**Supporting information for**

# Panchromatic Quasi-Monolayer of Ag Nanoparticles for High-Efficiency Dye-Sensitized Solar Cells

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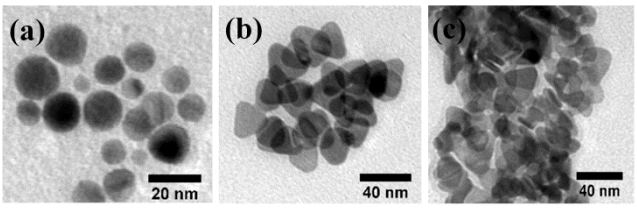


**Fig. S1** (a-c) HR-TEM images of three kinds of Ag NPs. The size is about (a) 15 ± 4, (b) 24 ± 3, and (c) 30 ± 4 nm.

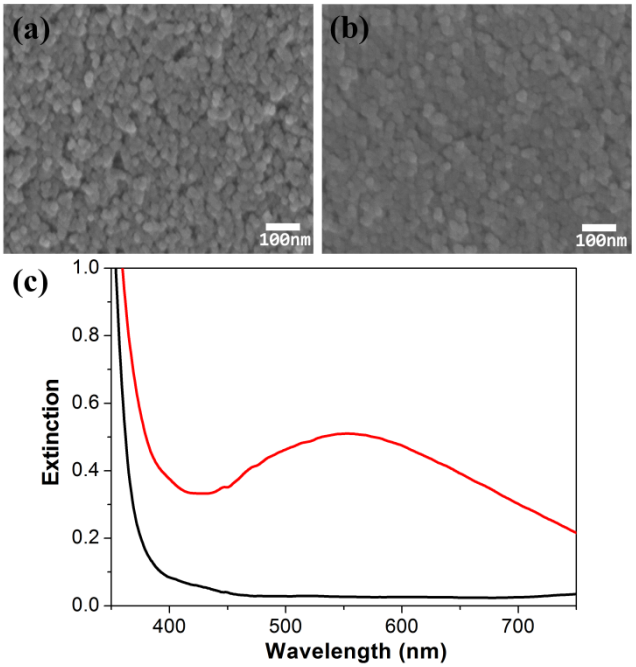


**Fig. S2** SEM images of (a) the film of $TiO_2$ NPs and (b) panchromatic quasi-monolayer of Ag NPs deposited on the film of $TiO_2$ NPs, and (c) their extinction spectra. The black spectrum was measured from the sample for (a), while red one from the sample for (b). Cover glass instead of FTO glass was used in fabrication of the samples.

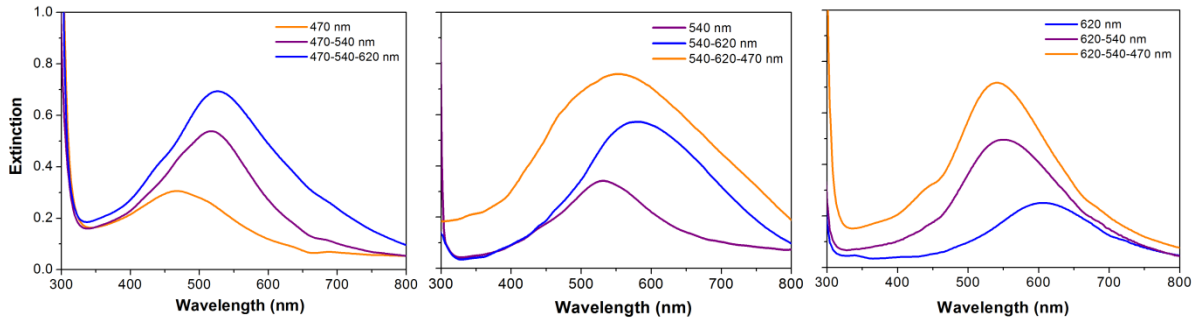


**Fig. S3.** Extinction spectra of Ag NPs immobilized on cover glass coated with P4VP. The legend represents the value of the $\lambda_{max}$ of the plasmon resonance peak of the Ag NPs in the solution phase and the order of immobilization. For example, 470-540-620 nm means that Ag NPs immobilized Ag NPs having $\lambda_{max}$ of 470 nm first, and then Ag NPs having $\lambda_{max}$ of 540 nm, and then Ag NPs having $\lambda_{max}$ of 620 nm.

