

Improvement of Perovskite Solar Cells Photovoltaic Performance by Localized Surface Plasmon Effect of Silver-alumina Core-shell Nanoparticles

Marziyeh Yaghubinia¹, Majid Ebnali², Mahmoud Zendeheel³ and Mohammadreza Yaghubinia⁴

¹Department of Electronic Engineering, Islamic Azad University of Najaf Abad, Isfahan, Iran

²Department of Electronic Engineering, Shahrekord University, Shahrekord, Iran

³Research and Development Section, Kimia Solar Company, Isfahan, Iran

⁴Department of Electronic Engineering, Islamic Azad University of Khorasgan, Isfahan, Iran

Keywords: Perovskite, Solar Cell, Plasmon Effect, Core-shell.

Abstract: Perovskite solar cells are new generation of nanostructure-based solar devices that could reach to highest efficiency records between third generation solar cells. In present project, for the first time, enhancement of the photovoltaic performance of planner perovskite solar cells is achieved by using localized surface Plasmon (LSP) effect of silver-alumina core-shell nanoparticles as a dopant in the perovskite layer. Photovoltaic performances of the devices are evaluated by FE-SEM, IV measurement, cyclic voltammetry, UV-Vis spectroscopy and electrochemical impedance spectroscopy. The results show significant increase of the overall efficiency and short-circuit current density of the devices by using LSP effect of Ag-Al₂O₃ nanoparticles.

1 INTRODUCTION

Solid-state thin film solar cells represent a promising technology to harvest and convert solar energy to electricity efficiently and cost-effectively (Sargent, 2012). There exists a plethora of technologies, ranging from thin film absorber layers of binary and tertiary semiconductor compounds (Katagiri et al., 2009), to demixed polymer blends, where nano to mesostructure is essential to efficiently ionize excitons (the primary excited state following light absorption) and extract charge. Very recently, organometal halide perovskites have been employed as the absorber layer in hybrid solar cells, exhibiting exceptionally low loss photovoltaic operation, as well as a simple solution based synthetic route from abundant sources (C, N, Pb and halogen). Miyasaka and coworkers first reported a 3.8% efficient CH₃NH₃PbI₃ “perovskite sensitized” solar cell (PSC), employing a liquid electrolyte in a conventional dye-sensitized solar cell (DSC) architecture (Kojima et al., 2009). By replacing the liquid electrolyte with a solid organic hole conductor spiro-OMeTAD (2,2',7,7'-tetrakis (N,N-di-p-methoxyphenylamine)-9,9'-spirobifluorene), Park

and coworkers and ourselves achieved between 8 to 9.7% efficiency based on perovskite sensitized mesoporous TiO₂ devices (Kim et al., 2012), and Etgar and coworkers demonstrated operating mesoporous TiO₂-perovskite solar cells without any additional hole-transporter (redox couple) (Etgar et al., 2012).

Since the inorganic-organic hybrid perovskite solar cell was first reported in 2009 (Kojima et al., 2009), its power conversion efficiency (PCE) was rapidly improved to as high as 19.3% by now, and could ultimately boost efficiencies to 25% as high as that of single-crystal silicon cell (Service, 2014). To further improve the efficiency, it is necessary to extend light absorption spectrum to harvest more energy in thin film solar cells, without increasing the thickness and the complexity of the devices (Ogomi et al., 2014). Although the absorption coefficient of hybrid perovskite at 550 nm is around $1.5 \times 10^4 \text{ cm}^{-1}$, as strong as organic materials, the absorption is drop-down around band edge (Kazim et al., 2014). Therefore, it should be promising to greatly enhance the light absorption of hybrid perovskite around the band edge.

To boost the solar cells' light absorption, one of the promising methods is to apply noble metal nanoparticles, on which localized surface plasmon (LSP) resonance can be excited under the light illumination. The confined electromagnetic energy based on LSP resonance could greatly improve the light absorption of active medium surrounding the nanoparticles (NPs) (Chen et al., 2013). The light absorption enhancement and efficiency improvement of different kinds of solar cells, including thin film Si solar cells, dye-sensitized solar cells (DSCs) (Qi et al., 2011), and organic photovoltaics (OPVs) (Lu et al., 2013), had been reported recently.

In present project, for the first time, localized surface Plasmon effect of core-shell structure of silver-alumina nanoparticles on photovoltaic parameters of perovskite solar cells with planner architecture based on $\text{Pb}(\text{CH}_3\text{NH}_3)_3\text{I}_3$ sensitizers, is investigated. Performance of the devices are evaluated by I-V measurement, cyclic voltammetry, UV-Vis spectroscopy and electrochemical impedance spectroscopy (EIS) and compared to perovskite solar devices without LSP effect.

