of 14% to 30% of energy using Forward Body Biasing (FBB) when saving/restoring NVM and 40% using Reverse Body Biasing (RBB). In the case of ii) we have been able to save about 30% of ASIC area on a circuit capable of detecting and correcting radiation induced errors with an extreme safe procedure thanks to MTJ integration into the CMOS logic. Both ASICs are presently under design finalization and will be fabricated on a hybrid CMOS/Magnetic silicon demonstrator on Q3 2016.

Geoffrey Burr, IBM Research Almaden (gwburr@us.ibm.com)

Accelerating Machine Learning with Non-Volatile Memory

As we seek to continue to improve computing systems, attention is turning to Non-Von Neumann algorithms, including computing architectures motivated by the human brain.

At the same time, memory technology is changing, as new nonvolatile memories (NVM) such as Phase Change Memory (PCM) and Resistance RAM (RRAM) emerge. Such memories have begun to enable Storage-Class Memory (SCM), by combining the high performance and robustness of solid-state memory with the long-term retention and low cost of conventional storage.

Large NVM arrays can also be used in non-Von Neumann neuromorphic computational schemes, with device conductance serving as synaptic "weight." This allows the all-important multiply-accumulate operation within these algorithms to be performed efficiently AT the weight data.

I will discuss our recent work towards using NVM in both of these applications. After briefly reviewing earlier work on SCM, I describe our recent work on quantitatively assessing engineering tradeoffs inherent in NVM-based neuromorphic systems.

If there is time, I will discuss our work on transcending Machine Learning, moving towards "Machine Intelligence" with algorithms such as HTM (Hierarchical Temporal Memory), which can learn from unlabelled sequences of temporal data.

Santosh Kurinec, Rochester Institute of Technology (skkemc@rit.edu)

Emerging CMOS Compatible Ferroelectric Devices

Recent discovery of ferroelectricity in doped HfO_2 in 2011 has opened the door for new ferroelectric based devices, such as Ferroelectric Field Effect Transistor (FeFET) and Ferroelectric Tunnel Junctions (FTJ) and Negative Capacitance Field Effect Transistor (NCFET). FeFETs can be used in memory as well as in logic and FTJs are being explored as memristive devices that can be used in developing neuromorphic computing architectures. NCFETs offer solution to reducing the power requirement by lowering the subthreshold swing, $SS = (d\log I_{DS}/dV_{GS})^{-1}$ (expressed in mV/decade) by introducing a negative capacitance i.e by including a capacitive component that exhibits negative slope of polarization versus electric field. Ferroelectrics may be exploited to realize negative differential capacitance.

The spontaneous polarization in ferroelectrics (FE) makes them particularly attractive for nonvolatile memory and logic applications. Non-volatile FRAM memories using perovskite structure materials, such as Lead Zirconate Titanate (PZT) and Strontium Bismuth Tantalate (SBT) have been studied for many years, however, suffer from incompatibility with CMOS beyond 130 nm node. Ferroelectric HfO_2 is an attractive candidate due to its proven integration as a high-k dielectric with the CMOS processes. The talk will present recent developments in FE HfO_2 based semiconductor devices.

Session A6: Energy Harvesting and Storage

Chair 1: Chair to be Announced

Karim Zaghib, Institut de Recherche en Electricité d'Hydro-Québec (zaghib.karim@ireq.ca)

Lithium Batteries for Energy Storage and Transportation: Past, Present and Future

Daniel Chua, National University of Singapore (danielchua@nus.edu.sg)

Applying Carbon-Based Materials and Beyond in Li-Based Batteries and PEM Fuel Cells

Carbon materials have attracted much attention due to their unique properties, ranging from low dimensional effects, good structural integrity, high electrical and thermal conductivity, and chemical stability. Increasingly, carbon-based materials have progressed from thin films to the nanoscale dimensioned carbon nanotubes and graphene.

In this talk, we will show that we can engineer various 1D and 2D carbon-based materials for direct applications on Libatteries and PEM fuel cells. We will further show and compare the fuel cell properties when other 2D materials are integrated with the carbon-based materials. A series of in-situ tests are also performed which includes accelerated degradation test and electrochemical impedance spectroscopy to validate the effectiveness and robustness of these materials. We will mention briefly other applications for these carbon-based materials.

Li Lu, National University of Singapore (luli@nus.edu.sg) with Y. Zhu, S. Song, M. Kotobuki, F. Zheng, Y. Zhang, and Y. Zong

Solid-State Electrolytes for Safe and Large-Scale Energy Storage

Due to high voltage, superior safety and long lives, all-solid-state batteries are regarded as the next-generation power sources. As one of the crucial components in all-solid-state battery, solid-state electrolyte materials with high lithium ion conductivity and good chemical stability against lithium metal and cathode materials have been received great attention in order to fulfil application demand.

The lithium analogues based on sodium superionic conductor (NASICON) structure is one of the most potential material as solid electrolyte. In recent years, a wide range of compositions based on NASICON structure have been studied including $LiTi_2(PO_4)_3$ system, $LiZr_2(PO_4)_3$ system and $LiZr_2(PO_4)_3$ system. Dopants with lower valence such as Al, Ga, In, Ti, Sc, Y, La, Cr are also adopted to substitute A^{4+} site and therefore enhance the material's ionic conductivity. However, the application of NASCION material is still restricted by relatively low total ionic conductivity.

To explore a possible solution, we have investigated the synthesis process of lithium aluminum phosphate (LAGP) in this study. Different synthesis methods are used to decrease the porosity of the material as well as increase the uniformity of composition. Detailed parameters were studied to understand their influence on phase transformation progress and to obtain the optimal processing procedure. Systematic characterizations on crystal structure and morphology are conducted for further analysis.

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Daniel Guay, INRS (guay@emt.inrs.ca) with A. Ferris, J. Viens, S. Garbarino and D. Pech

On-Board Energy Storage: Microsupercapacitor with Remarkable Areal Energy

Miniaturized energy storage devices are in increasing demand for autonomous electronic systems and wireless technology. Micro-supercapacitors have virtually unlimited life, great stability, great power density, low internal resistance, and work well at different temperatures, but their energy capacity is far weaker than batteries. To circumvent these limitations, a new 3D electrode was made using an electrochemical process to synthesize a very porous gold structure. Ruthenium oxide was then inserted into the structure. The resulting micro-supercapacitor reached an energy density 1,000 times greater than existing electrochemical capacitors and comparable to current Li-ion microbatteries.

Guihua Yu, University of Texas (ghyu@austin.utexas.edu)

Functional Nanostructured Polymers for Energy Storage and Environmental Technologies

This talk will present a novel class of polymeric materials we developed recently: nanostructured conductive polymer hydrogels (CPHs) that are hierarchically porous, and structurally tunable in size, shape, porosity and chemical interfaces. Given advantageous features such as intrinsic 3D nanostructured conducting framework, excellent electronic and electrochemical properties, and scalable processability, they have been demonstrated useful for a number of applications in energy, bioelectronics, and environmental technologies. Several examples on developing high-performance energy storage devices and multifunctional superhydrophobic coatings for environmental cleanup will be discussed to illustrate “structure-derived functions” of this special class of materials.

Jihua Chen, Oak Ridge National Laboratory (jihuac@gmail.com)

Polymer Nanostructures for Energy Storage and Harvest

Ion and electro active polymers are attractive materials because of their ease of process, wide tunability, and steadily improving performance. In the first part of the talk, we will focus on nanostructure driven ion conductivity enhancement in two poly(ethylene oxide)/LiTFSI based solid electrolyte systems. We correlate the changes in ion conduction mechanism (derived from impedance spectroscopy and equivalent circuit modeling) to nanomorphological insights from low-dose, energy filtered TEM experiments in both cases. In the second part of the talk, power conversion efficiency in organic photovoltaics will be discussed in the light of nanoscale phase separation of donor and acceptor components.

Acknowledgement: This research is conducted at the Center for Nanophase Materials Sciences, which is a DOE Office of Science User Facility

Shuhui Sun, INRS (shuhui@emt.inrs.ca) with G. Zhang, Q. Wei, N. Komba, X. Yang, X. Tong, X. Zhang, Y. Wang and A. Tavares

Nanomaterials for Energy Conversion and Storage in Fuel Cells and Batteries

PEM fuel cells are expected to play dominant role in future clean energy solutions for various applications. However, the high cost of Pt catalyst is one of the main obstacles for their wide-spread commercialization. Therefore, developing highly efficient low-Pt and Pt-free catalysts are the key solutions. Through green chemistry and/or ALD techniques, we fabricated various novel Pt nanostructures, including nanowires, nanotubes, and single atoms. Compared to the conventional Pt nanoparticle/C commercial catalyst, these novel Pt nanostructures exhibited much enhanced activity (up to 10 times) and stability (up to 6 times) for fuel cells. Very recently, we also achieved very interesting results on Pt-free catalysts (e.g., Fe/N/C) which exhibited equivalent activity to Pt. Both lithium-ion and sodium-ion batteries are promising technologies for energy storage. We developed a facile, inexpensive and scalable wet-chemical strategy to fabricate the diamond-like Fe_3O_4/graphene composites. The nanocomposite shows dramatically enhanced electrochemical properties including excellent reversible capacity, cyclability and rate performance.

Mohamed Mohamedi, INRS (mohamedi@emt.inrs.ca)

Advances in Catalyst Development for Direct Ethanol Fuel Cells

Direct ethanol fuel cells (DEFCs) an emerging technology have attracted much attention recently in the search for alternative energy resources. Ethanol is particularly interesting as a green, nontoxic fuel with high theoretical energy density and can be generated from biomass (corn crops, sugar cane, domestic cellulosic biomass, etc.), which could make DEFCs advantageous low GHG emission power sources. The future of DEFC technologies is strictly reliant on the discovery of novel anode catalysts; advanced structures and synthesis methods that permits tailor-designing of catalysts in a precise manner to enhance the potential of DEFCs.

This talk addresses the challenges and the developments of anode catalysts for DEFCs. In particular, we will emphasize our recent results obtained with nanostructured metal oxides (CeO_2, SnO_2, TiO_2, MnO_2)-Pt anodes. Correlations between surface morphology and electroactivity towards ethanol oxidation reaction will be discussed.

Ana Tavares, INRS (tavares@emt.inrs.ca) with D. Sebastian, C.L. Vecchio, G. Zhang, A. Stassi, V. Baglio, S. Sun and A.S. Aricò

Cost-Effective Non-Noble Metal Cathode Catalysts for Direct Alcohol Fuel Cells
The high cost and low tolerance of platinum to organic fuels have hindered the commercialization of Direct Alcohol Fuel Cells (DAFCs). Here, we will present our work on the development of low cost and methanol tolerant catalysts for the oxygen reduction reaction, carried out in the frame of a bi-lateral collaboration between the two institutes. In particular, we will focus on zirconium and tantalum based catalysts supported on carbon substrates prepared by wet chemistry. These catalysts are tolerant to methanol and showed good resistance to potential cycling. Correlations between structure and activity will be discussed.

Dongling Ma, INRS (dongling.ma@emt.inrs.ca)

Towards Harvesting More Photons by Designing and Realizing Nanostructures
Efficiently harvesting visible and near infrared (NIR) photons represents an attractive approach to improve the efficiency of photocatalysis, solar-to-fuel and solar-to-electricity conversion. Plasmonic nanostructures with unique surface plasmon resonance have recently been explored for enhancing solar energy harvesting in the visible and NIR regimes. On the other hand, NIR quantum dots (QDs) with size tunable bandgaps and high potential for multiple exciton generation represent a class of promising materials for new generations of solar cells. In this talk, I will present our recent work on plasmonic nanostructures and NIR QDs synthesis and their application in solar cells and photocatalysis.

Siva Krishna Karuturi, Australian National University (Siva.Karuturi@anu.edu.au)

Application of Atomic Layer Deposition in Solar Energy Conversion
The quest for abundant, renewable energy is currently one of the world's greatest technological challenges. One solution to this problem is the conversion of solar energy to storable chemical fuels, such as H_2. Hydrogen generated from photoelectrochemical conversion of water has the potential to provide clean, sustainable, abundant and transportable energy. A photoelectrochemical cell requires a semiconductor photoelectrode that fulfills several essential prerequisites: a small semiconductor bandgap for efficiently harvesting a large proportion of the

solar spectrum, appropriate band edges for water oxidation and reduction, high conversion efficiency of photogenerated carriers to hydrogen, durability in aqueous environments, and low cost. Atomic Layer Deposition (ALD) as a technique used for the fabrication of complex 3-Dimensional Nanostructures has been found to be very versatile for these applications. This work describes the use of ALD to build up semiconductor oxides such as titanium dioxide 3-dimensional nanostructures for solar hydrogen generation applications.

Neil Robertson, University of Edinburgh (Neil.Robertson@ed.ac.uk) with A. Ivaturi, M. Maciejczjk and R. Fuentes

New Hole-Transport Materials for Dye-Sensitised and Perovskite Solar Cells

Perovskite solar cells (PSCs) have brought a paradigm shift in efficiencies achieved via low cost solution based photovoltaics. Triarylamine (TAA)-based materials, especially Spiro-OMeTAD, have been the most promising hole-transport materials (HTM) in these devices. However Spiro-OMeTAD is one of the most costly layers of the PSCs. Considering this, novel cost effective Spiro analogue triarylamines with electron-donating substituents and with different alkyl chain have been synthesized. The series of triarylamines (DATPA) with varying electron-donating substituents and varying alkyl chain length have exhibited promising performance when tested in PSCs. The alkyl chain has been varied to explore the effect on charge mobility, material processing, stability and interfacial charge transfer dynamics. Spiro analogues with different oxidation potentials have been fully characterized by spectroscopic methods, elemental analysis and mass spectrometry. Intermolecular interactions were studied by X-ray single crystal and powder diffraction. High thermal stability of materials was revealed with differential scanning calorimetry. Based on these results, one Spiro derivative with appropriate energy levels was tested in PSCs, showing comparable efficiencies to the commonly used Spiro-MeOTAD.

Christine Luscombe, University of Washington (luscombe@uw.edu)

Direct Synthesis of Ligand-Free Nanoparticles and their Applications in Energy Conversion

Most commercially available photovoltaic units provide conversion efficiencies of about 25%. While extensive production of these devices could help alleviate current energy demands, high production costs have hindered product output. One way to lower the cost of devices is to manufacture devices using high throughput, roll to roll processing. In this talk, synthetic strategies to form solution processible organic/inorganic hybrid nanoparticles will be discussed along with their thin film properties and photophysical properties. Specifically, the use of polymeric sulfur as a solvent, ligand, and sulfide source will be discussed for the synthesis and processing of CdS, CIS, and CZTS.

Zetian Mi, McGill University (zetian.mi@mcgill.ca)

Solar Fuels Generation on III-Nitride Nanowire Arrays on Si

Track B: Nanotechnology

Session B1: Nanotechnology

Chair 1: Francis Balestra, MINATEC (balestra@minatec.grenoble-inp.fr)
Chair 2: Dominique Drouin, Université de Sherbrooke, UMI-LN2 (dominique.drouin@Usherbrooke.ca)

Thomas Szkopek, McGill University (thomas.szkopek@mcgill.ca)

Black Phosphorus Naked Quantum Well Transistors

Black phosphorus (bP) is the second known elemental allotrope with a layered crystal structure that can be mechanically exfoliated down to atomic layer thickness. We have fabricated bP naked quantum wells of 6±1 nm to 47±1 nm thickness in field effect transistor (FET) geometries with single and dual gate geometries. The effects of photo-oxidation were mitigated by using bP layers thicker than a few atomic layers and encapsulation. We have measured the electronic transport properties of bP FETs over the temperature range of 300 mK to 300 K. Our measurements reveal ambipolar transport, field effect mobilities of up to 900 cm^2/Vs, and on/off current ratios exceeding 10^5. At 300 K, dual gate bP FETs can be operated in a velocity modulated transistor (VMT) mode. Modulation of the hole density distribution within the bP quantum well leads to a two-fold modulation of hole mobility, and two-fold modulation of Schottky barrier resistance. Shubnikov-de Haas (SdH) oscillations were observed in bp FETs at 300 mK and magnetic fields of up to 35 T, confirming the 2-D nature of the hole accumulation layer at the bP surface. Our work explicitly demonstrates the critical role of charge density distribution upon charge carrier transport within 2D atomic crystals.

Abdelkader Souifi, INL-CNRS 5270 (abdelkader.souifi@insa-lyon.fr) with E. Cossec, K. Hamga, P.-V. Guenery, M. Troudi, G.K. El Hajjam, L. Benea, N. Baboux, L. Militaru, X. Hébras, C. Bonafos, G. BenAssayag, B. Pecassou, S. Ecoffey and D. Drouin

Integration and Electrical Characterization of Indium-Oxide Nanoparticles in Oxide Resistive Random-Access Memories

An attractive alternative for extending the scaling of embedded Flash-type memories is to replace the conventional floating gate by laterally isolated floating nodes in the form of nanoparticles. This floating-gate concept has led to the emergence of the so-called nanocrystal (NC) memories which have the potential of operating at lower voltages and higher speeds compared to the conventional NVMs, without compromising the criterion of non-volatility. The last few years, significant advances have been made in NC fabrication and prototypes of memory-based on NCs for low-power microcontroller applications have recently been demonstrated.

One alternative path to further increase the memory density is to investigate two terminals memory resistive devices such as metal oxide resistive switching memory (OxRAM).

Our presentation describes a new process for horizontal *metal/insulator/metal* (MIM) with embedded self-aligned Indium oxide NCs OxRAMs. The OxRAM cell fabrication is based on the combination of nano-damascene planarization process to define the nanodevice geometries and Indium-Ultra-Low Energy implantation for localized In_2O_3 NCs synthesis.

Electrical characterization results of the first prototypes of In_2O_3-NC OxRAM memories will be presented. Electrical switching has been studied as function of the operating temperature and a comprehensive study of the SET and RESET regime has been performed.

Muhammad Akhyar Farrukh, GC University Lahore (akhyar100@gmail.com)

Multiple Approaches to Synthesize the Multi-Metal Oxides Nanoparticles and Their Applications

Synthesis of single, double and triple metal oxides nanoparticles were synthesized via the sonication method, hydrothermal method, conventional method, anodization method and deposition-precipitation method under aqueous and non-aqueous conditions. Templating agents having non-ionic surfactant and ionic surfactant as well as surface directing agents having different organic solvents were used to control the particle size and morphology. Nanoparticles were characterized by TEM, SEM, EDX, TGA, XRD and FTIR. The particle size was found decrease with the increase in concentration of surfactant up to critical micelle concentration (CMC). The influence of surfactants and solvents on the activities of nanocatalysts in environmental hazardous materials was studied under UV-visible light. Others applications of the metal oxides nanoparticles in drug development, waste water, green fertilizer, forensics and their toxicological effects were also investigated.

Mauro Epifani, Consiglio Nazionale delle Ricerche
(mauro.epifani@le.imm.cnr.it)

Composing Metal Oxide Nanostructures for Gas-Sensing and Environmental Remediation

Intensive research is under way for modifying the properties of semiconductor nanocrystals by suitable combinations with other structures. In this work the composition of TiO_2 and SnO_2 nanocrystals with Wo_x and V_2O_5-like layers and WO_3 nanocrystals will be reviewed, from the synthetic point of view, as concerns the application of solvothermal/sol-gel techniques, and as concerns the enhancement of the surface chemistry mediated application such as gas-sensing and photodegradation. It will be shown that combining the catalytic properties of an oxide layer with the conduction properties of another base oxide is a powerful tool to obtain materials with enhanced surface properties.

Session B2: Nanotechnology

Chair 1: Eli Yablonovitch, University of California, Berkeley (eliy@eecs.berkeley.edu)
Chair 2: Francis Balestra, MINATEC (balestra@minatec.grenoble-inp.fr)

Jose Maria De Teresa, University of Zaragoza (deteresa@unizar.es)

The Use of FIB-SEM Dual Beam in Nanotechnology

A Focused Ion Beam (FIB) in combination with a Scanning Electron Microscopy (SEM) constitutes a powerful platform for application in Nanotechnology. Besides imaging capabilities, the FIB-SEM Dual Beam presents several capabilities for nanofabrication with resolution down to few nanometers. After a general introduction to such nanofabrication techniques, I will draw the attention towards the additive techniques. In particular, in Focused Electron Beam Induced Deposition (FEBID), the SEM is used to dissociate precursor gas molecules, producing nanomaterials in a single step with lateral resolution in the nanometer range. In the talk, various examples of magnetic FEBID nanostructures based on Co and Fe precursors will be given. Special emphasis will be put on applications using magnetic tips grown at the apex of cantilevers and magnetic-domain-wall propagation in 2D and 3D nanostructures, summarized in the review article De Teresa and Fernández-Pacheco, 2014 Appl. Phys. A 117, 1645. Alternatively, the FIB can be used to produce the precursor dissociation, the technique being in this case named Focused Ion Beam Induced Deposition (FIBID). We have used FIBID to grow superconducting nanomaterials based on a W precursor. Narrow nanowires showing finite-size superconducting effects have been prepared by FIBID (Córdoba et al., 2013 Nat. Commun. 4, 1437).

Gérard Ben Assayag, CEMES/CNRS (gerard.benassayag@cemes.fr) with C. Carles, C. Bonafos, B. Pecassou, X. Hebras, S. Schamm-Chardon2, D. Drouin, S. Ecoffey and K. Souifi

Ultra Low Energy Ion Beam Synthesis: An Original Method for the Fabrication of Nanocrystals in Dielectrics for Nanoelectronics, Nano-Optics and Plasmonic Applications.