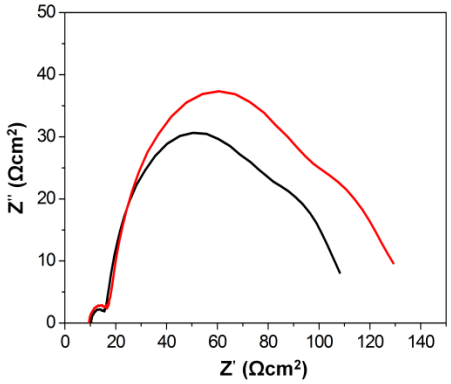


**Fig. S4.** Nyquist plot of the electrochemical impedance spectra, measured under dark conditions, of the DSSCs based on the photoactive film of $TiO_2$ NPs with (red) and without (black) including a panchromatic quasi-monolayer of Ag NPs between the layer of $TiO_2$ NPs and the scattering layer.

**Table S1.** Dependence of the photovoltaic parameters of the DSSCs included a quasi-monolayer of Ag NPs, whose $\lambda_{max}$ was at 470 nm, on the coating time of PVP. PVP was coated on the surface of the $TiO_2$ film by dipping FTO glass deposited a blocking layer and $TiO_2$ film in a PVP solution.

| **470 nm Ag NPs** | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 0.5 h | 0.80 ± 0.02 | 16.11 ± 0.21 | 0.70 ± 0.02 | 9.0 ± 0.2 |
| 1 h | 0.81 ± 0.02 | 16.53 ± 0.14 | 0.70 ± 0.01 | 9.4 ± 0.2 |
| 1.5 h | 0.81 ± 0.03 | 17.10 ± 0.11 | 0.69 ± 0.01 | 9.6 ± 0.1 |
| 2 h | 0.79 ± 0.02 | 17.01 ± 0.08 | 0.70 ± 0.02 | 9.4 ± 0.1 |
| 3 h | 0.81 ± 0.03 | 15.96 ± 0.33 | 0.71 ± 0.02 | 9.2 ± 0.3 |

**Table S2.** Dependence of the photovoltaic parameters of the DSSCs included a quasi-monolayer of Ag NPs, whose $\lambda_{max}$ was at 540 nm, on the coating time of PVP.

| 540 nm Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 0.5 h | 0.80 ± 0.01 | 17.00 ± 0.18 | 0.69 ± 0.02 | 9.4 ± 0.1 |
| 1 h | 0.79 ± 0.02 | 17.47 ± 0.14 | 0.71 ± 0.01 | 9.8 ± 0.2 |
| 1.5 h | 0.80 ± 0.01 | 18.68 ± 0.32 | 0.72 ± 0.01 | 10.7 ± 0.1 |
| 2 h | 0.81 ± 0.01 | 18.11 ± 0.20 | 0.71 ± 0.01 | 10.4 ± 0.2 |
| 3 h | 0.81 ± 0.02 | 16.27 ± 0.13 | 0.70 ± 0.01 | 9.2 ± 0.2 |

**Table S3.** Dependence of the photovoltaic parameters of the DSSCs included a quasi-monolayer of Ag NPs, whose $\lambda_{max}$ was at 620 nm, on the coating time of PVP.

| 620 nm Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 0.5 h | 0.79 ± 0.02 | 16.58 ± 0.11 | 0.72 ± 0.02 | 9.4 ± 0.1 |
| 1 h | 0.79 ± 0.02 | 17.21 ± 0.24 | 0.71 ± 0.01 | 9.6 ± 0.1 |
| 1.5 h | 0.80 ± 0.01 | 17.34 ± 0.43 | 0.70 ± 0.01 | 9.7 ± 0.2 |
| 2 h | 0.79 ± 0.01 | 18.59 ± 0.12 | 0.70 ± 0.02 | 10.2 ± 0.2 |
| 3 h | 0.79 ± 0.01 | 17.30 ± 0.33 | 0.68 ± 0.03 | 9.2 ± 0.2 |

**Table S4.** Dependence of the photovoltaic parameters of the DSSCs included a panchromatic quasi-monolayer of Ag NPs consisting of three kinds of Ag NPs, whose $\lambda_{max}$ were 540, 620 and 470 nm, on the first coating time of PVP. The second coting time was the same as 1 h.

| Panchromatic Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 0.5 h | 0.79 ± 0.03 | 16.42 ± 0.42 | 0.71 ± 0.02 | 9.3 ± 0.3 |
| 1 h | 0.79 ± 0.02 | 17.59 ± 0.23 | 0.70 ± 0.02 | 9.7 ± 0.2 |
| 1.5 h | 0.81 ± 0.02 | 18.99 ± 0.30 | 0.72 ± 0.02 | 10.9 ± 0.3 |
| 2 h | 0.80 ± 0.02 | 18.38 ± 0.11 | 0.72 ± 0.01 | 10.6 ± 0.2 |
| 3 h | 0.80 ± 0.02 | 17.82 ± 0.33 | 0.71 ± 0.01 | 10.1 ± 0.2 |

