Carbon Nanotubes as Transparent Electrodes for Photovoltaics

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Introduction

Eikos Inc. has developed single-walled carbon nanotube (SWNT) based materials technology, known as Invisicon®, that replaces transparent conductors such as Indium Tin Oxide (ITO) [1]. We report achieving **2.6% efficiency** on a non-optimized **organic photovoltaic cell employing SWNT as a transparent electrode**.

Eikos Inc. has previously demonstrated that highly transparent conductive films are formed when SWNT dispersions are applied at thicknesses less than 100 nm [2]. Transparent conductors (TC) are essential in many optoelectronic devices, including liquid crystal displays (LCD), organic light emitting diodes (OLED), touch screens, and photovoltaics (PV).

Why Carbon Nanotubes ?

Carbon Nanotubes (Fig. 1)
- ✓1-2 nm diameter
- ✓1 um long (1000:1 L:D)
- ✓Self assembling networks
- ✓P-type
- ✓Solvent stability

Carbon Nanotube Films (Fig. 2)
- ✓ Broad Surface Resistance, 10^2 - 10^7 Ω/□
- ✓ Optical transmittance >90%
- ✓ Work Function 4.8 eV
- ✓ 20 - 100 nm thickness
- ✓ Solution processing
- ✓ Flexible structure
- ✓ Porous nature
- ✓ Material availability
- ✓ Low-cost application methods

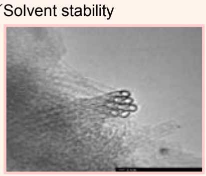

Fig. 1. TEM Image of CNT Ropes

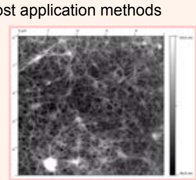

Fig. 2. AFM image of CNT transparent conductive film

Optoelectronic Properties

A unique advantage of the Invisicon® SWNT coating is its ability to tailor sheet resistance (R_s) over a broad range. R_s for the coating has continuously improved, and meets basic solar requirements for percent transmission (T) at 550nm for a given R_s. (Fig. 3) Transmission increases at longer wavelengths, making SWNT coatings especially beneficial in the near infrared (IR). (Fig. 4)

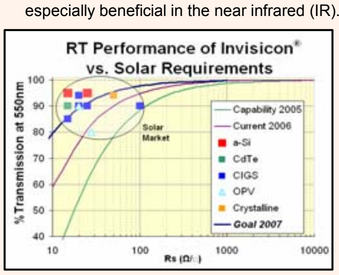

Fig. 3. RT performance of Invisicon® Transparent Coatings

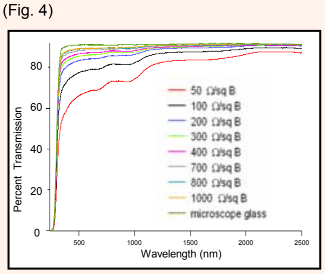

Fig. 4. Optical Transparency of Invisicon® Coatings

Mechanical Durability

The mechanical durability of the **Invisicon®** coating has been tested under **cyclic loading** and **tensile strain,** and compared against ITO [3]. These properties **exceed ITO**, and are ideal for flexible solar cells.

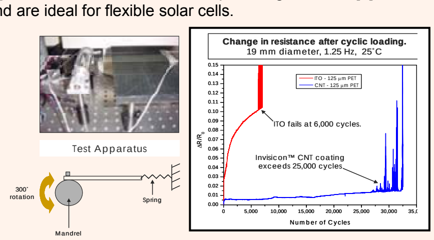

Fig. 5. Bending Fatigue of CNT & ITO Coatings

CNT Enabled Organic Solar Cell

These transparent electrodes were fabricated as follows: an aqueous suspension of SWNT was spray-coated onto a glass substrate under ambient process conditions. As the solvent and volatile compounds evaporate, SWNTs form into the network structure shown in Fig. 2. Optoelectronic properties are directly proportional the amount of SWNT deposited. Organic layers, PEDOT:PSS and P3HT:PCBM, were then spin-coated directly onto the SWNT layer. The top aluminum contact was then thermally evaporated through a shadow mask (Fig. 6). SWNT deposition was conducted by Eikos, and subsequent fabrication and evaluation was performed by NREL.

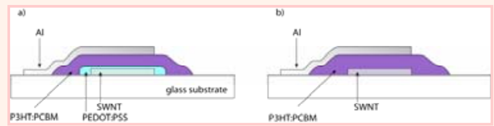

Fig. 6. Cross Section of the Organic Cells. (6a) represents a structure with PEDOT:PSS, whereas (6b) is without PEDOT:PSS

Performance of the cells was measured on an NREL X10 solar simulator under AM 1.5 conditions. Fig. 7 and Fig. 8 illustrate J-V curves for each cell type, with **efficiencies of 2.6% and 1.4%** for the PEDOT and non-PEDOT cells, respectively. These **are higher than any other organic devices employing carbon nanotubes reported to date.**

PERFORMANCE	PEDOT:PSS	w/o PEDOT:PSS
V_{oc} (V)	0.55	0.44
J_{sc} (mA/cm^2)	9.66	7.44
Eff. (%)	2.61	1.43
FF(%)	48.8	43.1

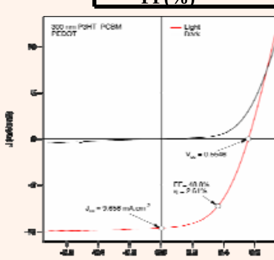

Fig. 7. J-V Curve under AM 1.5 for SWNT/PEDOT/P3HT:PCBM/Al cell

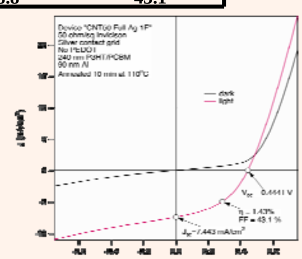

Fig. 8. J-V Curve under AM 1.5 for SWNT/P3HT:PCBM/Al cell

Conclusions

SWNT based Invisicon® films are an alternative to ITO, or other metal oxide conductors, as transparent electrodes in organic solar cells. Demonstrated efficiencies of 2.6% for non-optimized devices with PEDOT and 1.4% for structures without PEDOT, indicate that SWNT transparent conductors offer versatile materials options for photovoltaic applications. Invisicon® SWNT films also offer over traditional TCs the benefit of better IR transmission, better stress and strain performance, and also enable flexible, solution processed solar cells.

Literature Cited

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2. C.M. Trottier, P. Glatkowski, P. Wallis, J. Luo, "Properties and Characterization of Carbon Nanotube Based Transparent Conductive Coatings", *Journal of the Society for Information Display*, ***13****, 2005, Issue 9, pp. 759-763.*

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Acknowledgments

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For further information

•Please contact *cweeks@eikos.com* for additional information regarding this presentation. Visit *www.eikos.com* for more information on Invisicon® coatings.