High-Efficiency Polymer Solar Cells Achieved by Doping Plasmonic Metallic Nanoparticles into Dual Charge Selecting Interfacial Layers to Enhance Light Trapping

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Introduction

Due to poorer charge transport and shorter exciton diffusion length of organic semiconductors, more efficient light trapping and coupling strategies are needed to meet charge transport and light absorption trade-off for improving device efficiency. The employment of light trapping based on the surface plasmon resonance (SPR) effect of metallic nanostructures is a promising strategy to improve light harvesting for polymer solar cells (PSCs). The placement of plasmonic NPs at different locations of the device, the size of nanoparticles and the dielectric properties of their surrounding environments is critical for manipulating different mechanisms for optical enhancement in nanoscale.

Material synthesis and device fabrication

Au NPs with three different sizes, i.e., 20, 50, and 70 nm, were synthesized for this study. PSCs devices were fabricated by doping both the rear and the front interfacial layers of the device with different sized Au NPs to enhance light trapping within the BHJ layer. NPs were embedded in a C70-containing electron-selecting surfactant (C70-bis) at the rear side of PSC through orthogonal solvent processing. This enables the construction of dual plasmonic layer devices to further enhance light absorption. [1]

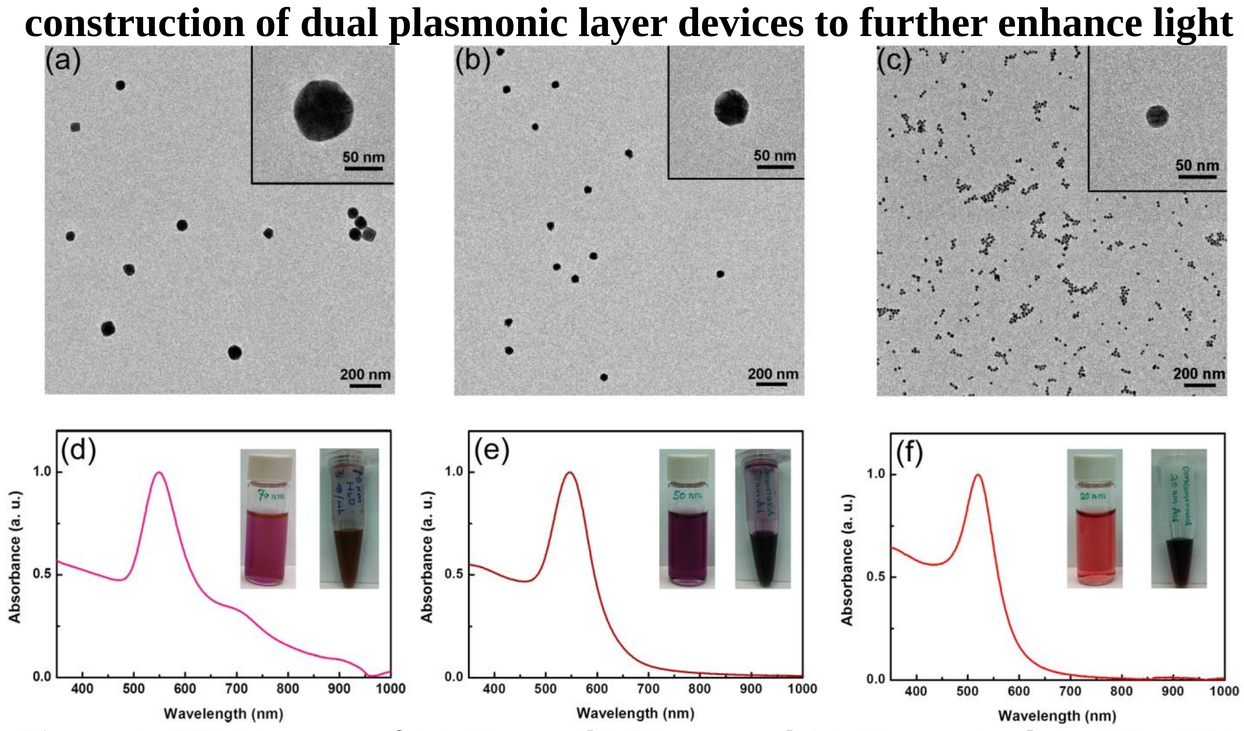

Figure 1. TEM images of (a) 70 nm, (b) 50 nm, and (c) 20 nm sized Au NPs. UV-Vis absorption spectrum of (d) 70 nm, (e) 50 nm, and (f) 20 nm sized Au NPs.

