Optimization of Perovskite Solar Cells for Indoor Applications

Kamil Anıl Işık[1], Deniz Cenk Temel[1], Konstantin Tsoi[2], Bahri Eren Uzuner[2,3], Amir Zarean Afshord[2,3], Mustafa Yaşa[2], Görkem Günbaş[2,4], Selçuk Yerci[1,2,3]

[1] Electrical Electronics Engineering, Middle East Technical University, 06800 Ankara, Turkey
[2] ODTÜ-GÜNAM, Middle East Technical University, 06800 Ankara, Turkey
[3]Department of Micro and Nanotechnology, Middle East Technical University, 06800 Ankara, Turkey
[4]Department of Chemistry, Middle East Technical University, 06800 Ankara, Turkey

corresponding authors, E-mail: syerci@metu.edu.tr, knstntn.ts@gmail.com

GÜNAM Center for Solar Energy Research and Applications

Introduction

- In recent years, Perovskite Solar Cells (PSCs) have become one of the most popular photovoltaic research objects because of their higher power conversion efficiency under direct sunlight illumination.
- Perovskites have also been gaining more interest for indoor applications due to better alignment of their absorption spectrum with indoor illumination. [1]
- In this study, an opto-electrical simulation-based optimization is performed to improve the efficiency of PSCs under various indoor illumination spectra.
- Optimization is performed in terms of absorber (perovskite) thickness and its bandgap.
- We employed the Transfer Matrix Method (TMM) to produce carrier generation profile inside the active layer.
- Then, using the calculated generation profiles as input to SCAPS, electrical performance of the solar cells is calculated.

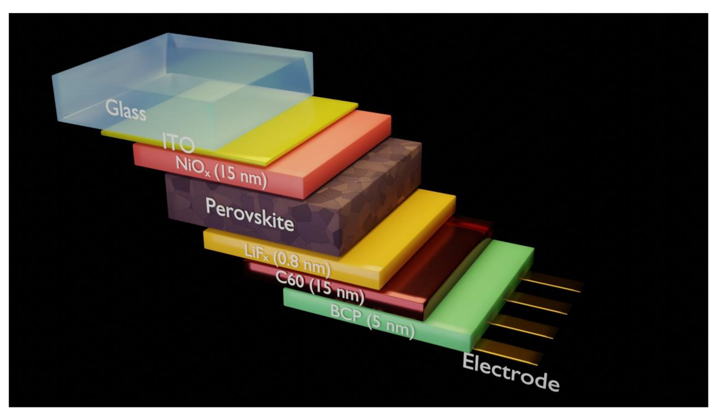

Figure 1: Structure of perovskite solar cell.

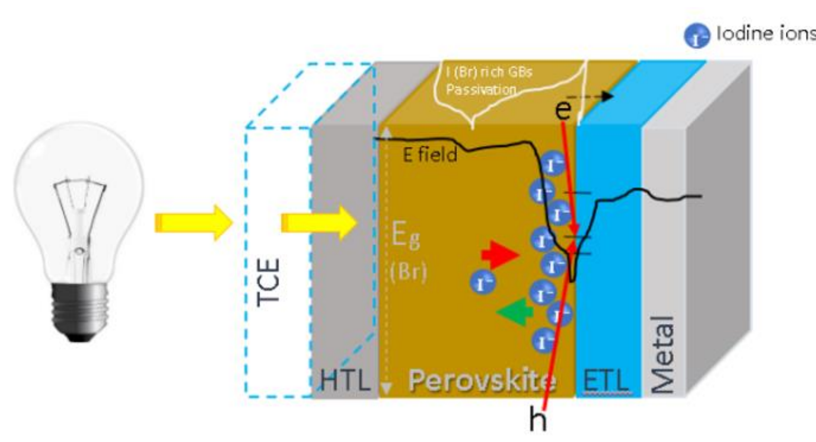

Figure 2: Symbolic visualization of PSC under indoor illumination

- Optimum bandgap and active layer thickness are then determined based on the electrical performance.

Methodology

- Complex refractive index parameters of materials (*n* and *k*), and indoor LED spectra (warm, natural, cold) are extracted from the literature.
- Materials with active layer variable thickness (400 - 1000 nm) and bandgaps are simulated.

