Achieving 20% Efficiency Perovskite Solar Cells with High Stability by using Semiconducting Single-walled Carbon Nanotube Grain Bridges

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Since liquid-junction perovskite solar cells (PSCs), the development of organo-lead halide perovskite photovoltaics research has gained momentum with the achievement of the solid-state PSCs in 2012. High absorption coefficient, long-range diffusion length and high defect tolerance of PSCs enable remarkable certified power conversion efficiencies (PCEs) over 20%. Although PSCs are proven to be promising next-generation solar devices, further breakthroughs in terms of efficiency and stability are necessary to supersede conventional silicon solar cells. With regard to the performance and stability of PSCs, perovskite grain boundaries play a significant role. Structural disorders at these boundaries induce shallow trap states and non-radiative recombination of localised charge carriers which serve as limitations to PSC performance. At the same time, these areas are also responsible for the perovskite degradation, as the reaction with moisture in air has been found to initiate from the grain boundaries. Therefore, technologies aiming at passivating the perovskite grains are highly desired.

Over the last two decades, carbon nanotubes (CNTs) with an exceptional charge carrier property with outstanding chemical and mechanical stability have generated a lot of excitement among researchers for their device applicability. Especially, single-walled carbon nanotubes (SWNTs) with a certain chirality possess a wide range of direct bandgap of up to 2 eV, qualifying for a light-harvesting medium with strong absorption and high carrier mobility. Semiconducting SWNTs (s-SWNTs) are highly conductive along the tube axis and therefore can function effectively as a charge-transporter between perovskite grains. While there have been a few reports on phenyl-C61-butyric acid methyl ester (PCBM) as a charge-transporter at the grain boundaries of perovskite films, fullerenes have inherently low carrier mobility and low stability compared to SWNTs. It has also been demonstrated that hydrophobic and air-stable SWNTs can protect the perovskite layer successfully from the oxygen and moisture.

Here, we fabricated PSCs in a configuration of glass/ITO/SnO_2/$CH_3NH_3PbI_3$/spiro-MeOTAD/Au in which the perovskite grains are passivated and connected by s-SWNTs. s-SWNTs here are functioning as a charge-transporter, light-harvester, and protector from the moisture in air. By incorporating a small amount of s-SWNTs in deionised water, 18.0% efficiency of the reference PSCs increased to 20% with reduced hysteresis. due to the increased perovskite grain size arising from favourable vapour pressure of the solvent. Upon addition of s-SWNTs, the PCE further increased beyond 20% with improved hysteresis and air/light stability. Ultimately, s-SWNTs added PSCs showed superior stability over the reference devices.