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Touch Panel

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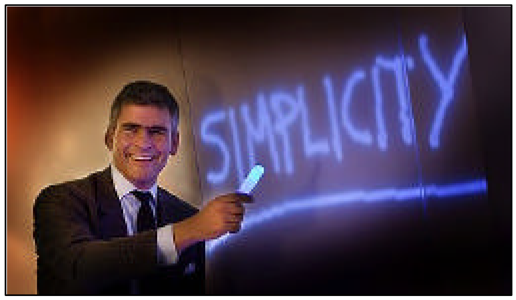

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The *Touch Panel* is focused on bringing news and commentary about the activities of the companies and technologies related to touch screens and related technologies for the displays industry. The *Touch Panel* is published electronically 10 times annually by Veritas et Visus, 3305 Chelsea Place, Temple, Texas, USA, 76502. Phone: +1 254 791 0603. www.veritasetvisus.com

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Carbon nanotube transparent electrodes for touch screens

by Chris Weeks

Chris Weeks is a senior engineer at Eikos Inc, working on device applications where transparent and conductive carbon nanotube inks are used as a wet-deposited alternative to Indium Tin Oxide (ITO). Prior to Eikos, Chris spent five years in the semiconductor industry, designing modems and digital signal processors at Analog Devices. He holds both a BS and MS in Electrical Engineering from Brown University.

Resistive and capacitive touch screen technologies require transparent electrodes for functionality. Though indium tin oxide (ITO) has been the transparent conductor of choice for touch screens, it is non-ideal. It is costly to pattern, has unappealing visible traces due to reflectance, and has a tendency to crack with use due to its brittle nature. In recent years Eikos has conceived and developed technologies to deliver novel alternatives using single walled carbon nanotubes (CNT). This is a review of CNT coating properties versus those of existing transparent conductors such as ITO.

CNT technology offers a variety of beneficial properties, including:

- broad range of conductivity (10-10^7 O/?)
- uniform and linear conductance
- excellent transparency
- low reflectivity
- neutral color tone
- wet processing
- good adhesion
- durability
- abrasion resistance
- good chemical resistance
- flexibility
- ease of patterning

These properties allow touch screen designers to create high-performance, low-cost devices with market differentiated form factors, such as conformal or flexible touch screens.

Overview: Transparent conductors are an essential component in many optoelectronic devices, including touch screens, LCDs, OLEDs, and photovoltaics. ITO has been the conductor of choice for four decades, but falls short in some material properties. Engineers at Eikos are developing transparent conductive films that form when carbon nanotube (CNT) dispersions are applied at thin thickness (<100 nm). Today, the highest quality Eikos Invisicon CNT films result in 90-99% visible light transmittance and 100-1000 Ω/□ sheet resistance – very close to the optoelectronic performance of sputtered ITO, and suitable for touch screen applications. These optoelectronic properties will improve further in the future with increased CNT purity and degree of dispersion. Additionally, the CNT coating is enhanced by a polymer binder layer, which maximizes the optoelectronic performance and increases adhesion, abrasion resistance, and flexibility.

Morphology: Carbon nanotubes are an allotrope of carbon formed in the presence of carbon, heat, and a metal catalyst. Pictured in *Figure 1*, these tubes are typically 1-2 nm in diameter, and over 1000 nm long. Eikos uses a proprietary purification process to produce high purity dispersions of carbon nanotubes. In this process, arc produced CNT powder (soot) is acid refluxed to separate the amorphous carbon, metal catalyst, and other contaminates from the carbon nanotubes. While dispersed, these carbon nanotubes bundle together to form "ropes". When applied through spray, slot-die, gravure, screen print and other wet-processing techniques, these ropes or bundles intertwine with 2D orientation on the substrate plane to form a conductive network. A scanning electron microscope (SEM) micrograph of the network is shown in *Figure 2 (next page)*.

