Significant light absorption improvement in perovskite/CIGS tandem solar cells with dielectric nanocone structures

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Abstract Here, we propose a novel perovskite/CIGS tandem solar cell geometry with tailored dielectric nanocone structure incorporated on the top surface for light manipulation. Absorption enhancement as high as 15.39% has been achieved both in the top and bottom subcells, leading to a 14.29% thickness reduction of the bottom subcell.

1. Introduction

Recent research into the field of thin-film solar cells has found an attractive technology that utilizes perovskite material as the solar absorber for high efficiency photovoltaic devices [1]. Since the first application of perovskite material in solar cells in 2009, the efficiency has soared from 3.8% to over 20% [2]. However, due to the bandgap limitation of the material, a perovskite-based single junction device can only response to the solar spectrum less than 900 nm for the electron-hole pair generations. Therefore, to obtain even higher efficiency photovoltaic devices, multi-junction devices with appropriate bandgap materials need to be combined with the perovskite material to harvest solar spectrum longer than 900 nm, and advanced light trapping method is deeply necessary. In this work, we utilize high bandgap perovskite material and low bandgap CIGS material to design a tandem solar cell model for harvesting more solar spectrum in the simulation. The detailed layers applied in our model are presented in Fig. 1, based on the individual single junction solar cell device design respectively. To trap light more efficiently in the designed device, ITO dielectric nanocone structures are placed on top of the solar cells, acting light scattering and anti-reflection elements [3]. Through the optimization of the thickness of each subcell for current matching and the nanocone parameters (height and the angle of the cone) for further absorption enhancement, a short current density (J_{SC}) as high as 18.49 mA/cm^2 is achieved, which is much higher compared to the 16.09 mA/cm^2 in flat cells without the nanocone structure, leading to a 15.39% J_{SC} enhancement.

2. Methods and Results

The perovskite/CIGS tandem solar cell integrated with dielectric nanocones on the top surface is illustrated in Fig. 1. Due to that the device performance is determined by the lowest J_{SC} value of each subcell, the appropriate thicknesses of perovskite and CIGS layers for J_{SC} matching need to be investigated first. For the flat solar cell case without nanocones, we choose perovskite absorber for the top subcell (ITO: 80 nm, TiO_2: 50 nm, perovskite: thickness to be optimized, Spiro: 30 nm) and the CIGS absorber for the bottom subcell (ITO: 80 nm, ZnO: 80 nm, CdS: 50 nm, CIGS: thickness to be optimized, MO: 100 nm) considering their bandgap. We utilize the Lumerical FDTD software to build up and simulate the model. To figure out the condition of the J_{SC} matching between each subcell, the thicknesses of perovskite layer are selected to be 100 nm, 150 nm, 200 nm and 250 nm while the thickness of the CIGS layer is swept from 500 to 2500 nm. Through the calculation of the J_{SC} values of each subcell as functions of the thicknesses of the subcells, it can be found that when the thickness of the CIGS layer is 1750 nm and the thickness of the perovskite layer is 150 nm, the J_{SC} value (16.09 mA/cm^2) matches between the top cell and the bottom cell.

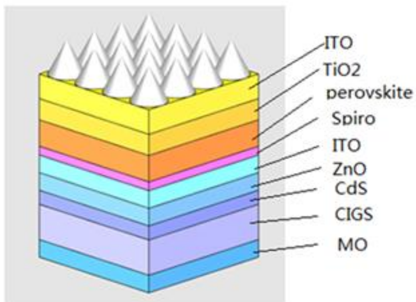

Fig 1. The perovskite/CIGS tandem solar cell structure with nanocones on the top surface.

To further enhance the flat tandem solar cell absorption, we place ITO nanocones on the top surface of the tandem solar cell with the thickness of perovskite layer 150 nm and the thickness of CIGS layer 1750 nm as shown in Fig. 1. For the top surface integrated nanocones, different aspect ratios (determined by the cone height and the cone angle) are optimized for the highest device absorption enhancement [4]. Fig. 2 presents the J_{SC} enhancement mapping in the bottom subcell as a function of the cone height and the cone angle (θ). The J_{SC} value with nanocones is normalized to that of the bottom subcell (16.09 mA/cm^2) in the reference flat tandem solar cell without nanocones. In Fig. 2 (a), it's obvious that the highest enhancement of 18.64% in the bottom subcell can be achieved with the optimized parameters of 500 nm in height and 70^o in cone angel for nanocones, leading to an increased J_{SC} value of 19.09 mA/cm^2.

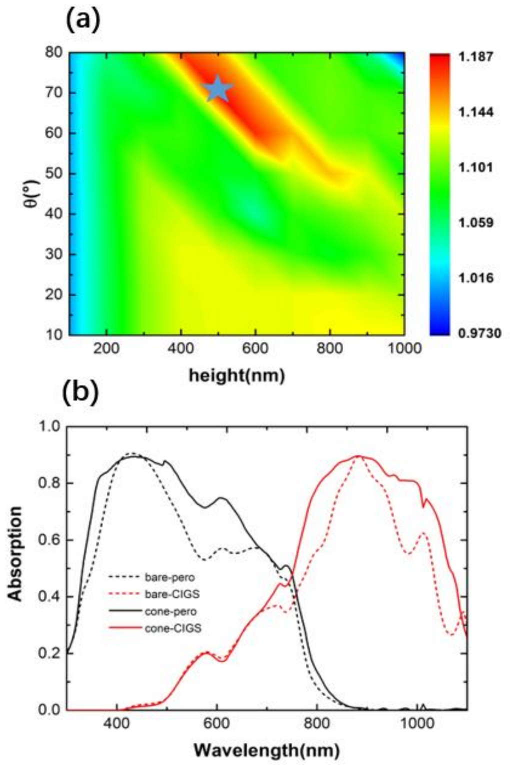

Fig 2. (a) J_{SC} enhancement of the bottom subcell as a function of the height and the cone angel of nanocones. (b) Absorption comparison of the perovskite top subcell and CIGS subcell with/without the optimized cone parameters with cone height of 500 nm and the cone angel of 70^o.

Nevertheless, in terms of top cell, the J_{SC} value is 18.48 mA/cm^2 increased about 15.37% under the same parameters. This can be ascribed to the scattering and anti-reflection effects of the nanocones, which increase the light path inside the bottom CIGS subcell and top perovskite subcell respectively. As shown in Fig. 2 (b), the absorption in the bottom subcell can be improved significantly in the wavelength range from 800 nm to 1100 nm due to the scattering effect, while for the perovskite subcell, the absorption in the wavelength from 300 nm to 700 nm is mainly improved. Under this circumstance, it's promising to reduce the thickness of the CIGS layer for cost savings without compromising the overall device performance compared to the flat solar cell device. Through the simulation of nanocones incorporated solar cell with thinner CIGS layer, we can find that the J_{SC} value of 18.49 mA/cm^2 can be obtained with a CIGS layer thickness of only 1500 nm. The matched J_{SC} value can be increased by 15.39% compared to the planar solar cell with a reduced bottom subcell thickness of 14.29%.

3. Conclusion

In summary, a perovskite/CIGS tandem solar cell geometry incorporated with nanocones is systematically investigated for achieving high efficiency perovskite-based thin film solar cells. Through optimizing the nanocone parameters, J_{SC} enhancement as high as 18.64% in bottom subcell can be obtained and the matched J_{SC} value of 18.49 mA/cm^2 is achieved with a reduction of CIGS layer thickness from 1750 nm to 1500 nm. This approach theoretically opens up a pathway for designing perovskite-based low cost high efficiency tandem solar cells.

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Reference

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