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High Temperature Integrated Technologies

2.1 Introduction

There is a growing desire to install electronic power and control systems in high temperature environments to improve the accuracy of critical measurements, reduce the amount of cabling and elimination of cooling systems. Typical applications include down-hole petroleum/gas/geothermal exploration and production, turbine engines for aircraft propulsion and power generation and power modules for electric/hybrid vehicles [1–4].

Fuel costs for aeroengines have approximately doubled over the past 10 years and now represent up to 50% of the operating costs of many modern widebody aircraft [5]. Reducing specific fuel consumption by reducing aircraft weight has become a major focus for research and development. The use of sensors developed to operate for long periods in high temperature environments allows sensors to be replaced close to the engine sensing and control units eliminating the need for complex heat sinks, special fuel pumping and interfacing, which in turn assists with the goal of aircraft weight reduction [6]. Mounting the engine sensing and control unit close to the sensors means ambient temperatures may easily reach 200°C. This requirement has posed a challenge to the bulk CMOS technologies which are typically qualified for operation between –55°C and 125°C. The leap in operating temperature to above 200°C in combination with high pressures, vibrations and potentially corrosive environments means that different semiconductors, passives, circuit boards and assembly processes will be needed to fulfill the target performance specifications. Although extensive research to investigate temperature related reliability effects in semiconductors such as leakage current, electromigration and time dependent dielectric breakdown (TDDB) has been carried out [7], understanding the design constraints, development of robust packaging systems and reliable interconnections are the key to the success of high temperature electronics systems. The main advantage of SOI technology in high temperature applications are the reduced leakage current due to the reduced junction area and reduced latchup due to isolated PMOS (P-type Metal Oxide Semiconductor Logic) and NMOS (N-type Metal Oxide Semiconductor Logic) transistors [8]. CMOS SOI technology has been shown to be better suited for high temperature operation over bulk CMOS [9–11]. The reliability of CMOS SOI for use at 250°C was presented in [12]. CMOS SOI integrated circuits have been designed and tested for high-temperature applications up to 300°C in [13–19] and up to 400°C in [20]. Silicon carbide (SiC) BJT, JFET and MOSFET based integrated circuits have been demonstrated up to 600°C [21–23]. High temperature electronics technologies and applications have been recently reviewed in [24]. The major effects of elevated temperature on semiconductor material and devices are:

- An exponential increase in leakage current of reverse-biased *pn* junctions. This might significantly limit the performance of bulk-CMOS ICs, where the transistors are isolated from the common bulk by means of a *pn* junction. In SOI technologies, however, buried oxide prevents any leakage current into the bulk, thus making this technology well suited for high temperature applications. Still, structures necessarily incorporating *pn* diodes, like ESD protection circuits, may adversely influence the performance of a system at high temperatures.
- Carrier mobility degradation, occurring with the rate of T^{-n} for MOS devices, where *n* ranges from 1.5 to 1.8 between 25°C and 200°C [17]. This directly impacts the transfer characteristics of MOS transistors since drain current of the saturated devices is proportional to the carrier mobility in the channel.
- Finally, the threshold voltage shifts by 1–3 *mV/°C* as the Fermi potential, the depletion width and charge under channel reduce with temperature [17].

The above mentioned temperature effects were accounted for during the design of the circuits presented in this book by using the Zero-Temperature Coefficient (ZTC) and "g_m/I_d" methodologies [25].

The European Union (EU) has taken a lead in green aviation technologies by funding projects such as Clean Sky1 and Clean Sky2 [26]. The Clean Sky Joint Technology Initiave started in 2008, and constitutes an industry wide program targeting very significant environmental gains: a reduction of CO_2 and NO_x emissions of 40% and 60%, respectively. General Electric was represented in Clean Sky by GE Aviation Systems (UK) and GE Global Research Munich as participants in the High Temperature Survival Electronic

Devices for Engine Control Systems (HIGHTECS) project working with Oxford University Materials.

The HIGHTECS design concept was to take the output from several on-engine sensors (temperature probe, thermocouple, strain gauges, frequency) and carry out the signal conditioning on the sensor signals, multiplexing, analogue to digital conversion, and transmission of the data through a serial data bus on a single ASIC (Application Specific Integrated Circuit) [6]. The unit was designed to meet the environmental requirements of DO-160 for a helicopter engine, with the specific needs of operation at 200°C with a lifetime of 50,000 engine operating hours. Due to the temperature and lifetime requirements, and the current feasibility of SOI technology over SiC, the HIGHTECS ASIC was fabricated as a custom CMOS SOI device to be assembled on a ceramic hybrid carrier [6, 27]. The hybrid was assembled in a stainless steel enclosure, mounted on an aeroengine during tests on the ground, and due to the shorter cables needed in between the sensors and the electronics, it helps reducing the weight of the aeroengine by several kilograms [28].

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