Improving electron transport in nanostructured photoelectrodes for dye sensitized solar cells

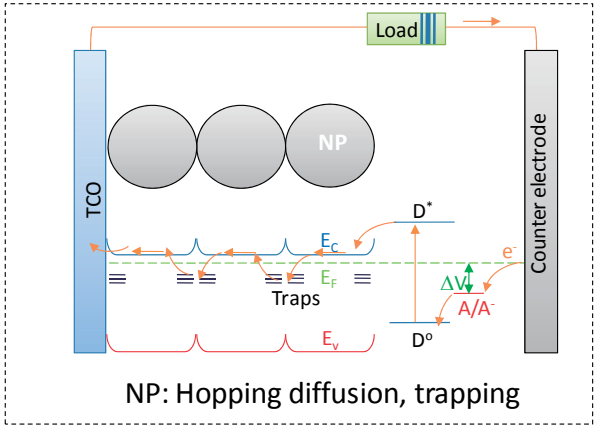
Ivan Turkevych[1], Koujirou Hara[1], Jari Malm[2], Maarit Karppinen[2] and Michio Kondo[1]

[1] *Research Center of Photovoltaics, National Institute of Advanced Industrial Science and Technology, Japan.*
[2] *Laboratory of Inorganic Chemistry of the Faculty of Chemistry, Helsinki Technical University, Finland.*

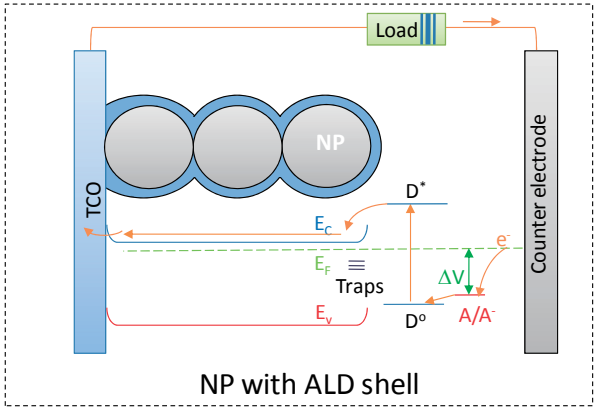
1. Introduction

The working electrode in conventional dye sensitized solar cell [1] is made of sintered titanium dioxide nanoparticles (NP), which provide high specific surface for the absorption of dye molecules. However, the electron transport in the NP electrode suffers from scattering and trapping of free electrons at structural disorders between the sintered nanoparticles. This issue stimulated development of DSSC photoelectrodes constructed of oriented one-dimensional nanostructures [2], such as nanotubes and nanorods. However, improvement of the electron transport in the photoelectrodes based on one-dimensional nanostructures usually comes at expense of lower specific surface available for dye absorption.

Another way to improve electron transport and simultaneously keep the high specific surface of the photoelectrode is to create an ultra-thin shell layer around sintered nanoparticles. The only method to achieve this is Atomic Layer Deposition (ALD), since it provides superior conformality and precise control over film thickness with atomic resolution. In this work, we fabricated several DSSC photoelectrodes based on sintered TiO_2 nanoparticles with TiO_2 shell layers created by ALD and studied dependence of their performance on the thickness of the ALD shell layers.



