

JAN. 2007
VOL 12 NO 1

Advantage
Business Media

MICRO NANO

THE NEWSLETTER OF
TOOLS AND PRODUCTS
IN MICRO AND
NANOTECHNOLOGY

From the Editors of R&D Magazine

CONTENTS

Microsystems

- 5 MEMS Briefs
- 7 Probe cards
- 16 Patent snapshots
- 16 Commercialization focus

Biotech

- 4 Dipstick detects drugs
- 7 Steering technology
- 8 Implant tests/monitors
- 12 Biotech Briefs
- 13 Magnetically separate blood cells
- 15 Device detects ricin
- 16 Patent snapshots

Nanotechnology

- 3 Nanotech Briefs
- 7 Phase-change technology
- 8 Robotic arm
- 9 Nano-ice
- 9 Reversible photonic circuit
- 12 Grow Si nanowires on aluminum
- 12 Solomon's knot
- 13 Nanotube photocopier
- 16 Commercialization focus

Process and Measurement

- 4 Surfaces
- 8 Complex photonic structures
- 11 CNTs made to order
- 13 Self-assembly scales up
- 14 Process and Measurement Briefs
- 14 Integrate dissimilar materials

Business

- 4 Valuation multiples
- 15 Worldwide MEMS grows

Departments

- 2 Industry Report
- 10 Book Review
- 17 Coming Events
- 18 Awards & Grants
- 19 Subscription

Nanotechnology

Green carbon nanotubes

By Chris Weeks, Paul Glatkowski, and David Britz, Eikos Inc.

For centuries, carbon has been synonymous with black. Then, discoveries in the 1990s showed that carbon can be transparent. Now, it is green. Carbon in the form of carbon nanotubes (CNTs) is becoming a popular material for renewable energy, enabling technologies from hydrogen fuel cells to solar cells. Single-walled carbon nanotubes (SWNTs) are useful as a transparent conducting electrode in photovoltaics (PVs), replacing indium tin oxide (ITO) and zinc oxide (ZnO) with the benefit of lower process cost and greater mechanical flexibility.

A special member of the nanotube family is the SWNT, which consists of one rolled

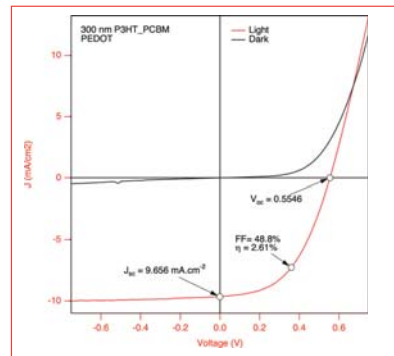


Fig. 1. Current voltage curve of organic PV with SWNT electrode. Source for all graphics: Eikos Inc., Franklin, Mass.

continued on page 6

BUSINESS NEWS

EpiCrystals, Tampere, Finland, won the European Venture competition as the best venture from among 18 finalists. The company uses molecular beam epitaxy methods to create GaAs- and InP-based laser diodes.

Reiner Peters from NASCOMED (www.nascomed.de), Germany, has coined the phrase nanoscopic medicine—a new nanotech discipline that analyzes/improves the nanoscopic fundament of the cell.

Ill.-based **AMCOL** (www.amcol.com) has devised a nanocomposite for plastic beer bottles that keeps oxygen molecules out and CO₂ molecules in.

MICRO NANO RENEWAL OFFER

KEEP YOUR NEWSLETTER COMING IN 2007.

Professional Discount Rate

| Regular Price | PROFESSIONAL DISCOUNT RATE | Professional Discount | Respond By |
|---------------|----------------------------|-----------------------|------------|
| \$195.00 | \$95.00 | 51% | 2/9/07 |

Check One: Payment enclosed Please bill me
Charge My: Amex Visa MC

If you are a student or outside the US., please provide your contact information and check the appropriate box to receive subscription rates. Student rates International rates

Acct. # _____ Exp. Date _____
Signature _____
E-Mail _____
Phone _____ Fax _____

Address all subscription mail to: MicroNano, 100 Enterprise Drive, Suite 600, Box 912, Rockaway, NJ 07866-0912
MicroNano is a trademark of Advantage Business Media

Act Today!

Don't take the chance of missing out on MicroNano Newsletter's in-depth coverage of the exploding technological revolution.

Green carbon nanotubes

continued from page 1

graphitic sheet ~1-nm dia. The physical structure of SWNTs makes them ideal for creating a 2-D network of nanowires which, due to high volume conductivity, is as conductive as ITO or ZnO at film thicknesses <100 nm. The physical, chemical, and electrical properties of CNTs make them suitable for green technology applications.

PVs are a well-known and prominent green technology. Industry and government initiatives in solar production are expected to grow the market 40%/year, from 2 GW of production in 2006 to almost 10 GW in 2010. Crystalline Si cells make up a majority of this market, but non-traditional technologies such as copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), dye sensitized, and organic polymer solar cells will outpace overall growth, expanding from 0.15 GW to 2 GW in the same time frame. These designs utilize roll-to-roll manufacturing methods and produce cells at a lower cost/watt. The ideal transparent conductor (TC) for these designs is mechanically flexible and can be applied in ambient conditions using wet-process equipment.

Making SWNT solar cells

SWNTs are ideal TCs for solar cell applications. Eikos has formulated a brand of Invisicon inks that are liquid dispersions of purified and functionalized SWNTs. These inks are applied using a variety of methods including slot-die coating, gravure coating and inkjet printing. Van der Waals forces pull together dispersed nanotubes as the ink solvent dries, assembling the nanotubes into a thin, uniform, conductive network. These open-pore networks can be made at a broad range of sheet resistance (1-10⁷ ohm/sq) and can be infiltrated with a polymer to make flexible, mechanically robust films.