Metallic or semiconducting nanostructures embedded in thin dielectric films are promising candidates for application devices in fields such as plasmonics, nanoelectronics and nanomemories. Within the different ways available to fabricate such systems, Ultra Low Energy Ion Beam (ULE-IBS) is an original method which has the advantage and disadvantage of ion implantation. About the advantage, the implanters are well-known in microelectronics for doping purpose and the method is fully compatible with the mainstream of nanoelectronic processes. But the defects have to be taken into account and thermodynamics limits the compatible species and dielectrics. In this talk we will expose the ULE-IBS method. We will describe the results in nanoelectronics memories with the couple Si Nanocrystals in SiO_2 ultrathin layers and in plasmonics with the fabrication of silver nanocrystals in Silica or Si_3N_4. Some recent results on resistive memories will be presented with In_2O_3 nanocrystals embedded in a nanometric silica cell for complementary OxRAM.

Junichi Shirakashi, Tokyo University of Agriculture and Technology (shrakash@cc.tuat.ac.jp)

Controlled Electromigration Method for the Fabrication of Nanoscale Junction Devices

Fabrication of nanogap-based nanoscale junction devices such as quantum point contacts (QPCs) and single-electron transistors (SETs) using electromigration is demonstrated. Feedback-controlled electromigration (FCE) has been a useful technique for creating nanogaps between metal electrodes. Here, the authors propose a new FCE method using a field-programmable gate array (FPGA) or a real-time operating system (RTOS), to immediately or precisely control atomic junctions of QPCs at room temperature. Furthermore, electromigration induced by a field emission current passing through the nanogap is used for the fabrication of SETs. We call this method "activation". In the activation procedure, the field emission current plays an important role in triggering the migration of metal atoms across the gap. These results imply that precise control of nanogap-based nanoscale junction devices can be achieved via the electromigration procedure.

Yoshitaka Naitoh, Osaka University (naitoh@ap.eng.osaka-u.ac.jp) with Y. J. Li and Y. Sugawara

Spatial Elastic Property of Ge(001) Surface at Sub-Atomic Scale with Multi-Frequency Atomic Force Microscopy

The ability of atomic force microscopy (AFM) is so excellent as to probe physical properties; magnetic, electronic and elastic properties of surfaces at the sub-nanoscale. However, the tip-surface interaction detected by the conventional AFM refers to the component normal to the surface and ignores the parallel one. Namely, the tip-surface interaction force was employed as a "scalar". In order to probe the spatial physical properties, the experimentally obtained force should be expressed as "vector". For this requirement, we challenge to detect the normal (z) and parallel (x and y) components of the tip-surface force at the same time. Experiments were performed in a home build AFM apparatus operating under ultra-high vacuum at room temperature. The Si cantilever, which was coated with tungsten in advance, was multiply oscillated at the 2nd flexural and the torsional resonant frequencies. The variations of the frequency shifts of the flexural and the torsional modes were simultaneously measured above the Ge(001)-c(4x2) surface and x, y and z components of the tip-surface force variation were calculated. We will discuss the force vector variation above the Ge(001) dimers at the sub-atomic scale in detail.

Byoung C. Choi, University of Victoria (bchoi@uvic.ca) with H. Xu, G. Hajisalem, G.M. Steeves and R. Gordon

Ultrafast Demagnetization Enhanced by Localized Surface Plasmon

Magnetic systems excited by ultrafast laser pulses undergo abrupt quenching of magnetic order within several hundred femtoseconds, due to rapid energy transfer from thermalized electrons to the spin system. This is followed by remagnetization occurring over the picosecond timescale as electrons equilibrate with the phonons, and eventually to complete cooling via nanosecond lattice diffusion. The timescale of laser-induced ultrafast demagnetization is orders of magnitude below the limit imposed by conventional switching of magnetic order via magnetic field pulse, and has been the focus of considerable research. In this talk we demonstrate that the demagnetization can be significantly enhanced without increasing the laser fluence by coating ferromagnetic thin films with gold nanorods (AuNRs), which are dimensionally-tuned to support localized surface plasmons (LSPs) near the peak laser frequency.

Guennadi Kouzaev, Norwegian University of Science and Technology (guennadi.kouzaev@iet.ntnu.no)

Simulation of Quantum and EM-Quantum Components using Available Circuit Simulators

The development of software for simulation and design of quantum components and their hybrid integrations with their electronic counterparts is a very important task for today's computer science. One of the approaches here is the adapting the PSPICE-based circuit simulators for these calculations.

In this report, an overview of the results on the developments of this technique is given. The approach is based on the method of the reduction of the order of partial differential equations applicable in quantum mechanics. The reduced-order differential equations are considered as the differential Kirchhoff's relations for the Kron's quantum currents and voltages. The finite-difference technique leads to a system of algebraic equations which coefficients can be considered as the values of quantum circuit elements. Additional techniques allow these, in general, complex circuits with the complex currents and voltages to be solved with the PSPICE-based simulators operating the real variables and circuit components without re-writing the simulation engine.

The applications of this technique to the electron transportation, trapped Bose-Einstein condensates, quantum Hall waveguides, EM-quantum equations, etc. are considered.

Bhaskaran Muralidharan, Indian Institute of Technology Bombay
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Improved Spintronic Device Functionalities Using Resonant Spin Filtering
We present novel magnetic tunnel junction (MTJ) structures that employ the physics of resonant spin filtering. Using spin-transport models based on the non-equilibrium Green's function formalism, we demonstrate an ultra-enhancement in the tunnel magneto resistance (TMR), well in excess of 2000%, as a result of highly sensitive and tunable spin filtering physics. With myriad applications possible by utilizing such a tunable spin filtering scheme, we present device designs catered towards three emerging functionalities: (i) ultra-high sensitivity magneto resistance H-field sensors (ii) Improved spin transfer torque switching resulting from the non-trivial spin current profiles, and (iii) high-power output microwave generators and oscillators based on spin-transfer torque dynamics.

Antonio Tricoli, Australian National University (antonio.tricoli@anu.edu.au)

Ultra-Porous Nanoparticle Networks: a Functional Morphology for Wearable Optoelectronic Devices
Nanostructured materials have the potential to significantly enhance the performance of several devices as recently demonstrated for solar cells, sensors and energy storage technologies. This has resulted in a gold rush toward novel applications ranging from flexible electronics to wearable nanogenerators. However, integration of nanomaterials in devices is challenging and their assembly in suboptimal morphologies may drastically limit the final performance. Here, we will present the fabrication of highly performing optoelectronic and chemical devices by integrated ultraporous nanoparticle networks. We will showcase the use of scalable and low cost flame-synthesis approaches for the wafer-level nanofabrication of tailored and well-reproducible 3D morphologies. The fundamental mechanisms controlling the gas-phase self-assembly of these nanostructures will be shortly reviewed with respect to current limitations and future opportunities. The commercial potential of these materials will be discussed along the example of non-invasive medical diagnostics and wearable photodetectors.

Curt Richter, National Institute of Standards and Technology
(curt.richter@nist.gov) with H-J. Jang

Organic Spin-Valves and Beyond: Spin injection and Transport in Organic Semiconductors for Future Nanoelectronics

Efforts are rapidly growing to realize novel technologies based on spin effects in organic semiconductors ranging from magnetic sensors to ultralow-powered spintronic logic devices. Organic materials in electronics can bring many advantages such as low production cost, light-weight, and mechanical flexibility, and organic semiconductors are considered to be promising media for spin transport due to their long spin lifetimes. However, a complete understanding of spin-polarized carrier injection and transport in organic semiconductors is still lacking and under debate. I will discuss our research into engineering materials and interfaces to optimize spin injection and spin effects in organic systems.

Gord Harling, Innotime Technical Services (gharling@innotime.ca)

TBA

Heike Riel, IBM Zurich (hei@zurich.ibm.com)

TBA

Session B3: Nanomaterials

Chair 1: Gord Harling, Innotime Technical Services (gharling@innotime.ca)
Chair 2: David Cumming, University of Glasgow
(David.Cumming.2@glasgow .ac.uk)

Toshiro Hiramoto, University of Tokyo (hiramoto@nano.iis.u-tokyo.ac.jp) with T. Mizutani, Y. Tanahashi, R. Suzuki, T. Saraya and M. Kobayashi

A New Variability Origin in Extremely Narrow Silicon Nanowire MOSFETs with Nanowire Width down to 2nm

This paper presents the experimental results on variability in nanowire FETs. The threshold voltage and on-current variability of extremely narrow silicon nanowire channel FETs is intensively measured and statistically analyzed. The minimum nanowire width is 2nm. It is found that the Pelgrom coefficient of 7nm-wide nanowire FETs is much smaller than that of fully-depleted SOI FETs, while it rapidly increases as the nanowire width decreases down to 2nm. The increase in variability is ascribed to a new variability origin: threshold voltage fluctuations due to the quantum confinement effect induced by nanowire width fluctuations.

Karen Kavanagh, Simon Fraser University (kavanagh@sfu.ca)

Imaging III-V Nanowire Electronic Junctions

This talk will highlight methods for characterizing individual semiconducting and magnetic nanowires including electrical probing in a scanning electron microscope, structural and compositional analysis using scanning transmission electron microscopy, and electrostatic potential and magnetization measurements using electron holography. Examples of lithography-free, direct analysis of nanowire metal contacts, and tunnel junctions will be described.

Simon Watkins, Simon Fraser University (simonw@sfu.ca)

Probing III-V Nanowire Devices using Nanoprobe Electrical Measurements

The characterization of the electrical properties of nanowires (NW) remains a key topic of interest for the implementation of these structures in devices. We report the growth and electrical characterization of III-V and ZnO NWs by the vapor liquid solid/metalorganic vapor deposition method. Recent measurements of nanowire electrical properties using a tungsten nanoprobe inside a scanning electron microscope are presented. The method allows rapid assessment of an ensemble of device structures using a two terminal measurement method. Core-shell, as well as axial pn structures, can be grown and rapidly assessed without lithographic processing. In addition to IV properties, carrier diffusion lengths can be directly measured by the electron beam induced current (EBIC) technique, allowing the rapid assessment of various surface passivation methods. As an example we demonstrate a significant reduction in the surface recombination of GaAs NWs after passivation with InGaP shells.

Bassem Salem, LTM-CNRS Grenoble (bassem.salem@cea.fr) with V. Brouzet, P. Periwal, T. Baron, F. Bassan and G. Ghibaudo

Elaboration and Electrical Characterisations of Si/$Si_{1-x}Ge_x$ *Heterostructure Nanowires Tunnel FET Device*

The power dissipation associated with a high off-state current (I_{off}) is become one of the major problem to the further scaling of CMOS devices. In order to decrease the I_{off} and the voltage supply (V_{DD}), it will be necessary to reduce the subthreshold slope swing (SS). To reduce the SS, various carrier injection mechanisms have been proposed. One of the most promising low energy consumption device is the Tunnel Field-Effect Transistor (TFET). In this context, we present the fabrication and electrical characterization of Ω-gate TFET based on p-Si/i-Si/n^+Si0$_{.7}$Ge$_{0.3}$ heterostructure nanowires grown by chemical-vapour-deposition (CVD) using the vapour-liquid-solid (VLS) mechanism.

Bich-Yen Nguyen, Soitec (bich-yen.nguyen@soitec.com) with W. Schwarzenbach, F. Allibert, C. Figuet, C. Girard and C. Maleville

Material and Device Innovation for Cost Effective CMOS Scaling Beyond 28nm

The quest to satisfy the low-power/low-leakage solution requirements of the portable/wearable consumer electronics is recently driving efforts in CMOS scaling. However, such power reduction cannot be achieved using classical materials and scaling of transistor dimensions, because leakage current exceeds standby power requirements and large variability caused by random doping effect limits the operation voltage scaling resulted in large dynamic power or total power consumption. Thus more innovations in material and device structure have been extensively explored to overcome the scaling constraints and to reduce the total power consumption. This paper reviews the advanced SOI substrate engineering, which enables the fully depleted device structure and boosting performance. The FDSOI device with undoped channel solves the leakage and variability challenge and thin BOX enables back bias capabilities to meet the power/performance and cost requirements for consumer mobile and wearable electronics.

Session B4: Nanomaterials

Chair 1: Muhammad Akhyar Farrukh, GC University Lahore (akhyar100@gmail.com)

Francis Balestra, MINATEC (balestra@minatec.grenoble-inp.fr)

New Materials and Innovative Architectures for Ultimate Nanoelectronic Devices

The historic trend in micro/nano-electronics these last 40 years has been to increase both speed and density by scaling down the electronic devices, together with reduced energy dissipation per binary transition. We are facing this last decade dramatic challenges dealing with the limits of energy consumption and heat removal, driving current, variability, inducing fundamental tradeoffs for the future ICs. A substantial reduction of the static and dynamic power is also strongly needed for the development of future ultra low power terascale integration and autonomous nanosystems. This presentation addresses the main trends, challenges, limits and possible solutions for strongly reducing the power and increasing the performance of future nanodevices with novel materials and innovative device architectures, using, on one hand, SiGe, Ge, III-V, strained layers, 2D materials, heterostructures and semimetals, and combined with, on the other hand, ultra-thin body Fully-Depleted On Insulator MOSFETs, Multi-gate devices, Nanowire structures, small-slope Switches (Tunnel FETs, Ferroelectric gate FETs, NEMS) and Hybrid devices for gate length down to sub-5nm.

Aaron Franklin, Duke University (aaron.franklin@duke.edu)

Promises and Challenges of Nanomaterials in Transistors: From High-Performance to Thin-Film Applications

Research into the many exciting possible applications of nanomaterials has exploded over the past twenty years. One of the foremost areas of interest is in the various forms of electronics that could be improved or enabled by harnessing the unique properties of nanomaterials. While consumers see a world of ever-improving technological gadgets, the underlying hardware has run into many ominous challenges. Many researchers have proposed that nanomaterials can provide remedies for the woes of silicon-based technology in addition to opening the way for completely new electronic platforms. From 1D carbon nanotubes (CNTs) to 2D nanomaterials (including graphene, transition metal dichalcogenides (TMDs), and the so-called X-enes), a big picture perspective of this growing list of options and their potential for facilitating new applications will be reviewed in this talk. In addition to the promises these nanomaterials offer, some of the major challenges to realizing a nanomaterial-based transistor technology will also be considered along with a few of the latest developments toward overcoming these obstacles. Finally, a brief review of how these nanomaterials could impact other aspects of electronics will be considered, including their ability to usher in a completely new form factor for computing.

Dominique Drouin, Université de Sherbrooke, UMI-LN2
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A Deep Understanding of Nanometer Scale Dielectric Junctions for the Fabrication of Low Power Nanoelectronic Devices

The development of new generation of nanoelectronic devices for low power electronics requires a deep understanding of materials at the nanoscale. With critical dimensions decreased below the tenth of nanometer and materials being stacked and patterned it is very challenging, sometimes impossible to characterize those materials using standard characterization techniques and tools. We have developed the nanodamascene technique that enable the fabrication of nanometer scale dielectric junctions using a scalable process. The junctions being fabricated with this process are critical elements that can be exploited to fabricate nanoelectronic devices. We propose to combine advance modeling of nanoelectronic devices and low temperature electrical characterization to characterize these junctions as well as the dielectric properties. We will present the impact of material surface interactions on electrical characteristics of metal nanowires, metal-insulator-metal junctions and single electron transistors. Finally, we will propose a process exploiting the nanodamascene technique for the fabrication of Quantum Cellular Automatas (QCAs). QCAs use charge localization rather than the number of electrons to encode the information. This paradigm shift enables the realization of ultra-low power electronic circuits. In its electrostatic form, QCA require extremely low capacitance tunnel junctions.

Mutsumi Kimura, Ryukoku University (mutsu@rins.ryukoku.ac.jp)

Cellar Neural Network using Thin-Film Devices

Artificial neural networks are promising information processors. However, conventional ones consist of intricate circuits. We demonstrate a cellar neural network using thin-film devices. We simplified elements: we formed a “neuron” from only eight transistors and reduced a "synapse" to only one device by employing degradations to adjust synaptic connection strengths. We formed a local interconnective network: we connected a neuron only to the neighboring neurons and classified the synapses into "concordant" and "discordant" synapses. These architectures are suitable for integrated circuits. Moreover, we tried to compose the synapses of thin-film devices. We confirmed correct working: logic learning, letter recognition, etc.

Swastik Kar, Northeastern University (S.Kar@neu.edu)

Nanomaterials for Advanced Tunable Emission, Detection and Actuation

The electronic, optical and mechanical properties of nanomaterials have always been intriguingly different from their bulk counterparts. In recent times, ultra-small nano-materials, which have dimensions that are a few atoms thick, have displayed revolutionary new properties with unprecedented applications. Our recent work on a range of atomically-sized materials such as graphene, 2D-transition metal dichalcogenides, and other similar layered and atomically narrow materials have revealed interesting electronic, optical and mechanical properties which has enabled us to design functional devices with unprecedented performances. In this talk, we will outline some of these works in the area of optoelectronics, nanoelectromechanical systems, and other sensors and detectors.

Shu-Jen Han, IBM (sjhan@us.ibm.com)

Nanoelectronics Based on Low-Dimensional Carbon Materials

Low-dimensional carbon materials are promising to replace silicon as the channel material for high-performance electronics near the end of silicon scaling roadmap, with their superb electrical properties, intrinsic ultrathin body, and nearly transparent contact with certain metals. This talk discusses two promising carbon nanomaterials and their applications that are actively investigated at IBM Research: single-walled carbon nanotubes for high performance logic and graphene for high-frequency analog electronics. I will cover the recent advances in experimental works that reveal the potential of these technologies, as well as a discussion that highlights most significant challenges from technology points of view, and provides perspectives on the future of carbon based nanoelectronics.

Oleksandr Ivasenko, KU Leuven (oleksandr.ivasenko@chem.kuleuven.be)

Molecular Self-Assembly on Graphene and Graphite: from Fundamentals to Applications

Nanostructured monolayers of molecules can be formed at a variety of interfaces. At a liquid-solid interface, such two-dimensional (2D) molecular assemblies can be created by depositing a solution of the compound of interest on top of the substrate (drop casting) or by immersing the substrate into a solution (dip coating).

In this presentation, we focus on several aspects of molecular self-assembly at the interface between a liquid or air, and substrates such as highly oriented pyrolytic graphite and graphene. Graphite can be considered as an excellent model surface for adsorption and self-assembly of molecules on graphene. We will reveal novel concepts of 2D crystal engineering including the effect of solvent, solute concentration and temperature, stimulus-driven self-assembly and self-assembly under nanoconfinement conditions, bringing insight into thermodynamic and kinetics aspects of the self-assembly process at the interface between a liquid and graphite or graphene. Based on these insights, we will demonstrate molecular self-assembly based functionalization of graphite and graphene. Various applications will be presented, including tunable doping of graphene based field effect transistors.

Juan Escrig Murúa, Universidad de Santiago de Chile (juan.escrig@usach.cl)

Synthesis and Characterization of Thin Films and Nanostructures by Atomic Layer Deposition

With the growing need for the miniaturization of sensors, storage devices and biomedical chips, magnetic nanomaterials have gained much importance in the last years. Technological applications of such systems require a deep knowledge of their magnetic behavior. Among the different geometric types of objects, tubes offer an additional degree of freedom in their design as compared to wires, in that not only the length and diameter can be varied but also the thickness. Besides, changes in the internal radii are expected to strongly affect the magnetization reversal mechanism and thereby the overall magnetic response. Additionally, the nature of the magnetic tubes may be suitable for applications in biotechnology, where magnetic nanostructures with low density, which can float in solutions, are very desirable. Then, a thorough understanding of the magnetic properties of nanotube arrays is of extreme importance for their implementation in future applications. Atomic layer deposition (ALD) of magnetic materials can be applied to ordered porous substrates to yield arrays of smooth tubes with a geometry that is tightly controlled and widely tunable. Thus, we have successfully used ALD to create Fe_3O_4 and Ni nanotubes in porous anodic alumina templates.

Chawki Awada, CEA (awada@emt.inrs.ca) with A. Boucherif, A. Ruediger and R. Arès

Effects of Crystallite Size Distribution on the Raman-Scattering Profiles of Germanium Nanostructures

Mesoporous Germanium (Ge) nanostructures have attracted rapidly increasing attention over the last few years. Due to its unique optical properties related to its near-infrared (NIR) and visible light emissions, mesoporous crystalline Ge opened up new opportunities for next generation optoelectronic and biomedical application. The samples were fabricated by bipolar electrochemical etching of Ge wafer in HF-based electrolyte. In previous work, high resolution scanning transmission electron microscopy (HRSTEM) provided strong evidence that NIR originates from the size reduction of the nanocrystallites. However, there still many questions to be revealed concerning the size-related emission of the nanocrystallites. In this work, we will show some results obtained by Raman spectroscopy. This one is a very sensitive technique that allows studying the physical properties of nanostructures. Among these properties, we will focus on the study of the size effects of the nanocrystallites of Ge and their distribution on the phonon modes, a phonon-confinement model was used to extract the size of the core and the minicrystallites for different etched films. The results were compared with the atomic force microscope (AFM) measurements.

Nori Hayazawa, RIKEN (hayazawa@riken.jp)

Micro/Nano Raman Spectroscopy for Carbon and Silicon Nanomaterials

Raman spectroscopy has been known as one of the promising analytical techniques, which reveals the physicochemical properties of various materials owing to its high sensitivity to molecular/lattice vibrations. In this presentation, I introduce Raman spectroscopy as a "Microscopy: Micro-Raman" and a "Nanoscopy: Nano-Raman", which employ a high numerical aperture objective lens and a sharp metallic tip to access the local properties of the materials, respectively. In our recent works, Raman spectroscopy with 1nm spatial resolution has been achieved by detecting various vibrational modes of single walled carbon nanotubes in ambient, which is currently the highest spatial resolution in the world.