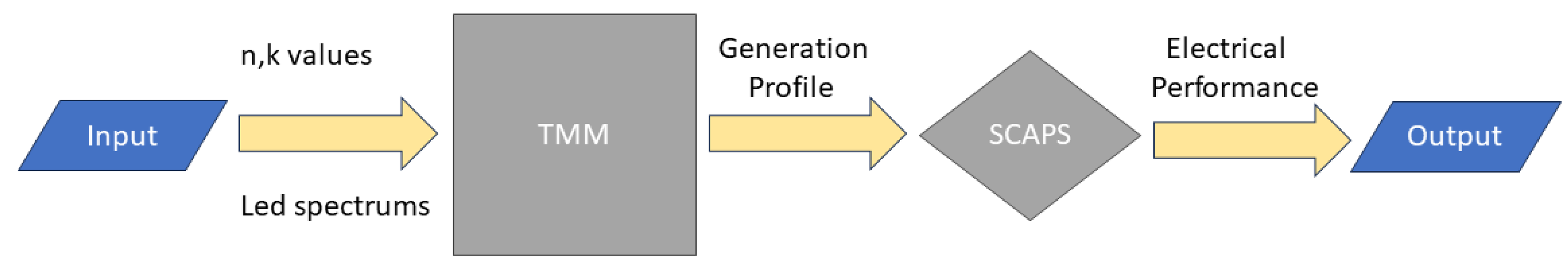

Figure 3: Workflow of the methodology

- Generation profiles under each LED spectrum are calculated.
- SCAPS is used for electrical simulations.

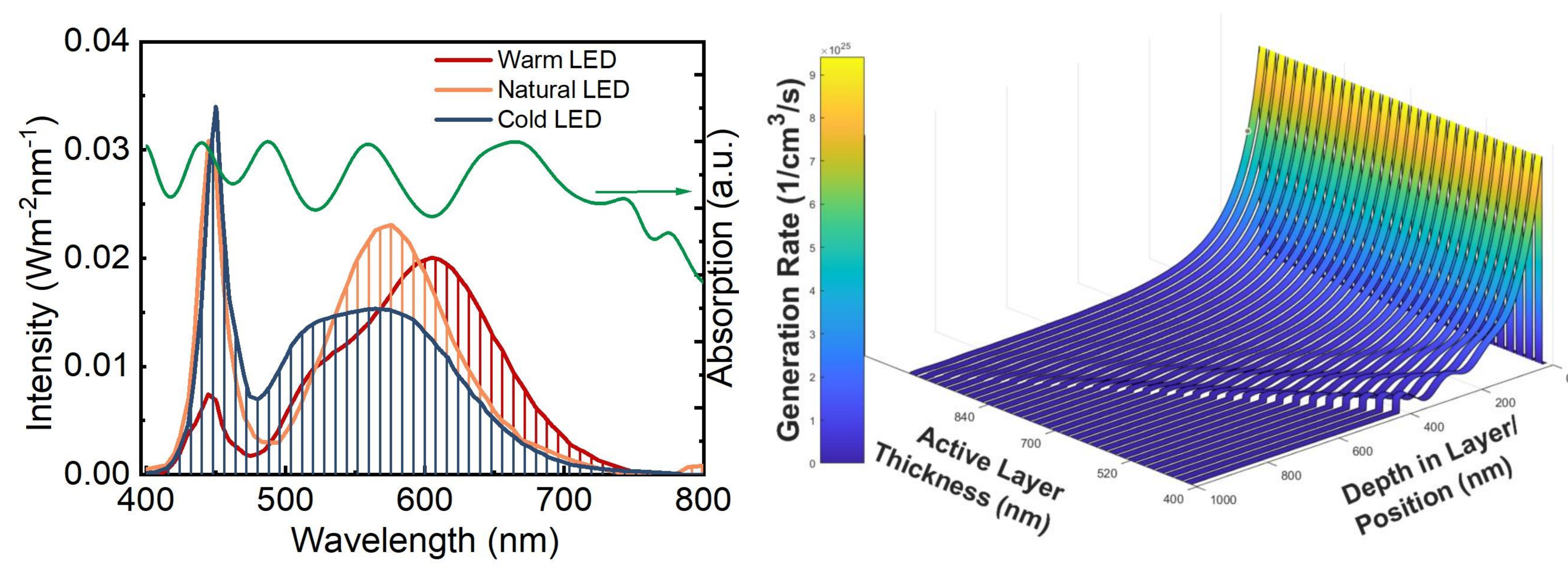

Figure 4: Different LED spectra and simulated absorption profile of PCS (left) and generation profiles calculated in TMM (right) for perovskite with 1.64 bandgap under natural LED illumination.

