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Modelling of Perovskite/InGaAs Tandem Solar Cells

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***Abstract*—Narrow bandgap photovoltaic materials play a crucial role in the development of perovskite tandem cells. The $In_{0.53}Ga_{0.47}As$ with a bandgap of 0.77 eV and excellent optical properties, is a kind of excellent bottom cell material for high efficiency tandem cells, as proven by III-V tandem cells. Here, we design and simulate perovskite/ InGaAs 4-terminal and 2-termianl tandem cells by wxAMPS, with efficiencies reaching 17.85% and 22.71%, respectively.**

I. Introduction

The perovskite tandem cells have been extensively researched for its excellent photovoltaic including tunability in bandgap, sharp bandgap cutoff and high photovoltage[1]. However, the perovskite tandem cells with narrow band gap materials as bottom cell can improve performance. InGaAs semiconductor materials of III-V process direct and narrow band gap, it can be formed by InAs and GaAs in any ratio (In1-xGaxAs). With X changed, bandgap varies from 1.43eV to 0.35 eV. In our work, we designed $In_{0.53}Ga_{0.47}As$ (0.77 ev bandgap) solar cell by simulate different thickness and different $MAPbI_3$/ $In_{0.53}Ga_{0.47}As$ tandem configuration, the results indicate that tandem solar cells with novel photovoltaic devices is worth to be researched and explored

II. Device Simulation Parameters

A. Theoretical Model

Two different stacking methods are used to simulate the perovskite/InGaAs tandem cells, including 4-termianl and 2-termianl configuration. The structure of tandem cells is schematically shown in Figure.1a and 1b, individually.

For the perovskite cell, we choose the appropriate model: FTO/TiO2/$MAPbI_3$/sprio-OMeTAD/Au. For the bottom cell, the n-doped $In_{1-x}Ga_xAs$ was deposited on the n-type InP substrate. When the value of x is 0.47, the lattice constant of $In_{0.53}Ga_{0.47}As$ highly matches (001) InP (0.55868 nm)[2]. Therefore, N-doped InGaAs and p-doped $In_{0.53}Ga_{0.47}As$ ensure the formation of a p-n junction in favor of photovoltaic performance.

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B. Parameter Simulation

In the device simulation, the temperature is set as 300 K. The standard sunlight spectrum is opted for the illuminating source. We set the reflection loss to be 10% because of the influence of electrodes and glass. Most of the material simulation parameters are extracted from recent articles[3,4,5].

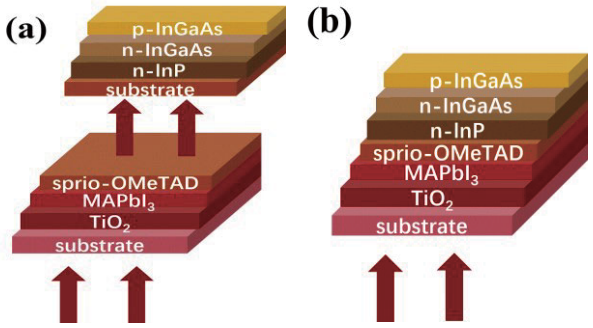

Figure 1. a) Structure of 4-termianl perovskite/$In_{0.53}Ga_{0.47}As$ tandem cells. b) Structure of 2-termianl perovskite/$In_{0.53}Ga_{0.47}As$ tandem cells.

III. Results And Discussion

A. Simulation of single junction solar cell

The perovskite solar cell with different $MAPbI_3$ thickness are simulated as shown in Figure. 2a. The simulation thickness of the light absorption layer is set as 400 nm, making the ideal open circuit voltage (V_{oc}) and the conversion efficiency (η).

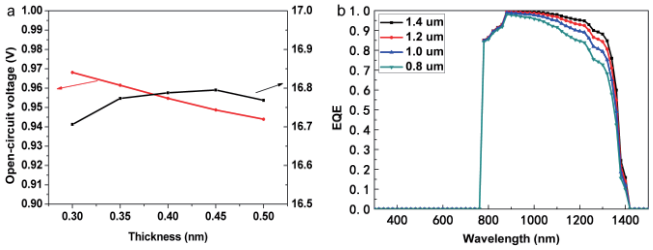

Figure 2. a) The efficiency and V_{oc} of perovskite cell with different $MAPbI_3$ thickness. b) Simulation QE curve of different thickness n-InGaAs.

For InGaAs solar cell, we can find the external quantum efficiency(EQE) between 750~850 nm decreases with the increasing of InP thickness by simulating. The InP thickness is selected as 0.12 μm as an effective substrate. The optimum n-InGaAs thickness bases on EQE performance over 800 nm. The results show the EQE between 1000 nm and 1300 nm accord with n-InGaAs thickness (Figure.2b). Therefore, the n-InGaAs thickness is set as 1.4 μm because too thick n-InGaAs is not easy to be prepared. And the EQE has no

change with p-InGaAs thicknesses between 0.1 μm and 0.2 μm. However,when the p-InGaAs layer is moved, the efficiency is only about 1%. Thus, the p-InGaAs layer mainly plays a significant role in a P-N junction, and its thickness is set as 0.15 μm. The figure. 3 shows the specific thickness of each layer of tandem solar cells, not the real solar cell model.