NP: Hopping diffusion, trapping



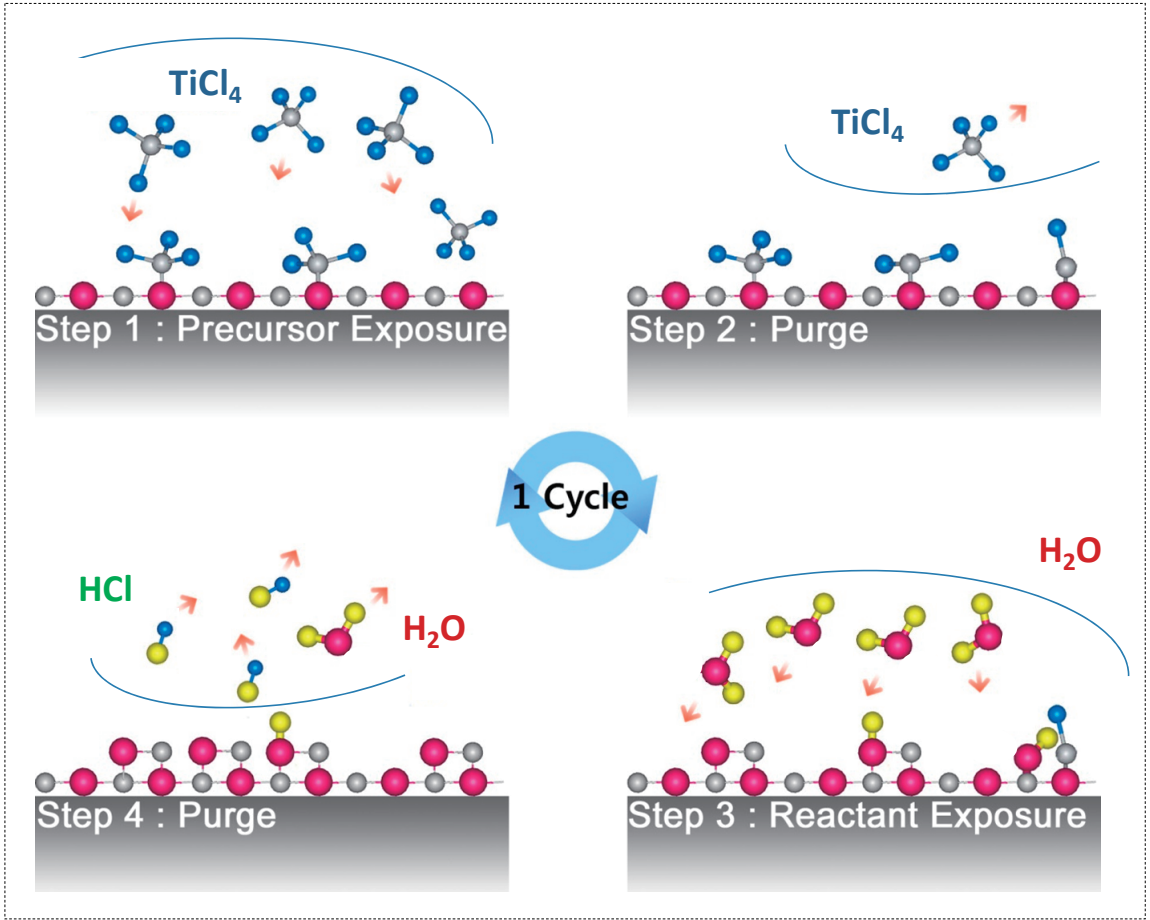
NP with ALD shell

2. Experimental

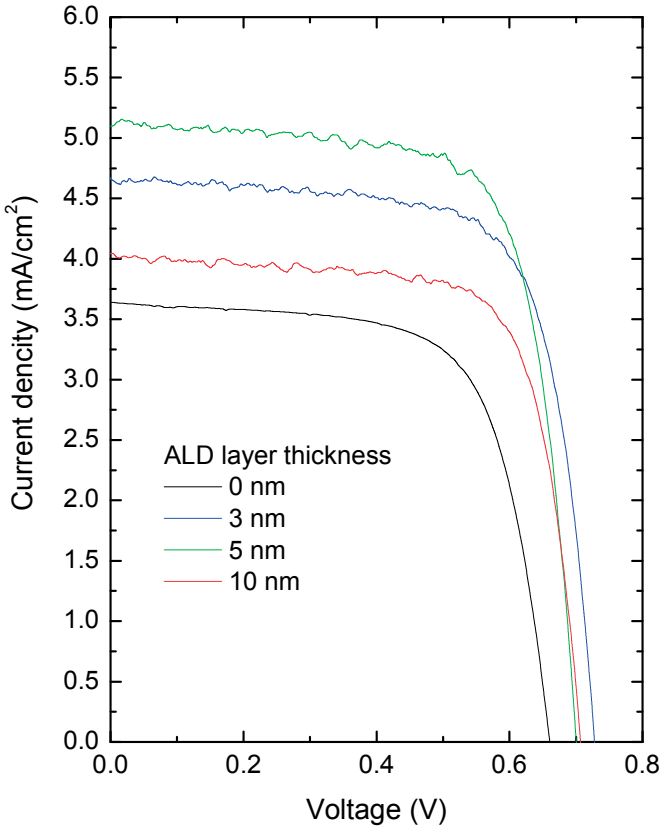
The Atomic Layer Deposition (ALD) consists of the cyclic process, in which reactants are pulsed alternately, one at a time, with purge steps between the pulses. The purge step removes excessive precursor and reaction by-products, and ensures that the next precursor reacts only with the surface monolayer of the previous one, thus producing only a monolayer of the desired solid product. ALD employ a self-limiting layer-by-layer growth mechanism, which allows control over the film growth at atomic scale level.

In this work, we fabricated DSSC photoelectrodes based on sintered TiO_2 nanoparticles, as described elsewhere [3] and covered them with 3, 5 and 10 nm TiO_2 shells by ALD.