Results

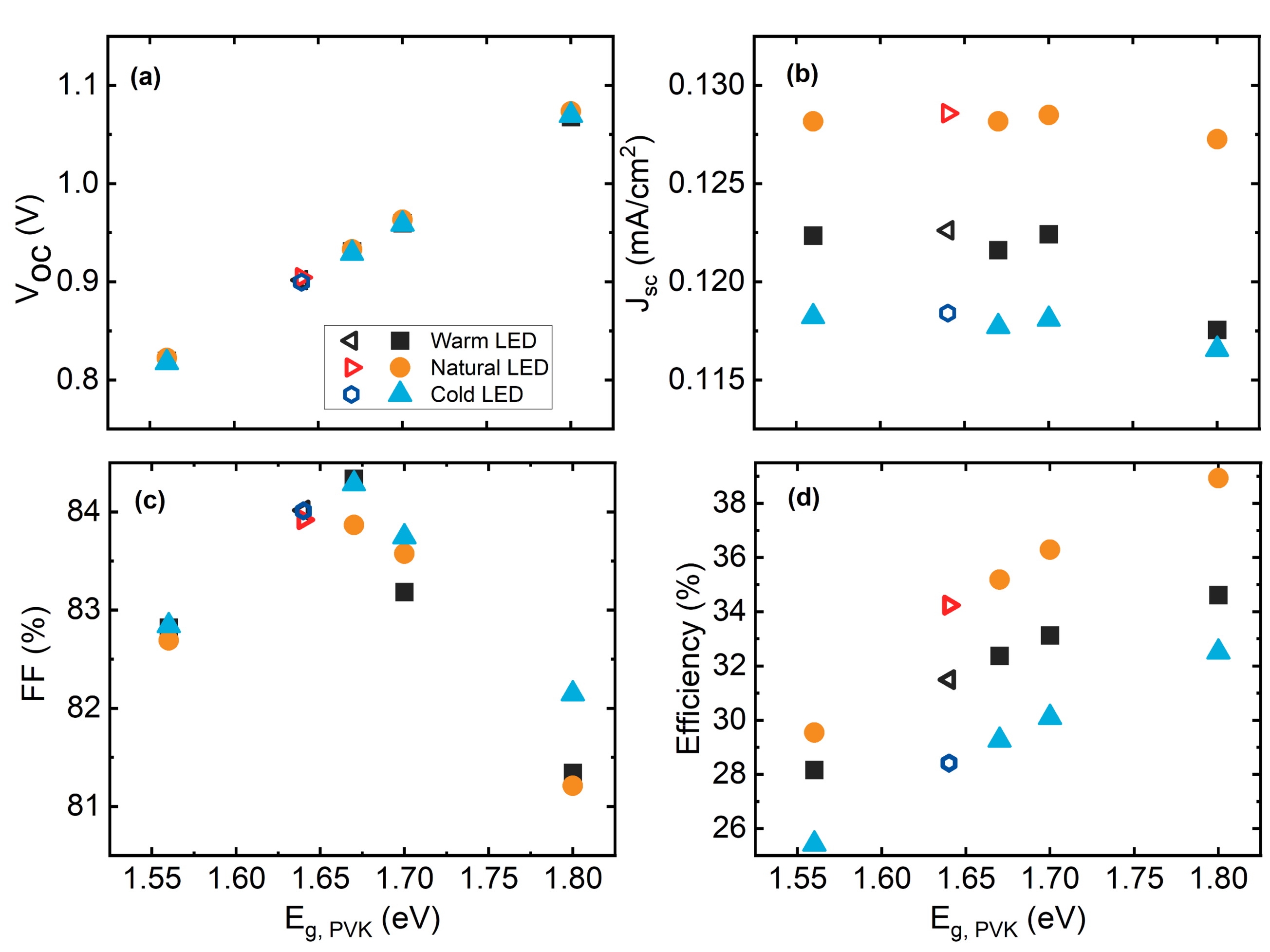

Figure 5: Electrical performance parameters (a) V_{oc}, (b) J_{sc}, (c) FF and (d) Efficiency of PSCs with optimum thicknesses for different bandgaps

- V_{oc} increases with the bandgap as expected.
- Jsc does not change significantly with Eg, due to spectral match.
- FF is optimum around a bandgap of 1.65 eV, most likely due to better band alignment with the chosen transport layers.
- Overall, higher bandgaps provide higher efficiencies.
- However, it is known in the literature that stability of perovskite is low at higher bandgap than 1.70 eV due to breakdown of I-Br bonds in chemical structure of perovskite.

