Plasmonic enhancement of light-harvesting efficiency in Perovskite solar cells embedding Ag nanorods

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***Abstract*—Perovskite solar cells have attracted great attention in recent years due to its advantageous features including low production cost. Incorporation of plasmonic metal nanocrystals is a promising approach for broadening and enhancing the light harvesting of Perovskite solar cells. In this paper, we report a facile and versatile route to tune the photoresponse of perovskite via embedding Ag nanorods with multiplexed length-to-diameter aspect ratios. Plasmonic Ag nanorods with length-to-diameter aspect ratio of 2 and 3 are embedded, exhibiting their plasmon peak at 789 nm and 798 nm, respectively. Furthermore, the mechanism of the absorption has been discussed.**

***Keywords*-Perovskite solar cells; Ag nanorods; Plasmonic.**

I. Introduction

The conversion of light into electricity is known as the photovoltaic effect, and the first solid state organo-metal halide perovskite solar cell that utilised this effect wereinvented in 2009 and with power conversion efficiency (PCE) of only 3.8%. After 10 years development PCE of perovskite solar cell has been increased by 6 times more than that when it was invented and maximised to 25.1%. With a high absorption coefficient, long charge carrier diffusion length and efficiently function for charge transport in the solar cell devices, and recent PCE improvement is achieved mainly by increase of efficiency of photon-electric conversion via optical absorption and heterojunctiondesign device to enhance material performance [1-2].

Meanwhile, plasmonic nanoparticles are particles whose electron density can couple with electromagnetic radiation of wavelengths that are far larger than the particle, which exhibit interesting scattering, absorbance, and coupling properties based on their geometries and relative positions. It has been reported that doping of plasmonic nanoparticles can elevate the optical absorption of perovskite photovoltaic devices. Hajjiah Ali and Yue Li respectively investigated the plasmonic effects of Ag nanoplates and silver–gold (Ag–Au) alloy popcorn shaped nanoparticles embedded in perovskite solar cells, and both confirmed their effects on increase of PCEs [3-4].

In this work, we study in detail on the near-field multiple scattering effects of plasmonic nanorods embedded into perovskite active layer by employing the rigorous finite-difference time-domain (FDTD) method. The fundamental physics of the optical absorption shows remarkable differences between the nanorods embedded into an active layer. The length-diameter ratio dependent features of near-field scattering from Nanorods significantly affect the absorption enhancement when nanorods are embedded into perovskite.

II. Structure and modeling

In Figure.1, we show the schematic drawings of plasmonic perovskite solar cells embedding Ag nanorods. The parameters of the Ag nanorods are represented by the diameter of top spheres (D), the lengh (L). The periodicity (*P*) was fixed as 300nm. The thickness of active perovskite was selected as 300nm. The carrier transport layer (ETL and HTL later) and the conductive ITO/glass were fixed as 50nm, respectively. Numerical simulations are performed using the FDTD package. Periodic boundary conditions are used in the x and y directions, and perfectly matched layer boundary conditions are used in the z direction. A normally incident electromagnetic wave within wavelength form 300nm to 1500nm. The length-diameter ratio (η) is defined as the length/diameter (L/D) of the nanorods.

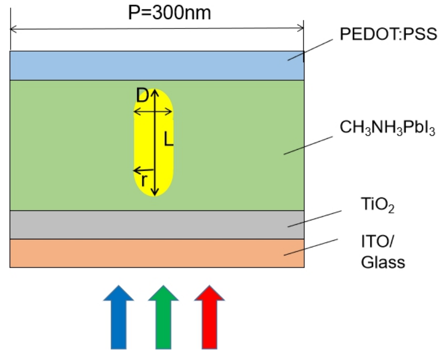

Fig. 1. Schematic of plasmonic perovskite solar cells embedding Ag nanorods

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III. Results and discussion

Fig.2 shows the Absorption spectrum of plasmonic perovskite layer ebedding Ag nanorods versus length-diameter ratio. In our model, the radius of nanorods is 40nm. When L=4r and D=2r, the length-diameter ratio is η=2. When L=6r and D=2r, the length-diameter ratio is η=3. Under these two parameters, the localized surface plasmon resonance peak of Ag nanorods appeared in the absorption spectra of the 300nm perovskite absorption layer and redshifted with the increase of the length-diameter ratio.

