

Numerical Analysis of All Inorganic Perovskite Tandem Solar Cell with PCE of 24.47 %

Mukesh Bharadwaj, Deboraj Muchahary

Dept. Of Electronics and Communication Engineering,

National Institute of Technology Raipur, Chhattisgarh, India.

mbharadwaj.mtech2023.etc@nitrr.ac.in, dmuchahary.ece@nitrr.ac.in

Abstract.

All-perovskite tandem solar cells (APTSCs) provides a strong pathway for exceeding the performance of conventional solar cells while maintaining low fabrication costs. This study presents a numerically designed APTSC using SCAPS-1D, featuring an inverted p-i-n configuration with a top cell of ITO/NiO_x/CsPbI₂Br/ZnO/Au and a bottom cell of ITO/PEDOT:GO/Cs₂SnI₆/GO(graphene oxide)/Ag. The design leverages all-inorganic perovskites—CsPbI₂Br (1.78 eV) and lead-free Cs₂SnI₆ (1.48 eV)—to enhance stability and efficiency. Through precise current matching, the proposed TSC achieves a maximum PCE of 24.47%, exceeding the experimentally reported 21.92%. Analysis of bulk defect density (10¹⁰ cm⁻³) yields a bottom cell PCE of 21%, with a current density of 11.83 mA cm⁻², open-circuit voltage, V_{OC} of 1.21 V, and fill factor of 84.7%, while interface defects (10¹⁰ cm⁻²) result in a PCE of 17.17%. The device operates optimally at 300 K, with layer thicknesses compatible with experimental fabrication. This work highlights the potential of all-inorganic APTSCs to deliver high efficiency and durability.

Keywords. Tandem, PCE, APTS, Spectrum, SCAPS-1D.

1. INTRODUCTION

Solar cells are sustainable source of green energy harvesting. Due to the SQE limitations of theoretical PCE of 34% associated with single-junction solar devices[1], researchers identified that tandem solar cell (TSCs) having multiple bandgap is the right approach to increase the PCE [2][3][4][5]. Among these, all-perovskite tandem solar cells (APTSCs) have garnered significant attention [6]. Cesium lead halides (CsPbX₃, where X = I, Br, Cl) have surfaced as viable contenders for the PV technology.[7][8][9]. Chenghao Duan et al. A ligand evolution approach using p-toluenesulfonyl hydrazide reported efficiency of 17.41% for a 1.31 eV CsPb_{0.4}Sn_{0.6}I₃:LE device and a champion efficiency of 22.57% for 2T IPTSC with top cell as CsPbI₂Br[10]. A. Chouhan et. al. established a standalone Cs₂SnI₆ based solar cell reported a PCE of 22.59 % [11]. Qiu et al. reported a Cs₂SnI₆-based perovskite with E_G(1.48 eV) reported efficiency of 1% [12]. Xiaofeng et al. reported a Cs₂SnI₆ perovskite solar cell (PSC) using ZnO as the ETL, demonstrating an efficiency of 0.857%, with inorganic absorber layers, ETL-ZnO, and HTL P3HT[13], Jun et al. observed Cs₂SnCl_{6-x}Br-based photodetectors[14].

In this study, an all-perovskite tandem solar cell (APTSC) is modelled using SCAPS-1D, with ITO/NiO_x/CsPbI₂Br/ZnO/Au as the top cell and ITO/PEDOT:GO/Cs₂SnI₆/GO/Ag as the bottom cell, both in an inverted p-i-n configuration. The APTSC's performance is optimized through current matching, and its performance is analyzed.

2. Methodology

In this study, the schematic of proposed device structure is shown in Figure 1. The simulation is conducted using SCAPS-1D software[15], which is based on Poisson's equation.

$$-\frac{\partial}{\partial x} \left(-\partial(x) \frac{\partial V}{\partial x} \right) = q[h(x) - e(x) + N_D^+(x) - N_A^-(x) + h_t(x) - e_t(x)] \quad (1)$$

The proposed device structure employs ITO/NiO_x/CsPbI₂Br/ZnO/Au as top cell and ITO/PEDOT:GO/Cs₂SnI₆/GO(Graphene Oxide)/Ag as bottom cell.

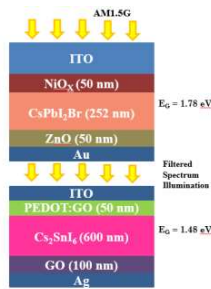


Figure.17. Schematic of Tandem Solar Cell.

