Enhancement of optical properties of Perovskite solar cells through added plasmonic nanostructures

N. Shehata[1,2,3,4*], H. Badran[5], I. Kandas[1, 2, 3], A. Hajjiah[5]

[1] Kuwait College of Science and Technology (KCST), Doha District, Safat 13133 Kuwait
[2]Department of Engineering Mathematics and Physics, Faculty of Engineering, Alexandria University, Alexandria 21544 Egypt.
[3]Center of Smart Nanotechnology and Photonics (CSNP), Smart Critical Infrastructure (SmartCI) Research Center, Alexandria University, Alexandria 21544 Egypt.
[4]USTAR Bioinnovation center, Faculty of Science, Utah State University, Logan, Utah 84341United States.
[5]Kuwait University, College of Engineering and Petroleum, Electrical Engineering Department, Safat, Kuwait
*E-mail:n.shehata@kcst.edu.kw

ABSTRACT

Hybrid organic-inorganic perovskites have been extensively studied as a promising research topic in solar energy harvesting, due to their simple process, developed optical and electrical properties, and relatively low-cost materials. However, the perovskite solar cells have some low optical absorption near red-visible region. This research work presents numerically the enhancement of optical characteristics of $Cs_{0.17}FA_{0.83}Pb(Br_{0.17}I_{0.83})_3$ (CsFA) perovskite solar cell through adding films of gold nanoparticles. The mean diameter of gold nanoparticles is selected to offer an optical spectrum overlap between plasmonic resonance spectrum with the low absorption spectrum of perovskite material.

Keywords: perovskite, gold nanoparticles, plasmonic resonance, EQE

1 INTRODUCTION

Over the last few years, hybrid organic–inorganic perovskites have been extensively studied due to their promising properties in optoelectronic applications. The power conversion efficiency (PCE) of perovskite based solar cells has been tremendously increased from 3.8% upon its inception in 2009 to a certified 27.3% in 2018 [1, 2]. There are different commonly used perovskite semiconductor material in solar cells such as methylammonium-lead (II)-iodide with the chemical formula $CH_3NH_3PbI_3$ ($MAPbI_3$), and $Cs_{0.17}FA_{0.83}Pb(Br_{0.17}I_{0.83})_3$ (CsFA) owing to its promising optical/electrical properties for photovoltaic applications. However, such materials suffer from a relative optical lower absorption in range near to red visible range [3].

One method for achieving light trapping in thin film solar cells is the use of metallic nanoparticles (NPs) [4]. Based on surface plasmon resonance shown up when illuminated with light of suitable frequency, it can lead to optical confinement around this resonance wavelength [5]. Plasmonic nanostructures such as gold nanoparticles (Au NPs) can be integrated with solar cell through being deposited on the front surface of the solar cell or to be embedded inside the cell [6, 7]. However, depositing the particles on the rear side of the absorber layer is realized to give better photocurrent with less optical absorption problems [8, 9].

In this paper, it has been theoretically investigated the impact of adding gold nanoparticles layer on the optical parameters of perovskite solar cells. The perovskite solar cells may have some lower optical absorption in the visible spectrum around the red region. Therefore, our contribution is to characterize the optical properties of perovskite solar cell through adding metallic nanoparticles whose plasmonic resonance wavelength is close to the spectrum range of lower absorption of the perovskite material.

2 SIMULATION PROCEDURE

Our targeted device in this work is the regular structure of n-i-p semi-transparent perovskite solar cell (area = 0.1 - 1 cm^2) with an architecture of glass/ ITO-front/ETL/Perovskite/HTL/ITO-rear, where SnO_2 is used as the electron transport layer (ETL) and spiro-OMeTAD is used as the hole transport layer (HTL). A schematic model of the semi-transparent perovskite solar cell used in our optical simulations can be seen in Fig. 1.

To investigate the effect of Au NPs on the performance of the perovskite solar cell, they are applied at the rear side of the perovskite solar cell with diameter of value 40 nm and beyond to get plasmonic resonance wavelength above 550 nm which can compensate the external quantum efficiency losses in the perovskite layer in this range of spectrum. Then, the Transfer-Matrix-Based Optical Simulation Method (TMM) was used to model the optical properties of thin-film layer stacks such as absorbance (A), along with external quantum efficiency (EQE).