Chahinez Dab, INRS-EMT (chahinez.dab@emt.inrs.ca) with A. Reudiger

Non-Linear Raman Spectroscopy at the Nanoscale

For almost a century, Raman spectroscopy has proven an indispensable tool for the chemical and structural characterization of materials. The optical near-field generated at the apex of a gold scanning probe tip in tip-enhanced Raman spectroscopy (TERS) enhances and confines the interaction of light and matter to a few nanometers, thus breaking the diffraction limit of light for spatial resolution. With the way paved to deploy Raman spectroscopy to surface nanostructures, we now investigate the possibility to push the limits to tip-enhanced hyper-Raman spectroscopy. In this two-photon process, detected at the second harmonic, the selection rules allow for additional information to be retrieved from the sample as compared to the first harmonic. Hyper-Raman scattering however suffers from an extremely low cross-section. We present theoretical considerations about the net enhancement factor, predicted to be proportional to the sixth power of the local electric field enhancement and the interplay with recently observed dissipation mechanisms through e.g. hot electrons. We suggest suitable sample systems for a proof of concept taking into consideration that resonant Raman scattering might occur even for a non-resonant first harmonic excitation.

Qiao Zhang, Soochow University (qiaozhang@suda.edu.cn)

Engineering Nanomaterials for Catalysis

In this presentation, I will summarize my recent efforts in the synthesis, stabilization and application of functional nanomaterials. By using silver nanoplates as a model system, we attempt to outline the key components that determine the formation of nanomaterials, clarify the roles of each reagent, provide highly reproducible recipes for synthesis, and therefore take a significant step towards the complete understanding of the mechanism behind the experimental phenomena. We have also focused on core-shell nanostructures-a class of nanoparticles encapsulated and protected by an outer shell that isolates the nanoparticles and prevents their migration and coalescence during the catalytic reactions.

Session B5: MEMS and NEMS

Chair 1: Mahmoud Almasri, University of Missouri (almasrim@missouri.edu)

Songbin Gong, University of Illinois at Urbana-Champaign (songbin@illinois.edu)

Piezoelectric MEMS Devices for Future Reconfigurable RF Front Ends

The growth in functionalities of modern wireless communication, coupled with the Defense's need for a programmable RF framework, is drawing great interest in developing reconfigurable radio frequency (RF) systems. Having access to programmable subsystems will revolutionize the RF design space, improve cost and yields, and enable in-field system adaptation to RF signals and novel RF transceiver architectures. Micro-scale RF passives, namely micro-electro-mechanical systems (MEMS) resonators, are ideal candidates for the implementation of such reconfigurable RF platforms.

This talk will present some the most promising RF MEMS technologies that I have developed for intelligent and efficient utilization of the RF spectrum, namely the Lithium Niobate (LN) laterally vibrating resonators (LVRs). The LN LVRs, which have record-breaking figure of merit (FoM) as well as the capability of covering multiple frequencies on a single chip, will be described as the key building blocks for programmable filtering. I will describe the design and fabrication challenges that have been addressed, and the subsequently demonstrated first LN LVRs for chip-scale reconfigurable filtering applications. The design and development of these RF micro-systems will be discussed with a special focus on how these devices can be assembled monolithically to enable unprecedented adaptive filtering capabilities on system level.

I will also show that in short term (2∼3 years), such system-level capabilities promise the highly sought-after multi-band (∼20) multiplexing solutions for the existing standards such as LTE, CDMA, WiFi, and GPS; and in long term, they can break down the design boundaries imposed by the conventional device/hardware infrastructure and favorably respond to the growing wireless bandwidth demand fueled by the uprising mobile paradigms such as cloud computing and internet of everything.

Davide Iannuzzi, Vrije Universiteit Amsterdam (d.iannuzzi@vu.nl)

All Optical Fiber-Top MEMS: Instruments for Life Science Research

Fiber-top technology was first introduced, more than 10 year ago, as an pragmatic way to get rid of an annoying spurious signal in a fundamental physics experiment. Since then, the technology has been brought to full maturity, up to a point that it is now a successful product on the market. In this talk, I will review the most important applications of this kind of devices, which allow one to combine MEMS and optical fibers in the development of easy-to-use tools for life science research. I will in particular focus the presentation on our most recent experiments on brain tissue, heart cells, and photoacoustic gas sensing. A short discussion on future perspectives will conclude the talk.

Thomas Le Brun, National Institute of Standards and Technology (thomas.lebrun@nist.gov)

MEMS-Based Optomechanical Sensors for Advanced Precision Measurements

Matteo Rinaldi, Northeastern University (rinaldi@ece.neu.edu)

Hybrid MEMS/NEMS for Advanced Sensing and Wireless Communications

Sensors are nowadays found in a wide variety of applications, such as smart mobile devices, automotive, healthcare and environmental monitoring. The recent advancements in terms of sensor miniaturization, low power consumption and low cost allow envisioning a new era for sensing in which the data collected from multiple individual smart sensor systems are combined to get information about the environment that is more accurate and reliable than the individual sensor data. By leveraging such sensor fusion it will be possible to acquire complete and accurate information about the context in which human beings live, which has huge potential for the development of the Internet of Things (IoT) in which physical and virtual objects are linked through the exploitation of sensing and communication capabilities with the intent of making life simpler and more efficient for human beings.

This trend towards sensor fusion has dramatically increased the demand of new technology platforms, capable of delivering multiple sensing and wireless communication functionalities in a small foot print. In this context, Micro- and Nanoelectromechanical systems (MEMS/NEMS) technologies can have a tremendous impact since they can be used for the implementation of high performance sensors and wireless communication devices with reduced form factor and Integrated Circuit (IC) integration capability.

This work presents a new class of hybrid MEMS/NEMS devices that can address some of the most important challenges in the areas of physical, chemical and biological detection and can be simultaneously used to synthesize high-Q reconfigurable and adaptive radio frequency (RF) resonant devices. By combining the unique physical, optical and electrical properties of advanced materials such as thin film piezoelectric materials, graphene, photonic metamaterials, phase change materials and magnetic materials, multiple and advanced sensing and RF communication functionalities are implemented in a small footprint. Particular attention is dedicated to the key attributes of such hybrid MEMS/NEMS devices in realizing intrinsically switchable and reconfigurable RF MEMS components and ultra-low power sensors.

Takashi Tokuda, NAIST (tokuda@ms.naist.jp) with H. Takehara, T. Noda, K. Sasagawa and J. Ohta

CMOS-Based Opto-Electronic Flexible Brain Interface Device

CMOS-based flexible opto-electronic brain machine interface (BMI) device is presented. Designing with multi-chip architecture, a flexible BMI device that can fit the curve of the brain and cover a wide are is realized. We integrated CMOS chips with switch and neural amplifier circuits on the device and we can perform random-access, multi-functional stimulation and sensing on the brain.

The multi-chip BMI device has a structure of solid, small-sized (typically 3–5mm) neural interface devices connected with flexible bridge structures. The solid neural interface device is realized with conventional printed circuit board technology. CMOS chip, LEDs for optogenetic stimulation, and neural electrodes are integrated on each solid device. Connecting the solid neural interface device with a polyimide flexible substrate, we can make the device flexible to fit the curvature of the brain surface.

Design, packaging, and functional demonstrations will be presented at the conference.

Track C: Optics and Photonics

Session C1: Radiation Detection

Chair 1: Chair to be Announced

Cyril Ponchut, European Synchrotron Radiation Facility (ponchut@esrf.fr)

Application of Novel Pixel Sensor and Readout ASIC Technologies to X-Ray Detectors for Synchrotron Experiments

Photon-counting X-ray pixel detectors based on CMOS readout ASICs are now routinely used on synchrotron beamlines, enabling users to collect noiseless, high dynamic range 2D data with fast frame rates and excellent detection efficiency. However, peripheral structures of the pixel sensors and of the readout chips result in discontinuous detection fields, preventing the use of these devices in certain applications.

Ongoing pixel detector developments at ESRF aim at overcoming this problem by associating active-edge pixel sensors to TSV-processed Medipix3 readout chips developed by CERN in order to form the building blocks of a new scalable pixel detector system. Dead areas around unit detector elements are thus reduced from several millimetres to less than a few hundred microns, enabling to achieve virtually gap-free planar detection areas of arbitrary shape.

This talk will present the technological grounds of these projects as well as some application examples.

Mokhtar Chmeissani, Institut de Física d'Altes Energies (mokhtar@ifae.es)

Circuit Design to Reduce the Impact of Charge Sharing in Pixel Semiconductor Detector

Pixel semiconductor sensors have matured significantly over the past decade and can be acquired at a competitive price. Such sensors can provide excellent energy and spatial resolution and these 2 features are priceless input values for most of X-ray/gamma-ray imaging devices. For these reasons, pixel semiconductor sensors are becoming the choice for various imaging applications in general and for medical applications in particular. Medical applications with hard X-ray such as in Computed Tomography (CT) or gamma-ray in nuclear medicine, favors high Z semiconductor material, such as Cd(Zn)Te, to increase the detection efficiency. However such semiconductor detector has limited mobility for electron/hole carriers. This causes the charge cloud, at the impact point of the X-ray/gamma-ray photon, to spread as it moves toward the electrodes and hence deposit the induced signal over many neighboring pixels. This is what we call charge sharing. The impact of charge sharing is more pronounced with smaller pixel size, say less than 300 μm. This poses serious limitations to the energy and spatial resolutions and hence to the quality of the reconstructed image. The future CT scanners, under developments, are made from pixel Cd(Zn)Te sensor with the aim to group the detected X-ray flux into 4, or more, energy levels compared to the current CT scanners which have only 2 energy levels. At the same time the X-ray flux used for CT scanner is very high and it can reach 1 GHz/mm2.This means that one needs to resolves the charge sharing problem among neighboring pixels at ultra high speed.

Dimitra Darambara, The Institute of Cancer Research and The Royal Marsden NHS Foundation Trust (dimitra.darambara@icr.ac.uk)

Performance Assessment of CdZnTe Detectors for Quantitative Multi-Spectral Photon-Counting X-Ray Imaging

Our team has been investigating–theoretically and experimentally–to which extent novel, energy-dispersive CdZnTe pixellated detectors and a dedicated fast photon-counting readout ASIC with dynamic energy binning are capable of overcoming fundamental performance limits and challenges of photon-counting multi-spectral x-ray imaging, and therefore, facilitating the realisation of this application type in clinical practice. We have successfully developed a dynamic multi-environment hardware approach, which provided us with the means to investigate the optimal geometrical and electronic configuration, the number of energy bins required for task specific imaging, the trade-off between spatial and energy resolution and high count rate and the imaging and dosimetric performance of a CZT-based multispectral medical x-ray imaging system. Further, we have been assessing the detector performance for spectral AuNPs imaging within a pre-clinical research platform and demonstrating the potential of Cone Beam Spectral Tomography as an advanced imaging technique for diagnostic and radiotherapy imaging. Results from both theoretical and experimental studies will be presented and the feasibility and the challenges of implementing CZT detectors and advanced photon-counting readout electronics for multi-spectral photon-counting medical x-ray imaging will be discussed.

Thomas Brunner, McGill University (thomas.brunner@physics.mcgill.ca)

Advanced Technologies for the Future Low-Background Detector nEXO

The nEXO collaboration is searching for neutrinoless-double beta decays in the isotope Xe-136. A positive observation of this decay would be the first observation of physics beyond the Standard Model of particle physics, i.e. it would be an observation of physics that the current theory does not include. The nEXO collaboration has started developing advanced detection techniques in order to reach sensitivities to the half-life on the order of 10^{28} years. They will be applied in a liquid-xenon time-projection chamber. These techniques include readout of ionization charge through tiles and application of 3D-integrated SiPM detectors. The most recent developments will be presented in detail.

Session C2: Nanophotonics

Chair 1: Fiorenzo Vetrone, INRS (vetrone@emt.inrs.ca)
Chair 2: Pablo Bianucci, Concordia University (pablo.bianucci@concordia.ca)

Taiichi Otsuji, Tohoku University (otsuji@riec.tohoku.ac.jp)

Emission and Detection of THz Radiation Using Double-Graphene-Layered van der Waals Heterostructures.

This paper reviews recent advances in the research of graphene-based van der Waals heterostructures for emission and detection of terahertz radiation. A gated double-graphene-layer (DGL) nanocapacitor is the core shell under consideration, in which a thin tunnel barrier layer is sandwiched by outer graphene layers at both sides. The DGL can excite symmetric optical and anti-symmetric acoustic coupled plasmon modes in the GLs. The latter mode can modulate the band-offset between the GL, giving rise to modulation of the inter-GL-layer resonant tunneling. This can dramatically enhance the THz gain or responsivity via plasmon-assisted inter-GL resonant tunneling.

Sivashankar Krishnamoorthy, Luxembourg Insitute of Science and Technology (sivashankar.krishnamoorthy@list.lu)

Photonic and Plasmonic Technologies with Application to Nanomedicine

Alexander O. Govorov, Ohio University (govorov@helios.phy.ohiou.edu)

Generation of Hot Plasmonic Electrons in Nanostructures with Hot Spots

The efficiency of generation of energetic plasmonic carriers in metal nanostructures strongly depends on the optical design and material composition. By combining the lithographic technologies and theoretical predictions, we demonstrate the ability to generate large numbers of hot plasmonic carriers in specially-designed hybrid nanostructures. The hot-electron generation becomes especially efficient in plasmonic nanostructures with electromagnetic hot spots. The energy distribution of optically-excited plasmonic carriers is very different in metal nanocrystals with large and small sizes. For metal nanocrystals with smaller sizes (less than 10nm) or in nanostructures with hot spots, the excited state gets a large number of carriers with high energies. Nanostructures with a strong plasmonic enhancement generate unusually large numbers of energetic electrons, which can be observed using the ultra-fast spectroscopy. The results obtained in this study can be used to design plasmonic hot-electron nanodevices for photo-catalysis, photo-detectors and solar-energy applications.

Peter Mascher, McMaster University (mascher@mcmaster.ca)

Light Emission from Doped and Undoped Silicon-Based Nanostructures

In order for Si-based materials to be used in solid-state lighting (SSL) schemes it is necessary to have precise control of the emission from these materials. This can be accomplished through the use of rare earth dopants such as Ce, Tb, and Eu to obtain blue, green, and red emissions, respectively. After a brief review of the latest developments in the field, this talk will focus on the luminescence of rare earth

(Ce, Tb, Eu) doped silicon oxides, nitrides, and carbides. We have demonstrated very high, optically active concentrations of the rare earths by using in-situ doping processes, using electron cyclotron resonance chemical vapour deposition (ECR-CVD) or inductively coupled plasma (ICP) CVD as low thermal budget processes for film deposition. I will describe the salient features of the deposition systems and correlate important process parameters with the observed luminescence. Finally, I will discuss some of the challenges in developing electrically driven lighting cells suitable for SSL and in particular, the development of white light emitters from rare earth doped Si-based materials.

Andries Meijerink, Universiteit Utrecht (A.Meijerink@uu.nl)

Lanthanide-Doped Nanocrystals for Spectral Conversion

Nanocrystals (NCs) doped with luminescent ions form an emerging class of materials. They serve as probes in physics, chemistry and biology and demonstrate unprecedented flexibility in spectral conversion (including up-and downconversion) for applications ranging from solar cells and white light LEDs to photodynamic therapy. In this presentation the synthesis and optical properties of lanthanide doped nanocrystals (both quantum dots and insulator nanocrystals) will be discussed with a focus on design strategies to tailor the luminescence properties and to enhance spectral conversion efficiencies.

Feng Wang, City University of Hong Kong (wang.feng@cityu.edu.hk)

Exploiting Lanthanide Luminescence in Core-Shell Nanoparticles

Spectral conversion of light radiation is essential for a variety of modern-day technologies including displays, photovoltaics, data storage, and cancer therapy. In the past decades, a variety of luminescent materials, including organic dyes and semiconductor quantum dots, were developed to realize photon energy conversion in the ultraviolet (UV) to near infrared (NIR) spectral range. However, practical application of these techniques is frequently limited by constraints such as toxicity and/or poor stability. In this context, lanthanide-doped nanoparticles have been developed as a promising alternative to conventional luminescent nanomaterials. By comparison, these nanoparticles offer low cytotoxicity, sharp emission peaks, long-lived excited electronic states, as well as high stability against photo bleaching and chemical degradation. In this talk, I focus on our recent efforts on lanthanide-doped core-shell nanoparticles that are generally composed of a layer-by-layer structure with a set of lanthanide ions incorporated into separate layer. I discuss how to fabricate these nanostructures by wet-chemistry method and how to characterize the nanostructure by a combination of electron microscopy and luminescence spectroscopy. Examples will be given to demonstrate how to enhance multiphoton upconversion emissions for exciting new technological applications.

Adolfo Speghini, Università di Verona (adolfo.speghini@univr.it) with P. Cortelletti, M. Pedroni, C. Facciotti, G. Lucchini, M. Quintanilla, A. Benayas and F. Vetrone

Optical Nanothermometers based on Core-Shell Alkaline-Earth Nanoparticles Activated with Lanthanide Ions

Lanthanide doped nanoparticles (NPs) based on alkaline-earth fluorides have been revealed to be very interesting for their possible use in various technological applications, for instance as diagnostic probes in nanomedicine. In this contribution, we present an investigation on water dispersible SrF_2 based NPs activated with lanthanide ions (such as Yb^{3+}, Nd^{3+}, Tm^{3+}, Er^{3+}). Upon near infrared (NIR) laser excitation at 980 nm or 800 nm, lanthanide emissions of colloidal dispersions in the visible and NIR are measured as a function of the temperature (10–50°C range). The emission intensities are used to investigate the thermometric properties through a ratiometric approach from the relative changes of different emissions. A rationally designed multishell architecture of the NPs is adopted in order to optimize the emission efficiency. The NPs show interesting sensitivities upon NIR excitation (in the biological window) and the multishell approach appears to be very useful to enhance their performance as nanothermometers.

Xiaogang Liu, National University of Singapore (chmlx@nus.edu.sg)

Controlling Photon Upconversion in Lanthanide-Doped Nanocrystals

Lanthanide-doped nanoparticles exhibit unique luminescent properties, including a large Stokes shift, a sharp bandwidth of emission, high resistance to optical blinking, and photobleaching. Uniquely, they can also convert long-wavelength stimulation into short-wavelength emission. These attributes offer the opportunity to develop alternative luminescent labels to organic fluorophores and quantum dots. In recent years, researchers have taken advantage of spectral-conversion nanocrystals in many important biological applications, such as highly sensitive molecular detection and autofluorescence-free cell imaging. With significant progress made over the past several years, we can now design and fabricate nanoparticles that display tailorable optical properties. In particular, we can generate a wealth of color output under single-wavelength excitation by rational control of different combinations of dopants and dopant concentration. By incorporating a set of lanthanide ions at defined concentrations into different layers of a core-shell structure, we have expanded the emission spectra of the particles to cover almost the entire visible region, a feat barely accessible by conventional bulk phosphors. In this talk, I will highlight recent advances in the broad utility of upconversion nanocrystals for multimodal imaging, bio-detection, display and photonics.

Benjamin Damilano, Centre National de la Recherche Scientifique (bd@crhea.cnrs.fr; benjamin.damilano@crhea.cnrs.fr)

Yellow and Red Light Emission with InGaN Quantum Wells

InGaN-based light emitting diodes (LEDs) are very efficient for light emission in the blue wavelength range. Extending their wavelength emission to yellow or even red colors is challenging and we will describe some strategies relying on polarization and strain engineering to improve the quality of these devices. We will show that by stacking different InGaN layers in a same LED structure, white light emission can be obtained without the help of phosphor conversion.

Pavle Radovanovic, University of Waterloo (pavler@uwaterloo.ca)

Generating Efficient and Tunable White Light Using Hybrid Transparent Metal Oxide-Based Nanoconjugates

Native defects are a source of many useful and often unexpected properties in transparent metal oxides. In this talk I will first briefly present our recent results on defect-based photoluminescence properties of colloidal wide band gap metal oxide nanocrystals (Ga_2O_3 and ZnO), and the effect of nanocrystal size on its energy, efficiency, and dynamics. Coupling of the native defects with selected chromophores bound to nanocrystal surfaces via resonance energy transfer allows for the generation of white light which can be tuned based on the nanocrystal size and the concentration of adsorbates on nanocrystal surfaces. The ability to modify nanocrystal surfaces allows for further optimization of the stability and functionality of the resulting nanoconjugates. The implications of our results for high-efficiency photonic devices, such as white light emitting diodes, will also be discussed.

Carlo Piermarocchi, Michigan State University (piermaro@msu.edu)

Large-Scale Simulations of Exciton Rabi Oscillations in Quantum Dot Random Media

A novel algorithm for computational representations of time-dependent incident and radiated electromagnetic fields in complex nanophotonic systems is presented. The method is based on an efficient time-domain integral equation approach, and is applied to the description of exciton Rabi oscillations induced by intense laser pulses in random system of quantum dots. The algorithm efficiently captures the exciton dynamics and field propagation in a self-consistent manner.

Roberto Myers, Ohio State University (myers.1079@osu.edu) with B.J. May and ATM Golam Sarwar

Nanowire Photonics Integrated on Metal for Scalable Nanomanufacturing

In the past few years, a large variety of photonic devices based on III-Nitride nanowires have been demonstrated. Using molecular beam epitaxy, (Ga, Al, In)N nanowire based LEDs across the visible and into the deep ultraviolet wavelength range were achieved making use of the very large band gap variation accessible in the III-N semiconductor family. Additionally, lasers, photodetectors, and photocatalysts were also demonstrated from such nanostructures, which are typically grown and often electrically integrated on rigid and single-crystalline silicon wafers. Here we propose and demonstrate the possibility of growing III-Nitride nanowire photonic devices on flexible metallic substrates (metal foil). Nanowires grown on Ti and Ta foil grow in well aligned vertical arrays within each grain of the metal foils. Spectrally and temporally resolved photoluminescence measurements demonstrate that nanowires grown on metal exhibit optical quality as good as nanowires grown on single crystalline Si wafers. Finally, AlGaN nanowire heterostructures are grown on Ta metal foil and processed into LED devices with turn on voltage near 5 V and an emission wavelength in the near UV (350 nm). These results demonstrate for the first time, the possibility of direct growth of nanophotonic devices on flexible metal foil and pave the way for scalable nanomanufacturing of such optoelectronics. This work was supported by the Army Research Office and by the National Science Foundation.

