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ZnO/N-Doped Carbon Nanotube Nanocomposites Charge Transport Layer for High Performance Optoelectronics

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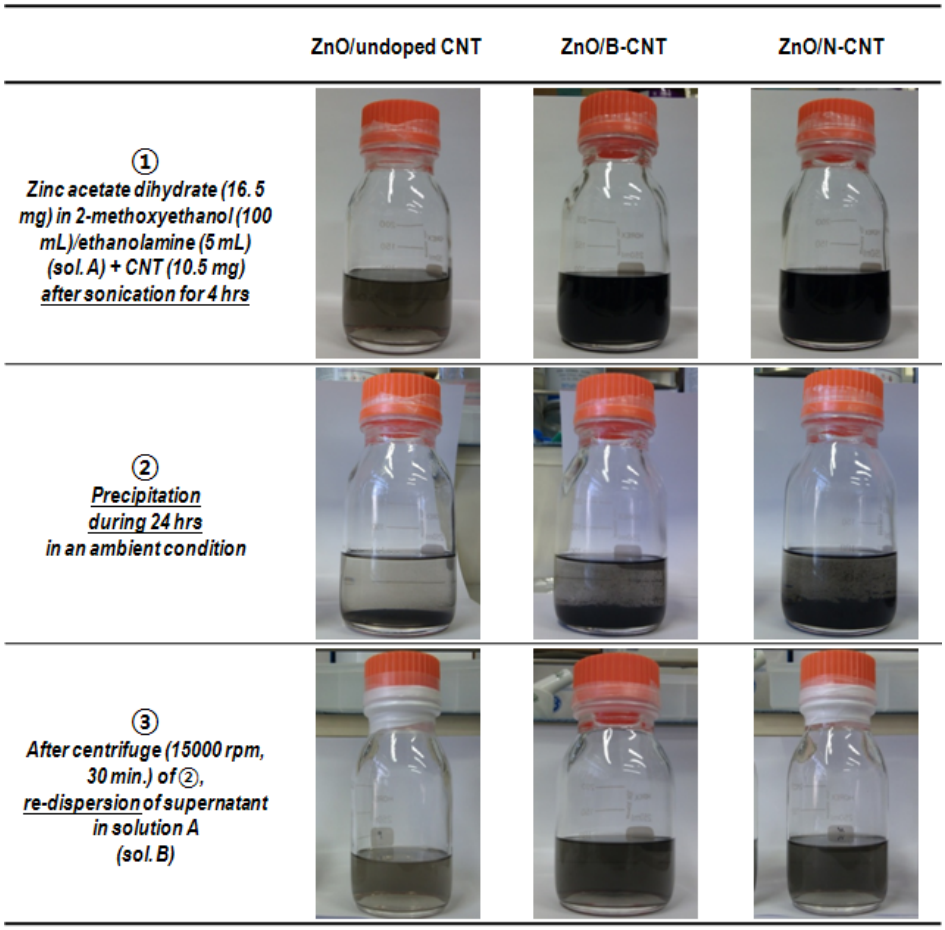


Fig. S1 Preparation of homogeneously dispersed ZnO/CNT precursor solutions with undoped CNTs, B-CNTs, or N-CNTs.

