

## Enhancing Efficiency of Low-bandgap Polymer Solar Cells with Plasmonic Effect from Gold Nanoparticles of Different Sizes

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### Introduction

Polymer solar cells (PSCs) have been one of the most promising replacement energy to fossil fuels. In recent years, since inverted PSCs with perfect stability have been reported, how to improve efficiency becomes the key issue of PSCs technology commercialization. Nowadays, many low-bandgap polymers were synthesized and applied to PSCs in order to enhance the harvest of infrared solar radiation. However, since the short carrier diffusion length, the absorption is hard to further increase by simply changing the active ink recipe and the layer thickness without sacrificing carrier transport efficiency. In addition, carriers generated from photovoltaic effect are hard to collect.

In this work, we applied ZnO nanorod array as electron transport layer (ETL) combined with gold nanoparticles (Au NPs) of proper sizes in inverted low-bandgap PSCs for optical enhancement. We add Au NPs in active layer to enhance absorption owing to localized surface plasma resonance (LSPR) and particle scattering effect. A novel low band-gap material PTB7 serving as electron donor and PC<sub>71</sub>BM as electron acceptor were used to fabricate inverted PSCs. Different spin speeds of 20 nm Au NPs were tried to find the proper quantity for performance improvement. By using the proper spin speed, the PSCs show high J<sub>SC</sub> 16.8 mA/cm<sup>2</sup>, leading to efficiency of 7.60%.

### Experiment

The devices were fabricated on cleaned ITO-coated glass substrate. The ZnO nanorod array with average length of 100-150 nm serving as the device ETL was fabricated by hydrothermal method. The active layer material PTB7/PC<sub>71</sub>BM was dissolved in CB with some additive solvent of DIO to deploy 2 kinds of active inks. The first is added with 4 nm Au NPs, which is suitable for infiltration into the hollow spaces among ZnO NRs. The second is deployed without adding Au NPs. The active layer was formed by spin-coating the first active ink on the surface of ZnO NRs. Then Au NPs of 20 nm that were suspended in IPA were spin-coated on the active layer surface to enhance absorption. The different spin speed was tried to find the best device performance. After that, the second active layer for preventing contact of Au NPs and hole transport layer (HTL), were fabricated by spin-coating method. Then all devices with a thin MoO<sub>3</sub> as HTL were also fabricated. Finally, the 250 nm back electrode was deposited by thermal evaporation.

### Result

The device optical enhancement and their performance are shown in Figure 1, and PSCs parameters are shown in Table I. The result shows that different quantities of Au NPs influent device absorption and carrier transport in the same time, and the proper trade-off can improve the device J<sub>SC</sub> and PCE significantly.

Table I PSCs parameters of devices fabricated by using 20nm Au NPs with different spin-coating speed

|            | PCE (%) | J <sub>sc</sub> (mA/cm <sup>2</sup> ) | V <sub>oc</sub> (V) | FF (%) | R <sub>s</sub> (Ω) | R <sub>sh</sub> (Ω) |
|------------|---------|---------------------------------------|---------------------|--------|--------------------|---------------------|
| w/o Au NPs | 7.27    | 15.2                                  | 0.710               | 66.9   | 4.04               | 493                 |
| 1000rpm    | 6.32    | 15.2                                  | 0.661               | 62.1   | 3.62               | 388                 |
| 2000rpm    | 7.60    | 16.8                                  | 0.700               | 64.9   | 3.86               | 538                 |
| 3000rpm    | 7.42    | 16.3                                  | 0.705               | 65.1   | 3.95               | 478                 |

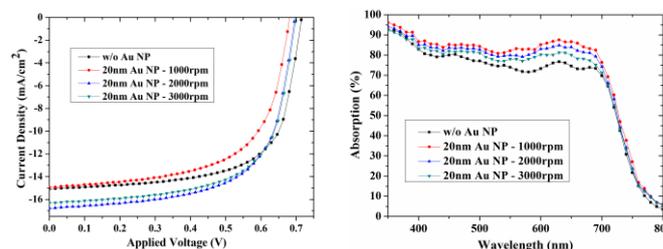


Figure 1. The J-V curves and absorption of all devices.

### 3. Conclusions

The combination of Au NPs and ZnO nanorod array in inverted PSCs enhances device absorption and carrier transport efficiency. By using the 4 nm and 20 nm Au NPs, the PSCs can exhibit high FF 64.9% and J<sub>SC</sub> 16.8 mA/cm<sup>2</sup>, leading to efficiency of 7.60%.

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