Roll to roll processable graphene-nanotube based hybrid transparent conductors for electrically switchable, flexible optical shutters

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Development of flexible, interactive electronic displays and devices has long been hindered due to the brittleness, processing limitations and fabrication costs of transparent conductive metal oxides like Indium Tin Oxide (ITO). Both Single Wall Carbon Nanotubes (SWNTs) and graphene offer ideal alternatives as flexible transparent conductors (FTC)[1]. A solution processable hybrid SWNT-graphene conducting film can be integrated into roll to roll manufacturing of devices requiring FTCs.

Polymer dispersed liquid crystal (PDLC) devices employ liquid crystal (LC) microdroplets embedded in a host polymer matrix, sandwiched between two transparent conducting electrodes[2]. In the absence of an external electric field, the LC director distribution (the average direction of the long molecular axis for uniaxial LC molecules) inside the LC microdroplets causes a refractive index mismatch between the LC and polymer matrix, resulting in strong forward scattering with a milky white or 'frosted' appearance and very low optical transmittance. Application of an electric field across the host polymer matrix embedding the LC microdroplets using the FTCs aligns the LC director distribution parallel to the field, making the device transparent. Figure 1(a) shows a schematic of flexible PDLC using SWNT-graphene FTCs.

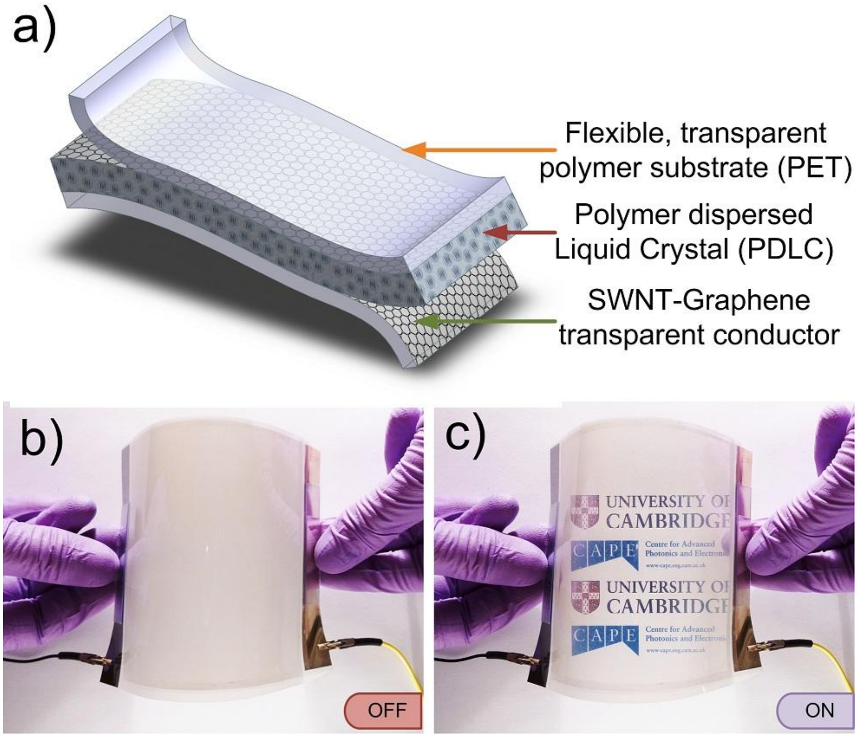
Here, we demonstrate an up-scalable SWNT-graphene hybrid FTC for a PDLC based smart window. We employ wire-wound rod coating for the aqueous dispersions of SWNTs and graphene on a 125µm thick polyethylene terephthalate (PET) substrate. First, the SWNT dispersions are ultrasonicated and centrifuged to remove residual bundles. Graphene flakes are then exfoliated in water by mild sonication with sodium deoxycholate (SDC), also centrifuged to remove un-exfoliated flakes. The centrifuged dispersions are then characterized using optical absorption spectroscopy (OAS), Raman spectroscopy and Transmission Electron Microscopy (TEM). OAS shows a SWNT and graphene concentration of 0.4 and 0.2 gL^{-1}, respectively. TEM reveals the presence of ~65% mono and bi-layer in the graphene flakes of 300-600nm dimensions. Raman spectroscopy also confirm the presence of pristine graphene flakes without structural defects. Rod coating accompanied by washing in an alcohol-water mixture results in an optically homogeneous FTC. The SWNT-graphene coating itself has 94-97% transparency across the entire visible spectrum with <2% standard deviation in transmittance across a ~200cm^2 FTC sample. The FTC has ~1kΩ/□ sheet resistance with a standard deviation of ~80Ω/□. The FTCs exhibit ~15% change in resistance when bent to a radius of ~3.5mm in 10 cycles, far surpassing the ~25000% increase in a 60 Ω/□ ITO sample on 125µm PET (Sheldahl, Accentia 430300 ITO Coated Films).

A ~120cm^2 smart window is then fabricated by laminating a YM55 nematic LC and Norland Optical Adhesive 65 as the polymer host between two FTCs. The fabricated smart window exhibits excellent electric field induced light transmittance (~60%) under applied electric field (Figs. 1(b,c)). When OFF, the device transmits <0.25%, giving a >230 contrast ratio.

References

[1] F. Bonaccorso *et al.*, Nature Photonics 4, 611 (2010)
[2] J.L. Fergason, US Patent 4435047, (1984)
[3] C.M. Lampert, Sol. Energy Mater. Sol. Cells 52, 207 (1998)
[4] T. Hasan *et al.* Submitted (2010)

Figures



a) Schematic of a flexible smart window with SWNT-graphene based FTC. b) In the absence of an electric field, the LC microdroplets cause strong forward scattering, with complete loss of transparency c) under applied electric field, the director distributions of the LC mocrodroplets align, resulting in a transparent state.