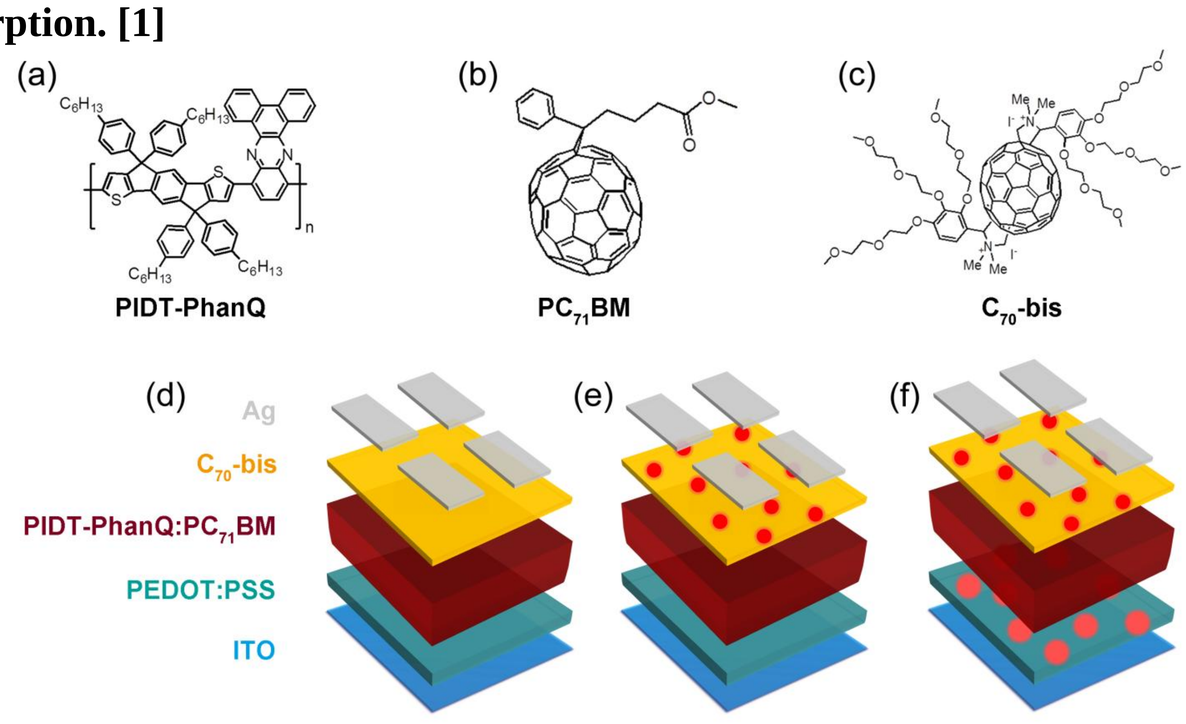

Figure 2. Chemical structures of (a) PIDT-PhanQ, (b) PC71BM, and (c) C70-bis and device architectures (d-f).

Device performance

Significantly improved efficiency in PSC by incorporating proper size Au NPs into charge-selecting layers was achieved. The PCE of the device was increased from 6.65% to 6.99% initially by incorporating Au NPs (50 nm) into the rear interfacial layer of the device. When larger Au NPs (70 nm) were also incorporated into the front layer of the device, a dual SPR effect was achieved to improve PCE further to 7.50% (13 % enhancement). These results show that plasmonic effect enhanced device performance can be achieved in a low bandgap polymer system.