Supriyo Bandyopadhyay, Virginia Commonwealth University (sbandy@vcu.edu) with S. Bandyopadhyay, M.I. Hossain and J. Atulasimha

Quantum Engineered Nanowire-Based Room-Temperature Infrared Photodetectors

Semiconductor-based infrared photodetectors employ narrow bandgap semiconductors (InSb, InAs, HgCdTe) which do not perform well at room temperature since phonons can excite electrons from the valence to the conduction band, creating electron-hole pairs in the dark and therefore a large dark current. To overcome this impasse, we have employed wavefunction engineering where we use wide gap semiconductors to block band-to-band transitions and allow infrared photons to excite electrons from filled shallow trap levels in the bandgap to the conduction band. The trap state wavefunctions are very localized, while the conduction band wavefunction is delocalized, which leads to a large matrix element for photon-induced transition and a small matrix element for phonon-induced transition. This allows room temperature infrared detection with reasonable light-to-dark conductance ratio. Self-assembled CdS nanowires have been used for such wavefunction engineered detectors and show a detectivity D* of 10^7 Jones at room temperature. We have also proposed and demonstrated a tunneling photodetector that provides gain without avalanching and is hence much less noisy than avalanche photodetectors.

The use of the nanowires provides frequency selectivity whereby infrared frequencies within a narrow window are detected. This functionality accrues from the van Hove singularities in the joint electron-hole density of state in a nanowire.

We have also demonstrated a capacitive detector where infrared light changes the capacitance of nanowires. When used in a resonant resistor-capacitor circuit, it results in large light-to-dark contrast ratio and low dark current.

Finally, we have proposed and demonstrated the principle of a spintronic photodetector implemented with a nanowire spin vale with Co and Ni contacts and InSb spacer. The effective magnetizations in the two contacts are made anti-parallel. Because electrons occupy only the lowest subband, the major spin relaxation mechanism (D'yakonov-Perel') is strongly suppressed in the spacer. Consequently, electrons injected by one contact arrive with their spin polarizations more or less intact at the other contact which blocks them. This makes the device resistance high. Infrared light excites electrons to higher subbands and shortens the spin relaxation length significantly. Spins therefore flip in the spacer under illumination and the flipped spins transmit resulting in lower resistance. This effect which implements a photodetector has been demonstrated at room temperature.

The spintronic detector work is supported by the US National Science Foundation under grant CMMI-1301013.

Rusli, Nanyang Technological University (erusli@ntu.edu.sg)

High Efficiency Si/PEDOT:PSS Hybrid Solar Cell Based on Periodic Nanopillars

The emerging hybrid Si/PEDOT:PSS solar cells have been actively explored in the recent years. In this study we present the hybrid solar cells based on periodic Si nanopillars with different pitches formed by plasma etching. We propose a simple surface treatment method using a mixed HF, acetic and HNO_3 solution (HAN) solution, which can dissolve the surface damage layer arising from the dry etching process, and also increase the surface roughness of the silicon nanopillars. Benefitting from the optimization of the surface quality and efficient light absorption of the Si nanopillars, a highest power conversion efficiency of 11.8% has been achieved for the hybrid cell with a pitch of 600 nm and nanopillars height of 600 nm. Our work also paves the way for the study of dimensional effect and optimization of the hybrid solar cell based on the periodic Si nanopillars.

Session C3: Silicon Photonics

Chair 1: Werner Hofmann, Technischen Universität Berlin (Werner.Hofmann@tu-Berlin.de)

Oussama Moutanabbir, École Polytechnique de Montréal (oussama.moutanabbir @polymtl.ca)

A Path Towards Silicon-Compatible Photonics

Compound semiconductor alloys have been successfully used for a precise and simultaneous control of lattice parameters and bandgap structures bringing to existence a variety of functional heterostructures and low-dimensional systems. Extending this paradigm to group IV semiconductors will be a true breakthrough that will pave the way to creating an entirely new class of silicon-compatible electronic, optoelectronic, and photonic devices. With this perspective, germanium-tin ($Ge_{1-x}Sn_x$) and germanium-silicon-tin ($Ge_{1-x-y}Si_xSn_y$) alloys have recently been the subject of extensive investigations as new material systems to independently engineer lattice parameter and bandgap energy and directness. The ability to incorporate Sn atoms into silicon and germanium at concentrations about one order of magnitude higher than the equilibrium solubility is at the core of these emerging potential technologies. In this presentation, we will address the epitaxial growth and stability of these metastable semiconductors. We will also discuss the optical and electronic properties as well as the nature of the atomic order in Sn-rich $Ge_{1-x-y}Si_xSn_y$. Moreover, based on *in situ* electron microscopy, we will present real time studies of their thermal behavior which reveal unprecedented insights into the key phenomena that govern the thermal decomposition and phase separation in these materials. These studies define the temperature window for the processing of $Ge_{1-x-y}Si_xSn_y$- based devices.

Nazir Kherani, University of Toronto (nazir.kherani@gmail.com)

Toward High-Efficiency Ultra-Thin Silicon Photovoltaics

Rehan Kapadia, University of Southern California (rkapadia@usc.edu)

III-Vs Grown on Si for Electronic and Optoelectronic Applications

We demonstrate the versatility of a previously developed low-cost compound semiconductor growth technique termed thin-film vapor-liquid-solid (TF-VLS) growth. Specifically, we show a variety of optoelectronic and energy devices with geometries and material combinations unavailable to traditional vapor-phase growth techniques. Critically, this is enabled by the confinement of a liquid metal solvent layer, enabling precise control over the position and shape of nuclei on non-epitaxial and hetero-epitaxial substrates. Unlike vapor-phase processes, in which control over the shape of a growing nuclei is extremely challenging and primarily defined by the growth rates of various crystal facets, the TF-VLS process enables full control over nuclei, enabling single crystal electron and photon devices regardless of substrate microstructure. In particular, we demonstrate growth and devices on a variety of substrates, including silicon and metals.

Joyce Poon, University of Toronto (joyce.poon@utoronto.ca)

Multilayer Silicon Nitride-on-Silicon Integrated Photonic Platforms

I will present my group's work in foundry-fabricated multilayer silicon nitride-on-silicon integrated photonic platforms. Silicon nitride enables improved passive photonic components in the telecommunication wavelength bands. These passive components can be integrated with active components in the silicon layer, including modulators, photodetectors, and potentially hybrid lasers. Silicon nitride-on-silicon platforms have been implemented at the A*STAR Institute of Microelectronics foundry on 8" substrates. The reduced losses, scattering, thermo-optic coefficient, and nonlinearity of moderate refractive index contrast silicon nitride waveguides compared to silicon waveguides motivate the development of such multilayer photonic platforms.

Abderraouf Boucherif, Canada-3IT (abderraouf.boucherif@usherbrooke.ca) with S. Fafard, V. Aimez and R. Arès

Virtual Substrates Engineering for High Efficiency Multijunction Solar Cells Applications

Most optoelectronic devices such as lasers, photodetectors, and solar cells are made by the epitaxial growth of semiconductor heterostructures on monocrystalline wafers. Defect-free epilayers are a primary requirement to achieve a high performance device. Today, the performance, the functionality, and the cost of those devices are restricted by the very few number of available monocrystalline wafers.

In this talk, I will discuss two strategies to access cost-effective virtual substrates for germanium and III-V materials epitaxy. The first one is a tuneable-lattice substrate, the second one is a layer transfer process for thin germanium membranes.

Session C4: Optical Devices

Chair 1: Mokhtar Chmeissani, Institut de Física d'Altes Energies (mokhtar@ifae.es)

Tony Chan Carusone, University of Toronto (tony.chan.carusone@isl.utoronto.ca)

Ultra-Short-Reach Interconnects for Package-Level Integration

Improving the functionality of solid-state systems is no longer simply a matter of cramming everything onto a single silicon die. Package-level integration of disparate technologies on either silicon interposers or organic packaging substrates is a key enabler for future optical and memory subsystems. High-performance computing and networking applications will require tremendous interconnection bandwidth between co-packaged dies. To make package-level integration seamless, transceivers for these "ultra-short-reach" links must fit within vanishingly small area and power footprints. This talk focuses on research opportunities in this emerging area and early technology demonstrations, including a 20Gb/s/wire 0.3pJ/bit single-ended die-to-die link on a silicon interposer.

Johan Bauwelinck, Ghent University (johan.bauwelinck@intec.ugent.be)

High-Speed Driver and Receiver Electronics for Next-Generation Optical Networks

Interface rates need to scale up to follow the increasing demand of data intensive applications such as cloud services, high-performance computing, video traffic, storage, 5G, etc. Datacenters have become the hot spots of the internet where various interconnect challenges reside: chip-to-chip, chip-to-module, board-to-board, rack-to-rack, etc. There is no single best solution among electrical and optical technologies due to the different technological constraints in terms of distance, footprint, power consumption, cost, etc. Research is approaching this challenge from different angles, with technological improvements on photonic and electronic devices and/or by applying more complex modulation and signal processing. In this talk, we highlight a number of our recent developments on the most critical building blocks of very high-speed transceivers targeting various applications at 56Gb/s and beyond.

Gabriela Nicolescu, École Polytechnique de Montréal
(gabriela.nicolescu@polymtl.ca)

Efficient Control Approach for Full Exploitation of Optical Integrated Networks

Electrical interconnects will reach their physical limitations as we scale down components on systems' designs. At the same time, the demand for high throughput communication architectures rises. Optical integrated interconnects are currently considered to be one of the most promising paradigm in this design context: they present high bandwidth and low power consumption. Still, such communication infra-structures lack a low latency controlling solution, which do not constrain (or limit) optical interconnects. In this context, the design of a low-latency controlling solution targeting Mach-Zehnder Interferometer (MZI)-based optical integrated networks is presented.

Roberto Morandotti, INRS (morandot@emt.inrs.ca) with M. Kues, C. Reimer, P. Roztocki, L. Caspani, B. Wetzel, B.E. Little, S.T. Chu and D.J. Moss

Quantum Combs in Integrated Optics

Integrated sources of single and entangled photons are currently one of the main research areas in quantum optics, aiming at pushing forward the implementation of e.g. quantum communication and quantum computation schemes in an integrated format.

Here we report an integrated "bi-photon frequency comb" source generating simultaneously multiple correlated photon pairs on different frequencies, based on the excitation of spontaneous four-wave mixing within an integrated CMOS-compatible microring resonator. The generated photon pairs cover the full telecommunication band (L + C) and their frequency modes are compatible with standard wavelength division multiplexing channels (DWDM, 200 GHz separation) and quantum memories (140 MHz bandwidth). Our source is extremely robust and capable to operating for several weeks without significant fluctuations in performance ($<5\%$). We measured photon coincidences between channels symmetric to the excitation frequency (coincidence to accidental ratio (CAR) exceeds 10 on each channel pair), while no photon coincidences are measured at non-symmetric channels. Furthermore, the generated photon pairs are single-frequency mode, and the measured heralded correlation of $g_h{}^{(2)}(\tau = 0) = 0.14 \ll 0.5$ underlines the quantum nature of our source and its suitability as a heralded single photon source. Our demonstrated quantum frequency comb constitutes an important step towards realizing practical integrated quantum optical technologies.

Mathieu Chagnon, McGill University (mathieu.chagnon@mail.mcgill.ca)

On the Viability of DSP Enabled Short Reach Optical Interconnects for Data Center Applications

Pedro Rojo-Romeo, INL/Ecole Centrale de Lyon (pedro.rojo-romeo@ec-lyonfr)
with B. Wague, X. Hu, S. Cueff, R. Orobtchouk, G. Saint Girons and B. Vilquin

Low Loss Hybrid Silicon/Ferroelectric Oxides Integrated Optical Devices on SOI

CMOS electronics is reaching limits in terms of speed, bandwidth and power consumption. To overcome these limits, on-chip optical interconnections seem to be a good candidate. To increase the performances of silicon photonics or to introduce new functionalities on a Silicon platform, functional materials seem very interesting. In that context, ferroelectric oxides with naturally strong electro-optical coefficients are promising candidates for high-speed modulators and switches. It is therefore of particular interest to implement these functional oxides on silicon based photonic platforms. However, the heterogeneous integration of such materials is still challenging. In a first section, we study the epitaxial growth of $BaTiO_3$ (BTO) and $Pb(Zr_x,Ti_{1-x})O_3$ (PZT) on silicon, using a $SrTiO_3$ template. A comparison is done between Molecular Beam Epitaxy (MBE) and sputtering deposition methods. Then we present the design of a photonic device based on a slot waveguide to both confine the optical mode and maximize the electro-optical overlap within the active ferroelectric layer. Technological process is detailed. We then present the first experimental results, and expose the potential origins of optical losses in such systems and how to avoid them. We further discuss on the latest experimental results, expected performances and future devices.

We acknowledge funding from the European Commission under project FP7-ICT-2013-11-619456 SITOGA.

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Electronic Enhanced Integrated Photonics for Efficient Data Communications

The recent advancement in photonic integration, particularly Silicon Photonics (SiP) technology, has enabled greater and more efficient data communications. Beyond the bandwidth density benefits, photonic integration allows for new approach in the co-design and co-packaging of photonics with its associated electronics leading to enhanced performance. Recent experimental results obtained related to this paradigm will be presented. Specifically, the following topics will be discussed: 1) a low-latency controller of SiP switch matrix for interconnection networks, 2) a low-power high-speed optical time sampling SiGe photoreceiver, and 3) a novel waveguide structure that can simultaneously support both high-speed optical and RF electrical signals.

Werner Hofmann, Technischen Universität Berlin (Werner.Hofmann@tu-Berlin.de)

Multimode Small-Signal Analysis of Ultra-High-Speed VCSELs

Optical interconnects, based on directly modulated VCSELs with ultimate speed ratings are an enabling technology for future access networks and data-centers.

The devices discussed here are an optimized version of our very successful high-speed, temperature-stable 980 nm VCSELs. The VCSELs showed modulation bandwidth around and exceeding 30 GHz.

Analyzing the small-signal data turned out to be non-trivial as the well calibrated measurement with low noise did not fit well with simplified single-mode rate equation models. Consequently, a detailed theoretical small-signal analysis was performed with the following findings:-In case of one common carrier reservoir, multi-mode rate equations fall back to the shape of the single-mode case. This is the reason why in many cases single-mode models used to work well in practice for multi-mode VCSELs.-For ultra-high-speed multi-mode VCSELs carrier reservoirs are formed self-organized due to spatial hole burning. These reservoirs communicate and change the dynamic properties of the device.

The measured data fits very well to the extended model. The common set of figures of merit is extended consistently to explain dynamic properties caused by carrier fluctuations.

Zhaojun Liu, SYSU-CMU Joint Institute of Engineering (liuzhaojun@mail.sysu. edu.cn)

Homogeneous Integration of GaN High Electron Mobility Transistors and Light Emitting Diodes (HEMT-LEDs) by MOCVD

Homogeneous integration of GaN-based high electron mobility transistors and light emitting diodes (HEMT-LEDs) have been attracting more and more attentions over the past years due to their wide application in displays, smart lighting, and high frequency switching applications such as visible light communications. Limited reports can be found about integrating these two kinds of devices successfully with superior performance. In this talk, I will review the work of integrating HEMTs and LEDs monolithically. A metal-interconnection-free integration scheme for InGaN/GaN LEDs and AlGaN/GaN HEMTs by combing selective epi removal (SER) and selective epitaxial growth (SEG) techniques. SER of HEMT epi was carried out first to expose the bottom unintentionally doped GaN buffer and the sidewall GaN Channel. The LED structure was regrown in the SER region with the bottom n-type GaN layer connected to the HEMTs laterally, enabling monolithic integration of HEMT-LEDs without metal-interconnections.

Glenn Cowan, Concordia University (gcowan@ece.concordia.ca)

Low-Power Optical Receivers for NRZ Data and Microwave Photonics Applications

This presentation will give an overview of on-going research activities in low-power optical receivers for two applications. The first is for NRZ data in short-reach links. Due to tighter integration between electronics and optical components, overall input capacitance is decreasing allowing for new design approaches, throwing out old assumptions of having a receiver bandwidth near the data rate for an NRZ link. Three emerging approaches, in some cases forgoing the traditional transimpedance amplifier include: 1) Integrate and reset 2) Dynamic offset modulation and 3) Equalization based receivers. In this presentation we show our preliminary, comparative analysis of these approaches.

The second application deals with the processing of radio-frequency signals in the photonics domain thereby allowing for high-Q filtering not possible using electronics. Such systems require highly linear circuits in the electrical to optical and optical to electrical converters. In this talk we present our work in main amplifier design for linear optical receivers.

Session C5: Optoelectronics and Photonics

Chair 1: Laurent Francis, Université Catholique de Louvain (laurent.francis@uclouvain.be)

Laurent Vivien, University of Paris-Sud (laurent.vivien@u-psud.fr) with P. Damas, X. Le-Roux, M. Berciano, G. Marcaud, C.A. Ramos, D. Benedikovic, D. Marris-Morini and E. Cassan

Silicon Photonics for Low Power Consumption Communications

Silicon photonics is being considered as the future photonic platform, mainly for the reduction of photonic system costs and the increase of the number of functionalities on the same integrated chip by combining photonics and electronics. However, silicon is a centrosymmetric crystal, which inhibits Pockels effect: a second order nonlinear effect, which allows for high speed and low power consumption light modulation Over the last few years, several research groups are exploring Pockels effect in strained silicon. In this work, we present recent developments on the subject taking into account parasitic effects including plasma dispersion effect and fixed charge effect under an electric field.

Nicolas André, Université Catholique de Louvain (nicolas.andre@uclouvain. be) with G. Li, G. Pollissard-Quatremère, N. Couniot, P. Gérard, Z. Ali, F. Udrea, Y. Zeng, L. A. Francis and D. Flandre

SOI Sensing Platforms for Water Vapour and Light Detection

In this paper, the performances of two sensors based on the same micro-machined silicon-on-insulator (SOI) suspended platform are reported. Our motivation is to develop a low cost, low power and reliable sensor with integrated electronics interface for applications from ambient to 200°C.

The first sensor is a humidity sensor based on coated electrodes embedded with its own temperature sensor. It exploits an atomic layer deposited 25 nm-thick Al_2O_2 coating, in opposite to conventional polymer-based humidity sensors. The %RH variations are transduced into capacitance then converted to oscillating voltage period variations with a 200 μW low power consumption. At 25°C, the sensitivity to humidity is equal to $\sim$2.5%/%RH. The frequency output shows $\pm$2% %RH level accuracy. This sensing micro-system was successfully tested up to 150°C.

The second sensor is a suspended photodiode with a lateral silicon-on-insulator P+P–N+ (PIN) diode. The gold bottom of ceramic packages acts as a back mirror and gives a global better responsivity up to 2.5x responsivity for specific wavelengths around 500, 600, 750 nm. The photodiode can work up to 200°C, with in-situ temperature sensing and control.

Pablo Bianucci, Concordia University (pablo.bianucci@concordia.ca)

The Interplay of Light and Matter in Optical Microresonators

An optical microresonator is a structure that tightly confines light at a microscopic scale. They are a very active research topic due to their remarkable optical properties and potential applications in areas as varied as sensing and photonics. Whispering gallery resonators are a particular kind, made of dielectric materials and characterized by a round cross-section, where light is tightly confined beneath the surface of the resonator by total internal reflection. Many geometries show whispering gallery-type optical resonances, such as spheres, rings, cylinders, etc. The optical confinement achieved in whispering gallery microresonators can significantly enhance the interaction between the confined light and the resonator material, both in quantitative and qualitative ways, and we can harness these changes to our advantage. In this presentation I will discuss the working principles of different optical microresonators, and the fabrication and characterization of some select whispering gallery microresonators, as well as some of their applications.

Tao Lu, University of Victoria (taolu@ece.uvic.ca) with W. Yu, W. Jiang and Q. Lin

Whispering Gallery Microcavity Optomechanical Sensing of Single Molecules

When on resonance, light circulating in a whispering gallery microcavity produces radiation pressure that can drive the cavity in mechanical oscillation. This is known as optomechanical oscillation (OMO). The mechanical oscillation frequency f_{OMO} are related to both the effective mass keff and spring constant keff of the cavity according to the Hooke's law $f_{\mathrm{OMO}} = 1/(2\pi)\sqrt{(k_{eff}/m_{eff})}$. A particle adsorbed on the surface of the cavity increases the effective mass, leading to a shift of OMO frequency. Traditionally, by detecting this mass induced frequency shift, researchers can detect a particle with a minimum mass around 1 picogram. In our research, we observed that a nanoparticle landing on the whispering gallery cavity surface also detunes the cavity resonance wavelength, which induces a shift of the optical spring constant. This shift results a change of f_{OMO} orders of magnitude larger than that induced by the addition of particle mass. Using this principle, single 10-nm-radius silica beads and Bovine serum albumin (BSA) molecule with molecular weigth of 66 kDalton was detected at a high signal-to-noise ratio. The theoretical analysis further predicts a sub-atomic resolution using this technique by further optimization of the system.

Qijie Wang, Nanyang Technological University (qjwang@ntu.edu.sg)

Graphene Mid-Infrared and Terahertz Optoelectronics

Graphene has attracted significant attention in the past few years for mid-infrared and Terahertz applications owing to its promising optical properties. I am going to present our recent research in graphene mid-infrared photodetectors, mid-infrared plasmonics and Terahertz modulators.