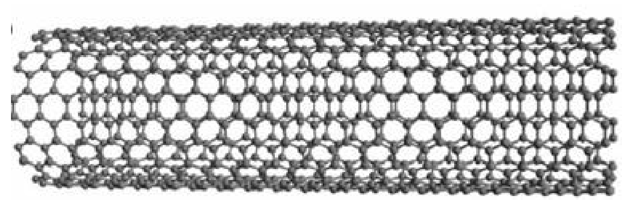

Figure 1: The high aspect ratio of carbon nanotubes makes them ideal wires

Optoelectronic performance: Three different transparent conductor materials were evaluated: 1) ITO sputtered onto glass substrate and PET substrates; 2) Poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) wet-coated onto polyester film substrate (PEDOT/PSS); and 3) CNT spray coated onto glass substrate and PET substrates. The ITO films were sputtered at 30 nm (± 10 nm) thickness onto 0.7 mm OA10 NIHON-DENKI-GLASS non-alkali glass substrate (similar to Corning 1737). The sheet resistance of the ITO layer was approximately 200 Ω/□. Note that a proprietary antireflective coating was used to optimize visible light transmittance. ITO films on 175 µm PET contained no antireflective coating. The PEDOT/PSS films were wet-coated (Meyer rod method) to 24 µm (wet film thickness) by Bayer onto 175 µm polyester (PET) film. Sheet resistance of the PEDOT layer was approximately 250 Ω/□. This PEDOT sample is representative of a "high conductivity" grade (BAYTRON FHC). The CNT films were spray coated by Eikos onto 0.7 mm OA10 NIHON-DENKI-GLASS non-alkali glass substrate (similar to Corning 1737) and 175 µm polyester (PET) film. Sheet resistance of the CNT layer was varied from 200 to 650 Ω/□ and contained a melamine/acrylic coat.

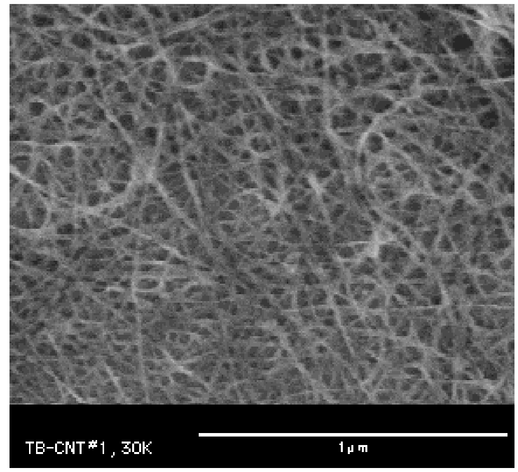

Figure 2: SEM Micrograph of CNT Film at 100 Ω/□

The visible light transmittance of ITO, PEDOT, and CNT films is shown in *Figure 3*. All transmittance values were measured using a Perkin-Elmer Lambda 3B UV-vis spectrophotometer and refer to the transparent conductor layer only (with substrate effect removed). The CNT film displays high transparency across the complete visible light spectrum. In comparison, ITO has a maximum transparency in the range of 500-550 nm, at the expense of significantly lower transparency at other wavelengths. For the same level of conductivity, current CNT films show somewhat lower transparency at 550 nm compared to the peak transmittance of ITO. However, CNT films exhibit significantly higher transparency across the whole visible light spectrum. CNT films are much more transparent than PEDOT. The gap between CNT and ITO will be minimized by further product optimization. As shown in *Figure 4*, optoelectronic performance of Invisicon coatings has been continuously improving over the last four years. An advantage of the CNT coatings is the ability to tailor the sheet resistance over a large resistive range from one order of magnitude up to as high as 10 orders of magnitude (ESD). Wet processing and the ability to tune sheet resistance make Invisicon a preferred material for manufacturing.