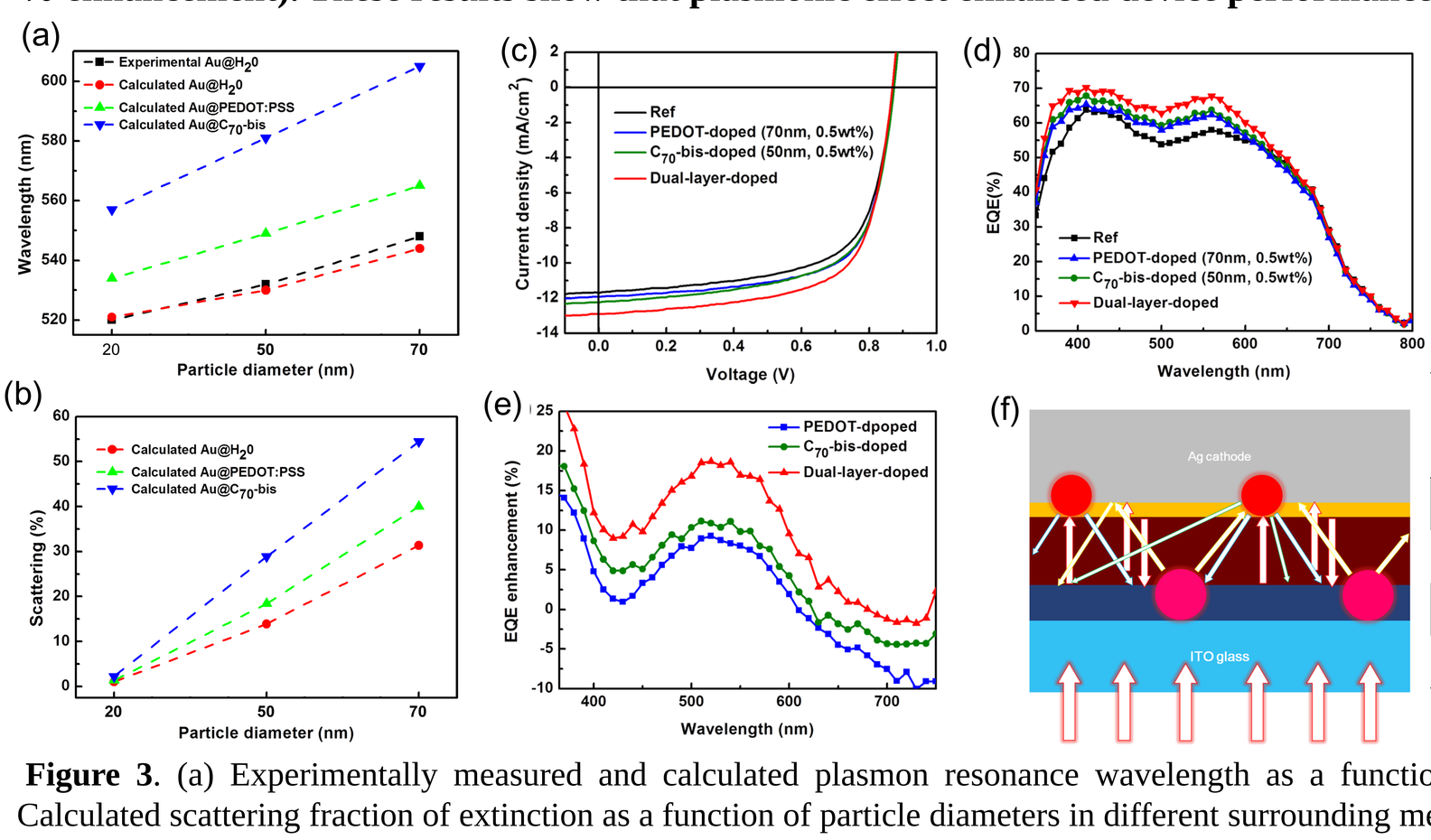

Table 1. Performance of PEDOT:PSS doped, C70-bis doped, and dual interfacial layer doped plsmonic devices under AM 1.5GIllumination (100 mWcm-2). The doping weight ratio was the optimized condition.

device	V_{OC} [V]	J_{SC} [mA/cm^2]	FF	PCE [%]
Reference	0.87±0.01	11.69±0.30	0.65±0.01	6.65±0.25
C_{70}-bis doped (50 nm, 0.5wt%)	0.87±0.01	12.24±0.30	0.65±0.02	6.99±0.20
PEDOT doped (70 nm, 0.5wt%)	0.87±0.01	11.92±0.40	0.68±0.01	7.07±0.15
Dual-layer doped	0.87±0.01	12.90±0.30	0.67±0.02	7.50±0.15

Figure 3. (a) Experimentally measured and calculated plasmon resonance wavelength as a function of particle diameters in different surrounding medium. (b) Calculated scattering fraction of extinction as a function of particle diameters in different surrounding medium. (c) J-V characteristics and (d) EQE spectra of the devices. (e) The calculated EQE enhancement against wavelength of plasmonic PSCs by PEDOT:PSS doping, C70-bis doping, and dual interfacial layer doping. (f) The schematic figure of dual interfacial layer doping showing the light trapping and optical reflection by the scattering and excitation of localized surface plasmons.

Acknowledgements

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References

[1] X. Yang, C. Chueh, C. Li, H. Yip, P. Yin, H. Chen, W. Chen and A. K-Y. Jen, *Adv. Energy. Mater.* 2013, 5, 666.