Session C6: Wireless

Chair 1: Minoru Fujishima, Hiroshima University (fuji@hiroshima-u.ac.jp)

Ioanis Nikolaidis, University of Alberta (nikolaidis@ualberta.ca)

Exploiting Multi-Packet Reception Capabilities in Multi-Hop Wireless Networks

We present a series of attempts to create a Medium Access Control (MAC) protocol suitable for multi-hop communication for wireless nodes with transceivers capable of Multi-Packet Transmission/Reception (MPT/MPR). Whereas the MPT/MPR capability appears to be a straightforward extension (and relaxation) of the conventional collision channel model, exploiting its full potential is far from obvious. Correspondingly, the MPT/MPR solution space cannot be sufficiently described by the conventional collision graph models. We introduce a benchmark model based on a formulation amenable to water-filling algorithmic treatment and we use the benchmark to assess the potential of MAC protocols specialized to MPT/MPR under various coordination assumptions, ranging from local to global. A common characteristic of the considered MAC protocols is their reliance on approximate forms of a "backpressure" mechanism. We note that from the simulation results collected, while the performance obtained can be superior to a, suitably scaled, 802.11 system, it is dependent on the coordination scheme assumed. We subsequently reflect on what kinds of coordination information needs to be conveyed and, even more fundamentally, what is the nature of the underlying discrete graph problem whose solution such protocols must approximate.

This is joint work with Dr. Ke Li and Prof. Janelle Harms.

Harish Krishnaswamy, Columbia University (hk2532@columbia.edu)

Rethinking The Functional Boundaries of Integrated Radio-Frequency Systems Enables New Wireless Communication Paradigms

Ramesh Harjani, University of Minnesota (harjani@umn.edu)

Ultra-Low-Power Radio Designs

With the advent of the internet of things (IoTs) and the increased desire for untethered patient monitoring has made it critical to design extremely energy efficient radios. In particular, we will describe novel transmitter and receiver architectures for 802.15.6 compliant wireless body area networks (WBAN). Our standard compliant designs focus on the 118 channels available in the new Medical Body Area Network (MBAN) band (2360–2400 MHz) and Industrial Scientific & Medical (ISM) band (2400–2483.5 MHz). However, the novel architectures are primarily designed for energy efficiency and the concepts developed here are equally applicable to other ultra-low-power radio requirements. In particular, we will describe a WBAN transmitter using phase multiplexing and a WBAN receiver employing frequency translated mutual noise cancellation.

Okundu Omeni, Toumaz (Okundu.Omeni@toumaz.com)

Performance Analysis of Low Power Wireless Standards using Statistical QoS for Wearable and Implantable Medical Use Cases

Replacing traditional wired patient monitoring devices in hospitals with wireless equivalents requires wireless connectivity with very high QoS. This is however at odds with the requirement for low power operation needed to support small form factors for wearable and implantable use cases. A limited radio power budget results in a link which is more susceptible to interference, hence leading to potentially unreliable communication. In this talk we present statistical QoS analyses for a number of candidate low power wireless technologies at various BER and channel interference conditions. BLE, 802.15.4 and 802.15.6 wireless protocols were investigated by running packets through a model of the PHY and LL/MAC under a variety of channel conditions. Our results show that the most recent standard-802.15.6 (WBAN) – which was developed specifically for this type of application, provides the best QoS, and the talk will highlight key protocol features which underpin this QoS provision.

Marvin Onabajo, Northeastern University (monabajo@ece.neu.edu)

Subthreshold RF Circuit Design for Short-Range Wireless Communication Applications

A major challenge in many emerging battery-powered wireless devices is that the radio frequency (RF) front-end section consumes excessive power. It is essential to create novel analog circuit design methods with significant power reductions for short-range communication applications. In this talk, linearity enhancement techniques for analog RF front-ends will be presented with simulation and measurement results of low-noise amplifier and active down-conversion mixer designs in CMOS technologies. The linearization methods involve extra passive components to accomplish partial cancellation of third-order nonlinearity products, thereby reducing the distortion caused by subthreshold biasing to enable more widespread adoption of low-power design methods.

Sudhakar Pamarti, University of California, Los Angeles (spamarti@ee.ucla.edu)

Linear Periodically Time Varying Circuits for Radio Receiver Applications

Sharp, programmable, linear, integrated filters are enabling components for software defined and cognitive radio applications. However, they are difficult to realize: SAW and MEMS based filters are sharp and linear but not very programmable; active filters can be sharp and programmable but are not very linear; sampled charge domain filtering is sharp and programmable but the burden of the linearity is on the front end V-I converter. This talk describes an alternative approach that uses time varying (as opposed to LTI) circuits. The technique exploits sampling aliases to effectively realize very sharp, linear filtering prior to sampling. Measurement results from recent ICs will be presented and the LPTV filters compared to mixer-first and N-path filters.

Ehsan Afshari, Cornell University (ehsan@ece.cornell.edu)

THz: The Untapped Spectrum

Zheng Wang, University of California, Irvine; Qualcomm (wangz1@uci.edu)

Terahertz Fundamental Frequency Transceivers in Nanoscale Silicon

The vastly under-utilized spectrum in the sub-THz frequency range enables disruptive applications including 10Gbps chip-to-chip wireless communications and imaging/spectroscopy. Owing to aggressive scaling in feature size and device $f_T/f_{\max}$, nanoscale CMOS technology potentially enables integration of sophisticated systems at this frequency range. In the terahertz frequency range, the system's operation frequency is getting more and more close to the maximum oscillation frequency $f_{\max}$ of transistor. The lack of front-end amplification results in high power consumption and noise figure. Some techniques back to 1960s, which are overlooked by the main-stream CMOS designers, are revisited and employed for the purpose of obtaining enough amplification in the THz frequencies. Based on this study, a 210GHz fundamental transceiver is demonstrated which exhibits higher efficiency compared harmonic-based transceiver.

Kenichi Okada, Tokyo Institute of Technology (okada@ssc.pe.titech.ac.jp)

Millimeter-Wave CMOS Transceivers Toward More Than 1Tbps

In this presentation, a way to realize 1Tbps in wireless will be discussed, and millimeter-wave transceivers in a 65-nm CMOS are introduced. A 60GHz CMOS transceiver achieves a data rate of 42.24-Gb/s using 64QAM in IEEE802.11ad/ay, and a W-band CMOS transceiver achieves 56-Gb/s using 16QAM with a frequency-interleave architecture.

Minoru Fujishima, Hiroshima University (fuji@hiroshima-u.ac.jp)

300GHz CMOS Wireless Transmitter

We have demonstrated wireless transmission of 17.5Gbps/ch over 6 channels in the 300GHz band (275GHz to 305GHz), which is in terahertz (THz) band and anticipated for new international frequency allocation. Conventionally, THz wireless communication mainly used compound semiconductors with simple modulation. On the other hand, we have used CMOS integrated circuits for a 300GHz wireless transmitter, which are easy to combine digital circuits. In the 300GHz CMOS transmitter, frequency conversions from the intermediate frequency band to the 300GHz band without distorting modulated signals by a newly-proposed "cubic mixer". These conversions are realized by simultaneously providing the local-oscillator signals and the modulated signals in the "cubic mixer" with third nonlinear characteristics. Moreover, power-combining technique which enhances the output signals in the 300GHz band by connecting 32 RF (300GHz) signals in parallel. And a proposed active balun effectively generates the differential signals required for wireless communication circuits with distributing and amplifying the input signals. As a result, this new technology has realized wireless communications of quadrature amplitude modulation (QAM) in the frequency range beyond the maximum operation frequency (*fmax*) of a MOSFET.

Brian Moore, ACAMP (bmoore@acamp.ca)

Practical Considerations for Simulation and Characterization for Antenna Design Certification

The "Internet Of Things" (IOT) is bringing unprecedented opportunities to create efficiency and convenience in a variety of fields.

The plethora of ideas from the DIY and the maker-space communities is creating new products for advancing awareness and for general utility especially in the IOT area.

One area often overlooked is when IOT concepts are applied to industrial applications specific problems arise. Industrial applications require robustness and reliability not addressed in consumer level products. In addition to existing standards IOT concepts are challenged by environmental and lack of reliable power supply infrastructure in industrial and remote areas.

We show the challenges involved in the case of a remote wireless sensor used in the energy industry. Specifically the challenge and solutions involved in a custom antenna for cellular data services. Here we show simulation and prototyping are a must before attempting regulatory testing. Successful technical design for the technologies going into new products is key for business success.

Hangue Park, Georgia Tech (hpark90@gatech.edu)

Wireless Intraoral Device: Recent Advances and Remaining Hurdles

The intraoral device holds a unique position to efficiently interact with intraoral organs and is recently being developed for several purposes such as tongue-computer interface, blind navigation, artificial larynx, and drug diffusion. The intraoral device can also be firmly fixed onto the teeth and maintain its relative position to intraoral organs. Furthermore, the intraoral device gives users a certain degree of privacy by being completely hidden inside the mouth.

In the implementation of the intraoral device, size constraint is very important because the intraoral device should not interrupt natural functions of intraoral organs. Fortunately, the rapid development of integrated circuit and battery miniaturization technologies alleviated the technological burden in reducing the size of the intraoral device.

The wireless connectivity is essential function of the intraoral device, to monitor the operation of the intraoral device, to change its operation parameters, or to receive data from it. However, human body is strong attenuator of the radio frequency signal. Furthermore, the intraoral device stays inside the mouth where the intraoral environment keeps changing, which potentially worsens the wireless connectivity.

This talk will introduce recent advances and remaining hurdles, in the implementation of the intraoral device and its wireless connectivity.

Track D: Biotechnology

Session D1: Bioelectronics

Chair 1: Fabio Cicoira, École Polytechnique de Montréal (fabio.cicoira@polymtl.ca)
Chair 2: Kalle Levon, New York University (kalle.levon@gmail.com)

Derek Ho, City University of Hong Kong (derekho@cityu.edu.hk)

Nanoscale Biological and Chemical Sensors: Recent Progress and Future Perspective

Advances in nanoscale CMOS circuits and nanostructured material synthesis have brought a revolution in biological and chemical sensor technologies. Sensors are becoming more sensitive, selective, and are able to sense an unprecedented large range of targets. In this talk, I will present noteworthy recent discoveries from the Atoms-to-Systems Lab at the City University of Hong Kong. I will provide a walkthrough of sensor prototypes, such as a hybrid quantum dot-CMOS microsystem for fluorescence DNA detection and a nanostructured metal-oxide thin-film sensor for chemical detection. These technologies are expected to be an integral part of sensor development in the next decade.

Clara Santato, École Polytechnique de Montréal (clara.santato@polymtl.ca)

Melanin Pigments: En Route Towards Environmentally Benign Electronics

Melanins are biomacromolecules responsible for the pigmentation of many plants and animals. The biological functions of melanins, also present in the inner ear and the substantia nigra of the human brain, include coloration, photoprotection, anti-oxidant behavior, and metal chelation.

We will discuss extended structure properties relationships in melanins. The interfaces of melanin with metals and electrolytes under electrical bias will be critically presented considering the metal binding properties of melanins.

The study is relevant to demonstrate biodegradable and biocompatible electrochemical energy storage devices and novel technologies based on hybrid ionic and electronic transport.

Roisin Owens, École des Mines de Saint-Étienne (owens@emse.fr) with G. Malliaras

Multi-Parameter Monitoring of in vitro Tissue Models using Organic Electronics

Organic bioelectronics refers to the coupling of conducting polymer based devices with biological systems, proven repeatedly in the last decade to provide numerous advantages to a wide variety of biomedical applications in terms of sensitivity, specificity and most importantly, bridging of the biotic/abiotic interface. We focus on the unique properties of organic electronic materials that allow easy processing, and flexibility in design as well as chemical tunability, to develop state-of-the-art tools to (1) develop relevant *in vitro* models by creating more "*in vivo*" like environments and (2) monitor cells i.e. for diagnostic purposes for monitoring toxicology *in vitro*. We previously successfully demonstrated the use of the organic electrochemical transistor (OECT) for monitoring *in vitro* models of the gastrointestinal tract, the kidney and the blood brain barrier. In this presentation, I will focus on new work that we have carried out to increase the sensitivity of our devices for monitoring a broader selection of tissues *in vitro*, integration of our devices with cells in 3D formats, and finally, inclusion of multi-parameter monitoring by additional functionalities such as metabolite sensing and high resolution optical imaging into our devices.

Pedram Mohseni, Case Western Reserve University (pxm89@case.edu)

An Integrated Neurochemostat for Closed-Loop Regulation of Brain Dopamine

New enabling technologies for real-time, high-fidelity sensing and manipulation of brain neurochemistry at microscopic scales can provide the framework for ultimately developing new neuromodulation devices that impose therapeutic neurochemical profiles or maintain optimal neurochemical levels in disease states via real-time feedback control.

This talk will first introduce the fundamentals of fast-scan cyclic voltammetry (FSCV) at a carbon-fiber microelectrode (CFM) as the preferred method for probing brain neurochemical dynamics with high temporal, spatial, and chemical resolution. The talk will then focus on integrated systems that combine FSCV-based recording, embedded signal processing, and electrical stimulation on a single chip for high-fidelity manipulation of brain neurochemistry. System-and circuit-level solutions to handle stimulus artifacts along with chemometrics-based algorithms to resolve the target analyte from common interferents *in vivo* will be discussed. One such system realizing a neurochemostat for closed-loop regulation of brain dopamine levels will be showcased and validated through neurobiological experiments in the forebrain of an anesthetized laboratory rat.

Session D2: Biomaterials

Chair 1: Šeila Selimović, American Association for the Advancement of Science (sselimov@gmail.com)
Chair 2: Usha Varshney, National Science Foundation (uvarshne@nsf.gov)
Konrad Walus, University of British Columbia (konradw@ece.ubc.ca)

Lab-on-a-Printer: New Concepts in 3D Printing and 3D Bioprinting

Michael Hilke, McGill University (hilke@physics.mcgill.ca) with E. Whiteway, V. Yu, W. Yang, Y. Zhang and W. Reisner

High Quality Graphene-Based Devices for Nanometer Imaging of Solutions and Bio Molecules

In-situ dynamic imaging of nanometer scale objects in solution is important for many applications, particularly in biological systems, where live motion is usually associated with wet environments. However, wet environments and very high resolution imaging are often incompatible, since typical electron microscopy requires high vacuum conditions. To circumvent these limitations we developed a wet cell with an atomic graphene window which allows us to combine high dynamic resolution with liquid environments. To minimize impurities on the membrane, the growth of large single graphene crystals, with minimal defects were optimized by Chemical Vapor Deposition (CVD).

Giorgio Contini, Università degli Studi di Roma "Tor Vergata" (giorgio.contini@ism. cnr.it)

Surface-Confined Polymerization as Emerging Technology for Electronic Devices

Novel nanostructured low-dimensional materials have received marked interest in the last decade since they could be employed as active media in organic electronics devices. Graphene-like two-dimensional organic materials can be grown and confined with different strategies onto suitable surfaces depositing and activating selected molecules. In this respect, the surface-confined polymerization is a very promising bottom-up approach that allows the creation of layers with desired architectures and tunable properties changing the molecules used as precursor.

In this talk I will report on some of the progresses made on surface-confined polymerization and on our studies on π-conjugated polymeric structures obtained in ultra-high vacuum (UHV) and at the solid-water interface by using Ullmann and Schiff-base coupling reactions, respectively.

Diego Mantovani, Université Laval (Diego.Mantovani@gmn.ulaval.ca)

Innovative Materials and Coatings for the Next Generation of Cardiac and Vascular Device

Over the last 50 years, biomaterials, prostheses and implants saved and prolonged the life of millions of humans around the globe. The main clinical complications for current biomaterials and artificial organs still reside in an interfacial mismatch between the synthetic surface and the natural living tissue surrounding it. Today, nanotechnology, nanomaterials and surface modifications provides a new insight to the current problem of biomaterial complications, and even allows us to envisage strategies for the organ shortage. Advanced tools and new paths towards the development of functional solutions for cardiovascular clinical applications are now available.

In this talk, three distinct but complementary applications will be targeted with the overall aim to envisage today how far innovation can bring tomorrow medical devices. They provide short, medium and long-term solutions for cardiovascular clinical problems, respectively. First, how to improve the adhesion and stability of functional nano-coatings for medical devices will be addressed. The adhesion and the stability of nano-coatings (thickness less than 100 nm) are a major concern, and a recognised main short term challenge in blood-contact applications. In one hand, nano-coatings bring functionalities and provide unconventional properties to devices, tools and medical technologies. In the other hand, the assessment of the adhesion of nano-coatings onto metallic or polymeric substrates is not trivial, especially in reason of their low thickness.

Second, the potential of nanostructured metallic degradable metals to provide innovative solutions at medium term for the cardiovascular field will be rapidly depicted. Finally, a new approach for processing materials and cells directly into scaffolds rather the incorporating cells into porous scaffolds will be described. The potential of dynamic cell culture in 2D and 3D will be discussed.

The intrinsic goal of this talk is to present an extremely personal look at how nanotechnology can impact the innovation in materials, surfaces and interfaces, and how the resulting extreme properties allowed biomedical functional applications to progress, from the glory days of their introduction, to the promising future that nanotechnology may or may not hold for continuing improve the quality of the life of millions worldwide.

Fabio Cicoira, École Polytechnique de Montréal (fabio.cicoira@polymtl.ca)

Conducting Polymers for Bioelectronics and Flexible Electronics

Organic electronic devices, based on semiconducting and conducting polymers, have found wide commercial applications in lighting panels, smartphone screens, and TV screens using OLEDs (organic light emitting diodes) technology. Many other applications are foreseen to reach the commercial maturity in future in areas such as OFETs (organic field effect transistors), sensor devices, and organic photovoltaics. This success was due to many unique and desired properties of organic semiconductors in comparison to their inorganic counterparts such as mechanical flexibility, tunability of electrical and optical properties via chemical synthesis, ease of processing, and low temperature fabrication.

My talk will give an overview of the activity of my research group on processing and characterization of conducting polymer films and devices for flexible and stretchable electronics. I will particularly focus on micro-patterning of conducting polymer films for flexible and stretchable devices and on grafting of biological species on conducting polymer surfaces.

Hedi Mattoussi, Florida State University (mattoussi@chem.fsu.edu) with W. Wang, A. Kapur and X. Ji

Enhancing the Biological Compatibility of Inorganic Nanocrystals using an Amphiphilic Polymer

Nanocrystals such as those made of semiconductors and metal oxides possess unique photo-physical properties that are appealing for use as probes in a variety of biomedical applications. Here we develop a set of multifunctional polymers as metal-coordinating ligands optimized for interfacing a variety of nanocrystals with biological systems. The ligand design relies on the introduction of several anchoring groups, hydrophilic moieties and reactive functionalities into the same polymer chain. We show that polymer-coated QDs are compact, colloidally stable, and can engage in charge transfer interactions. Additionally, when coupled to specific peptides the nanocrystals are easily uptaken by live cells.

Kalle Levon, New York University (kalle.levon@gmail.com)

Hybrid FET Array with CMOS and Organic Electronic Components

The disadvantages of CMOS based ISFET arrays in biodetection include poor performance under aqueous conditions, unstable EDL performace and limited immobilization chemistry. Advantages on the other hand are the well-known great opportunities for multiplexing, low cost and sensitivity. Organic electronics are suitable for surface bioconjugation strategies due to the convenient organic chemistry routes. They also as advantageous hybrid materials for microelectronic biosensors due to their high bandgap sensitivity for the capacitance tuning, possibilities for nanoscale surface area formation and stabilization of the EDL. We shall present how organic conductors can be used to functionalize ion sensitive floating gate field effect transistors (ISFGFETs) designed to measure biological binding events. Our conductive polymer modified ISFGFET sensor arrays are a promising alternative to potentiometric biosensors due to their signal amplification, high throughput and scalability advantages.

Cindi Dennis, National Institute of Standards and Technology (cindi.dennis@nist .gov)

Role of Surface Coating of Magnetic Nanoparticles on their Effectiveness for Biomedical Applications

In recent years, there has been significant progress in the development of magnetic nanoparticles (MNPs), especially for biomedicine. One important synthetic aspect is the MNP's coating, which ensures stability of the MNPs in solution. However, it is typically assumed that individual MNPs are coated uniformly, and that there is no structure to the colloid. Here, we will show that this assumption is not necessarily valid, and demonstrate the impact of the coating on the structure, magnetic properties, and application-specific efficacy of the colloid. We will consider two different coatings on iron oxide nanoparticles: soft (dextran) and hard (SiO_2). Both coatings provide stability for months to years. However, the hard silica coating does not coat individual MNPs, but rather clusters. This rigid binding of the MNPs increases the coercivity of the colloid. In contrast, the soft dextran coating can coat individual MNPs, but they lose their individuality through collective behavior even at very low applied magnetic fields, forming local "magnetic flux-closure" structures (e.g. rings). This changes the magnetization dynamics. These changes in the magnetic properties result in different efficacies of the colloids for the cancer treatment hyperthermia and magnetic imaging.