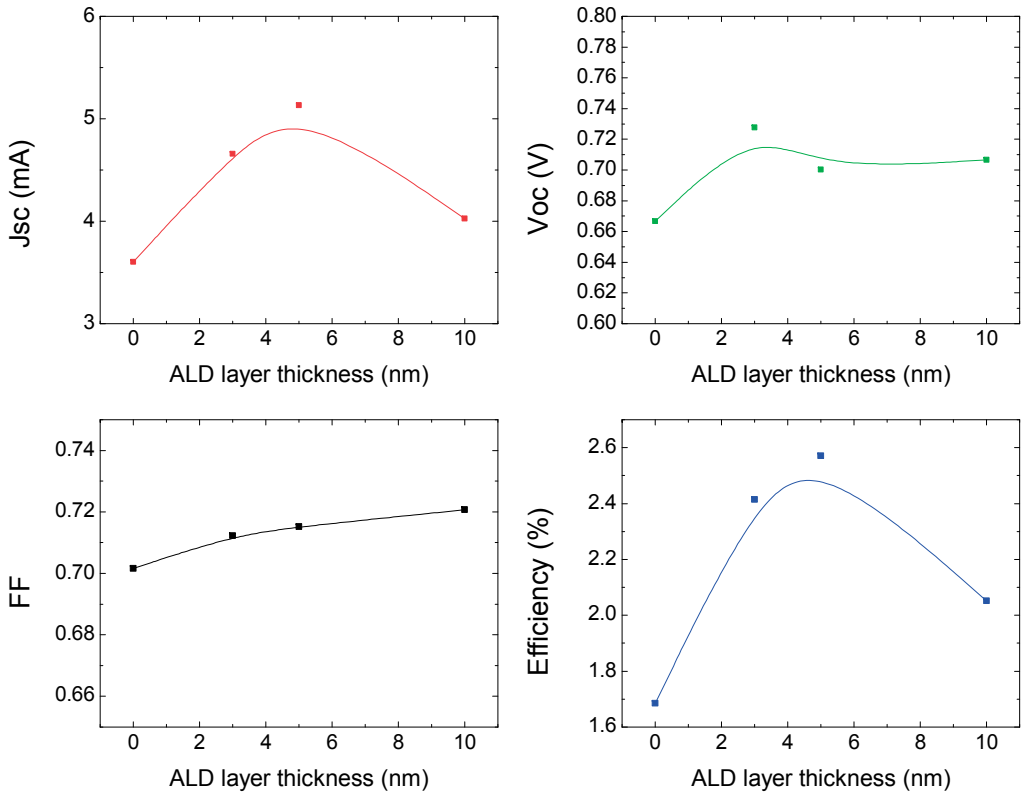
Then, the photoelectrodes were sensitized by immersion into the N3 dye solution, which was 0.3 mM solution of Ru(4,4'-dicarboxy-2,2'-bipyridine)$_2$(NCS)$_2$ in acetonitrile, for 20 hours. The DSSC cells were assembled by clipping the sensitized photoelectrode and Pt-coated TCO glass (counter electrode) together with a polyethylene spacer in between. The redox electrolyte (0.6M 1,2-dimethyl-3-propyl imidazolium iodide, 0.1M lithium iodide, 0.05M iodine and 0.5M 4-tertbutylpyridine in acetonitrile) was introduced between the electrodes and the current–voltage characteristics of the cells were measured under illumination of simulated AM1.5 solar light at 100 mW/cm^2.



2. Results



This figure shows voltage-current characteristics of the DSSC photoelectrode with ALD shell of 3, 5, 10 nm thickness and without the ALD shell, which is referred as 0 nm. The samples with the ALD shell have higher Voc and Jsc in comparison with sample without the ALD TiO_2 shell.



These figures show dependence of Jcs, Voc, fill factor (FF) and overall efficiency on the thickness of the ALD TiO_2 shell. The ALD shell thickness has the most pronounced effect on Jsc, which undergoes maximum at 5 nm. Since the efficiency undergoes similar trend, we can say that it is primarily influenced by the variation of the Jcs parameter. Both Voc and FF show a little increase with the thickness.

4. Conclusions

1. In this work, we fabricated several DSSC photoelectrodes based on sintered TiO_2 nanoparticles with different thicknesses of TiO_2 shell layers created by ALD and studied dependence of their performance on the thickness of the ALD shell layer.

2.The samples with the ALD TiO_2 shell have both higher Voc and Jsc in comparison with the sample without the ALD layer.

3.The most pronounced effect on the efficiency has Jsc parameter, which strongly depends on the ALD shell thickness and undergoes maximum at 5 nm. We attribute the increase of the Jsc parameter to the improved electron transport. However further increase of the ALD shell thickness decreases the specific surface available for the absorption of dye molecules, which in turn decreases the Jsc parameter.

References

1) M. Grätzel, Nature, 2001, 414, 338.
2) G. K. Mor, K. Shankar, M. Paulose, O. K. Varghese and C. A. Grimes, Nano Lett., 2006, 6, 215.
3) K. Hara, T. Horiguchi, T. Kinoshita, K. Sayama, H. Sugihara, H. Arakawa, Sol. Energy Mater. Sol. Cells 64 (2000) 115.