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Photocurrent Enhancement in Dye-Sensitized Solar Cells with Au-loaded TiO_2 on Metallic Grating Surface

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1. Introduction

Nowadays dye-sensitized solar cell (DSSC) is one of the important solar cells due to its high efficiency and low cost. Therefore, many studies on DSSCs have been reported [1-3]. One of the ways to enhance the efficiency of DSSCs is the use of metal nanoparticles to improve optical absorption, light scattering and surface plasmon excitation [1]. Moreover, noble metal nanoparticle can act as electron acceptor from the photo-excited semiconductors to enhance electron transfer rate to increase the photocurrent [2]. As another way, we have reported the use of grating surface with propagating surface plasmon excitation the improvement of light scattering and light trapping to increase photocurrent of DSSCs [3].

In this work, dye/Au-loaded TiO_2 films were fabricated on a metal grating surface to couple with surface plasmon resonance for further enhancement of photocurrent in DSSCs.

2. Experimental procedure

Preparation of Au-loaded TiO_2 nanopowders

Titanium dioxide (TiO_2) nanopowders were synthesized by the modified sol–gel method [4]. Titanium tetraisopropoxide ($Ti[OCH(CH_3)_2]_4$, Aldrich, England), absolute ethanol (C_2H_5OH, Merck, Germany) and ammonia (NH_3, Merck, Germany) were used as the starting materials. The solution of titanium tetraisopropoxide in absolute ethanol was loaded into cellophane membrane pouch and placed in solution containing absolute ethanol, deionized water and ammonia. The solutions inside and outside the cellophane pouch were kept constant stirring at 70-80°C for 1h. Then, the the obtained nanopowders were dried in an oven at 60 °C for 24h. The white powders then were calcined at 400 °C for 3h. Then, unloaded TiO_2 nanopowders were obtained. Au–loaded TiO_2 nanopowders were prepared by the impregnation method. The appropriate amounts of gold (III) chloride hydrate ($(H(AuCl_4).H_2O$, Electron Microscopy Science) in absolute ethanol were added into unloaded titanium dioxide nanopowders to obtain the Au–loading level of 0.25, 1.00 and 2.00 at.% Au. Then, the as–prepared samples were dried at 60 ^oC for 24h and calcined at 400 ^oC for 3h. Finally, 0.25, 1.00 and 2.00 at.% Au–loaded TiO_2 nanopowders were obtained.

Preparation of the fabricated DSSCs

The DSSCs were prepared by following our previous work [3]. BD-Rs (LTH type, TAIYO YUDEN) were used to obtain diffraction grating substrates (Λ=320 nm). BD-Rs were cut into a rectangular shape (2.5x4.0 cm) and then were soaked in nitric acid for 20 min to get rid of the dye layer deposited on the polycarbonate grating side. Dish washing liquid solution, water, distilled water and DI water were used for grating substrate cleaning respectively. After the cleaning process, BD-Rs were coated with 150 nm Au film by using a vacuum evaporation technique. The Au-loaded TiO_2 nanopowders obtained from the modified sol-gel method were coated on the Au film by using electrophoretic deposition technique. 1.7 V were applied between BD-R/Au cathode and ITO anode for 300 s in 25 mM of Au-loaded TiO_2 nanopowders dispersed in water. After the deposition of Au-loaded TiO_2, the BD-R/Au/Au-loaded TiO_2 substrates were annealed at 100 ^oC for 3 h under ambient conditions. For the dye, 5, 10, 15, 20-Tetrakis (1-methyl-4-pyridinio) porphyrin tetra(p-toluenesulfonate) (TMPyP, Sigma-Aldrich) and sodium copper chlorophyllin (SCC, Sigma-Aldrich), were used for layer-by-layer dip coating technique. The BD-R/Au/Au-loaded TiO_2 substrates were soaked in SCC (0.25 mg mg/1) and TMPyP (0.25 mg mg/1) respectively for 15 min each and continued repeating until 20 bilayers. Each layer was rinsed twice with DI water for 2 min. Ferrous sulfate heptahydrate ($FeSO_4.7H_2O$, 0.1 M, Sigma-Aldrich), and sodium sulfate (Na_2SO_4, 1 M, Sigma-Aldrich) were used as electrolyte. ITO glass substrate with a sheet resistance of 10 Ω/sq was used as the cathode. The fabricated DSSC is illustrated in Fig. 1.

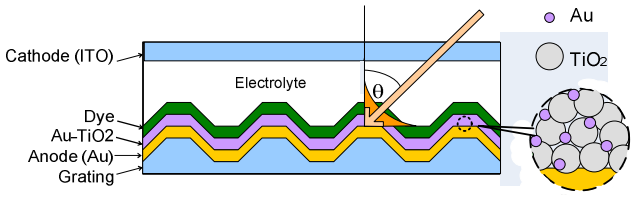

Fig. 1 Fabricated dye-sensitized solar cells (DSSCs)