Paulo Tambasco de Oliveira, University of São Paulo at Ribeirão Preto (tambasco @usp.br) with R.B L. Bueno, L.N. Teixeira, A.L.G. de Almeida, A.C. Soares, M.M. Beloti, C.E. Sverzut, O.N. de Oliveira Jr., A. Nanci and A.L. Rosa

Growth and Differentiation Factor 5 (GDF-5)-Functionalized, Nanostructured Titanium Surfaces: in vitro and in vivo Osteogenic Differentiation

It has been demonstrated that a nanostructured (Nano) titanium (Ti) surface obtained by treatment with 1:1 sulfuric acid/hydrogen peroxide and functionalized with growth and differentiation factor 5 (GDF-5) by simple adsorption promotes the enhancement of mineralized matrix formation *in vitro*. In order to extend these findings, the present study aimed to evaluate 1) *in vitro* the acquisition of the osteogenic phenotype by rat calvaria-derived cell cultures grown on machined Ti and Nano Ti disc surfaces functionalized with 200 ng/mL GDF-5 by either simple adsorption or layer by layer (LbL) films, and 2) in rabbit tibia key parameters of bone formation adjacent to Nano Ti implants functionalized with GDF-5 by the two methods described above. The simple adsorption method was performed on the day before primary cell plating or implant placement in bone. Briefly, Ti discs and Nano Ti implants were incubated overnight at 4°C with 200 ng/mL recombinant human (rh) GDF-5 (PeproTech, Rocky Hill, NJ). For the LbL films, the cationic polyelectrolyte and the polyanion used were, respectively, poly(allylamine hydrochloride) (PAH) and rhGDF-5; immersion time was 10 min for each solution. The growth of GDF-5 films was measured by ultraviolet-visible spectroscopy. The results showed that either the Ti surface topography or the method used for GDF-5 functionalization quantitatively affected mineralized matrix formation, with the higher osteogenic differentiation for the Nano Ti functionalized with GDF-5 by simple adsorption and the lower one for the LbL films, irrespective of the Ti surface topography on which they were mounted. Alkaline phosphatase activity was higher for cultures grown on the Nano Ti, including the GDF-5-functionalized Nano Ti, whose values, however, did not necessarily correspond to the higher osteogenic activity. Despite that, all groups expressed osteoblast differentiation markers, with a remarkable increase in osteopontin and osteocalcin mRNA levels for cultures grown on the LbL films. The microtomographic, histologic and histomorphometric analyses revealed no qualitative or quantitative differences *in vivo* among the Nano Ti implants, yet a tendency for enhanced bone formation was observed for the functionalized surfaces and, between them, for the LbL films. Taken together, our results contribute to a better understanding of osteoblastic cell and bone tissue responses to the functionalization of Nano Ti surfaces with rhGDF-5 aiming to optimize osseointegration.

Session D3: Medical and Biological Imaging

Chair 1: Chair to be Announced

Ralph James, Brookhaven National Laboratory (rjames@bnl.gov)

Compound Semiconductors for X-and Gamma-Ray Spectroscopic and Imaging Applications

Compound semiconductors are important for detecting and imaging X-and gamma-ray radiation. Cadmium Zinc Telluride (CZT) is the most extensively studied material today due to its band-gap, high atomic number, availability of large crystals, and good charge-carrier transport properties. We are pursuing a two-pronged approach to advance the technology, (1) Identify and fix defects in the crystals, and (2) Use the best material for fabricating detectors and incorporating them into instruments. We will report on the physical properties of CZT at the micro-scale level, correlations of the crystal's defects with device performance, and development of field-portable instruments using the technology.

Stefan Ulzheimer, Siemens (Stefan.Ulzheimer@siemens.com)

Directly Converting Detector Materials in Medical Computed Tomography – A Status Update

Roger Lecomte, Université de Sherbrooke (Roger.Lecomte@USherbrooke.ca)

An Overview of Molecular Imaging Technologies

Session D4: Medical Technologies

Chair 1: Konrad Walus, University of British Columbia (konradw@ece.ubc.ca)
Chair 2: Sivashankar Krishnamoorthy, Luxembourg Insitute of Science and Technology (sivashankar.krishnamoorthy@list.lu)

Šeila Selimović, American Association for the Advancement of Science (sselimov@gmail.com)

From Lab-on-a-Chip to Organism-on-a-Chip: Advances in and the Future of Tissue Chips

In this talk, I will offer a view of the most recent developments in the organ-on-a-chip area of tissue engineering. From initial single-cell experiments on-a-chip, the field has seen an exciting development of various tissues: lung, heart, skin, liver, and even bone. The next goal for scientists and engineers is to combine several of these TissueChips for a better understanding of the intricate relationships between multiple organs in a body. I will discuss the major hurdles in this endeavor and the most promising avenues for solutions.

Hao Yu, Nanyang Technological University (haoyu@ntu.edu.sg)

CMOS Integrated Lab-on-a-Chip System for Personalized Biomedical Diagnosis

Considering the current aging society, the future personalized biomedical diagnosis requires portable biomedical devices with miniaturization of bio-instruments. The recent development of lab-on-chip (LoC) has provided a promising integration platform of sensor and microfluidic channel. This talk will report our recent progress in smart multi-modal sensor at NTU CMOS Emerging Technology Group (www.ntucmosetgp.net) with two focused topics. The first work (highlighted by IEEE VLSI-SYMP 2014 and IEEE TBME 2015) is about the CMOS integrated ion-sensitive-field-effect-transistor (ISFET) sensor for DNA sequencing. The existing ISFET sensor has low accuracy due to faulty pH values as well as poor device non-uniformity. With the development of a dual-mode (chemical + optical) CMOS ISFET sensor (in 0.18um and 65nm), one can improve sequencing accuracy significantly by correlated readout with data fusion. The second work is about a high-sensitivity backside-illumination CMOS image sensor (3Mega in 65nm) and its application in lensless microfluidic imaging for blood cell counting, where machine-learning enhanced super-resolution will be also briefly discussed.

Daniel Milanese, Politecnico di Torino (daniel.milanese@polito.it) with
E. Ceci-Ginistrellia, D. Pugliesea, N.G. Boettib, C. Vitalea, G. Novajraa and
J. Lousteauc

Bioresorbable Phosphate Glass Fibers for Diagnosis and Therapy

Optical fibers are widely employed for numerous biomedical applications, such as diagnosis (imaging, fluorescence spectroscopy), therapy (laser delivery and surgery) and real-time sensing. Typically, the implementation of optical fibers in the biomedical field has foremost focused on the biocompatibility of the fiber material. The development of bioresorbable optical fibers could pave the way towards novel biomedical devices that combine several health diagnostic functionalities in compact format.

We will report our recent activities concerning the design and fabrication of bioresorbable phosphate glass compositions, able to combine solubility in aqueous media, transparency in the near UV region, low intrinsic attenuation loss and thermal stability during fiber drawing. The prepared glasses were characterized in terms of their thermal and optical properties. Suitable core and cladding glass pair was selected and multi-mode and single-mode optical fibers were fabricated by preform drawing, using an in-house delevoped drawing tower. The dissolution rate of the so-obtained fibers was measured by prolonged exposure in simulated body fluid. In the prospect of drug delivery combined with light guiding for photodynamic therapy, fiber capillaries were drawn from glass tubes obtained by rotational casting technique. Future developments of biophotonic applications will be highlighted and compared with existing solutions.

Mark Trifiro, McGill University (mark.trifiro@staff.mcgill.ca) with P.J.R. Roche, M. Najih, M. Paliouras and A.G. Kirk

Real Time Q-Plasmonic PCR: How Fast is Ultra-fast?

Polymerase Chain Reaction (PCR) is a critical tool for all biological investigators and is set to make a significant impact in clinical and industrial applications. Plasmonic PCR using gold nanoparticles is a simple and powerful methodology to drive PCR reactions by the application of light. Next generation plasmonic PCR technology will allow various forms of PCR applications from small footprint handheld point of care diagnostic devices to large footprint central laboratory multiplexing devices reflecting its extreme scalability properties. In a significant advance, we introduce real time ultrafast plasmonic PCR, compatible with both label-free and fluorescence monitoring of amplicon production. Furthermore, plasmonic PCR has been substantially optimized to deliver a 30 cycle PCR in 54 seconds. This paper explores and demonstrates the label free plasmonic measurement concept, the delivery of ultra-fast cycling and performs all measurements using conventional PCR volumes. The utility of nanoparticle photothermal heating is reflected in its energy efficiency, simplicity, ease of use and cost effective fabrication of nanoparticles. These advances will have an immediate impact on the further development of PCR mediating critical roles in health-related diagnostic devices.

Fulvio Ratto, Consiglio Nazionale delle Ricerche (f.ratto@ifac.cnr.it)

The Development of Cellular Vehicles of Plasmonic Particles for the Photothermal Ablation and the Photoacoustic Imaging of Cancer

The clinical exploitation of plasmonic particles such as gold nanorods has become a remarkable mission for a broad community of scientists. These particles are proposed as contrast agents for various applications in biomedical optics, including the photothermal ablation and the photoacoustic imaging of cancer.

At present, one of the greatest challenges in nanomedicine is to optimize the delivery of functional nanoparticles into tumors. PEGylated gold nanorods exhibit hydrodynamic sizes that are ideal to leak into hyperpermeable tumors and are suitable for bio-conjugation with targeting units. PEGylated and bio-conjugated gold nanorods display high specificity *in vitro*, but their vast majority gets captured by the mononuclear phagocyte system upon injection into the bloodstream.

One radical alternative may be to exploit the chemotactic migration of cells such as macrophages, T cells, mesenchymal and neural stem cells, which are able to infiltrate tumors across all barriers and may be used to take up and to deliver functional cargos. Here, we disclose our recent achievements in the preparation of polycationic gold nanorods for a robust design of cellular vehicles that combine high optical absorbance, viability and chemotaxis. We discuss perspectives and limitations for their use as contrast agents for photoacoustic imaging, CT and photothermal treatments.

Aaron Fenster, Robarts Research Institute (afenster@robarts.ca)

Image-Guided Focal Ablation Systems to Treat Cancer

It is recognized that prostate cancer (PCa) is over-treated, and that conventional, whole gland therapies may be excessive for a large proportion of men with PCa. In this paper we describe our development of a mechatronic focal ablation system to treat PCa with minimal side effects. The system is MRI-compatible for accurate delivery of needles to the prostate for focal laser thermal ablation therapy. The system is operated while the patient is in the bore of the MRI system and can be used to plan, guide, and monitor the procedure and ensure that the complete tumour has been ablated.

Fiorenzo Vetrone, INRS (vetrone@emt.inrs.ca)

Harnessing Upconverted Light for Applications in Nanomedicine

The usefulness of upconverting nanoparticles (UCNPs) for applications in biology stems from the fact that they can be excited in the NIR region, which is silent to tissues. Moreover, they have the ability to (up)convert NIR light to higher energies spanning the UV-visible-NIR regions via a multiphoton process known as upconversion. Here, we present the synthesis and surface functionalization of various UCNPs and demonstrate how they can be used for various biological applications. Furthermore, we show how the upconverted light can be harnessed to trigger other light activated modalities.

Sungho Lee, Korea Electronics Technology Institute (slee@keti.re.kr)

Development of a Patch-Type Skin Sensor for Healthcare

Skin-type patch sensor as a wearable devices can be promising device in the sense that biological body condition can be measured unconsciously. In this talk, a skin-type patch sensor will be introduced. On the flexible patch, several electronics including temperature and humidity sensors are mounted. Thin-film PT-based temperature sensor shows linear temperature performance with flexibility. Also, polyimide-based humidity sensor helps the sensor flexible. To extend the battery time, a dedicated very low-power analog frond-end (AFE) IC is developed. The AFE contains the low-noise amplifier, sigma-delta modulator and analog and digital filters with only 150μA total current consumption. We developed a system prototype with Bluetooth low energy communication and flexible battery. With this efforts, the designed skin-type patch prototype was successfully measured on human bodies.

Mahmoud Almasri, University of Missouri (almasrim@missouri.edu)

An Impedance Biosensor with Rapid Detection Capability of Low Concentration of Foodborne Pathogens

An impedance biosensor for rapid detection of low concentration Escherichia coli O157:H7 was designed, fabricated and tested. The biosensor has the following innovative features: (1) a focusing region consisting of ramped down vertical (electroplated) gold electrode pair made along with 45o tilted thin film finger pairs. This configuration generates p-DEP force to concentrate the bacteria into the center of the microchannel, and direct them toward the sensing microchannel which has a diameter smaller than one-third of the first channel. The bulk fluid flows into the outer channel towards the waste outlets. (2) Bacteria sensing region consists of three interdigitated electrode arrays (IDEA) with varying number of fingers (30, 20 and 10 pairs respectively) coated with anti-*E.coli* antibody. As *E.coli* reaches the sensing region it binds to the antibody on IDEA surface, and results in impedance change. This has enabled detection of a very low concentration of bacteria with a very high sensitivity and rapidly. Fabrication of the biosensor was performed on a glass substrate using SU8 negative photoresist to form the microchannel, gold electroplating to form the vertical focusing electrode pair, thin gold film to form the detection electrode, the finger electrodes, traces and bonding pads, and PDMS to seal the device. Various low concentration *E.coli* samples were tested to determine the sensitivity of the biosensor and the lowest detection limit of the biosensor was found to be 39 CFU/ml. The total turnaround time, from antibody immobilization to pathogen detection was about 2 hours.

Maysam Ghovanloo, Georgia Tech (mgh@gatech.edu)

An Adaptive Q-Modulation Based Wireless Power Transmission to Implantable Microelectronic Devices

In this talk I am going to compare various methods for near-field inductive wireless power transmission to Implantable Microelectronic Devices (IMD) and discuss pros and cons of each method. Then I introduce one of the new approaches that we have called Q-modulation. It would allow adaptive on-the-fly adjustments on the wireless power transmission (WPT) link properties to accommodate the dynamic environment of IMD and a few other similar applications, while maintaining high power transmission efficiency (PTE) and power delivered to the load (PDL).

Valeriu Beiu, United Arab Emirates University (vbeiu@uaeu.ac.ae)

Elucidating the Low Power of the Brain – Why Ions Really Matter

Session D5: Microfluidics

Chair 1: Chair to be Announced

James Li, University of Texas (xli4@utep.edu) with S.T. Sanjay and M. Dou

A Paper/PMMA Hybrid Microfluidic 3D Microplate for ELISA

Enzyme linked Immunosorbent assay (ELISA), usually performed on multi-well plates, is one of the most widely used laboratory diagnosis methods. However, the applications of ELISA in low-resource settings are often limited by long incubation time, consumption of large volumes of precious reagents, and expensive and sophisticated equipment. Herein, we developed a simple, miniaturized PMMA (Poly (methyl methacrylate))/paper hybrid microfluidic ELISA microplate for low cost and high throughput infectious disease diagnosis. The novel use of paper inserted in microwells in this hybrid microplate facilitates rapid antigen immobilization, avoiding complicated surface modifications. The top reagent delivery channels and vertical flow-through wells in the middle PMMA layer can simply transfer reagents to multiple wells (7x8 wells), thus avoiding repeated manual pipetting and washing steps in conventional ELISA or the use of costly robots. Unlike traditional microplates, ELISA can be completed within an hour in this microplate. Additionally, results of colorimetric ELISA could be observed by the naked eye. Quantitative analysis was achieved by calculating the brightness of images scanned by a desktop scanner. Using this hybrid microplate, IgG and hepatitis B surface antigen (HBsAg) were analysed. Although no specialized ELISA equipment was used, the limits of detection of 1.56 ng/mL for IgG and 1.60 ng/mL for HBsAg have been achieved, which are comparable to commercial ELISA kits. We envisage that this hybrid microplate can be used to perform enormous bioassays that are currently performed in traditional microplates, in resource-limited settings. Financial support from NIH and UTEP MRAP is gratefully acknowledged.

Xinyu Liu, McGill University (xinyu.liu@mcgill.ca)

Paper-Based Microfluidic Biosensors: Moving Towards Practical Uses

This talk will present our recently development of the first microfluidic paper-based origami nano-biosensor, which integrates semiconductor zinc oxide nanowires (ZnO NWs) and electrochemical impedance spectrometry (EIS) biosensing mechanism, for label-free, ultrasensitive immunoassays. An ultralow limit of detection has been achieved for HIV p24 tests in human serum. Our ongoing efforts on the clinical evaluation of this biosensor will also be discussed.

Frédéric Sarry, Université de Lorraine (frederic.sarry@univ-lorraine.fr)

SAW Devices (Surface Acoustic Wave) for Microfluidic and Biological Applications

Nowadays there is a huge need to make low cost and highly integrable devices for biomedical applications. The reduction of device scales allows the decrease of sample volumes leading to reduce costs of reagents, reaction time and enhance efficiency and sensitivity of the analysis. Microfluidic systems are great technology to achieve these goals. During the last decade, it has become an important research axis in the world to achieve micro-total analysis systems (μTAS) with many embedded biological and or chemical reaction as DNA sequencing, protein analysis, PCR reaction, cell culture, immunoassay.

Common microfluidic chips are developed with closed silicon, glass or plastic channel. To move and interact with liquid or microdroplet, it is required to use microvalves and micropumps, which are difficult to develop due to several microtechnology steps. Moreover, the requested power to move liquid is inversely proportional to the microchannel dimensions. The smaller the chip, the higher is the required pumping power. This causes difficult integration. Furthermore, the surface to volume ratio being high, the reaction yield should decrease because the adhesion of reagents on the wall of channel.

In the last decades Surface Acoustic Wave (SAW) devices have been widely used in sensor and actuator applications such as chemical and biochemical sensors and Lab-on-a chip (LOC) system. LOC are important microsystems with promising applications in point-of-are (POC) testing that are intended to be used at or near the site where the patient is located, which do not require permanent dedicated space, and which are performed outside the physical facilities of clinical laboratories. Such an approach will not replace central laboratories but it should give a first response within less time and with no need of highly trained personnel. In order to conduct chemical analysis, it is essential to manipulate small quantities of biofluids and immobilize probe molecules on the surface of a transducer that react with the target molecules in the sample. LOC based on SAW devices can couple both microfluidic and sensor capabilities. The SAW device technology is relatively cost-effective because of the use of well-established MEMS microfabrication procedures. Due to their small size, they can be added into microscale system promising an excellent solution for fluid miniaturised platforms. This reduction of device scales allows the decrease of reaction times and reagent volumes, reducing the analysis cost, and enhancing the efficiency and sensitivity of analysis.

To realize sensor devices, for example, Shear Horizontal Surface Acoustic Wave (SH-SAW) are generated. This type of wave presents a reduce attenuation under liquid environment. This allows, for example, to detect protein or DNA by mass loading effects. Moreover, the wave should be perturbated with temperature, pressure and humidity.

Rayleigh Surface Acoustic Waves (R-SAW) are also used in microfluidic. This wave type interacts with discrete droplet. Compared with SH-SAW, this kind of SAW is coupled with the liquid and exhibits a longitudinal mode, which propagates in this one. Depending on the operating frequency and on the wave's power, the dynamics of the droplet can show different behaviors enabling to observe some phenomena such as internal mixing, heating, motion and atomization of droplet. These four effects have allowed to develop many µTAS or LOC such as concentrator and/or collector of microparticles, the control of liquid motion in two dimensions and in microchannel arrays, miniature inhalation therapy for pulmonary drug administration with atomization...Moreover, SAW devices can be coupled with continuous-flow microfluidic chips to focus microparticles or to select the path of microparticles between different directions.

These huge possibilities to interact with liquid and the ability to realize sensor devices show the potential of SAW devices to be used in microfluidic and biological applications.

Dave Sinton, University of Toronto (sinton@mie.utoronto.ca)

Microfluidics and Optofluidics for Energy Applications

Microfluidic and optofluidics methods developed primarily for medical applications have much to offer the energy sector. This talk will describe my group's recent work in two such areas: (1) microfluidics and optics for bioenergy and (2) microfluidics for fluids underground: CO_2, oil and gas. Within the bioenergy theme, we are developing photobioreactor architectures that leverage micro-optics and microfluidics to quantify and increase the productivity of microalgae. Within the fluids underground theme we are developing a suite of methods to study (a) pore-scale transport and reactivity, and (b) relevant fluid properties.

David Juncker, McGill University (david.juncker@mcgill.ca) with A. Olanrewaju, A. Tavakoli and F. Possel

Capillarics: Microfluidic Circuits using Capillary Effects Designed and Built using a Library of Capillary Elements

Capillary microfluidics are self-powered, peripheral free and can be made at low cost, and thus of great potential for point-of-care diagnostic applications. However, capillary flow is perceived as affording only limited control and restrictive with regards to the applications that can be addressed. We have developed a set of capillary elements, including pumps, channels, trigger valves, retention valves, and programmable retention burst valves that can be used to create advanced microfluidic circuits that deliver multiple reagents in predetermined sequences and different flow rates. Akin to electronics, these fluidics circuits can be assembled from basic capillaric building blocks. To reflect this analogy, we coined "capillarics". Capillaric circuits can be made by microfabrication or by rapid prototyping and 3D printing. The application of capillaric circuits to bioanalysis will be illustrated with immunoassays and bacterial assays, and specifically with a rapid test for urinary tract infection.

Ricardo Izquierdo, Université du Québec à Montréal
(izquierdo.ricardo@uqam.ca)

Integration of Organic Optoelectronic Devices on a Microfluidic Platform for Sensing Applications

Since the emergence of microfluidic platforms, optical sensor integration has been a major challenge. With the advances in miniaturization of these platforms, there is a need of solutions to integrate various optical components in order to build sensors, which will offer different detection characteristics such as several emission and sensing wavelengths. In this perspective, organic optoelectronic devices could be a solution. The integration of a fluorescent sensor into a microfluidic platform and the different characteristics (optical, electrical, geometric), advantages and disadvantages that offer organic light-emitting diodes (OLED) and organic photodetectors (OPD) for fluorescent sensors are discussed. Finally, an example of integration of organic optoelectronic components into a microfluidic chip for phytoplankton fluorescence detection will be described.

Track E: Flexible Electronics and Materials

Session E1: Flexible Hybrid Electronics

Chair 1: Bob Reuss, Consultant (rreuss@cox.net)

Eric Forsyth, US Army (eric.w.forsythe.civ@mail.mil)

Flexible Hybrid Electronics: Defense Department Perspective

The Defense Department has recently established the Flexible Hybrid Electronic (FHE) Manufacturing Institute that will serve as a public-private partnership between industry, government, and academia to address the manufacturing challenges associated with the materials, packaging, design, and testing of flexible hybrid electronics packaged systems.

Dorota Temple, RTI International (temple@rti.org)

Flexible Hybrid Electronics Compatible with Commercial Off-the-Shelf Integrated Circuits

The compatibility with COTS Si or compound-semiconductor ICs avoids the cost and time penalty of custom IC design and fabrication, and offers greater design flexibility. The fabrication process for this FHE microsystem takes advantage of techniques developed for 3-D integration of silicon ICs, such as wafer and die thinning, die-to-wafer bonding and direct interconnects.