Five different solar cell designs were fabricated using spray applied transparent SWNT electrodes (Table 1, below), which represent a diverse selection of non-traditional thin

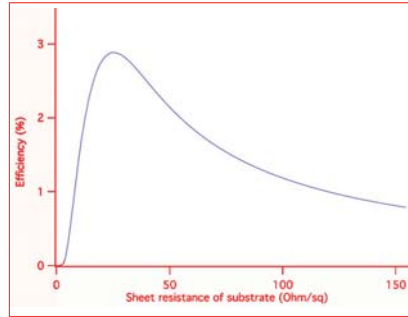


Fig. 2. Modeled efficiency vs sheet resistance for SWNT enabled OPV.

film and novel PVs. They were fabricated in collaboration with the National Renewable Energy Laboratory (NREL), Golden, Colo., and leading solar companies. For most cell types, SWNT sheet resistance ranged from 50-200 ohm/sq with a transparency of 70%-92%, respectively. Though not fully optimized, these processes yielded cells with efficiencies on par with control devices made with standard TCs. For processing and technical reasons, the most promising devices are organic photovoltaics (OPVs) cells. With SWNT electrodes, they are true organic, green energy sources.

Fully organic PVs

Despite lower efficiencies, OPVs are being developed for their low-cost manufacturing. SWNT electrodes are ideal for this device type with a 4.9 eV work function and p-type conduction. Two OPV constructions were fabricated with NREL (Table 1). A maximum efficiency of 2.61% was achieved when ITO was replaced with an SWNT electrode. This device was spray coated on microscope glass to 50 ohm/sq with an associated transmittance of 70% at 650 nm. Poly(3,4-ethylenedioxythiophene) polystyrenesulfonate (PEDOT:PSS) was spun on and thick (0.5-1 μ m) films of poly-3-hexylthiophene (P3HT) and [6,6]-phenyl C61 butyric acid methylester (PCBM) 1:1 were drop cast on top and allowed to slowly dry for 30 min in an argon (Ar)-atmosphere glove box. Aluminum (Al) top contacts (~100 nm) were then deposited onto the device by thermal or

e-beam evaporation. Finally, the devices were annealed at 120°C for 30 min in the glove box. The current density-voltage (J-V) curve of this 2.61% efficiency device is shown in Fig. 1 (page 1). Except for the Al contacts, the replacement of inorganic ITO with SWNT electrodes yields an OPV device.

The OPV in Fig. 1 can be optimized further. Samples were made at 50, 75, 100, and 150 ohm/sq SWNT sheet resistance with a trend that lower resistance values (more nanotubes) allow more current to flow, creating higher solar conversion efficiency. This trend continues until very low sheet resistance occurs as additional layers of SWNTs decrease transparency, which lower photo induced current and efficiency. This trade off is modeled in Fig. 2 (left) with a maximum efficiency of nearly 3% at an optimal SWNT sheet resistance of ~25 ohm/sq. To lower OPV cost further, fewer polymer layers can be used. Table 1 shows an efficiency of 1.43% for an organic device with SWNT and Al electrodes sandwiching the P3HT:PCBM active material, replacing ITO and PEDOT:PSS in the reference device. ITO electrodes will not function in these devices because of their n-type conductivity. Though the efficiency is lower for this device, its simple construction could be useful for low-cost, recyclable PVs.

Green future

SWNT transparent electrodes have comparable performance to ITO and ZnO electrodes while offering the benefit of solution processing and mechanical flexibility. These factors are critical in the new generation of thin film and novel renewable solar energy technologies, which are manufactured in low cost roll-to-roll processes. Due to work function matching and p-type conduction, these electrodes are suited to OPVs and can create a fully organic device. The CNTs are produced from renewable materials. Ethanol, a carbon source for producing quality nanotubes, is generated in volume from plant sources, making it an ideal renewable precursor for green nanotubes. SWNTs are used by Eikos to produce Invisicon transparent conductive coatings for applications ranging from solar cells to LCD displays and touch screens. At the end of product lifetime, nanotube coatings can be recycled or incinerated to their carbon and hydrogen components.

Chris Weeks (cweeks@eikos.com) is a Sr. Engineer at Eikos Inc., Franklin, Mass., leading the adoption of SWNT transparent conductors into photovoltaics under a DOE contract.

Paul Glatkowski (pflatkowski@eikos.com) is VP of Engineering at Eikos and the inventor of CNT Invisicon transparent conductive coatings.

David Britz (dbritz@eikos.com) is a Sr. Engineer at Eikos and has seven patents pending relating to CNT composites, film, and apps.

Five different solar cell designs

| Cell | Name | Structure | Efficiency, SWNT TC | Efficiency, control TC |
|--------|----------------------------------|-------------------------------|---------------------|------------------------|
| OPV | Organic photovoltaic | SWNT/PEDOT:PSS/P3HT:PCBM/Al | 2.61% | ~3% |
| OPV | Organic photovoltaic | SWNT/P3HT:PCBM/Al | 1.43% | N/A |
| DSSC | Dye sensitized solar cell | Ti/TiO ₂ /dye/SWNT | 2.86% | 2.20% |
| CIGS | Copper indium gallium diselenide | SWNT/i-ZnO/CdS/CIGS/Mo | 12.98% | ~15% |
| Tandem | Cadmium telluride top cell | ITO/CdS/CdTe/CuTe/SWNT | 12.4% | 12.9% |

Table 1. For variety of cells, SWNT conductors offer benefits at similar efficiencies.