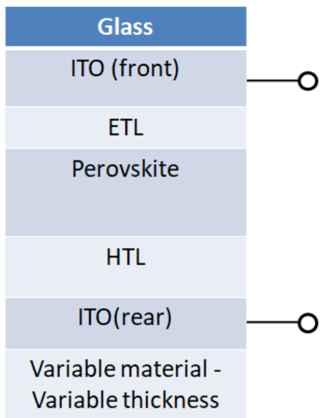

Figure 1. Schematic model of the semi-transparent n-i-p CSFA perovskite solar cells applied in optical simulations. The variable material layer is Au NPs, which is included in our simulations.

In order to investigate the effect of Au NPs on the performance of the perovskite solar cell, optical loss analysis was considered by varying the thickness of both Au films at the rear side of the perovskite solar cell in the used TMM simulations. According to the limitations of the used coding we have assumed that Au NPs are deposited as one layer over the perovskite with negligible grain boundaries problems that can be found in the real design.

3 RESULTS AND DISCUSSION

The real and imaginary parts of permittivity of Au NPs, with radius of 50 nm, are shown in Fig. 2. As noticed, the real part of permittivity is negative for a wide range of wavelengths, which is responsible for the appearance of resonance wavelength. The imaginary part is responsible for the absorption loss.

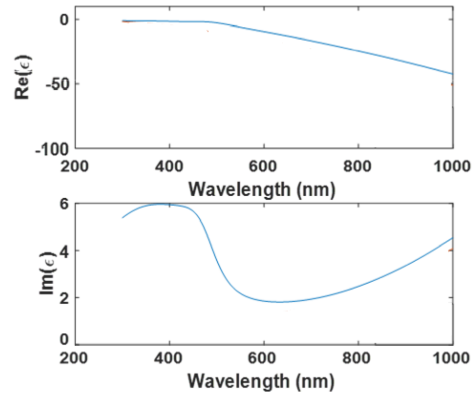

Figure 2. Real and imaginary parts of permittivity for Au NPs.

Figure 3 shows the simulated cross sections of Au NPs of radius 50 nm with assuming that surrounding medium is a glass with refractive index of value 1.5. The resonance wavelength is size - and shape-dependent. So, whenever the nanoparticle mean size increases, red shift occurs for Au cross- sections is expected. Here, we are assuming spherical shape of nanoparticles.

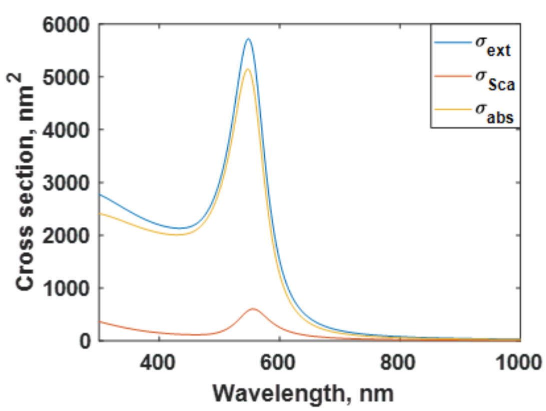

Figure 3. Cross - sections of Au NPs

Figure 4 shows the optical absorption of perovskite cell with added layer of Au NPs at different diameters, which is equivalent to variable layer thickness. It can be noticed that the absorption has been improved due to optical coupling within plasmonic resonance of the added gold. The resonance wavelength is varying from approximately ~ 550 nm to ~ 600 nm when the particle diameter is changing from 40 nm to 300 nm, respectively, for surrounding medium of refractive index of 1.5. Then, Fig. 5 shows the improvement of EQE at wavelength range close to the plasmonic resonance frequency. The EQE

TechConnect Briefs 2019, TechConnect.org, ISBN 978-0-9988782-8-7

enhancement can be explained due to the impact of reflected photoelectrons which is trapped according to the added layer of plasmonic NPs, beside the optical enhancement of absorption due to plasmonic resonance of the added layer. Within higher thickness of Au NPs layer, the EQE shows slight improvement with a saturation behavior at relatively higher NPs size up to 300 nm diameter.