Val R. Marinov, Uniqarta (val.marinov@ndsu.edu)

Back-End Chip Technology for Flexible Hybrid Electronics: Challenges and Solutions

The use of conventional monolithic ICs provides the lowest cost and shortest time to market for the Flexible Hybrid Electronics (FHE) devices. However, the relatively thick silicon chips must be thinned to less than 30–40 microns to acquire the flexibility and conformity essential for the reliable operations of the FHE device. Most of the back-end operations used in the microelectronics industry today are not suitable for such ultrathin chips. Discussed are the major challenges encountered throughout the entire manufacturing process for assembly of ultrathin chips onto flexible substrates, from wafer thinning and dicing to chip attachment and interconnection to reliability testing of the assembled ultrathin chip. Presented are results from two novel end-to-end assembly technologies specifically designed to handle ultrathin chips.

Mark D. Poliks, Binghamton University (mpoliks@binghamton.edu)

Roll-to-Roll Manufacturing of Flexible Hybrid Electronics: From Wafers to Thin Flexible Glass

This talk will describe recent results to create flexible hybrid electronic devices using combinations of thin flexible substrates, traditional electronics processing along with printed inks and high performance components. Applications will include: sensors, medical electronics, antennas, displays and energy conversion devices.

Jim Sturm, Princeton University (sturm@princeton.edu)

Hybrid Large-Area /CMOS Systems for Human-Machine Interfaces

This talk will focus on the design and system performance of self-powered novel systems for human machine interfaces based on sensors distributed over large area and novel interfacing to CMOS. A key aspect of the talk will be the relationship between the parameters of the large-area components and devices and the overall system performance.

Sheng Xu, University of California, San Diego (shengxu@ucsd.edu)

Wearable Health Monitoring Using Hybridized Electronic Components

In this talk, approaches toward flexible/stretchable health monitors by hybridizing the conventional commercial off the shelf chips and the house-made low form factor sensors and interconnects will be discussed, in terms of its motivation, design guidelines, experimental techniques, and exemplary devices with wireless energy and clinical quality data communication capabilities.

Session E2: Printed Electronics

Chair 1: Bob Reuss, Consultant (rreuss@cox.net)

Bob Reuss, Consultant (rreuss@cox.net)

CRTs to Large Area, Flexible Hybrid Electronics

This talk will review the evolution of flexible electronics from the early efforts to replace CRTs to recent developments in combining printed electronics with conventional electronics to create flexible/stretchable/conformal hybrid electronics with novel form factors and high performance.

Joseph Chang, Nanyang Technological University (EJSCHANG@ntu.edu.sg)

Development Kit for a Fully-Printed All-Air Low-Temperature Printed Electronics Process

To facilitate the realization of Printed Electronics (PE) circuits – both for PE-only and Hybrid Electronics – we present a Process Development Kit (PDK) for our Fully-Additive All-Air Low-Temperature process. The PDK embodies a printed transistor model which is simple, accurate and fully compatible with industry standard integrated circuit design automation tools, and embodies passive elements. The PDK further includes process variations (statistical data) and matching based on various layout techniques. On the basis of this PDK, several fundamental analog and digital printed electronic circuits are designed and realized, and their measured parameters agree well with that obtained from the PDK.

Ahmed Busnaina, Northeastern University (busnaina@coe.neu.edu)

High-Rate Nanoscale Printing for Electronics

Current electronics and 3D printing using inkjet technology, used for printing low-end electronics are slow and provide only micro-scale resolution (20,000 nm or larger). We describe a new nanoscale printing process that can use a variety of nanomaterials and can print onto a variety of substrates with nanoscale resolution to match the present state of the art silicon electronics circuit line width.

Sean Garner, Corning Inc. (garnersm@corning.com)

Flexible Glass Substrates for Electronic Applications

Definition of flexible glass substrates. Compatibility with roll-to-roll device fabrication. Specific examples of printed electronic, optical, and other flexible electronic devices on glass substrates.

Devin MacKenzie, Imprint Energy Inc. (info@imprintenergy.com)

Technology Approaches for Printed Flexible Electronic and Conventional IC Hybrids

An overview of technologies for printed flex electronic and conventional IC hybrids and example system. This will be followed by process flows for all printed flexible systems for low cost and high performance hybrid printed + IC systems.

Stan Farnsworth, Novacentrix (stan.farnsworth@novacentrix.com)

Photonic Curing: Advanced Thermal Processing for Printed Electronics Applications

This talk will present recent advances in materials and thermal processing being used currently in the production of state-of-the-art consumer electronics.

Manos Tentzeris, Georgia Tech (etentze@ece.gatech.edu)

Inkjet Printed Flexible Reconfigurable Electronics and Sensors for Wearable Applications

Beatrice Fraboni, University of Bologna (beatrice.fraboni@unibo.it)

Organic Semiconducting Single Crystals for Printed and Flexible Large-Area Ionizing Radiation Sensors: Charge Carrier Generation and Transport Processes

The light weight, simple processability, and mechanical flexibility of π-conjugated organic small molecules and polymers has recently led to remarkable research efforts towards the realization of new opto-electronic devices. Moreover, organic materials can be deposited and grown by means of easy, low temperature and low cost technologies as inkjet printing. In the field of ionizing radiation detection, organic semiconductors have been proposed so far mainly in the indirect conversion approach, i.e. as scintillators, which convert ionizing radiation into visible photons, or as photodiodes, which detect visible photons coming from a scintillator and convert them into an electrical signal.

Organic semiconductors are very promising candidates also for the direct detection of higher energy photons (X-and gamma rays) and we recently reported how organic semiconducting single crystals (OSSCs) provide a stable and linear electrical photo-response to increasing X-rays dose rates, at room temperature.

As organic materials are based on Carbon, their low effective atomic number is similar to the average human tissue-equivalent Z and makes them ideal candidates for radiotherapy and medical applications.

We will report and discuss the different X-ray photo-response and sensitivity of different solution-grown OSSCs, based on molecules that impart quite different chemical and physical properties, from the crystal shape to its charge carrier mobility. The aim is twofold: i) to achieve a better understanding of the photo-conversion and charge transport processes within the organic semiconducting crystal, providing an adequate model to describe them; ii) to optimize and select the better performing molecules towards the implementation of a flexible, large-area 2D matrix of OSSCs pixel detectors fabricated with printing technologies.

Pooi See Lee, Nanyang Technological University (pslee@ntu.edu.sg)

Flexible, Stretchable Transparent Conductors for Interactive Devices

This talk discusses our recent progress on developing flexible and stretchable conductors for emerging wearable electronics, stretchable displays, pressure sensors and deformable visual electronic devices. The key challenge of achieving flexible and stretchable conductors using embedded nanostructuring and layering approaches will be elucidated. Our innovative approaches have been integrated into deformable energy devices such as stretchable battery or stretchable electrochromics. We further extend the efforts into realizing bifunctional devices such as electrochromo-supercapacitor and piezo-supercapacitor that deliver unique functions and properties for interactive devices and flexible hybrid electronics.

John Wang, National University of Singapore (msewangj@nus.edu.sg)

Flexible Supercapacitors of Metal Oxide/Reduced Graphene Oxide with High Energy and Power Density

Mechanically flexible supercapacitors with high energy density, comparable with those of rechargeable batteries, and long term device cycling ability (>50 000 cycles) are inevitably required for next-generation energy storage devices. The energy density and overall performance of graphene/carbonaceous material electrodes in supercapacitors can be effectively engineered by combining with certain transition metal oxides/hydroxides. For this purpose, we have successfully developed a new class of hierarchical graphene/carbon framework, which are surface decorated with thin layers/nanofibers of transition metal oxide and hydroxides, such as Mn_xO_4, NiO, $Fe_2O_3$and $Ni(OH)_2$. Taking Mn_xO_4 as an example, a highly flexible Mn_3O_4/reduced graphene oxide (rGO) nanohybrid paper with high electrical conductivity and high mass loading of metal oxide nanofibers of >0.70 gcm^{-3} is developed via a facile gel formation and subsequent electrochemical reduction. When assembled with an electrochemically reduced rGO paper as the anode, the resultant flexible ASC device demonstrates a remarkable electrochemical performance: a high volumetric capacitance of $\sim$54 F cm^{-3} ($\sim$540 mF cm^{-2}) outstanding volumetric energy and power density of $\sim$0.005 Whcm^{-3} and $\sim$10.00 W cm^{-3}, together with excellent cycling ability.

Session E3: Materials

Chair 1: Peter Wilson, Renesas Electronics (peter.wilson@renesas.com)

Armand Soldera, Université de Sherbrooke (armand.soldera@usherbrooke.ca)

Multi-Scale Approach for the Design of Advanced Materials

The transition from the structure of a molecule to the final functionality of a material is far from being straightforward. To describe real systems, a series of models is required. Models must first be chosen to efficiently describe the system of interest. After the crucial step of validation, designing optimized materials can be undertaken. To illustrate this link between experiments and simulation in the design of advanced materials, several examples stemming from our lab are discussed: membranes for fuel cell applications; liquid crystal for non-linear optical applications; effect of shearing on membranes.

Bertrand Vilquin, École Centrale de Lyon (bertrand.vilquin@ec-lyon.fr) with B. Wague, Q. Liu, A. Belarouci, J.-J. Delaunay, N. Baboux, C. Malhaire, Y. Robach and P. Rojo Romeo

Multifunctional Metal Oxide Nanostructures and Heteroarchitectures for Energy and Device Applications

Metal oxides exhibiting fascinating physical/chemical properties have been focused on for decades in experimental and theoretical studies. They are used nowadays in key applications across all industrial sectors. This makes them attractive candidates in modern technology, as like energy harvesting from vibrational and thermal sources cheaper, nanoelectronics and sensors. In the talk, we will describe novel applications for energy systems, semiconductors, electronics, and thin films.

Tohru Sekino, Osaka University (sekino@sanken.osaka-u.ac.jp)

Photo-and Physico-Chemical Multifunctions of Titania Nanotubes by Structure Tuning

Solution chemically-derived titania nanotube (TNT) has significant multifunctions such as photocatalytic, molecular adsorption, photoluminescence, biocompatible properties, and so on, due mainly to its unique synergy functions of semiconductive properties and low-dimensional nanostructure. In this paper, synthesis, nanostructural feature, physical, chemical and photochemical properties of TNTs have been investigated. Special emphasis has been placed to modify the TNT by loading metal nanoparticles and doping various elements to tune TNT's photochemical functions. Obtained TNTs exhibited excellent photocatalytic properties including degradation of organic molecules and water-splitting hydrogen evolution functions. In addition, metal ion doping such as Cr, Nb to TNT or simple chemical treatment of TNT provided visible light responsible photocatalytic function due to the lattice level structure modification and resultant bandgap tuning of TNTs. Correlations between materials processing, nanostructures and environmental and energy functions will be reviewed in detail.

Jerome Claverie, Université du Québec à Montréal (claverie.jerome@uqam.ca with J. Zhang, Y. Wang, G. Chen, H. Liu, X. Jin and L. Razzari

Novel Photocatalytic Materials for Water Splitting and Depollution

TiO_2 is the run-of-the-mill heterogeneous photocatalyst. It shows high activity in the UV domain, but near zero activity in the visible and IR range. We will present our work on the generation of TiO_2 based photocatalysts which are active in the visible and NIR range. They include novel TiO_2@C photocatalysts whereby the thickness of the carbon layer is precisely designed, as well as plasmonic photocatalysts whereby the plasmonic effect is significantly enhanced by the intervention of whispering gallery mode resonances.

Lionel Vayssieres, International Research Center for Renewable Energy (lionelv @xjtu.edu.cn)

On the Design of Advanced Photocatalysts for Solar Water Splitting

Latest advances in nanodevices for low cost solar (sea)water splitting at neutral pH, low bias and without sacrificial agents will be demonstrated. Visible-light active photocatalyst heteronanostructures based on earth abundant semiconductors engineered to efficiently drive aqueous chemical reactions at their interfaces have been fabricated and tested intensively. Their structural, optical, electronic structure, photoelectrochemical, dimensionality effects and interfacial properties along with their overall efficiency have been thoroughly investigated at synchrotron radiation facilities as well as in our laboratories. The most promising structures for large scale solar water splitting will be discussed.

Muhannad Bakir, Georgia Tech (muhannad.bakir@mirc.gatech.edu)

3D Materials

Session E4: Materials Processing and Device Fabrication

Chair 1: Andrew Carroll, ACAMP (acarroll@acamp.ca)

Jeffry Kelber, University of North Texas (kelber@unt.edu)

Scalable Methods for Direct Growth of BN and Graphene Heterostructures without Physical Transfer

The direct growth of large-area graphene and hexagonal-BN multilayer heterostructures, by practical and scalable methods, is a critical issue in the development of devices based on these materials. Spintronics applications, in particular, demand rigorous azimuthal alignment between layers and atomic-level control of film thickness. Atomic layer deposition (BCl_3NH_3) and molecular beam epitaxy of graphene can meet these requirements. Photoemission, TEM and LEED data will be presented to discuss how substrate/film interactions impact a variety of specific device applications. The presentation will focus on BN growth on metal substrates, and graphene growth on boron nitride and on oxides.

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Crystallization of Low-Temperature-Grown $In_xGa_{1-x}As$ on InP Substrate Induced by Thermal Annealing

The authors report here thermally induced structural transition of low-temperature-grown (LTG) $In_xGa_{1-x}As$ on InP substrate towards development of photoconductive antennas for terahertz-wave emission and detection which can be activated by femtosecond fiber lasers. LTG $In_xGa_{1-x}As$ sample with thicknesses of 1.0 μm was grown on semi-insulating (001)InP substrate by MBE at a substrate temperature of 180°C. After the growth, the sample was annealed at 400–600°C for 1 h in an H_2 atmosphere with a cover wafer of GaAs. While the as-grown LTG-$In_xGa_{1-x}As$ sample did not exhibit X-ray diffraction (XRD), it was confirmed after thermal annealing. Especially, high-resolution XRD reciprocal space mapping (RSM) measured around (115)InP of the sample showed that the diffraction peaks of both LTG $In_xGa_{1-x}As$ and substrate were aligned parallel to the qz axis after annealing at over 400°C, implying the same in-plane lattice parameters for annealed LTG-$In_xGa_{1-x}As$ layer and InP substrate. These indicate that the as-grown $In_xGa_{1-x}As$ layer grown at 180°C was amorphous and the crystallization of the layer was induced by thermal annealing. Cross-sectional transmission electron microscope and electron beam diffraction images demonstrated this thermally induced structural transition of the LTG-$In_xGa_{1-x}As$ sample.

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InGaAs FinFETs on Si: Integration and Nickelide Contacts

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Wafer-Level Monolithic Integration of III-V and Si CMOS Devices Using a CMOS Process Flow

We describe an integrated circuit platform that incorporates non-CMOS materials and devices into a standard CMOS process flow, allowing for the creation of novel hybrid integrated circuits using existing CMOS processes and infrastructure. Our initial demonstration goal is the wafer-level integration of III-V devices with foundry 0.18 μm CMOS devices on 200 mm wafers, and we report on the progress made in materials, device and circuit design towards this goal.

Maxime Darnon, Université de Sherbrooke (maxime.darnon@usherbrooke.ca)

Plasma Etching Process for Germanium Patterning

There is a growing need for patterning germanium for photonic and photovoltaics applications. We will present deep germanium etching using a time multiplexed plasma etch process (Bosch process). We will show that germanium etching presents a strong aspect ratio dependent etching and that patterns present scallops mostly on the upper part (aspect ratio below 0.8). Passivation layers are formed during the passivation step by neutrals' deposition and are reinforced during the etching step by the redeposition of sputtered fluorocarbon species from the etch front. When the sidewalls are passivated, reactive neutrals diffuse through Knudsen-like diffusion down to the bottom of the pattern to etch the germanium. The Knudsen-like diffusion is responsible for the aspect ratio dependent etching and makes difficult the etching of holes with aspect ratios above 10 while trenches with aspect ratio of 17 are still etched faster than 2 μm/min.

Sasa Ristic, McGill University (sasa.ristic@mcgill.ca)

AFM-Enabled Nanofabrication

Thermal Scanning Probe Lithography is an AFM-based technique that, in addition to *in situ* imaging, provides controllable sublimation of a specially designed polymer resist with microsecond-scale heat pulses using an electrostatically actuated silicon cantilever with a sharp tip. Three-dimensional patterns with better than 10nm of lateral and about 1nm of vertical resolution have been demonstrated. At McGill Institute for Advanced Materials, we use a commercially available tool, "NanoFrazor Explore," for fabrication of a variety of nanodevices, including fiber-to-chip optical grating couplers based on multilevel-blazed gratings etched in silicon substrate. The latest results are demonstrated in this presentation.

MSM Saifullah, Institute of Materials Research and Engineering (saifullahm@imre.a-star.edu.sg) with Y.C. Loke, A. Cheng, Q. Ong, F.L. Yap and K.S.L. Chong

Nanoinjection Molding – Empowering Manufacturing Through Accessing Nanoscale On Three-Dimensional Free-Form Products

Nanoinjection molding is a novel technique that combines elements of nanoimprinting with traditional injection molding that enable access of nanoscale onto macroscale three-dimensional free-form products. By tapping into the synergy of both nanoimprinting and injection molding whilst alleviating their disadvantages, nanoinjection molding not only leads to the generation of new product lines in the consumer and biomedical sector, but also adds value to existing products by imparting surface functionalities. Thus the use of nanostructures that was demonstrated on thin plastic films to elicit properties like anti-reflectivity, anti-fog, superhydrophobicity, anti-microbial activity, anti-fouling, etc., can now be realized more effectively and widely in free-form three-dimensional products.

A key element in the nanoinjection molding process is the inserts. Our technique utilizes inserts with nanoscale features produced via nanoimprinting to achieve surface structuring on the molded products. These inserts are placed at requisite areas of the molding jig to impart nanostructures on three-dimensional molded products during the injection molding process. Our nanoinjection molding technique can be easily integrated into existing injection molding processes with minimal additional cost, thus making it attractive for manufacturing industries to adopt. Using this technique we have prototyped lenses and goggles with anti-reflection structures, topographically structured wells for cell culturing, and superhydrophobic plastic surfaces, among others. Since this technique is new, it also faces teething problems from different fronts. In my talk, I will discuss some of the exciting prospects as well as challenges associated with this technique.

Andrew Wee, National University of Singapore (phyweets@nus.edu.sg) with Y. Huang, Y.J. Zheng, Y. Chen, S.Y. Quek, W. Chen, L-J. Li and W. Zhang

2D Van der Waals Heterostructures

Graphene, an atomically thin layer of carbon, is a semi-metal that can be used in applications such as transparent conducting electrodes in flexible electronics. The electronic and chemical properties of graphene can be engineered through a variety of methods such as by molecular adsorption, or fabricating graphene nanoribbons. Unlike graphene, transition metal dichalcogenides (TMDs) such as MoS_2 and WSe_2, are semiconductors with tunable direct bandgaps dependent on the number of atomic layers, and have potential electronic and optoelectronic applications. We use high resolution scanning tunneling microscopy/spectroscopy

(STM/STS) to study the atomic structure and intrinsic electronic properties of MoS_2 layers (mono-, bi-, tri-) directly deposited on HOPG substrates by chemical vapour deposition (CVD). We report an unexpected bandgap tunability with distance from the grain boundary in single-layer MoS_2, which also depends on the grain misorientation angle. We have similarly investigated the atomic scale electronic properties of CVD-grown WSe_2 monolayers as well as their interactions with molecules. In particular we show that a monolayer TMD can effectively screen an organic-inorganic heterointerface. We also demonstrate giant photoluminescence enhancement in WSe_2-gold plasmonic hybrid heterostructures.

Ji Ung Lee, SUNY Polytechnic Institute (jlee1@sunypoly.edu)

Bipolar Devices in 2D Systems: Fabrication, Characterization and Applications

The three pillars in semiconductor device technologies are (1) the P-N diode, (2) the MOSFET and (3) the Bipolar Junction Transistor (BJT). They have enabled the unprecedented growth in the information technology that see today. For any new material, therefore, the development of these three devices is critical for providing benchmark performance against highly scaled Si-based technologies. Here, we will describe our efforts to fabricate and characterize these three benchmark devices in 2D materials, including graphene and transition metal dichalcogenide (TMD) semiconductors.

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Parallel and Distributed 3D IC Layout Design Optimisation

The task of 3D ICs layout design involves the assembly of millions of components taking into account many different requirements and constraints, just to mention topological, wiring or manufacturability ones. It is a NP-hard problem that requires new non-deterministic and heuristic algorithms. Considering the time complexity, the commonly applied Fiduccia-Mattheyses partitioning algorithm is superior to any other local search method. Nevertheless, it often fails to reach a quasi-optimal solution in 3D spaces.

The presented approach uses an original 3D layout graph partitioning heuristics implemented with a use of the extremal optimization method. The goal is to minimize the total wire-length in the chip. In order to improve the time complexity of the proposed approach the parallel and distributed Java implementation is applied. Inside one Java Virtual Machine separated optimizations are executed by independent threads. The work may also be shared among different machines by means of The Java Remote Method Invocation system. In the client-server architecture, the server generates and spools optimization tasks. The clients list is managed dynamically and allows machines to join/leave the computing system at any time. The unfinished tasks are automatically discovered and assigned to different clients which makes the system fault tolerant.

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Power Efficiency of TSV-Based 3D vs 2D Ics

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Novel Layout Techniques for MOSFETs to Boost the Radiation Tolerance

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Latest Advances in Atomistic Simulations for Microelectronic Processing

As microelectronic technology continues following the Moore's law and transistor devices keep getting smaller and smaller, standard Technology CAD models require a profound revision to deal with a) the presence of new materials in the processing, and b) the appearance of new physical mechanisms. In particular, the combination of new materials, 3D designs and topologies with increasing interface to bulk ratios require a) new parameterizations and b) deep knowledge of the physical mechanisms involved.