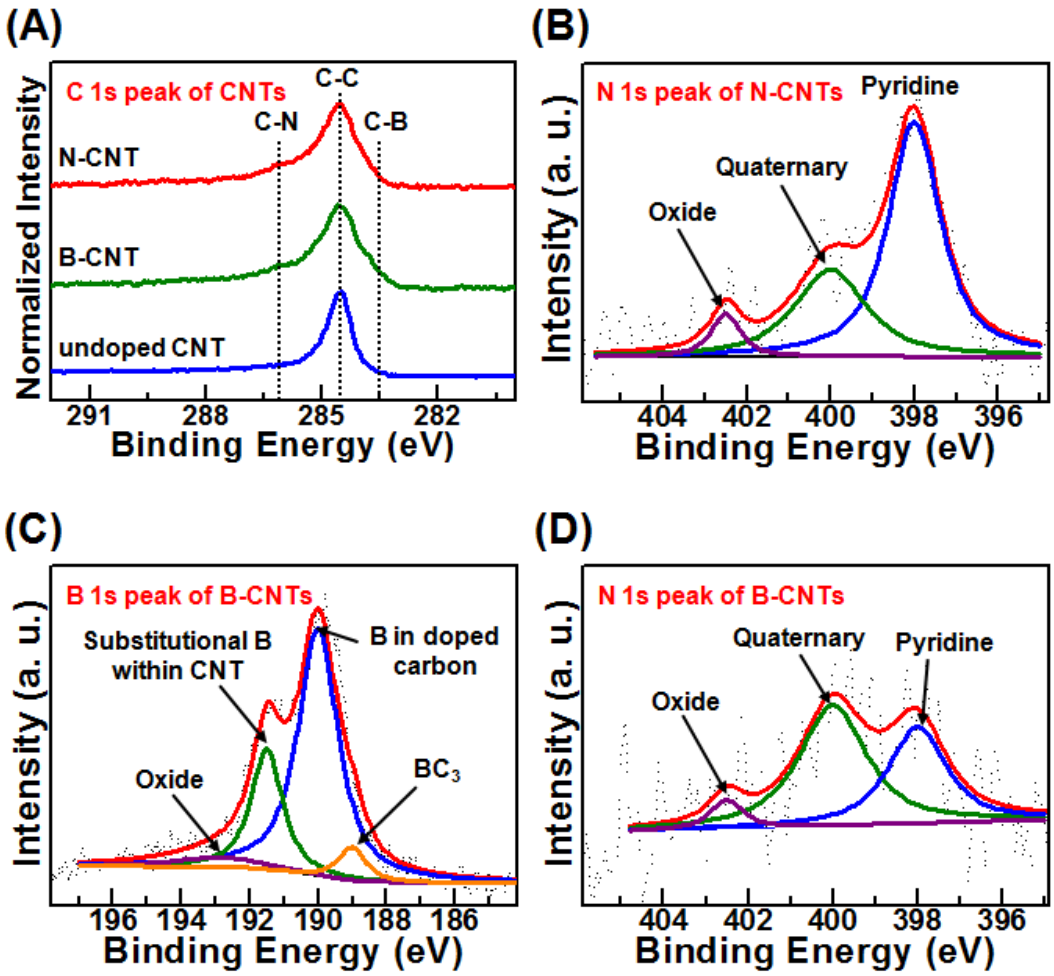