3. Results and Discussion

Photocurrent measurements were investigated by irradiating the collimated light from a 350 mW xenon lamp. The p-polarized light was used for the excitation of SP, while s-polarized light was used for the non excitation of SP to compare the results. The effect of surface plasmon (SP) excitation on the short-circuit photocurrent was studied by the irradiation of the visible light (490-740) on the fabricated DSSCs. The short-circuit photocurrent with SP (p-pol) and without SP (s-pol) excitation were measured as shown in Fig. 2. It was found that using the visible light with SP excitation could result in the higher photocurrent much more than that using the visible light without SP excitation. The enhancement of the short-circuit photocurrent by the excitation of surface plasmon with the Au loading was studied. We plotted the enhanced photocurrent factor, that is, the ratio of the current of all samples to the current with unloaded TiO_2 without propagating SP excitation, as a function of the incident light angle, as summarized in Fig. 3. As can be seen in the Fig. 3, the enhanced photocurrent of unloaded TiO_2 with grating-coupled propagating SP excitation increased more than the factor of 2 as compared to that without the surface plasmon excitation. In the case of 1.0 at% Au-loaded TiO_2 without grating-coupled propagating SP, an enhancement factor of more than 3 could be obtained as compared to that of unloaded (0%Au) TiO_2 without grating-coupled propagating SP. Larger amount of Au loading could result in the stronger enhancement. Moreover, when the 1.0 at% Au-loaded TiO_2 was combined with grating-coupled SP excitation, an enhancement factor of more than 7 at 25° was obtained. These resulted from the strong field enhancement of surface plasmon excitation due to the interaction between the grating structure and the nanoparticle together with the effect of light scattering from the Au nanoparticle [3,5-8]. Larger amount of Au loading could result in the stronger surface plasmon field that could enhance the photocurrent and p/s factor. Besides the effect of SP excitation on the grating-Au loaded TiO_2, the loaded Au could also increase light scattering property. Therefore the photocurrent was increased in both cases of with SP and without SP excitation as compared to the DSSCs with unloaded TiO_2.

4. Conclusions

In this work, the dye-sensitized cell composed of the Au grating/Au-TiO_2/TMPyP-SCC LbL (20 bilayers)/ electrolyte/ITO substrates were fabricated. The results showed that the grating-coupled surface plasmon excitation together with Au-loaded TiO_2 could enhance the short-circuit photocurrent of the fabricated cells.

Acknowledgements

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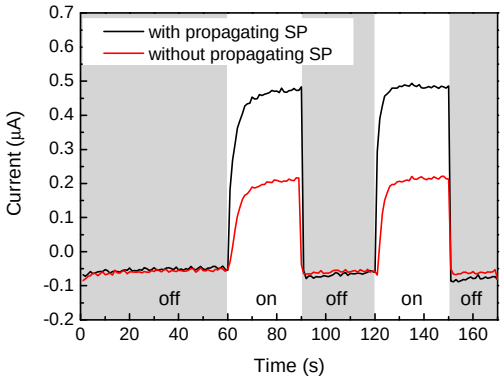

Fig. 2 Short-circuit photocurrent properties of the dye-sensitized cell composed of the Au grating/ Au-TiO_2/TMPyP-SCC LbL (20 bilayers)/electrolyte/ITO substrate upon irradiation of visible light with surface plasmon excitation (p-pol.) and without surface plasmon excitation (s-pol.).

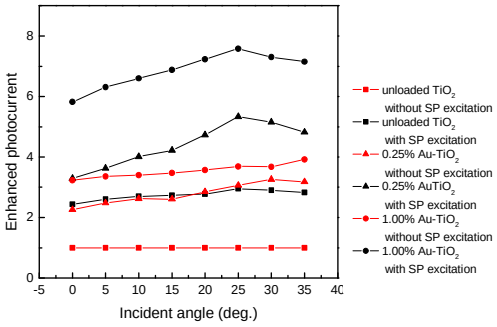

Fig. 3 Enhanced photocurrent factor, that is, the ratio of the current of all samples to the current with unloaded TiO_2 without propagating SP excitation, as a function of the incident light angle.

References

[1] K.G. Deepa, P. Lekha and S. Sindhu, Sol. Energy. **86** (2012) 326.

[2] S. Muduli, O. Game, V. Dhas, K. Vijayamohanan, K.A. Bogle, N. Valanoor and S.B. Ogale, Sol. Energy. **86** (2012) 1428.

[3] A. Baba, K. Wakatsuki, K. Shinbo and F. Kaneko, J. Mater. Chem. **21** (2011) 16436.

[4] N. Wetchakun and S. Phanichphant, Curr. Appl. Phys. **8** (2008) 343.

[5] I-K. Ding, J. Zhu, W. Cai, S.-J. Moon, N. Cai, P. Wang, S.M. Zakeeruddin, M. Grätzel, M.L. Brongersma, Y. Cui and M.D. McGehee, Adv. Energy Mater. **1** (2011) 52.

[6] D. Derkacs, W. V. Chen, P. M. Matheu, S. H. Lim, P. K. L. Yu, and E. T. Yu, Appl. Phys. Lett. **93** (2008) 09107-1.

[7] S. H. Lim, W. Mar, P. Matheu, D. Derkacs, and E. T. Yu, J. Appl. Phys. **101** (2007) 104309-1.

[8] D. M. Schaadt, B. Feng, and E. T. Yu, Appl. Phys. Lett., **86** (2005) 063106-1.