2 MATERIALS AND METHODS

The patterned substrates FTO were cleaned in an ultrasonic bath, using detergent with de-ionized water, acetone and isopropanol (10 minutes for each step). Patterning of the TiO_2 layer about 50nm was achieved by using the dip coating method (multi-purpose dip coating machine of Kimia Solar Co, model: mpDCTT-1200). DektakVeeco 150 profilometer was used for measurement the thickness of the blocking layer.

The lead iodide solution (PbI_2 in N,N-dimethylformamide, 460 mg ml⁻¹) was made. Then 10 ppm silver-Alumina nanoparticles added in the solution of PbI_2 , finally spin coated with 6000 r.p.m for 10 sec then dried at 70 °C for 1 hr.

$\text{CH}_3\text{NH}_3\text{PbI}_3$ crystallization was achieved by dipping the PbI_2 layer in a methylammonium iodide solution ($\text{CH}_3\text{NH}_3\text{I}$ in anhydrous 2-propanol 10 mg ml⁻¹) for 2 minutes then immediately washed with 2-propanol by spin coating method at 6000 r.p.m for 10 sec and dried at 70 °C for 30 min.

The hole-transporting layers was deposited by spin-coating a 75 mg ml⁻¹ solution of 2,20,7,70-tetrakis-(N,N-dip-methoxyphenylamine)9,9'-spirobifluorene (Spiro-OMeTAD), doped with 8 μl of tert-butylpyridine and 11 μl of Lithium Bis(Trifluoromethanesulfonyl)Imide (Li-TFSI)

solution (520mg in 1 ml of acetonitrile), was spin coated by 2000 rpm for 45 second and thickness was around 250nm (the thickness of all samples checked by DektakVeeco 150 profilometer).

Samples were introduced into a high vacuum chamber (10⁻⁶ mbar) to thermally evaporate Au back contacts (thickness 80 nm).

Masked devices were tested under a solar simulator (Kimia Solar sun simulator model: SSTT-1100) at AM1.5G and 100 mW cm⁻² illumination conditions calibrated with a certified reference Si Cell (RERASolutions RR-1002). Incident power was measured with a Skye SKS 1110 sensor. The absorbance was measured with a BLACK-Comet UV-VIS Spectrometer. The morphology and grain size of the PbI_2 , perovskite and HTM layers obtained with Scanning Electron Microscopy (FE-SEM). Electrochemical analysis was measured with Autolab Instrument.

3 RESULTS

The Scanning electron microscopic images and UV-Vis measurement of the perovskite layers shows in the figures 1 and 2, respectively. The SEM shows that the perovskite layer is quite homogenous and the size of the crystal was around 100 nm. From the UV-VIS measurement it observed with adding the Silver-alumina nanoparticle as a dopant in the perovskite the absorbance increased which is relate to the LSP effect as we expect from the theoretical investigation.

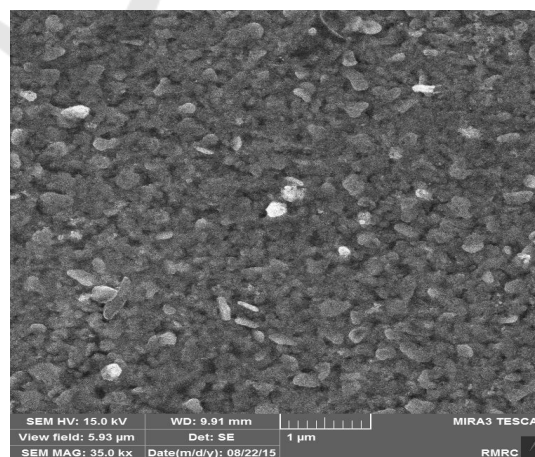


Figure 1: FE-SEM image of perovskite layer containing Ag- Al_2O_3 nanoparticles.

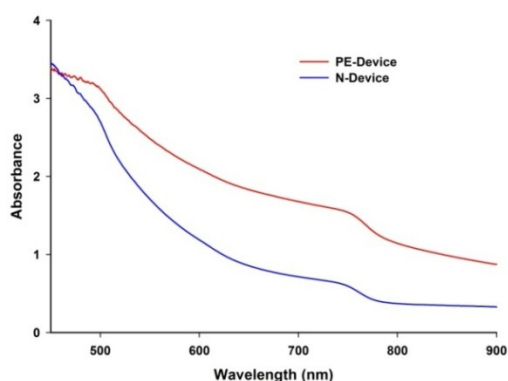


Figure 2: UV-Vis absorbance spectra of perovskite layers.