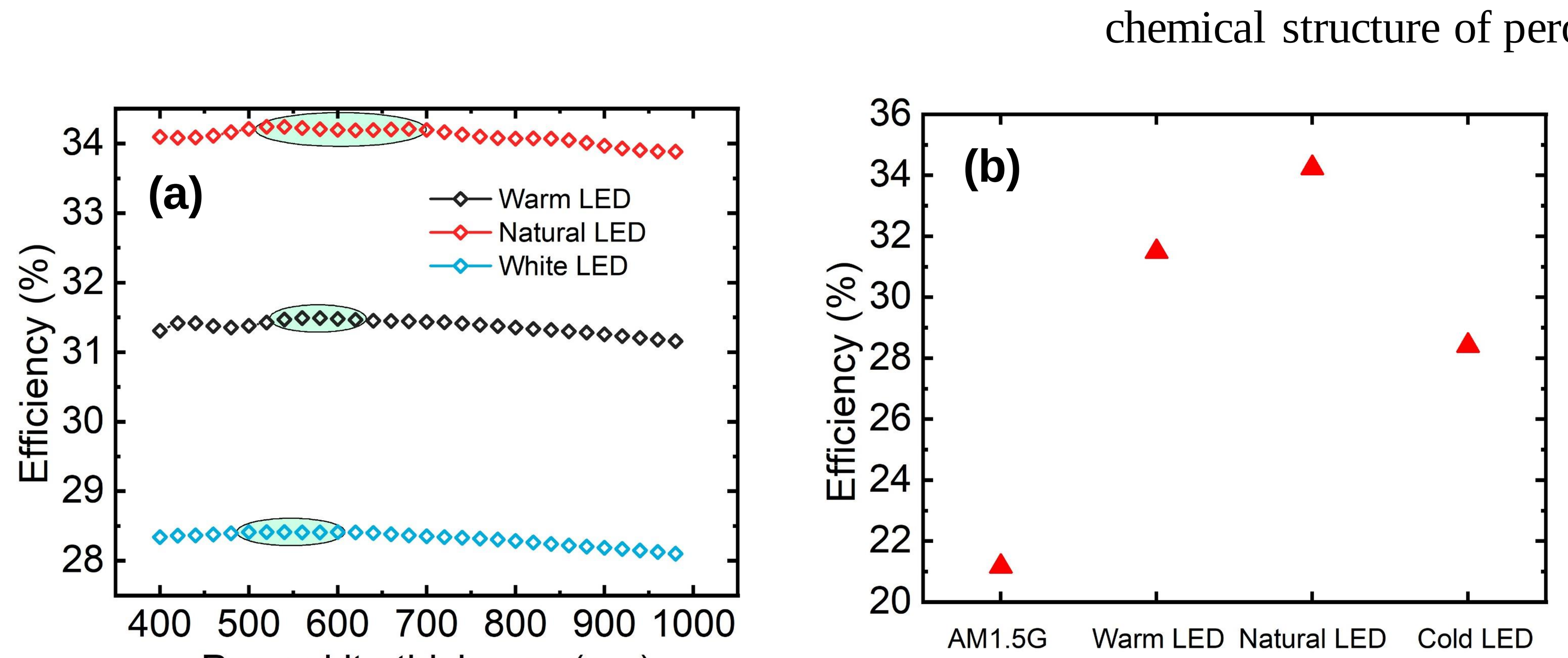

Figure 6: (a) Optimum thickness range corresponding to each LED spectra, (b) Efficiency of perovskite with 1.64eV bandgap under different illuminations

Conclusion

- Among 3 different LED spectra namely warm, natural and cold, best efficiency is observed under natural LED light illumination due to higher coherence with perovskite absorption spectrum.
- 500-600 nm thickness is determined as optimum thickness range to obtain best efficiency.
- Increasing bandgap of perovskite is beneficial as calculated from theoretical analysis. However, when perovskite of large bandgap is fabricated, its quality deteriorates. This needs to be taken into accountt
- High efficiency of solar cells is expected when fabricated for indoor applications.
- Fabricated perovskite solar cell has an efficiency of 26.2% under white LED illumination.