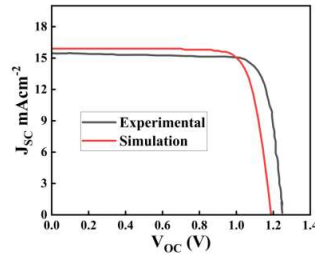


Figure.2. Matched JV-Curve of top cell with experimental data.

2.1. Calibration to experimental device.

At the beginning the modelled bottom cell is calibrated with a similar experimental device reported in the literature[10] as shown in Figure.2. The slight variation in J_{SC} and V_{OC} may be due to non-availability of exact materials properties used in the simulation.

3. Results and Discussions

The Design of Tandem Solar cell is done, Firstly, the bottom cell which is optimized for its best performance by evaluating the condition for both bulk and interface defect density.

3.1. Design of Tandem Solar cell.

The TSC is modelled by matching the current in both top cell and bottom cells. The filter spectrum is calculated using Beert lamberet law as given in eq.2.

$$S_{Filtered}(\lambda) = S_{Incident}(\lambda) * exp \left\{ \sum_{p=1}^4 -(\alpha_{Material}(\lambda) * d_{Materialp}) \right\} \quad (2)$$

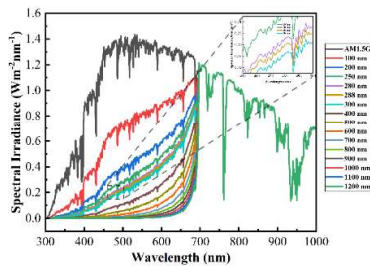


Figure.4. Matched JV-Curve of top cell with experimental data

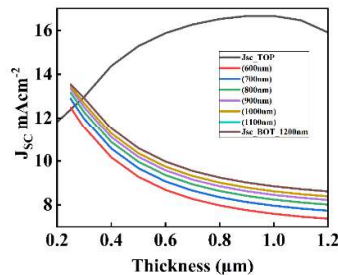


Figure.5. Standard transmitted spectrum from the top cell for absorber thickness from 600 to 1200 nm

The J_{SC} matching thickness for WBG is found to be 252 nm and NBG is 600 nm at 12.44 mAcm^{-2} . The designing of TSC is carried out by calculating Filter Spectrum from 200 nm to 1200nm of WBG absorber. The performance of tandem configuration J_{SC} , V_{OC} , FF % and PCE % is obtained as 12.11 mAcm^{-2} , 2.25 V, 79.74 %, 24.47 % for the proposed device structure showcasing maximum PCE of 24.47 %.

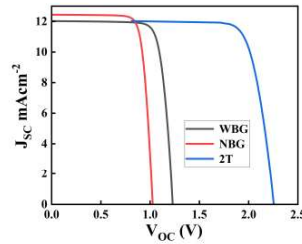


Figure.6. J-V curve of standalone tandem cell.

Table.2. Performance Parameters of Proposed APTSC.

Parameters	J _{SC} (%)	V _{OC} (%)	FF (%)	PCE (%)
Top Cell	12.02	1.22	79.26	13.15
Bottom Cell	12.44	1.02	79.54	17.55
Tandem	12.11	2.25	79.74	24.47
Experimental[10]	14.57	1.90	81.44	22.57

4. Conclusion

Upon comparison of power conversion efficiency the PSC of proposed TSC is 24.47 % which is higher compared to experimentally reported PCE i.e. 21.92 % [10]. Upon the analysis of Bulk defect density, the maximum performance of all the SC parameters are obtained at 10^{10} cm^{-2} while interface defect is observed to be maximum at $10^{10} \text{ mAcM}^{-2}$. The spectrum range is analyzed within the visible spectrum range. The thickness of both the LA aligns within the boundary of experimental findings making it suitable for fabrication analysis.