The results of I-V measurement analysis spectra and the photovoltaic parameters of the devices under AM1.5G illumination are present in figure 3 and table 1, respectively. By insertion of Ag-Al₂O₃ nanoparticles in the perovskite layer, short circuit current density (J_{sc}) of the device is significantly enhanced which led to increase of the overall efficiency from 10% to 13.9%. Furthermore, the other photovoltaic parameters have not been varied by insertion of Ag-Al₂O₃ nanoparticles. These results proof our proposal for enhancement of the perovskite absorbance by positive LSP effect of core-shell nanoparticles.

Table 1: Photovoltaic parameters of perovskite solar cells with and without LSP effect.

Sample	$V_{oc}(v)$	J_{sc} (mA/cm ²)	FF	PCE (%)
PE-cell	0.934	24.5	0.61	13.9
N-cell	0.969	17.5	0.59	10.0

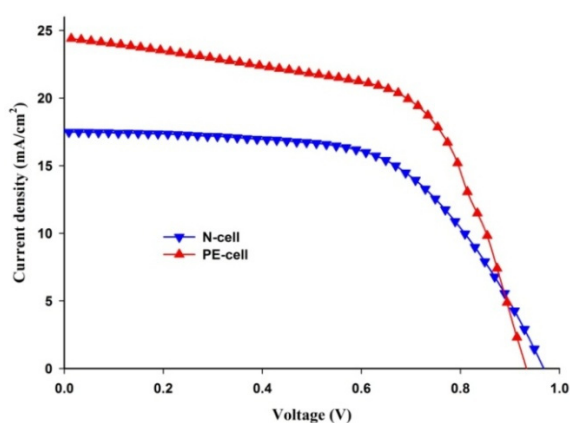


Figure 3: I-V measurement plots of the perovskite solar cell devices with LSP effect (PE-cell) and normal device without LSP effect (N-cell).

4 CONCLUSIONS

In this project, for the first time, effect of localized surface Plasmon on the perovskite solar device with planner structure is successfully investigated. Photovoltaic performance of the devices shows enhancement of J_{sc} and overall efficiency by using LSP effect of silver-alumina core-shell structure nanoparticles inside the perovskite layer as dopant.

ACKNOWLEDGEMENTS

This study was financially supported by Kimia Solar Co, Isfahan, Iran and Islamic Azad University of Najaf Abad, Isfahan, Iran.

REFERENCES

- Sargent, E. H. *Nat Photonics* 2012, 6, (3), 133-135.
- Katagiri, H.; Jimbo, K.; Maw, W. S.; Oishi, K.; Yamazaki, M.; Araki, H.; Takeuchi, A. *Thin Solid Films* 2009, 517, (7), 2455-2460.
- Kojima, A.; Teshima, K.; Shirai, Y.; Miyasaka, T. *J Am Chem Soc* 2009, 131, (17), 6050-6051.
- Kim, H. S.; Lee, C. R.; Im, J. H.; Lee, K. B.; Moehl, T.; Marchioro, A.; Moon, S. J.; Humphry-Baker, R.; Yum, J. H.; Moser, J. E.; Grätzel, M.; Park, N. G. *Sci Rep-Uk* 2012, 2.
- Etgar, L.; Gao, P.; Xue, Z. S.; Peng, Q.; Chandiran, A. K.; Liu, B.; Nazeeruddin, M. K.; Grätzel, M. *J Am Chem Soc* 2012, 134, (42), 17396-17399.
- R. F. Service, *Science*, 2014, 344, 458.
- Y. Ogomi, A. Morita, S. Tsukamoto, T. Saitho, N. Fujikawa, Q. Shen, T. Toyoda, K. Yoshino, S. S. Pandey, T. Ma and S. Hayase, *J. Phy. Chem. Lett.*, 2014, 5, 1004-1011.
- S. Kazim, M. K. Nazeeruddin, M. Grätzel and S. Ahmad, *Angew. Chem., Int. Ed.*, 2014, 53, 2812-2824.
- H. Chen, L. Shao, Q. Li and J. Wang, *Chem. Soc. Rev.*, 2013, 42, 2679-2724.
- J. Qi, X. Dang, P. T. Hammond and A. M. Belcher, *ACS Nano*, 2011, 5, 7108-7116.
- L. Lu, Z. Luo, X. Tao and L. P. Yu, *Nano Lett.*, 2013, 13, 59-64.