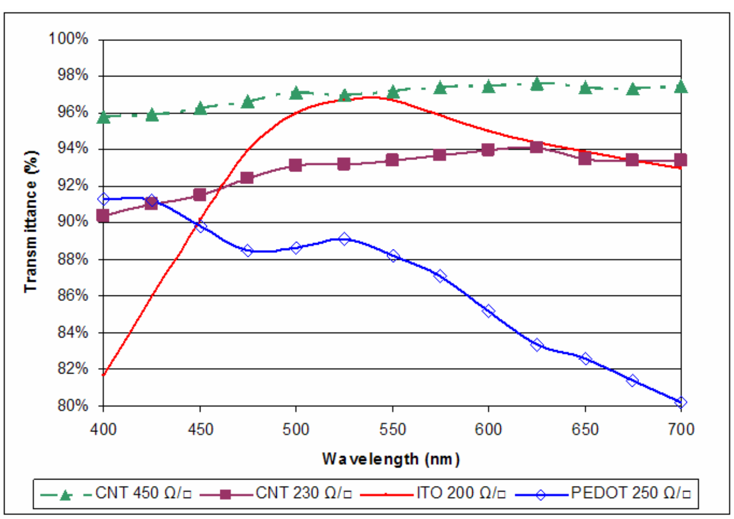

Figure 3: Optical performance: visible light transmittance of ITO, PEDOT and CNT films

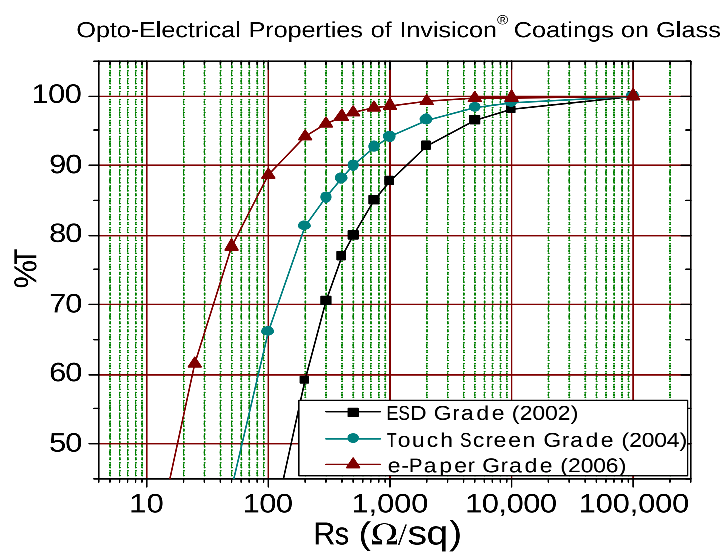

Figure 4: Optoelectronic performance of carbon nanotube transparent conductive coatings

For most touch screen display applications, neutral color is desired. Color measurements using a MacBeth Colorimeter with a D65 illuminant and a 10º Observer confirm that CNT films are much closer to neutral color than both ITO and PEDOT, which show their characteristic yellow and blue hues respectively. *(See Figure 5)*

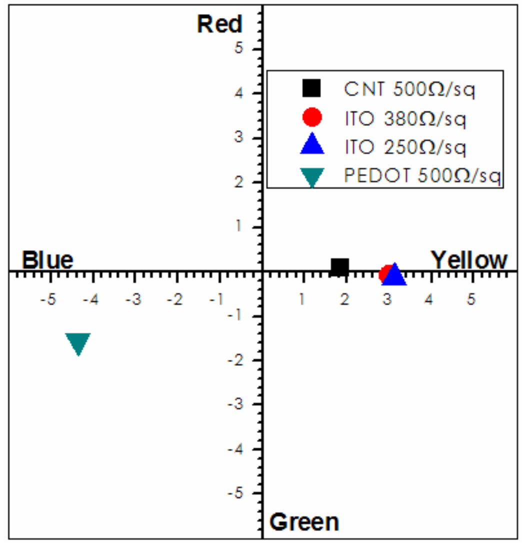

Figure 5: Color measurements: CNT films exhibit much closer to neutral color (closest to origin) than ITO and PEDOT

Mechanical and chemical durability: To evaluate the mechanical and chemical functionality of Invisicon CNT coatings, test specimens were made via spray coating a purified CNT dispersion onto heat stabilized PET film. A binder coat of melamine/acrylic was applied by dip coating, followed by air drying and curing at 135°C for 5 minutes. The CNT/binder was ~75 nm thick, with sheet resistance ~ 650 Ω/□.