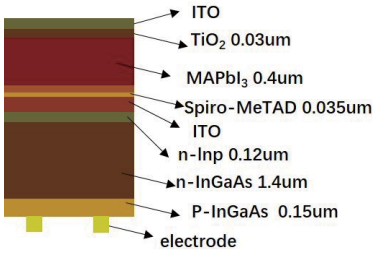

Figure 3. The each layer thickness of tandem solar cells.

B. Simulation of MAPbI3/$In_{0.53}Ga_{0.47}As$ tandem cell

For the 2-termianl tandem cells simulation, the results are abtained by inputting the parameters of the simulated perovskite cell and InGaAs cell into the wxAMPS3.0. The current-voltage(I-V) characteristic curve and the EQE are shown in Figure. 4a and 4b, severally.

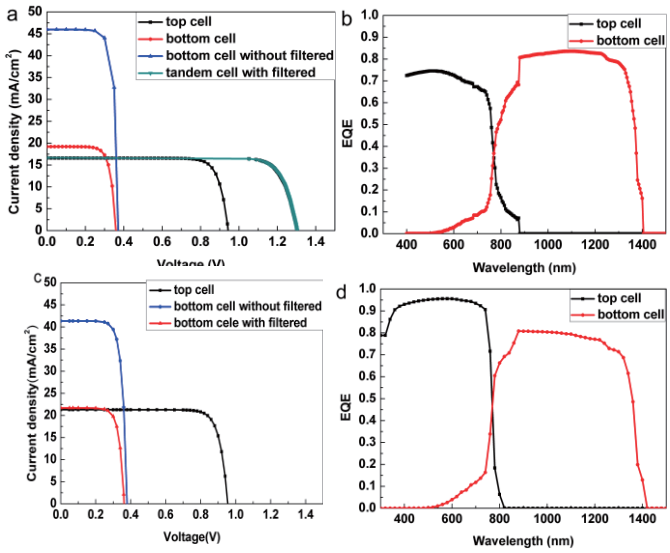

Figure 4. I-V curves a) and EQE spectra b) of 2-termianl tandem cells, I-V curves c) and EQE spectra d) of 4-termianl tandem cells.

For the 4-termianl tandem cells simulation,the solar spectra illuminating the bottom cell equals the solar spectra that passes through the glass multiplied by transmission coefficient of each layer of the perovskite cell.The I-V characteristic curves and EQE can be gained by simulation and calculation as shown in Figure 4c and 4d, respectively. Details of current and voltage characterstic are given in Table 1.

In the simulation, the results show the current of bottom cell and top cell are highly matched in 2-termianl tandem cells. Hence, $In_{0.53}Ga_{0.47}As$ is quite suitable for 2-termianl perovskite tandem cells. However, the perovskite top cell has to be illuminated through the spiro-OMeTAD layer, leading to a loss of severe parasitic absorption in the UV and visible spectrum. In our later work, we will optimize current of the top cell by changing the hole transport layer and a mixed-cation/halide perovskite material. In 4-terminal tandem cells, the efficiency is higher owing to a better ability of capturing light, and no requirement on current matching, illumination direction for the top cell with freedom.

TABLE I. PERFORMANCE OVERVIEW OF SINGLE AND TANDEM CELL

	V_{oc}(V)	J_{sc}(mA/cm^2)	FF(%)	η (%)
Top cell	0.9547	21.3062	82.5297	16.7988
Bottom cell (without filtered)	0.3792	41.3711	75.9118	11.9081
Bottom cell (with filtered)	0.3619	21.6792	75.5578	5.9283
4-termianl tandem cells	1.3166	/	/	22.7171
2-termianl tandem cells	1.3030	16.6594	82.2636	17.8568

IV. CONCLUSION

We simulated $MAPbI_3$/ $In_{0.53}Ga_{0.47}As$ tandem cells with 2-termianl configuration reaching efficiency of 17.85%, and conversation efficiency of 4-termianl configuration with 22.71%. It is worth noting that the single junction perovskite simulation efficiency has not reached the actual maximum efficiency of this structure, which means that the conversation efficiency of $MAPbI_3/In_{0.53}Ga_{0.47}As$ tandem solar cells is highly possible to break the existing conversion efficiency record. In addition, the development of $In_{0.53}Ga_{0.47}As$ low temperature growth process makes it possible to prepare perovskite /$In_{0.53}Ga_{0.47}As$ tandem cells.

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REFERENCES

[1] J. P. Mailoa *et al.*, "A 2-terminal perovskite/silicon multijunction solar cell enabled by a silicon tunnel junction," *Appl. Phys. Lett.*, vol. 106, no. 12, 2015.

[2] C. Ladous, F. D. Newman, H. A. Atwater, J. M. Zahler, K. Tanabe, and T. Pinnington, "InGaAs Solar Cells Grown on Wafer-Bonded InP/Si Epitaxial Templates," vol. 1012, 2007.

[3] S. de Wolf *et al.*, "Organometallic Halide Perovskites: Sharp Optical Absorption Edge and," *J. Phys. Chem. C*, vol. 5, pp. 1035–139, 2014.

[4] F. Gao *et al.*, "Enhance the optical absorptivity of nanocrystalline TiO2 film with high molar extinction coefficient ruthenium sensitizers for high performance dye-sensitized solar cells," *J. Am. Chem. Soc.*, vol. 130, no. 32, pp. 10720–10728, 2008.

[5] M. Photodetectors, A. F. Salem, S. Member, K. F. Brennan, and S. Member, "Theoretical Study of the Response of InGaAs," vol. 31, no. 5, pp. 944–953, 1995.