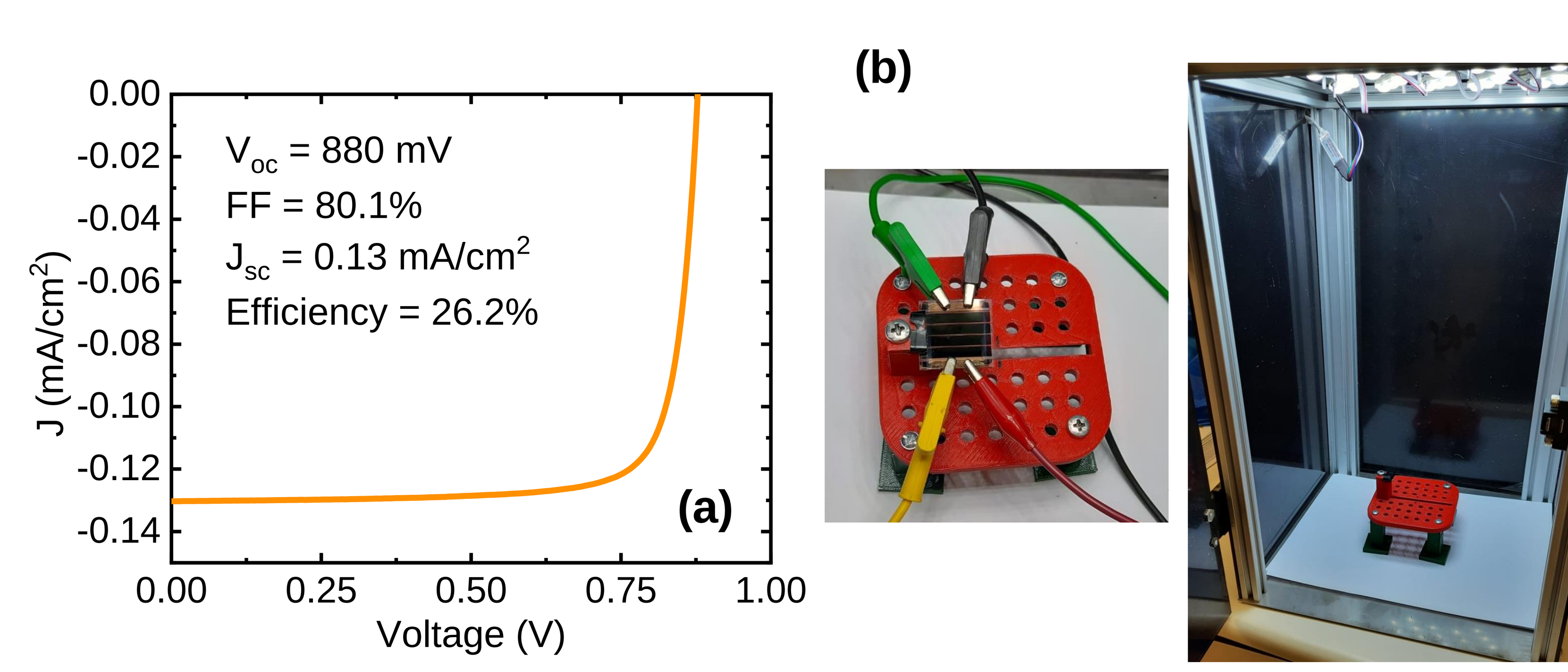

Figure 7: a) J-V curves of fabricated PSCs. Inset: performance parameters of the solar cell. b) A pictures of a setup for indoor illumination (left) and of a fabricated device during the measurement (right).

References

[1] Ho, J. K. W., Yin, H. & So, S. K. (2020). From 33% to 57% – an elevated potential of efficiency limit for indoor photovoltaics. Journal of materials chemistry. A, Materials for energy and sustainability, 8(4), 1717–1723. https://doi.org/10.1039/c9ta11894b

[2] Burkhard, G.F., & Hoke, E.T. (2011), *Transfer Matrix Optical Modeling.*

Acknowledgements

We would like to acknowledge the support of TUBITAK via 221M472.