Cyclic loading tests were conducted at Brown University using a "Roll Fatigue Tester" 1 (mandrel diameter 19.1 mm). Samples were precision cut to 165 x 25 mm. Testing was at 0.7% strain amplitude, 1.25 Hz, 25°C and resistance was measured continuously throughout the experiment. As shown in *Figure 6*, Invisicon CNT coating showed < 0.5% change in resistance after 2,500 cycles, whereas ITO control samples showed > 2% change after only 1,000 cycles. The difference is even more dramatic when one compares rate of change in resistance. From 200 ~ 1,000 cycles, the slope of the ITO curve is more than 10x larger than the slope for the Invisicon CNT coating throughout 2,500 cycles. The degradation in ITO resistance during flex testing is attributed to cracking of the ITO film. As flex cycling continues, these cracks continue to grow, ultimately leading to catastrophic failure (open circuit). At these strain levels, this failure mechanism is not observed for Invisicon CNT coatings.

The same Invisicon CNT coated PET samples were tested at 25°C in a Minimat tensile testing machine at 0.1 mm/min strain rate, in uniaxial tension, up to 18% strain. Samples were cut into traditional "dog bones" (25 mm long, 3.5 mm wide). The resistance was measured in-situ using a digital multimeter. Below 1% strain, there appears to be fixture slack, as evidenced by near-zero change in both measured stress and resistance, as shown in 7. Between 1 ~ 5 % tensile strain, the Invisicon CNT coated PET film behaves elastically. Above 5% strain, there appears to be plastic deformation in the PET substrate, which dominates the electrical resistance response. However, even after 18% tensile strain, only 14% change in resistance was observed. Note that ITO coated PET has been extensively evaluated by Crawford *et al*. They report that the onset of cracks in the ITO film occurs at ~ 2.5% tensile strain, with ITO failing catastrophically before 5% tensile strain is reached (resistance change > 20,000%).

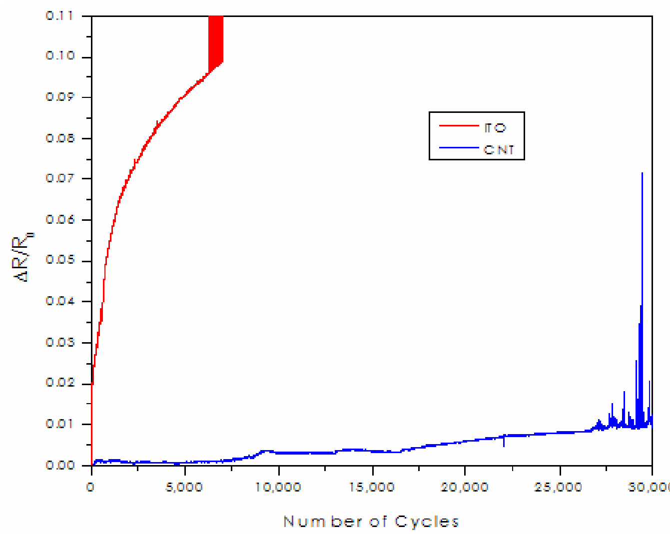

Figure 6: Cyclic testing of Invisicon CNT coating on 175 µm PET compared to ITO on PET

To further evaluate the robustness of CNT films, we evaluated the change in transparent CNT electrode visible light transmittance after exposure to chemical and heat treatments commonly used in manufacturing. Overall, the CNT film performed quite well, except in the case of immersion for 30 minutes in 5% NaOH solution. This alkaline test is very challenging for many organic coatings. However, the CNT films exhibited high resistance to alkaline attack. But, since the NaOH solution is able to penetrate through the CNT film, the film/glass interface is readily attacked by this aggressive alkaline solution, resulting in delamination of the CNT film. The CNT film exhibited excellent resistance to strong acid, organic solvents and high temperature exposure (250°C). This is consistent with the expected stability of CNT materials and summarized in *Figure 8*.