5. references

- [1] S. Sharma, S. Basu, N. P. Shetti, and T. M. Aminabhavi, "Waste-to-energy nexus for circular economy and environmental protection: Recent trends in hydrogen energy.," *Sci. Total Environ.*, vol. 713, p. 136633, Apr. 2020, doi: 10.1016/j.scitotenv.2020.136633.
- [2] F. Jiang *et al.*, "A two-terminal perovskite/perovskite tandem solar cell," *J. Mater. Chem. A*, vol. 4, no. 4, pp. 1208–1213, 2016, doi: 10.1039/C5TA08744A.
- [3] J. H. Heo and S. H. Im, "CH₃NH₃PbBr₃–CH₃NH₃PbI₃ Perovskite–Perovskite Tandem Solar Cells with Exceeding 2.2 V Open Circuit Voltage," *Adv. Mater.*, vol. 28, no. 25, pp. 5121–5125, Jul. 2016, doi: <https://doi.org/10.1002/adma.201501629>.
- [4] A. Rajagopal *et al.*, "Highly Efficient Perovskite–Perovskite Tandem Solar Cells Reaching 80% of the Theoretical Limit in Photovoltage," *Adv. Mater.*, vol. 29, 2017, [Online]. Available: <https://api.semanticscholar.org/CorpusID:205281011>
- [5] G. E. Eperon *et al.*, "Perovskite-perovskite tandem photovoltaics with optimized band gaps.," *Science*, vol. 354, no. 6314, pp. 861–865, Nov. 2016, doi: 10.1126/science.aaf9717.
- [6] D. Zhao *et al.*, "Efficient two-terminal all-perovskite tandem solar cells enabled by high-quality low-bandgap absorber layers," *Nat. Energy*, vol. 3, no. 12, pp. 1093–1100, 2018, doi: 10.1038/s41560-018-0278-x.
- [7] I. M. Maafa, "All-Inorganic Perovskite Solar Cells: Recent Advancements and Challenges," 2022. doi: 10.3390/nano12101651.
- [8] J. Duan *et al.*, "Inorganic perovskite solar cells: an emerging member of the photovoltaic community," *J. Mater. Chem. A*, vol. 7, no. 37, pp. 21036–21068, 2019, doi: 10.1039/C9TA06674H.
- [9] B. Li *et al.*, "Surface passivation engineering strategy to fully-inorganic cubic CsPbI₃ perovskites for high-performance solar cells," *Nat. Commun.*, vol. 9, no. 1, p. 1076, 2018, doi: 10.1038/s41467-018-

03169-0.

- [10] C. Duan *et al.*, “Durable all-inorganic perovskite tandem photovoltaics,” *Nature*, vol. 637, no. 8048, pp. 1111–1117, 2025, doi: 10.1038/s41586-024-08432-7.
- [11] A. Chauhan, A. Oudhia, and A. K. Shrivastav, “Analysis of eco-friendly tin-halide Cs₂SnI₆-based perovskite solar cell with all-inorganic charge selective layers,” *J. Mater. Sci. Mater. Electron.*, vol. 33, no. 3, pp. 1670–1685, 2022, doi: 10.1007/s10854-022-07723-x.
- [12] Y. Jiang, H. Zhang, X. Qiu, and B. Cao, “The air and thermal stabilities of lead-free perovskite variant Cs₂SnI₆ powder,” *Mater. Lett.*, vol. 199, pp. 50–52, 2017, doi: <https://doi.org/10.1016/j.matlet.2017.04.046>.
- [13] H. Kumar, P. Verma, and B. Raj, “Design and Analysis of Lead-Free Tin-Halide-Based All-Inorganic Perovskite Solar Cell for High Efficiency,” *Nano*, vol. 18, no. 07, p. 2350049, May 2023, doi: 10.1142/S1793292023500492.
- [14] X. Qiu *et al.*, “Lead-free mesoscopic Cs₂SnI₆ perovskite solar cells using different nanostructured ZnO nanorods as electron transport layers,” *Phys. Status Solidi - Rapid Res. Lett.*, vol. 10, no. 8, pp. 587–591, 2016, doi: 10.1002/pssr.201600166.
- [15] M. Burgelman, K. Decock, S. Khelifi, and A. Abass, “Advanced electrical simulation of thin film solar cells,” *Thin Solid Films*, vol. 535, pp. 296–301, May 2013, doi: 10.1016/j.tsf.2012.10.032.

Biographies



Mukesh Bharadwaj B.Tech (BIT Durg), Currently final year student, pursuing M.tech in (VLSI & Embedded systems engineering) at NIT Raipur. Project area: All perovskite Tandem Solar Cell.



Dr. Debora Muchahary pursued his Ph.D from (NIT Arunachal), M. Tech (NIT Arunachal) and B. Tech (CIT Kokrajhar) currently he is working as Assistant professor in Dept. Of Electronics and communication engineering at NIT Raipur, his Research area mainly include Silicon and Perovsskite solar cell, Semiconductor device simulation, VLSI.