Scalable Ultrahigh Conductive Transparent Single-Walled Carbon Nanotube Films for High-Efficiency OLED Lighting

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Project Objectives

The project will develop a low-cost scalable ultrahigh conductive transparent single-walled carbon nanotube films fabricated on low surface roughness, high light extraction efficiency flexible polymer substrates for high efficiency OLED lighting. The project target is to demonstrate white OLEDs with a target EQE of 60% and 150 lm/W efficacy without the use of any additional light extraction structures. The technical benefits from creating carbon nanotubes are important for moving beyond rare earth metals and other environmentally unsustainable materials being used in LEDs and OLEDs. The economic benefits for reducing the costs of OLEDs are important for improving the position of OLEDs in the market place. And there is a high likelihood of success. During Phase I, the team will (1) identify the composition and process protocols for the ultrahigh conductive transparent single-walled carbon nanotube film substrate and (2) carry out preliminary OLED device fabrication to characterize the substrate performance in OLED efficiencies and operational stability.

Milestones and Expected Results

- high conductivity transparent SWCNTs thin films
- light outcoupling polymer embedded high conductivity transparent SWCNTs thin films
- OLED fabrication on light outcoupling polymer embedded SWCNT thin films with >150% light extraction efficiency
- scalable and cost reduce

Company & Team

The collaborative team of this project holds great expertise spanning across technical research and development, product engineering and scale up, quality control, and business development. Founded in 2013, Atom Inc. innovates scalable and high throughput fabrication technologies for low cost and low power consumption yet high performance optoelectronic devices for displays and lighting electronics. Atom Inc. will carry out and oversee the entire proposed project and will partner with UCLA to evaluate OLED device performance (Task 3) and back iterate process optimization and develop coating systems and parameters for scalable processes.

BACKGROUND

Ag NWs have been investigated as a potential ITO replacement, exhibiting sheet resistances from 10 Ω/□ to 300 Ω/□, high transmittance > 90% and low surface coverage (1%). While the thermal and mechanical stabilities of silver are often cited as a critical issue for Ag NWs. In these aspects, carbon nanotubes (CNT) show strong mechanical strength and thermal stability, providing a promising prospect for transparent conductive films (TCF). The first 50 nm single-walled carbon nanotubes thin films made through filtration method was reported 30 Ω/□ at 70% transmission.[1] The amine doped CG300 received from SWeNTs is about 100 Ω/□ with 70% transmission. There are a large number of literature reports on carbon nanotube transparent conductive films. Among these, the direct film deposition of in-situ synthesized carbon nanotube aerosol is attractive prospect for TCF showing sheet resistance of 100-300 Ω/□ at 90% transmission. After doping with $AuCl_3$, these CNT TCF can reach to 40 Ω/□ around 90% transmission.[2,3] We conducted extensive researches on these CNT TCF since 2012. We successfully repeated CNT TCF dip-coated from $ClSO_3H$ dispersion with sheet resistance of 1~2 kΩ/□ @ 90% transmission.[4] After doping with $AuCl_3$, the sheet resistance can be ranged around 200~400 Ω/□. CNT TCF made by other solution processes like spraying and drop-drying normally greater than 10 kΩ/□ at 90% transmission, no matter the type, the dispersion method. These are summarized in **Figure 1**.

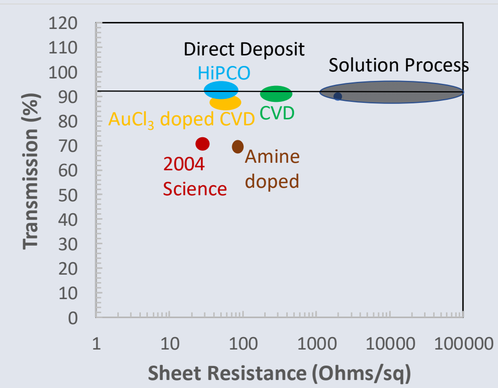

Figure 1. The current status of CNT TCF.

Project Elements

We are building chemical vapor deposition (CVD) reactor to repeat direct CNT film deposition from CVD reactor (**Figure 2**).

Figure 2. Photographic images of 1200 °C three zone furnace (left), direct deposited CNT TCF without (middle) and with (right) $AuCl_3$ doping.

From our high pressure carbon monoxide conversion (HiPCO) reactor licensed from Rice University,[5] we peeled off CNT TCF from its filter. These HiPCO CNT TCF shows transparent areas with sheet resistance down to 4 Ω/□. Though these nice TCF was contaminated by carbon dusts (**Figure 3**).

Figure 3. Photographic images of CNT TCF (top left) from HiPCO reactor filter (top right), zoomed images of transparent CNT TCF contaminated by carbon dusts (bottom left), resistance characterization (4 Ω/□).

By learning the direct CVD film deposition experiences, we are engineering our HiPCO reactor to produce high quality HiPCO TCF (**Figure 1**) with sheet reistance down to 10 Ω/□ at 90% transmission.

Project Elements

Our subcontractor, Professor Qibing Pei's research group @ UCLA has researched on light outcoupling composites based on Ag NWs. By using these Ag NWs based light outcoupling composites, OLED with structure: Ag NWs composite (Anode)/PEDOT:PSS (HIL)/TAPC (HTL)/yellow (PO-01) and blue (NPB) emissive layer/Bepp2 (ETL)/CsF (EIL)/Al (cathode) showed warm white with CRI ~55, typical performance of 127 cd/A, 107 lm/W, and 49% EQE at 1000 cd/m². Results for the control OLEDs based on ITO/glass were 46 cd/A, 47 lm/W, and 18% EQE. The light extraction enhancement factor is ~2.7X (**Figure 4**).[6] Following Ag NWs composites, the 40 Ω/□ CNT TCF has been fabricated into light outcoupling composites for OLED validation.

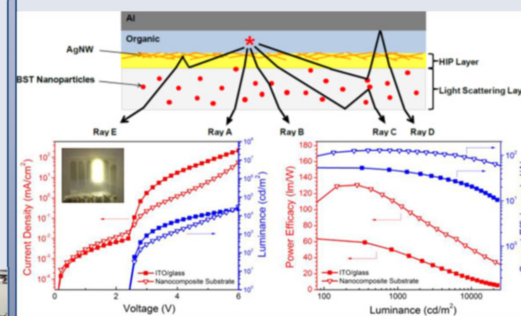

Figure 4. Schematic diagram of an OLED device with Ag NWs based light outcoupling and waveguide modes (top). Comparison of performance characteristics of OLED devices with ITO and Ag NWs based composite (bottom).

CONCLUSION & IMPACT

HiPCO TCF directly deposited from HiPCO reactor showing promising metrics to be <10 Ω/□ with 90% transmission. Integrated with light outcoupling nanoparticles and reflectance guided mode, HiPCO TCF composites could be ITO replacement for high efficiency OLED lighting targeted as 60% EQE and 150 lm/W efficacy.

REFERENCES

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