# CARBON NANOTUBE FILMS FOR PEROVSKITE SOLAR CELLS

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A film of single-walled carbon nanotubes (SWNTs) can be a dual-functional layer as electron-blocking-layer and transparent electrode in various solar cells. We have demonstrated efficient SWNT/Si solar cells using dry-deposited high-quality SWNTs and honeycomb-structured SWNTs [1-3]. The dual functionality is also demonstrated for organic and perovskite solar cells. For organic solar cells, the SWNT/MoOx/PEDOT:PSS layer was demonstrated as a dual functional layer replacing ITO and organic electron-blocking-layer. The power conversion efficiency (PCE) is comparable to those this using ITO. As the advantage of the film of SWNTs, the flexible organic solar cells can be easily demonstrated [4]. Similar replacement of ITO was demonstrate for Perovskite type solar cells [5].

In addition to the replacement of ITO, it is also possible to replace electron-blocking-layer and metal electrode for both inverted-type organic [6] and normal-type Perovskite solar cells [7]. Those devices can have comparable PCE as conventional design using organic electron-blocking layer and top metal electrode. In addition to the expected lower cost and stability, those solar cells using the transparent SWNT film can be semi-transparent and can be illuminated from both sides. The normal-type Perovskite solar cell, composed of ITO/$TiO_2$/$CH_3NH_3PbI_3$/SWNTs, can achieve the high PCE of 13 % without doping of SWNTs [7]. The PCE can be as high as 17 % with the preliminary doping of the film of SWNTs using Spiro-MeOTAD, which is the typical electron-blocking-layer used for normal type Perovskite solar cells. The PMMA layer on top of the film of SWNTs can also contribute as doping and protection layer. Furthermore, the modified structure with Perovskite layer sandwiched by $C_{60}$ and SWNTs, i.e. ITO/$TiO_2$/$C_{60}$/$CH_3NH_3PbI_3$/SWNTs, can lead to the solar cells without hysteresis and with much improved air-stability [8]. The effective passivation of the degradation of Perovskite material by moisture can be achieved with $C_{60}$ and SWNTs [8]. This device with about 17 % PCE so far [8] can be a good candidate for scale-up demonstration of practical Perovskite solar cells.

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