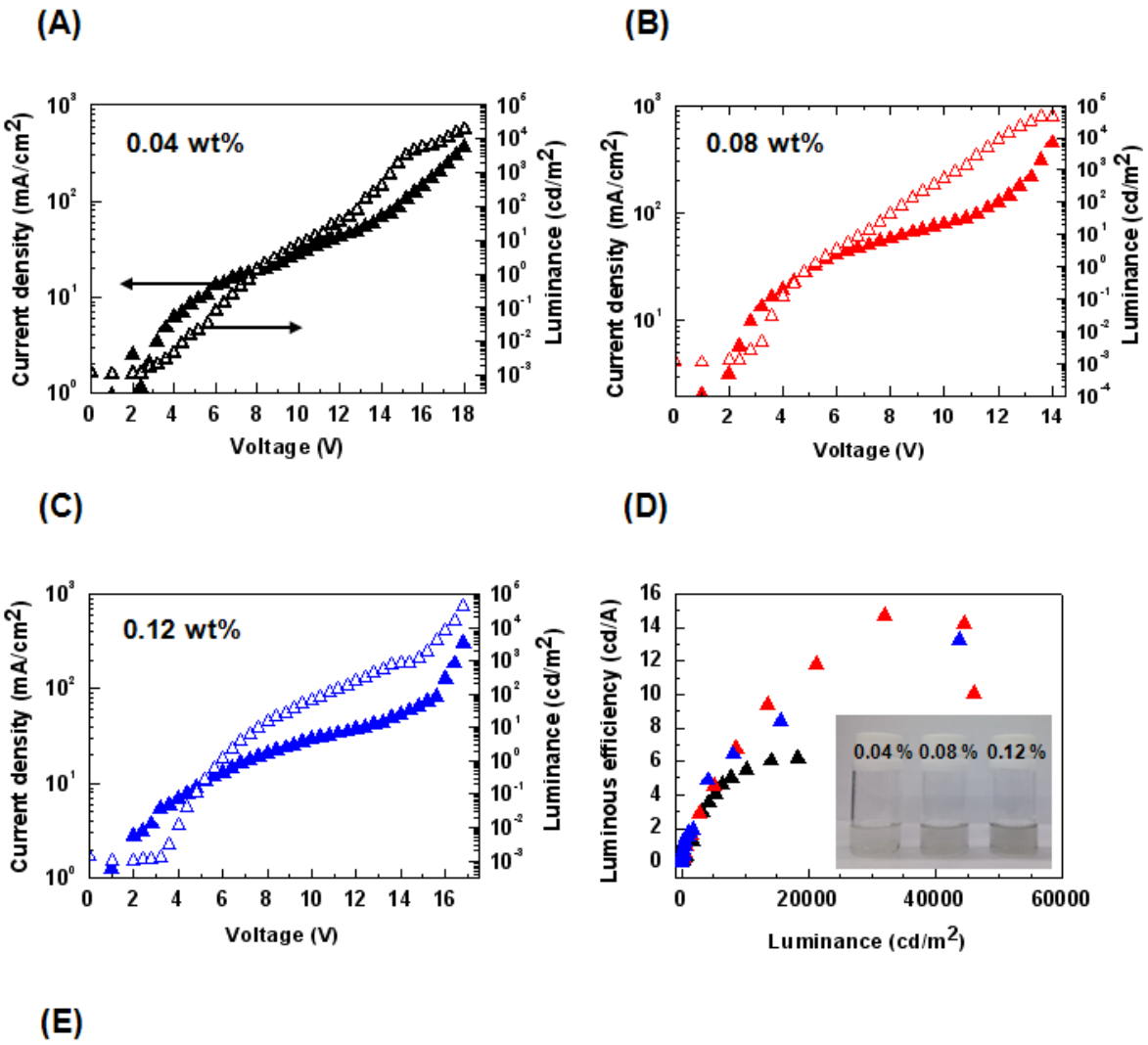


