Metamaterial Perfect Absorber Solar Cell for Light Absorption Enhancement of P3HT:PC_{61}BM

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Organic thin-film solar cells (OSCs) are one of the candidates of the next-generation solar cells due to their properties such as flexibility, light weight, low cost, and easy for mass production. The obtained highest power conversion efficiency of OSC is 11.7% in a laboratory [1]. Further improvement in power conversion efficiency is an urgent issue for its practical use. However, the conversion efficiency of OSC cannot be increased linearly just by increasing its active layer thickness. The thicker active layer can absorb more light and generate a large number of excitons compared to the thinner film, on the other hand, the thicker film will also increase the charge recombination rate due to the enlarged migration lengths of the carriers to the electrodes. Therefore, increasing the active layer thickness is not a practical way to enhance the conversion efficiency of OSCs. In order to improve conversion efficiency, light absorption should be increased without changing the thickness of the active layer.

To solve this problem, we propose the use of metamaterial perfect absorbers (MPAs) which can confine light into a thin film [2]. The metamaterial perfect absorber is composed of metal nanostructures and a metal thin film with a dielectric thin film as a spacer in between them. When the metal nanostructure is irradiated with light, surface plasmons are excited, resulting in the light confinement into the dielectric thin film. We introduced MPAs into OSCs, in which the active layer act as the dielectric spacer. This configuration increases light absorption in the active layer without changing its thickness.

The OSC with MPAs was prepared as follows. Periodically aligned Ag nanostripes were fabricated on an indium tin oxide (ITO) substrate by electron beam lithography (Fig. 1(a)). Layers of zinc oxide (ZnO) and poly (3-hexylthiophene): [6, 6]-phenyl-C61-butyric acid methyl ester (P3HT:PC_{61}BM) were deposited by spin coating as the electron transport layer and the photoelectric conversion layer. A hole transport layer of molybdenum oxide (MoO_3) and aluminum (Al) electrode were deposited by vacuum evaporation. The combination of Ag nanostripes and an Al thin film composes the MPA configuration (Fig. 1(b)). The observed absorption enhancement (AE) of the MPA solar cell is shown in Fig. 2(a). Absorption enhancement was calculated by dividing absorption spectrum of MPA solar cell with that of a reference solar cell without MPAs. Large AE was observed at a wavelength region from 600 to 650 nm where P3HT:PC_{61}BM absorption is small. The average AE at the absorption band (500 to 650 nm) of P3HT:PC_{61}BM was 1.18. Next, the pitches of the silver nanostripes were changed. The average AEs of the MPA solar cells with various pitches are shown in Fig. 2(b). The maximum AE was observed at a pitch of 400 nm, and its average AE was 1.29. It was found that the pitch of the silver nanostripes greatly influences the AE of the MPA solar cell.

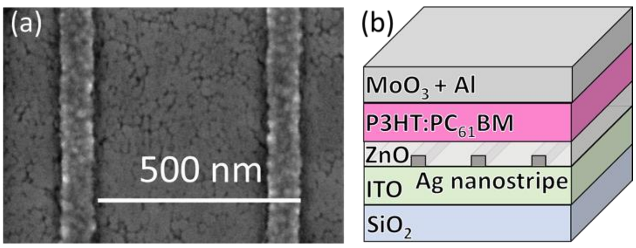

Fig.1 (a) SEM image of Ag nanostripes (pitch: 500 nm) and (b) schematic of the metamaterial perfect absorber solar cell.

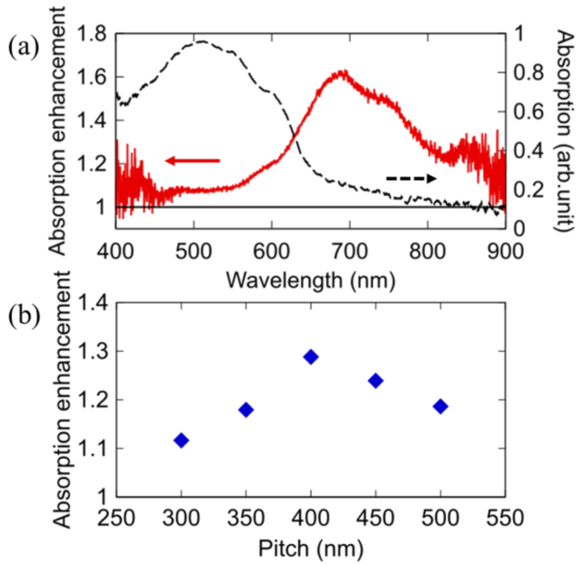

Fig.2 (a) Absorption enhancement of the metamaterial perfect absorber solar cell (red line) and the absorption spectrum of P3HT:PC_{61}BM (black dashed line) and (b) the average absorption enhancements as a function of Ag nanostripe pitches.

References

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[2] N. I. Landy et al. Phys. Rev. Lett. **100** (2008) 207402.