Although standard simulation tools based on solving sets of partial differential equations using the finite element analysis will still be important, the use of atomistic simulators and models is now inevitable: Ab-initio simulations are required to understand the most fundamental properties of new materials and interfaces, and will be used as the standard tool to parameterize models. Molecular dynamics offers an extended view of the mechanisms involving millions of atoms, and will have an impact in the development of atomistic mechanics, and Lattice Kinetic Monte Carlo (LKMC) models are called for realistic sizes to integrate several mechanisms into one comprehensive model of the device.

In this presentation, we will explore advances in the use of such atomistic methods for microelectronic processing. In particular, we will focus on the three mentioned atomistic techniques. For ab-initio, the methodology and results of the ab-initio to Process (ATP) methodology to compute fundamental parameters (formation and migration energies and entropies) by automatically running ab-initio simulations on computer-generated significant configurations, including III-V materials (GaAs, etc) and alloys (SiGe) will be shown. In Molecular Dynamics we will review how it can be used to explore further process involving more complex configurations. Finally, we will introduce LKMC and its particular applications to the epitaxial growth of semiconductors from a gas phase. These three examples will serve as test cases of the use of atomistic techniques for microelectronic processing.

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M. Kimura

Relationships between the Defects and Electrical Properties of Oxide Semiconductors

Defects in multimetallic oxide semiconductors play important roles in electrical properties of the materials. Therefore, the defects in $InGAZnO_4$ (IGZO) were investigated using electron spin resonance (ESR). Thermal stabilities and g factors of two ESR signals (A and B observed at g = 1.939 and 2.003, respectively) in IGZO were different from those of the ESR signals observed in component materials such as Ga_20_3 (signal observed at g = 1.969), In_2O_3 (no signal), and ZnO (signal observed at g = 1.957). Signal A in IGZO increased upon annealing at 300°C for 1 h, but decreased when annealing was continued for more than 2 h. On the other hand, signal B decreased upon annealing at 300°C for 1 h. The ESR signal in ZnO decayed in accordance with a second order decay model with a rate constant of 2.1E-4 s-1, however, this phenomenon was not observed in other materials. This difference might have been due to randomly formed IGZO lattices such as asymmetrical (Ga, Zn)O and In-O layers. Defects in signals A and B in IGZO would be formed in trap states (at the deep level) and tail states, respectively.

Session E5: Optical and Photonic Materials

Chair 1: Dongling Ma, INRS (dongling.ma@emt.inrs.ca)

Peter Bermel, Purdue University (pbermel@purdue.edu)

Selectively Controlling Thermal Emission with Applications in Thermophotovoltaics

Most materials and structures thermally emit over a broad range of wavelengths, angles, and polarizations, with the distribution dictated mostly by temperature. However, selectively altering this thermal emission has potential to greatly improve performance for a wide variety of applications, particularly thermophotovoltaics, but also photovoltaics, photon-enhanced thermionic emission, selective solar absorption, incandescent lighting, and spectroscopy. While prior work has explored a wide range of structures providing some degree of control of one or more of these attributes, there is an ongoing challenge in combining readily-fabricated, simple structures made of appropriate materials with the desired functionality. We study the interaction between geometry and function in nanoscale refractory structures, with the goal of creating arbitrary emission sources that can help focus selected wavelengths polarizations to increase the efficiency and intensity of the output radiation at select target geometries. Modeling is performed using rigorous coupled wave analysis (RCWA) of absorption, plus Kirchhoff's law of thermal radiation, which is further validated using finite-difference time domain (FDTD) as well as a direct thermal emission simulation.

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Chemical Beam Epitaxy Grown AlGaNAs for Photovoltaic Applications

State-of-the-art multi-junction solar cells consist of three InGaP (1.8 eV)/ InGaAs (1.4 eV)/Ge (0.67 eV) p-n junctions inter-connected. The bandgap difference between the Ge and the InGaAs subcells results in thermalisation losses that could be reduces by adding a fourth junction of $\sim$1 eV bandgap. (In)GaNAs is a good candidate as the desired bandgap can be reached by adding N to GaAs while In ensures lattice-matching to Ge. However, GaInNAs remains limited by structural defects, low N incorporation efficiency and phase separation. Our approach consists in introducing a low Al concentration ($<$15%) in GaNAs to improve the material quality.

Joris Lousteau, University of Southampton (J.Lousteau@soton.ac.uk) with E. Ceci-Ginistrelli, D. Pugliese, N.G. Boetti, W. Belardi, D. Milanese and F. Poletti

Mid-IR Glasses and Fibers

The mid-IR spectral range, laying between 2 to 10 μm wavelengths, is of particular interest for optical spectroscopy as many molecules exhibit signature optical absorptions in this wavelength range. Detection of these chemical species is essential for many applications, such as in-situ and remote sensing of gases for toxic chemicals or explosives detection or for medical diagnosis.

Silica based glasses are the most widespread glass materials used for photonic systems, thanks to their excellent optical properties combined to high thermal and mechanical robustness. However, they exhibit high intrinsic absorption beyond 2.4 μm, which precludes their use in the mid-IR range.

The development of optical fiber devices and components both for Mid-IR light generation and transmission requires therefore alternative glass materials. Glass systems such as heavy metal fluorides, heavy metal oxides and chalcogenides possess not only the necessary mid-IR transmission, but also other important properties, such as high rare-earth ions solubility and high nonlinearity suitable for the development of Mid-IR sources. We will review the main advances of the Mid-IR optical fiber devices developed using these glass families. We will also discuss the limitation and prospects of the current mid-IR glass based fiber technologies.

Bozena Kaminska, Simon Fraser University (kaminska@sfu.ca)

Novel Media Surface with Extraordinary Optical Effects and Data Storage at the Nano Scale

This presentation explores and expands modes of expression in media arts and communication practices through the development of nanotechnology and nano-manufacturing processes. The demonstration showcases techniques, prototypes and possible applications of “nano-media,” from publishing and security to interactive wearable fabrics and entertainment. This new kind of media surface uses nano-sized pixels to produce extraordinary optical effects for displays while also storing analog or digital data, fusing the instruments and matters of vision and information. Emerging from technology developed for security/authentication, our ongoing collaboration with artists and media scholars has resulted in scientific and aesthetic breakthroughs in the field of nano-optics by drawing inspiration from many analog media techniques, such as Dufay color film. Here we show examples of our ongoing developments.

Luca Razzari, INRS-EMT (razzari@emt.inrs.ca)

Nanoantenna Enhanced Terahertz Spectroscopy

The challenge of performing terahertz spectroscopy on tiny quantities of nanocompounds has recently been addressed by exploiting the unique properties of resonant nanoantennas (i.e. nanodevices capable of efficiently converting the energy of free-space radiation into localized energy). Indeed, the high localization and strong field enhancement featured by terahertz nanoantennas can increase the absorption of nano-objects up to several million times. Recent applications of this technique to the terahertz characterization of semiconductor nanocrystals and molecular assemblies will be reviewed, with a glimpse on future perspectives and extensions of the method.

Session E6: 1D and 2D Materials

Chair 1: Armand Soldera, Université de Sherbrooke
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François Léonard, Sandia National Laboratories (fleonar@sandia.gov)

Optoelectronics in 1D and 2D Materials

Low-dimensional materials such as semiconducting nanowires, carbon nanotubes, graphene, and MoS_2, have attracted attention for applications in electronics and photonics, as well as for the wealth of new scientific phenomena that arise at reduced dimensionality. In this presentation I will discuss our experimental and theoretical work to develop a fundamental understanding of optoelectronic phenomena in such systems, and to exploit these nanomaterials for photodetection applications. For example, we use spatially-resolved photocurrent measurements combined with other techniques (e.g. thermoelectric measurements, Raman thermography) to identify the origin of the photocurrent in nanowires and 2D materials. In the case of Si nanowires, the photocurrent is dominated by electron-hole separation due to band-bending near the contacts, while for GaN/AlGaN nanowires, we observe the coexistence of photogating and photothermoelectric effects. We reveal a new regime of operation in MoS_2, $MoSe_2$, and their alloys, where the photocurrent depends superlinearly on light intensity. Finally, I will discuss the realization of broadband infrared and terahertz photodetectors using macroscopically aligned carbon nanotubes.

Sanjay K. Banerjee, University of Texas at Austin (banerjee@ece.utexas.edu)

Beyond CMOS Devices in 2D Materials

Graphene and transition metal dichalcogenides have opened up avenues in beyond-CMOS device concepts involving single or many-particle 2D-2D tunneling, leading to NDR. They can also be used in high frequency, mechanically flexible FETs.

Hualing Zeng, Chinese University of Hong Kong (Hualingzeng@hotmail.com)

Emerging Optical Properties of 2D Semiconductors: a Hint for Valleytronics

The ultimate goal of making atomically thin electronic devices stimulates intensive research in layered materials, in particular the group-VI transition metal dichalcogenides (TMDs). Atomically thin group-VI TMD crystals with 2H stacking order, emerging as a family of intrinsic 2-dimensional (2D) semiconductors with a sizeable bandgap in the visible and near infrared range, satisfy numerous requirements for ultimate electronics and optoelectronics. In addition, the characteristic inversion symmetry breaking presented in monolayer 1H-TMDs leads to non-zero but contrasting Berry curvatures and orbit magnetic moments at K/K' valleys located at the corners of the first Brillouin zone. These features provide an opportunity to manipulate electrons' additional internal degrees of freedom, namely the valley degree of freedom, making monolayer 1H-TMDs a promising candidate for the conceptual valleytronics. In this talk, we show recent advances in optical study on quantum confinement effects, valley dependent optical selection rules, and the interplay of spin and valley degrees of freedoms in this class of atomic 2D semiconductors.

Kevin Jones, University of Florida (kjones@eng.ufl.edu) with S.S. Perry, X. Zhao, R. Murray and K. Schuller

Doping and Defects in the 2-D Semiconductor MoS_2

Transition metal dichalcogenides have received significant attention as potential materials to replace Si in future microelectronics. Much of the focus has been on MoS_2 thanks to its desirable bandgap. Studies have shown the advantages of MoS_2 devices in key performance metrics such as a high ION/IOFF ratio and a subthreshold swing that approaches or potentially exceeds the fundamental 60 mV/dec limit. However, the contact resistance remains prohibitively high, and questions remain regarding the ability to dope these materials. Numerous routes for doping MoS_2 have been reported, including surface charge transfer via molecular adsorption, cation substitution during growth, chalcogenide substitution via immersion in solution, and plasma-assisted doping. The effectiveness of these doping methods is displayed by reductions in contact resistance, increases in drive current, and in some instances a change from n-type to p-type behavior. This talk will review these recent reports on MoS_2 doping.

Recent experiments have begun to explore the possibility of doping MoS_2 by ion-implantation, which is a legacy doping technique that is often avoided with 2D materials due to their ultra-thin nature. These experiments utilize ultra low implant energies of 200 eV which places the species of interest (Cl^+ and Ar^+) completely within the 3–5 layers of MoS_2 being investigated. Cl is potentially a donor in MoS_2 whereas Ar was used to determine the effect of the implant damage on the electrical properties. These studies focused on room temperature implants at doses between $1 \times 10^{13}/cm^2$ and $1 \times 10^{15}/cm^2$. Preliminary structural studies utilizing angle-resolved XPS indicate a Cl peak is around 1 nm deep into the MoS_2, in rough agreement with Monte Carlo TRIM calculations. STM studies have revealed a number of defects present after implantation, including sub-surface defects that may be sulfur vacancies as well as surface sulfur vacancies. The density of these defects track with the dose. Relative to the pristine surface, STS studies have shown little change in tunneling current associated with the sub-surface defects, but enhanced tunneling current associated with the sulfur vacancies. It was observed that as the dose increases the oxidation of the surface as measured by XPS after exposure to the air increases. Additionally, we are performing transmission line measurements to observe the electrical effect of the implantation. Using lithography, transmission line masks were patterned onto individual exfoliated flakes. Photoresist was used as a mask to protect the channel and the implantation preceded contact metal (Ni/Au) deposition. Thus, only the contact area was implanted. Prior to implantation, primarily non-linear IDS-VDS curves are observed for few-layer (<=10 layers) MoS_2 flakes with no applied back-gate voltage. After implantation at lower doses, linear IDS-VDS curves are observed implying more ohmic contacts. This is prior to annealing implying the electrical nature of the implant damage is contributing to better contacts. However the effect is greater for Cl^+ implants than Ar^+ implants implying that the effect is not strictly a damage-related phenomenon. At higher doses the contacts went back to being non-ohmic and this may be associated with the aforementioned oxidation after higher dose implantation. The dose dependence of the role of implant doping on contact resistivity will be discussed as well as the results from post implant annealing to facilitate dopant activation.

Jun Song, McGill University (jun.song2@mcgill.ca)

Flexible Phase Engineering of 2D Transition-Metal Dichalcogenide through Electron Doping and Lattice Deformation

2D transition-metal dichalcogenides (TMDs) promise new possibilities in the design of new optical and electronic devices. One unique feature of the TMD material is the existence of multiple metastable crystal phases. Depending on the crystal phase it assumes, a TMD can be either semiconducting or metallic. This provides a novel route towards engineering the properties of TMDs to great expand their spectrum in applications. Employing first-principles density functional calculations, we investigate the phase stability and transition within a series of 2D TMDs under coupled electron doping and lattice deformation. With the lattice distortion and electron doping density treated as state variables, the energy surfaces of different phases were computed and the diagrams of energetically preferred phases were constructed. These diagrams assess the competition between different phases and predict conditions of phase transitions for the TMDs considered. The interplay between lattice deformation and electron doping was identified as originating from the deformation induced band shifting and band bending. Based on our findings, a potential design strategy combining efficient electrolytic gating and lattice straining to achieve controllable phase engineering in 2D TMDs was demonstrated.

Susan Fullerton, University of Pittsburgh (fullerton@pitt.edu)

Using Ions to Control Transport in 2D Materials for Low-Power Transistors and Memory

Electrolyte gating is a popular technique for the reconfigurable p-and n-type doping of transistors based on two-dimensional (2D) semiconductors. Under an applied gate voltage, ions in the electrolyte create an electrostatic double layer (EDL) at the interface between the electrolyte and the semiconductor; the EDL can induce sheet carrier densities on the order of 10^{14} cm^{-2} for both electrons and holes. I will describe our work using electrolytes to gate transistors and memory devices based on graphene and transition metal dichalcogenides (TMDs). In an $MoTe_2$ transistor, we use PEO:$CsClO_4$ to reversibly reconfigure the device between n- and p-channel operation with ON/OFF ratios of $\sim 10^5$ and subthreshold swings of 90 mV/decade. We have also demonstrated pn junctions formed by ions in both $MoTe_2$ and graphene. The doping profile can be "locked" into place by lowering the temperature below the Tg of the electrolyte, and we demonstrate a room-temperature locking method by modifying the chemical structure of the polymer electrolyte.

Gautam Gupta, Los Alamos National Laboratory (gautam@lanl.gov)

Design Principles for Enhanced Catalytic Activity in 2D Materials

Hydrogen is a promising fuel with a potentially limitless supply available from electrochemical water splitting. Similarly, efficient oxygen reduction is desired, and is a significant challenge in fuel cells. Both these reactions can be achieved efficiently via precious group metals such as Pt and its alloys. Therefore it is desired to obtain earth abundant cheap catalyst for efficient hydrogen evolution reaction (HER) and oxygen reduction reaction (ORR). To date there is a lack of design principles for achieving high catalytic activity for a particular reaction. How one can efficiently decrease kinetic, thermodynamic and transport losses need to be addressed. To achieve this, one needs increase number of active sites, enhance diffusion of reactants, optimize charge transfer, and address durability issues. Here in this talk, I will present a comprehensive way of synthesizing and modifying transition metal dichalcogenide architectures to obtain HER with minimum over potential. Secondly, we have developed design principles for obtaining nitrogen doped graphitic materials for efficient ORR. We report highly active and durable graphitic catalysts in acidic media. In a 0.5 M H_2SO_4 electrolyte, a huge shift in half wave potential and a significant decrease in peroxide production is obtained depending upon the graphene oxide treatment.

Berardi Sensale-Rodriguez, University of Utah (berardi.sensale@utah.edu)

Enabling High-Speed and Terahertz Electronics with Atom Thick Materials

In this talk I will discuss graphene, an atom-thick material, as a platform for (i) efficient THz devices and (ii) new high-speed electronic device concepts. First, I will discuss how by combining electrically reconfigurable graphene layers with passive metallic structures, augmenting the intensity of the electric field in the graphene, control over THz wave propagation can be greatly enhanced. These devices can be employed as the building blocks for novel THz systems. Second, I will discuss how graphene and other 2D materials could be used in the context of tunneling-based field-effect structures, and how these, in-turn, might enable high frequency and terahertz operation.

Carl Ventrice, University at Albany-SUNY (cventrice@sunycnse.com)

Synthesis of Device-Quality Graphene Films

Graphene is a single atomic layer of carbon that is crystallized in the honeycomb configuration. It has many unique properties that are of particular interest for the development of nanoscale electronic devices and sensors. In particular, it is a semimetal whose charge carrier density can be continuously tuned from n-type to p-type by applying an external electric field and has a linear energy-momentum dispersion in the vicinity of the Dirac point, which results in carrier mobilities that are higher than almost all semiconductors. It also has a very large in-plane thermal conductivity and exceptional mechanical properties. However, one of the primary issues that must be addressed before nanoscale electronic devices and sensors can be routinely fabricated is the development of methods for growing large-scale, device-quality, graphene films with uniform thickness at a relatively low cost. An overview will be given of the techniques currently used for graphene synthesis and the research being done in my laboratory to synthesize single crystal films of graphene.

Fabian Ezema, University of Nigeria, Nsukka (fiezema@yahoo.com)

Chemically Deposited Nanocrystalline Metal Oxide Thin Films and their Applications

The use of chemical solution processing technique in synthesizing thin film materials is currently attracting much interest because it is most cost saving, simple and allows large area deposition of the films. There is a great interest in the methods of creating nanostructured materials with high performance nano-devices for the solar cell, Dye-sensitized solar cells (DSSC), gas sensor and supercapacitor applications.

We present the use of chemical bath deposition (CBD) and Successive ionic adsorption and reaction (SILAR), for the preparation of nanostructured metal oxide thin films from aqueous solutions. Such soft solution chemical methods allow bottom-up approach to tune morphology of nanocrystalline materials in thin film form with better control of particle size, shape, size distribution, particle composition, and degree of particle agglomeration. The systematic studies on the preparation of nanostructured metal oxide thin films such as ZnO, CuO and NiO by using chemical reactions from aqueous solutions is explored.

Finally, the applications of thin films in photoelectrochemical cells, gas sensing and supercapacitive performance of various materials such as ZnO, NiO, and CuO films are discussed.

Guojun Liu, Queen's University (gliu@chem.queensu.ca)

Clear, Durable, and Fluorine-Free Coatings for Anti-Fingerprint and Anti-Graffiti Applications

Fluorine-free anti-smudge coatings that are transparent, wear-tolerant, and adherent to different substrates are very useful. For example, on the windows of skyscrapers, they should inhibit stain formation and reduce window cleaning costs. On historic buildings and statues, they can provide protection against graffiti. On kitchen hoods and fans, they should make these appliances self-cleaning. In addition, on the touchscreens of hand-held electronic devices, they should reduce fingerprint deposition and facilitate smudge removal. Dream coatings that are practical and possess all of the above-mentioned properties have been developed by us recently. We report in this talk our nano-design for this type of coatings and discuss example systems developed using this design principle.

The coating matrices that we have used so far include polyurethane and epoxy. These matrices were utilized because polyurethane and epoxy coatings are currently widely used. In addition, the coatings adhere well to many substrates.

To render anti-smudge properties, we grafted liquid polymers such as poly(dimethyl siloxane) (PDMS) unto the surfaces of the traditional polyurethane or epoxy coatings. The grafted liquid polymers turned the original solid coating surfaces into a slippery liquid surface. Since a liquid cannot grab foreign objects as well as a solid surface, liquids with surface tension above 22 mN/m, which is 2 mN/m above that of PDMS, all cleanly slid down such coatings without leaving a trace behind, when the substrate was slightly tilted. The repelled liquids included water, cooking oil, paints, ink, and artificial fingerprint liquids.

PDMS was also embedded as nano-reservoirs throughout the coating matrices. The nanosize of the reservoirs minimized light scattering and the coatings were thus optically clear. Upon coating wearing, the embedded PDMS chains initially underneath were released, replenishing the surface with new PDMS chains. Therefore, these coatings retained their anti-smudge properties after extensive wear or damage.

Xu Li, Institute of Materials Research and Engineering (x-li@imre.a-star.edu.sg)

Advanced Polymer Composite Food Packaging

Oxygen barrier of materials used to wrap food plays an important role in making sure the product reaches consumer in the best possible condition. Proper food packaging can also reduce energy consumption for storing food and hence reduce carbon emission. In order to enhance the oxygen barrier, layered-silicate fillers with high aspect ratio such as montmorillonite (MTM) have been incorporated into plastic materials to form polymer composites. Although the oxygen barrier of polymer matrix can be enhanced through incorporating layered-silicate fillers, various studies have shown that the maximal improvement on oxygen barrier with layered-silicate/polymer composite fabricated through conventional compounding or mixing is about 2/3 in maximum. Inspired by the principals found in natural composites, a facile approach is developed for preparing flexible and optically transparent MTM polymer composite layer with excellent oxygen barrier through applying gelatinous MTM polymer suspension onto PET film. Laminated flexible food packaging is then fabricated through laminating the coated PET film with polyolefin film. Nano-structured Fe/carbon oxygen scavenger has developed for further reducing oxygen transmission.