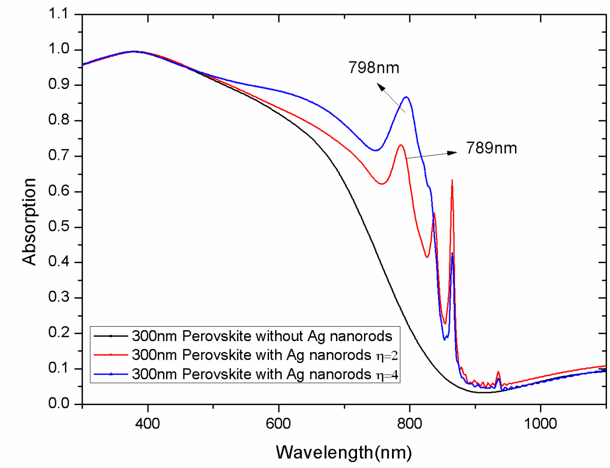
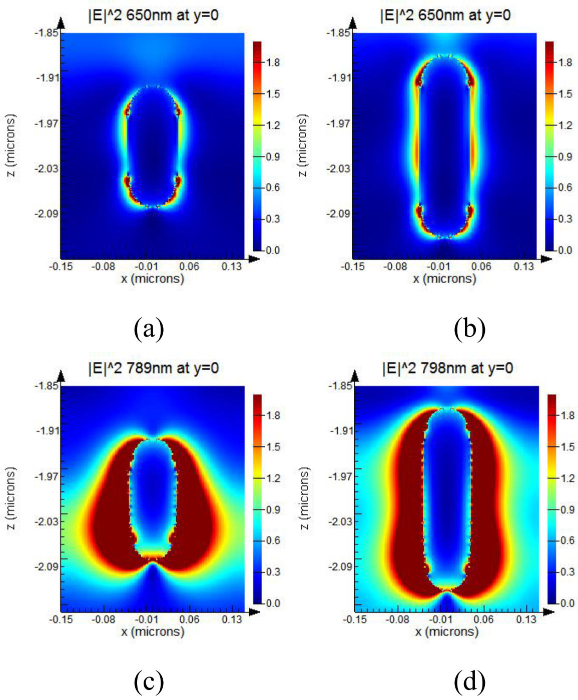
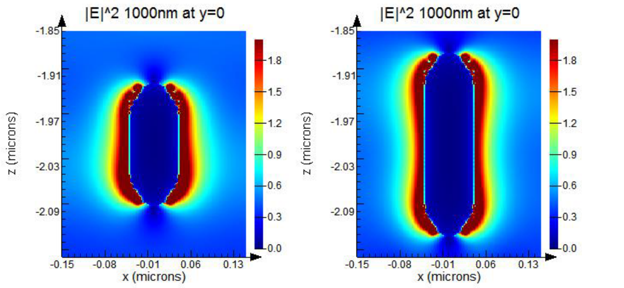


Fig. 2. Absorption spectrum of plasmonic perovskite layer ebedding Ag nanorods versus length-diameter ratio

Fig.3 shows the electric intensity distribution at the cross section of plasmonic perovskite layer ebedding Ag nanorods versus length-diameter ratios.





(e) (f)

Fig. 3. Electric intensity distribution at the cross section of plasmonic perovskite layer ebedding Ag nanorods versus length-diameter ratio (a) η=2, λ=650nm; (b) η=4, λ=650nm; (c) η=2, λ=789nm; (d) η=4, λ=798nm; (e) η=2, λ=1000nm; (f) η=4, λ=1000nm.

The interaction between longitudinal and transverse modes supported in the nanorods chain plays a key role in the absorption enhancement. Through properly engineering the position and the Length to diameter ratio of nanorods, theoretical results show that the absorption enhancement in the range of 600-800nm. Moreover, The work provides the physical guidelines for plasmonic perovskite solar cells.

IV. Acknowledgment

The project is supported by research fund of Changshu Industry Technological Innovation (No.CQ201602), Jiangsu Province Natural Science Research Programs of higher schools (No.17KJB510001), Suzhou Industry Technological Innovation (No.SYG201819), Jiangsu Science and Technology Department of China (Grant No.BY2018203) and National Natural Science Foundation of China (Grant Nos.61674022).

REFERENCES

[1] Ghahremanirad E , Olyaee S , Nejand B A , et al. Improving the performance of perovskite solar cells using kesterite mesostructure and plasmonic network[J]. Solar Energy, 2018, 169:498-504.

[2] Wenqiu, Deng, et al. Plasmonic enhancement for high-efficiency planar heterojunction perovskite solar cells[J]. Journal of Power Sources, 2019.

[3] Hajjiah Ali, Kandas Ishac, Shehata Nader. Efficiency Enhancement of Perovskite Solar Cells with Plasmonic Nanoparticles: A Simulation Study[J]. Materials, 11(9):1626.

[4] Yue L , Yan B , Attridge M , et al. Light absorption in perovskite solar cell: Fundamentals and plasmonic enhancement of infrared band absorption[J]. Solar Energy, 2016, 124(feb.):143-152.