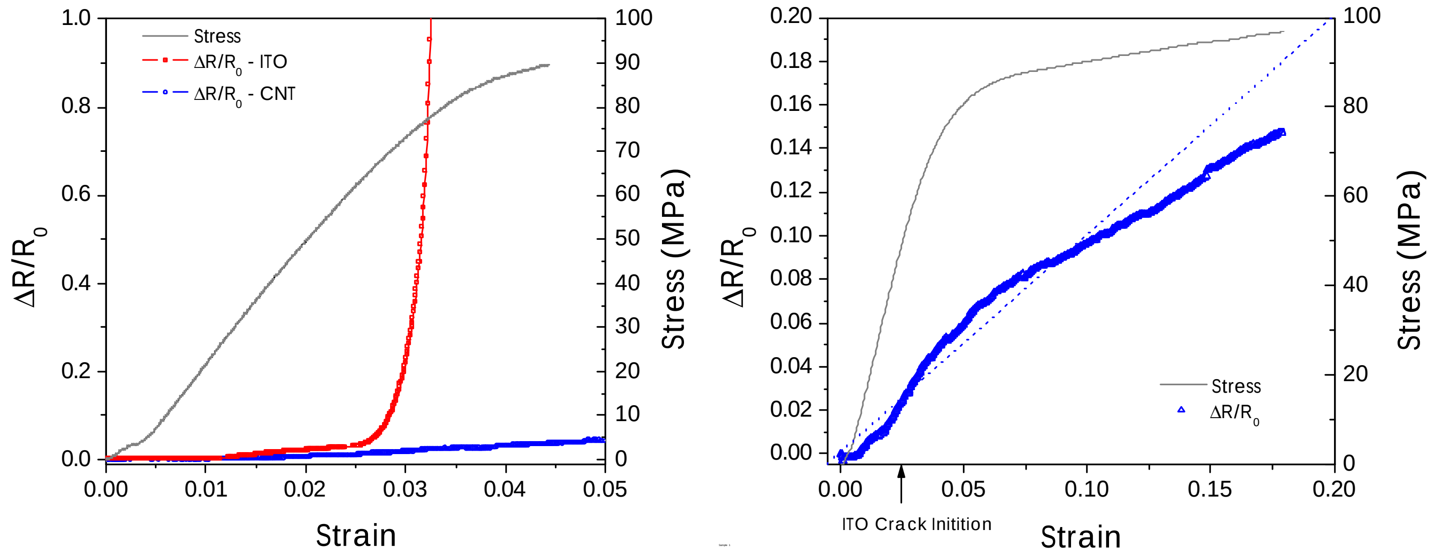

Figure 7: Minimat tensile testing machine at 0.1 mm/min strain rate, in uniaxial tension comparing CNT and ITO coated PET

Harsh Environment	Duration (minutes)	Appearance	Transparency (T%@550nm)		
			Before	After	ΔT%
5% H_2SO_4	30	○	93.91	94.3	0.39
5% NaOH	30	x	94.1	–	–
γ-Butyrolactone	30	○	93.46	94.44	0.98
NMP	30	○	94.48	94.57	0.09
250°C	60	○	93.99	93.66	-0.33

○ - no change; x - peel off

Figure 8: Compatibility with LCD CF Process: CNT films exhibit excellent chemical and heat resistance

Conclusion: This study confirms that transparent CNT electrodes are a viable alternative to ITO for touch screen applications, offering good durability and flexibility, ease of processing (wet coating and patterning), low reflectance, and neutral color. As optoelectronic properties improve, CNT films can also be expected to be used as common electrodes for a variety of touch and display applications.

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