**Table S5.** Dependence of the photovoltaic parameters of the DSSCs included a panchromatic quasi-monolayer of Ag NPs consisting of three kinds of Ag NPs, whose $\lambda_{max}$ were 540, 620 and 470 nm, on the second coating time of PVP. The first coating time of PVP was the same as 1.5 h for all the samples.

| Panchromatic Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 0.5 h | 0.80 ± 0.01 | 18.95 ± 0.33 | 0.71 ± 0.01 | 10.8 ± 0.1 |
| 1 h | 0.79 ± 0.03 | 19.27 ± 0.53 | 0.71 ± 0.03 | 11.0 ± 0.4 |
| 1.5 h | 0.81 ± 0.02 | 19.00 ± 0.11 | 0.72 ± 0.02 | 11.0 ± 0.1 |
| 2 h | 0.80 ± 0.03 | 18.95 ± 0.23 | 0.70 ± 0.02 | 10.6 ± 0.3 |
| 3 h | 0.82 ± 0.01 | 18.63 ± 0.12 | 0.70 ± 0.02 | 10.7 ± 0.2 |

**Table S6.** Dependence of the photovoltaic parameters of the DSSCs included a panchromatic quasi-monolayer of Ag NPs consisting of three kinds of Ag NPs, whose $\lambda_{max}$ were 540, 620 and 470 nm, on the immobilization time of Ag NPs. Ag NPs whose $\lambda_{max}$ was 540 nm was immobilized first, and then those of 620 nm, and then those of 470 nm. The immobilization time of each kind of Ag NPs was the same.

| Panchromatic Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 3 h | 0.78 ± 0.01 | 16.42 ± 0.11 | 0.70 ± 0.01 | 9.1 ± 0.2 |
| 6 h | 0.77 ± 0.02 | 17.65 ± 0.31 | 0.69 ± 0.02 | 9.7 ± 0.2 |
| 9 h | 0.79 ± 0.02 | 18.11 ± 0.22 | 0.70 ± 0.02 | 10.3 ± 0.3 |
| 12 h | 0.79 ± 0.03 | 19.27 ± 0.53 | 0.71 ± 0.03 | 11.0 ± 0.4 |
| 15 h | 0.79 ± 0.02 | 17.55 ± 0.32 | 0.70 ± 0.03 | 10.1 ± 0.2 |

**Table S7.** Dependence of the photovoltaic parameters of the DSSCs included a panchromatic quasi-monolayer of Ag NPs consisting of three kinds of Ag NPs, whose $\lambda_{max}$ were 540, 620 and 470 nm, on the immobilization order of three kinds of Ag NPs. The immobilization time of each kind of Ag NPs was the same as 4 h.

| Panchromatic Ag NPs | $V_{oc}$ (V) | $J_{sc}$ (mA/cm$^2$) | *ff* | $\eta$ (%) |
|---|---|---|---|---|
| reference | 0.78 ± 0.02 | 16.20 ± 0.41 | 0.70 ± 0.03 | 8.9 ± 0.3 |
| 540-620-470 | 0.79 ± 0.03 | 19.27 ± 0.53 | 0.71 ± 0.03 | 11.0 ± 0.4 |
| 620-540-470 | 0.82 ± 0.01 | 18.68 ± 0.14 | 0.72± 0.02 | 10.9 ± 0.3 |
| 470-540-620 | 0.79 ± 0.01 | 18.34 ± 0.10 | 0.72± 0.02 | 10.4 ± 0.2 |

**Table S8.** Parameters determined by EIS.

| DSSCs based on $TiO_2$ NPs | $R_k$ | $R_w$ | $R_k/R_w$ | $\tau_{eff}$ (ms) | $K_{eff}$ ($s^{-1}$) | $D_{eff}$ ($cm^2s^{-1}$) | $L$ (μm) | $L_n$ (μm) |
|---|---|---|---|---|---|---|---|---|
| without | 61.14 | 24.54 | 2.49 | 7.49 | 21.23 | $1.07 \times 10^{-5}$ | 4.5 | 7.10 |
| With including a panchromatic layer of Ag NPs | 76.14 | 24.11 | 3.15 | 7.49 | 21.23 | $1.35 \times 10^{-5}$ | 4.5 | 7.98 |