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Two dimensional titanium oxide-based electron transport layer for high performance perovskite solar cells

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Abstract

Nowadays, perovskite solar cells have been thought as an next generation green energy. However, there still has some challenges limited their applications. In this work, we have demonstrated all low temperature process, high efficiency and highly stable perovskite solar devices by using a novel 2D-TiO_2 as electron transport layer.

1. Introduction

Recently, organic–inorganic perovskite-based solar cells by using $CH_3NH_3PbX_3$ (X = Cl, Br, I) as light harvesting materials, had demonstrated remarkably high power conversion efficiencies of nearly 21%. However, most state of- the-art perovskite solar cells typically are based on a high temperature sintered metal oxide (compact TiO_2) as electron transport layer (ETL) which may cause the limitation of perovskite solar cells deposited on flexible substrates and affect their compatibility with fabrication processes in multi-junction solar cells.[1] Furthermore, TiO_2 has been known as a typical photocatalyst for oxidizing water, which will make perovskite unstable.[2,3] Here, we demonstrate that the atomically thin titania (atomic $Ti_{0.92}O_2$) as an ultra-thin electron transport layer in perovskite solar cells can overcome all the difficulties described above. Through Langmuir-Blodgett deposition process at room temperature, atomic $Ti_{0.92}O_2$ was conformally deposited on FTO substrate with a high coverage and eliminated the requirement of high temperature process (over 500°C) to deposit compact TiO_2. The incorporation of multi-layer $Ti_{0.92}O_2$ (around 5 nm) effectively decreased the recombination of electron and hole and leaded to a reduced leakage current. This resulted in a promising device performance (14.5%) that is compatible to the device fabricated using high-temperature sintered metal oxide as electron selection layer. With the atomic $Ti_{0.92}O_2$ electron transport layer, we can successfully make a whole low temperature solution process and a stable device with high performance.

2. Results and discussion

We have demonstrated the low temperature deposition methods for the atomic layers which was shown in Figure 1. First, via the centrifugal separation technique, the exfoliated 2D titania suspension with the upper suspension containing only monolayer of 2D titania was prepared by the Langmuir－Blodgett (LB) deposition process. The FTO substrates were immersed into the suspension, then slowly lifted out and the 2D-titania were uniformly deposited on the FTO glasses. After that, 2D titania-coated FTO substrates were dried at 100C for 10 mins to remove the moisture residue. For multilayer deposition by using the LB process, UV irradiation on pre-coated layer was applied for 30 mins to decompose tetrabutylammonium (TBA^+) ions used in the exfoliation process and further improve the hydrophilicity of surface. [4]

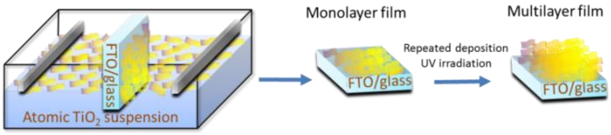

Figure 1. Illustration of LB deposition process.

Afterwards, we deposited $CH_3NH_3PbI_{1-x}Cl_x$ perovskite, Spiro-OMeTAD and Au on these 2D titania-coated and conventional compact TiO_2-coated FTO substrates as the active layer, hole transport layer, and electrodes respectively to fabricate perovskite solar devices. The A. M. 1.5 illumination solar simulator was used to measure the device performances at the intensity of 100 mW/cm^2. Figure 2 (a) exhibits the current-voltage plots of the devices LB1, LB3, and LB5 that represent repeating the LB process for 1, 3, and 5 times, respectively. As we know, the coverage of the electron transport layer (ETL) will affect the electron diffusion ability, where worse coverage can produce more defect states to trap electrons and decrease the device efficiency. As a result, it can observe that due to the better coverage of the atomic $Ti_{0.92}O_2$, that nearly cover full FTO substrate, LB5 TiO_2 based device had higher short circuit current (J_{sc}), open circuit voltage (V_{oc}) and highest device efficiency. For comparison of the capabilities of different ETLs, the device performances of the solar cells without an ETL (bare-FTO), with LB5 TiO_2 ETL and with a conventional compact TiO_2 ETL (c-TiO_2) were presented in Figure 2(b). It shows that the efficiency of devices containing LB5 TiO_2 ETL and c-TiO_2 ETL has no obvious difference but more than two times higher than that without ETL. Because ETL plays an important role for assisting electrons to diffuse to the back contact, the power cell efficiency of the bare-FTO device without using an ETL is only 6.4 %, where the efficiency of LB5 TiO_2 ETL based device is about 14.5%. It is worth mentioning that, despite LB5 TiO_2 ETL is only around 5 nm thickness, which is much smaller than the thickness of c-TiO_2 ETL about 100 nm, it still demonstrates comparable device performance. This result indicated that the atomic transport layers of 2D titania atomic sheets deposited via the room-temperature solution processes not only solve the biggest issue of c-TiO_2 which needs to be sintered at high temperature above 600°C, but also decrease the thickness of ETL. Therefore, it can be used as a promising ETL in lead halide perovskite solar cells and broaden the applications of perovskite optoelectronic devices.

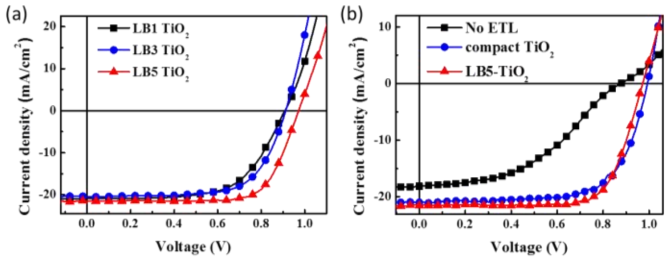

Figure 2. (a) Current-voltage plots of the devices (LB1, LB3, and LB5) consist of atomic transport layers of titania. (b) Current-voltage curves of the perovskite solar cells consist of no ETL, a compact TiO2 ETL and an atomic TiO_2 layers ETL.

3. Conclusion

In this work, we have successfully used atomic $Ti_{0.92}O_2$ as an alternative electron transport layer for perovskite solar cells. The most impressive feature of this material is that it is only few nano-meters thick but still has comparable power cell efficiency with conventional compact TiO_2 based solar cells which have approximately 100 nm thickness. In addition, through using Langmuir-Blodgett deposition method to deposit $Ti_{0.92}O_2$ staking layers on FTO substrates, we provide a whole low temperature process for the fabrication of perovskite solar cells. These novel perovskite solar cells can be used in flexible optoelectronic devices and show significant promising as a next generation green energy source.

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