Doctoral Dissertation

Study on the Improvement of Perovskite Solar Cell Efficiency

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ABSTRACT

Study on the Improvement of Perovskite Solar Cell Efficiency

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Perovskite solar cells have recently attracted a great attention because they have shown excellent photovoltaic performance, obtainable via a facile and cheap process. In the last decade, perovskite solar cells based on methylammonium lead halides have shown exceptional progress in terms of power conversion efficiency. The device performance highly depends on the film morphology and the film morphology is influenced by factors such as the material composition, additives, film treatment and deposition method. The key to obtaining high quality film morphology and performance is to essentially lower the energy barrier for nucleation and to form uniform growth of the perovskite crystals. In this work, we present a versatile laser-induced heat treatment, which can be used to control the morphology and grain size of perovskite and hence improving the PCE of PSCs. The structure of PSC devices is as follows: FTO glass substrate/compact (TiO_2)/mesoporous (TiO_2)/perovskite $CH_3NH_3PbI_3$/Spiro-MeOTAD/silver film. A nanosecond-pulsed ytterbium-doped fiber laser with a wavelength of 1064 nm was used to induce local heating on a perovskite film after the reaction between methyl ammonium iodide (MAI) and lead iodide (PbI_2) was completed. The laser operation parameters, such as the defocusing distance and scan speed, were investigated to control the grain size of the perovskite.

Based on optimized laser operation parameters, the best and average PCEs of 13.03% and 12.45 ± 0.28%, respectively, were achieved, which are higher than those obtained with conventional thermal heating (the best and average PCEs of 11.43% and 10.98 ± 0.25%, respectively). A perovskite layer temperature of 115°C was predicted by simulating the energy absorption of the perovskite film under optimized laser operation conditions using COMSOL software.

Beside, we also report a fully solution-processed fabrication of perovskite solar cell using silver nanoparticle film as the top electrode by lamination. The lamination process is an excellent alternative to replace vacuum deposition method due to its low cost, ease of processing, and potential to scale-up. The configuration of perovskite solar cell is FTO/cp-TiO_2/mp-TiO_2/$CH_3NH_3PbI_3$/Spiro-MeOTAD/PEDOT:PSS/D-sorbitol/silver nanoparticle film. The silver nanoparticle film was produced by spin-coating the nanoparticle silver ink onto a poly(ethylene terephthalate) (PET) substrate followed by post-annealing at 150 °C for 5 min. Introduction of a thin layer of Poly(3,4-ethylenedioxythiophene) polystyrene sulfonate PEDOT:PSS/D-sorbitol, plays an important role in improving the adherence of devices and electrical contact during lamination. Thereby, laminated perovskite solar cells with average power conversion efficiency (PCE) of 10.03% were achieved, almost of 90% of the PCE obtained for conventional devices (11.19%) with evaporated silver contact. The electrical and morphological properties of thermally annealed silver nanoparticle film were also investigated.

Keywords: Perovskite solar cells, two-step solution deposition, laser-induced heat treatment, simulation, COMSOL software, lamination method, silver nanoparticle film.