Fig. S2 (A) X-ray photoelectron spectroscopy (XPS) analysis of normalized C1s peaks (284.5 eV) for B-CNT, and N-CNT. C1s peak of B-CNT shows shoulder peaks at 283.5 and 286.8 eV, which originated from C-B bonding and C-N bonding respectively. C1s peak of N-CNT shows a shoulder peak at 286.8 eV due to the C-N bonding. (B) N1s XPS peak of N-CNT. Nitrogen atoms in CNT existed as quaternary nitrogen (400.8 eV), pyridinic nitrogen (398 eV), and nitrogen oxide (402.5 eV). (C) B1s XPS peak of B-CNT. Boron atoms in CNT existed as quaternary boron (191.5 eV), pyridinic boron (190 eV), BC_3 (189 eV), and boron oxide (192.8 eV). (D) N1s XPS peak of B-CNT. Nitrogen atoms in CNT existed as quaternary nitrogen (400.8 eV), pyridinic nitrogen (398 eV), and nitrogen oxide peak (402.5 eV).



(E)

Device Configuration	L_{max} (cd/m²) @ bias	LE_{max} (cd/A) @ bias	LE_{max} (lm/W) @ bias	EQE_{max} (%) @ bias
ZnO/N-CNT (0.04 %)	18,300 (@ 18.0 v)	6.2 (@ 18.0 v)	1.1 (@ 18.0 v)	1.9 (@ 18.0 v)
ZnO/N-CNT (0.08 %)	46,100 (@ 14.0 V)	14.3 (@ 13.6 V)	3.5 (@ 13.2 V)	4.3 (@ 13.2 V)
ZnO/N-CNT (0.12 %)	43,750 (@ 16.8 V)	13.2 (@ 16.8 V)	2.5 (@ 16.8 V)	3.9 (@ 16.8 V)

Fig. S3 Light-emitting characteristics of OLEDs with various concentrations of N-CNTs in ZnO layer. (A) 0.04 wt%, (B) 0.08 wt%, and (C) 0.12 wt%. (D) η_{EL}-V characteristics (inset: photographs of homogeneously dispersed ZnO/N-CNT precursor solutions). (E) Detailed device performance parameters. FTO cathode and MoO_3 deposited Au anode are commonly used for all devices.

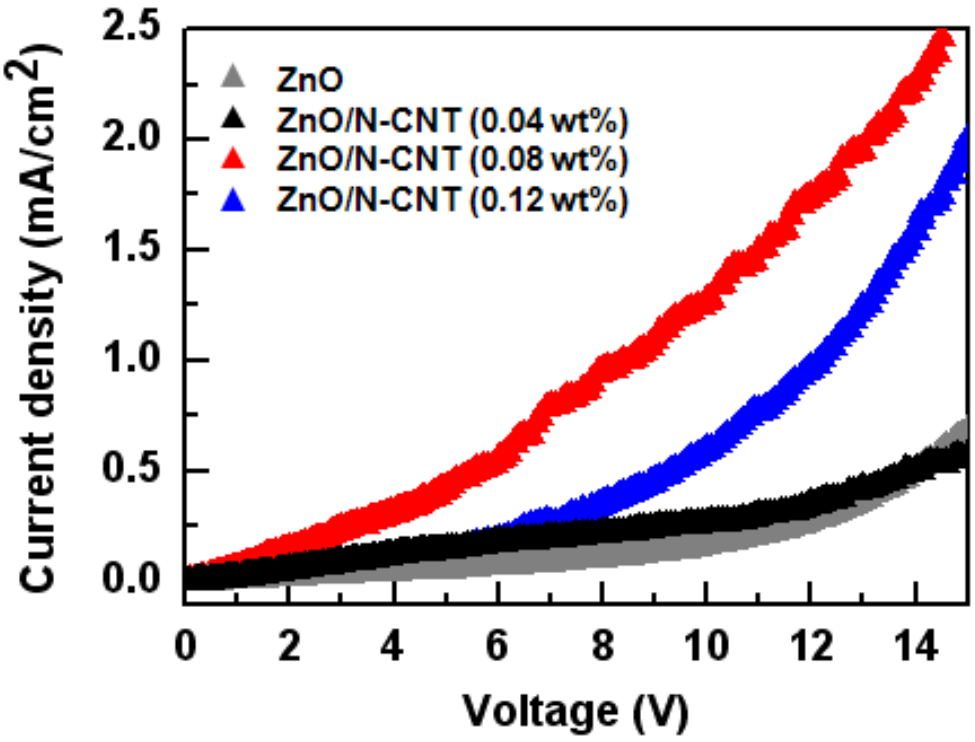


Fig. S4 *J-V* characteristics of electron-only devices (FTO / (ZnO/CNT) / CS_2CO_3 / F8BT / Ca / Al) with various concentrations of N-CNTs (0.04, 0.08 and 0.12 wt%) in ZnO layer.