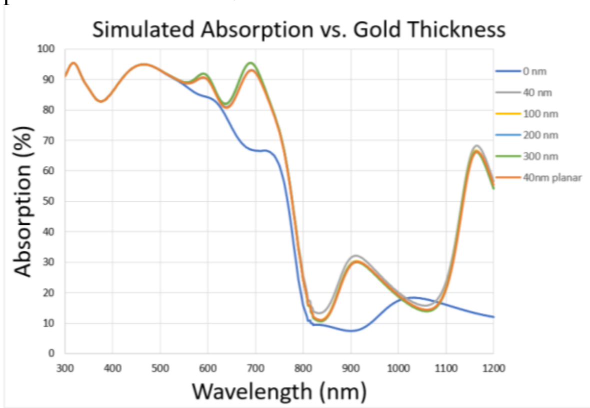

Figure 4. Optical absorption of CSFA perovskite cell with added gold nanoparticles of different radii.

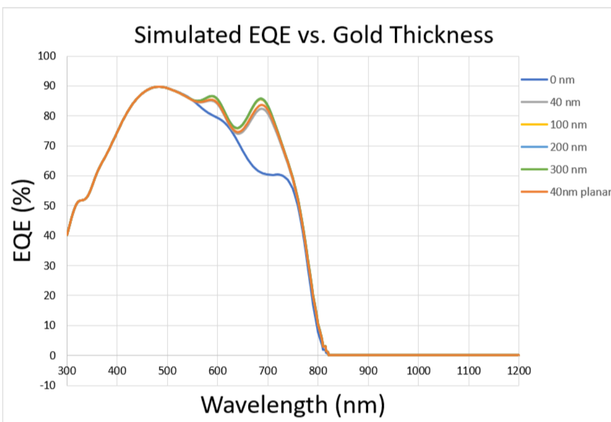

Figure 5. EQE of CSFA perovskite cell with added gold nanoparticles of different radii.

4 CONCLUSION

In this paper, the effect of adding plasmonic layer of Au NPs to the rear side of the perovskites solar cell is analytically studied. The resonance wavelength of the plasmonic NPs is adjusted to enhance the optical absorption of the solar cell in the visible range especially around the red wavelength. Then, the absorption has been improved and the overall EQE enhancement is achieved.

ACKNOWLEDGEMENT

This project was funded “Fully” by Kuwait Foundation for the Advancement of Sciences under project code: PN18-14SP-01.

REFERENCES

[1] Kojima, A.; Teshima, K.; Shirai, Y.; Miyasaka, T. Organometal Halide Perovskites as Visible-Light Sensitizers for Photovoltaic Cells. Journal of the American Chemical Society 2009, 131, 6050-6051.

[2] https://www.power-technology.com/news/new-record-perovskite-solar-cell-efficiency/ (lastaccessed: April 2019).

[3] H A. Hajjiah, I. Kandas, N. Shehata, Efficiency Enhancement of Perovskite Solar cells with Plasmonic Nanoparticles: A simulation study, Materials, 2018, 11(9), pp. 1626.

[4] Dabirian, A.; Byranv, M.; Naqavi, A.; Kharat, A.; Taghavinia, N. Theoretical Study of Light Trapping in Nanostructured Thin Film Solar Cells Using Wavelength-Scale Silver Particles. ACS Applied Materials Interfaces 2016, 8, 247−255.

[5] Pillai,S.; Catchpole, K.; Trupke, T.; Green, M. Surface plasmon enhanced silicon solar cells. Journal of Applied Physics 2007, 101, 093105.

[6] Proise, F.; Joudrier, A.; Pardo, F.; Pelouard, J.; Guillemoles, J. Ultrathin mono-resonant nano photovoltaic device for broadband solar conversion. Optics Express 2018, 26. A806.

[7] Atwater, H.; Polman, A. Plasmonics for improved photovoltaic devices. Nature Mater. 2010, 9, 865.

[8] Beck, F.; Mokkapati, S.; Catchpole, K. Light trapping with plasmonic particles: beyond the dipole model. Optics Express 2011, 19(25), 25230–25241.

[9] Saleh, Z.; Nasser, H.; Özkol, E.; Günöven, M.; Altuntas, B.; Bek, A.; Turan, R. Enhanced Optical Absorption and Spectral Photocurrent in a-Si:H by Single- and Double-Layer Silver Plasmonic Interfaces. Plasmonics 2014, 9, 357–365.