Single-walled Carbon Nanotube Transparent Electrode-based Flexible Perovskite Solar Cells

Il Jeon*, Jungjin Yoon**, Namyoung Ahn**, Esko I. Kauppinen***, Mansoo Choi**, Yutaka Matsuo*, and Shigeo Maruyama*

** Department of Mechanical Engineering, The University of Tokyo, Japan*

*** Department of Mechanical and Aerospace Engineering, Seoul National University, South Korea*

**** Department of Applied Physics, Aalto University School of Science, Finland*

E-mail: maruyama@photon.t.u-tokyo.ac.jp

In the past five years, organohalide lead perovskite solar cells have shown remarkable progress in terms of their power conversion efficiency (PCE) while retaining the potential of being flexible devices. In order to maximize flexible prospect of perovskite solar cells (PSCs), carbon-based transparent conductors, such as carbon nanotubes (CNTs)[1] and graphene[2], have been used to replace indium tin oxide (ITO). Natural abundance and mechanical resilience of the carbon materials supersede ITO, which cracks under 60° bending angle.[3] Unfortunately, only few studies have reported flexible, and tin oxide-free PSCs using carbon electrodes. Most of the flexible PSCs reported rely on metal oxide transparent conductors, which limit their efficiency and flexibility.[4]

Here, we demonstrate flexible ITO-free perovskite solar cells by using aerosol-synthesized single-walled CNT (SWCNT) films. Using the CNT films as the bottom electrode, the two mainstream HNO_3 and MoO_x doping methodologies were employed to enhance the conductivity and to control the wettability. Throughout the fabrication, we compared the two doping methods with different conditions and investigated various mixed halide perovskite layers in the energetics point of view. Moreover, graphene-based PSCs were fabricated to compare with the CNT-based PSCs. We discovered that thin MoO_x layer-deposited CNT PSCs were more reproducible than either HNO_3-doped CNT PSCs or graphene-based PSCs. Whereas, HNO_3-doped CNT PSCs gave the highest PCE of 16%. Based on this result, we fabricated flexible devices and demonstrated successful flexible application of CNT in PSCs.

[1] I. Jeon, T. Chiba, C. Delacou, Y. Guo, A. Kaskela, O. Reynaud, E. I. Kauppinen, S. Maruyama, Y. Matsuo, *Nano Lett.* **15**, 6665 (2015).

[2] P. You, Z. Liu, Q. Tai, S. Liu, F. Yan, *Adv. Mater.* **27**, 3632 (2015).

[3] M. Grätzel, *Nat. Mater.* **13**, 838 (2014).

[4] X. Yin, P. Chen, M. Que, Y. Xing, W. Que, C. Niu, J. Shao, *ACS Nano* **10**, 3630 (2016).