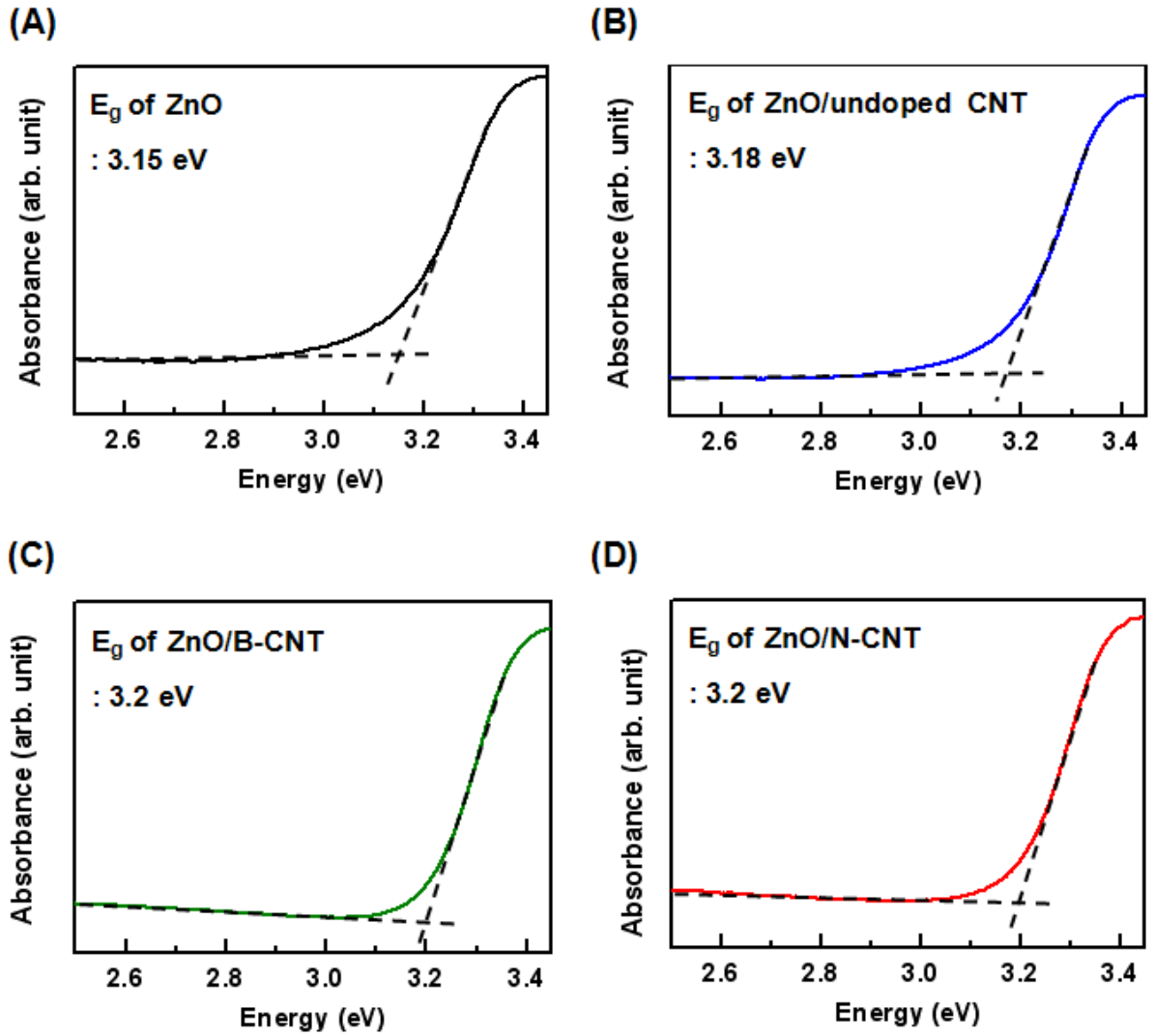


Fig. S5 Bandgap energy of ZnO/CNT nanocomposite layers obtained from the UV-VIS absorption spectrum. (A) ZnO, (B) ZnO/undoped CNT, (C) ZnO/B-CNT, and (D) ZnO/N-CNT layers.

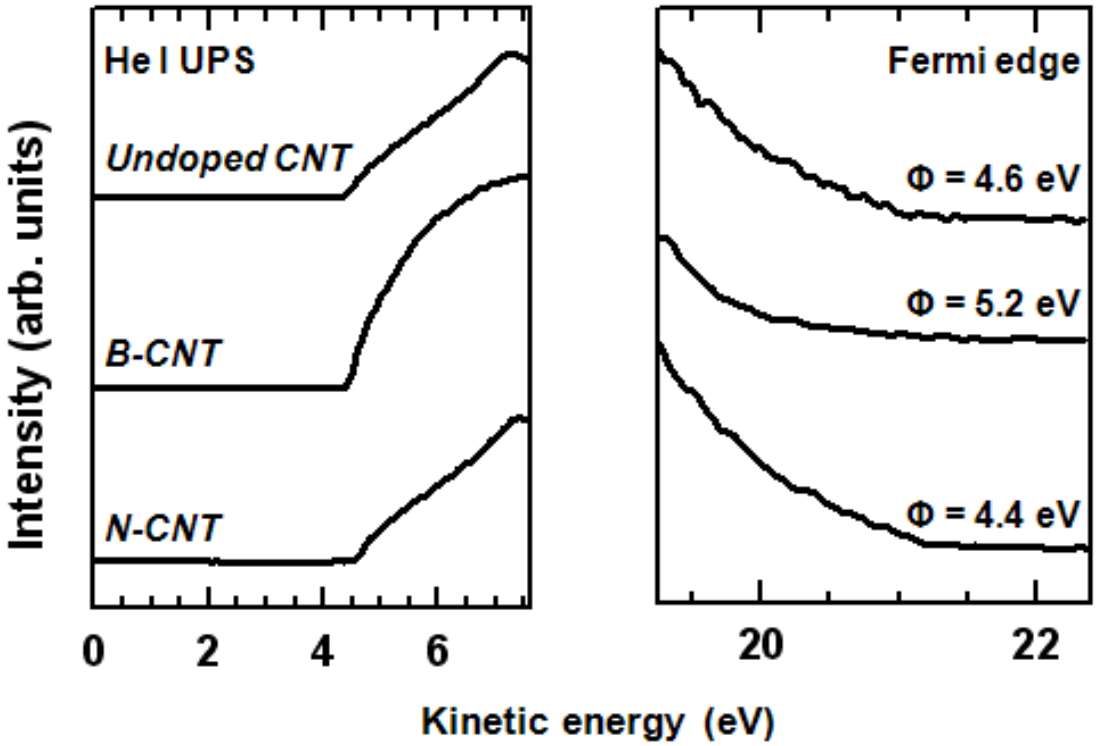


Fig. S6. Work function measurement of undoped CNT, B-CNT, and N-CNT by ultraviolet photoelectron spectroscopy (UPS, AXIS-NOVA, Kratos Inc.). The samples were prepared by drop-casting CNT films on 70-nm-thick gold coated silicon substrates. The work functions could be obtained from the difference between the inelastic cutoff (4.6 eV for CNTs) and the Fermi edge (21.2 eV for CNTs).[1] The work function of pristine CNTs was Φ = 21.2 eV − (21.2 eV − 4.6 eV) = 4.6 eV. Since Boron has only three valence electrons (1 less than carbon), the B-doping decreases the π electrons of CNTs and, thus, significantly increases the work function down to 5.2 eV. In contrast, the work function of N-CNTs slightly decreased down to 4.4 eV, due to the additional π electrons from the doped nitrogen atoms.

Reference

1 Y. Park, V. Choong, Y. Gao, B. R. Hsieh, and C. W. Tang, *Appl. Phys. Lett.*, 1996, **68**, 2699.