Development of Conductive Polymer Film and R2R Coating Process

Nizamidin Jappar, Ph.D.
General Manager of R&D
Kimoto Tech Inc.
Cedartown, Georgia USA
njappar@kimototech.com

1. Introduction

The development and commercialization of flexible-display technologies have gained substantial momentum and will experience double-digit growth rates within the next 5 years. The transformation of rigid, glass based display concepts to flexible, lightweight, and bendable structures requires innovation not only in the development of new materials, but also in substrate handling and process technologies. One of the challenges facing developers of flexible-display technology is the need for low-cost durable transparent electrodes. Conventional transparent conductive materials include semiconducting metal oxides, such as indium tin oxide (ITO), and to a lesser degree, conducting polymers. ITO is inherently brittle and expensive. Recently, alternate conductors based on conductive polymer (CP) that overcomes many of the shortcomings of both ITO and carbon nano-tube materials have emerged.

Substrates easily get scratched and degradated from sun light. Through a process, a thin but extremely durable film is applied on the surface of the substrate that protects the substrate from scratching. In order to protect the substrate, a UV hard coated the protection layer is needed.

2. Conductive Polymer Film Characteristics

Most display technologies require one or more transparent electrode layers. ITO has been the transparent conductor of choice due to its optoelectronic performance and lack of alternatives, but ITO exhibits certain drawbacks: It is costly to manufacture and pattern, and has a tendency to crack with use due to its low modulus. The newest conductive polymer material delivers low-cost flexible
alternatives. CP coated films enable flexible-display designers to create high-performance low-cost devices with fully flexible form factors.

Orgacon\(^{[1, 2]}\) is the trade name for Agfa Materials’ conductive polymer product line. The active component in Orgacon products is the water based electronic conductive polymer dispersion PEDOT/PSS (polyethylene dioxathiophene). The Orgacon line covers a wide range of products designed for applications such as EL-lamps, touch pads, touch screens, displays, dashboard panels, or any other application requiring a flexible and highly-transparent conductive material. The structure of PEDOT PSSA is shown in Figure 1.

![Figure 1: Structure of PEDOT PSSA](image)

3. Wet-Coating Application

Materials that combine electronic conductivity with optical clarity are sought for the fabrication of flat panel displays and other electronic devices. PEDOT has excellent transparency in the visible region, good electrical conductivity, and environmental stability. Unfortunately PEDOT, like most conducting polymers, is infusible and insoluble and therefore difficult to process in a thin-film form or in any other shapes. Lack of process ability has been a major impediment to the commercial acceptance of this polymer. Transparent conductive polymer coatings can be applied as thin coating (100-300nm) by conventional wet-coating methods. These include spray-coating, gravure, dip, spin, screen-print, and slot-die. Kimoto Tech Inc. (KTI) has developed a roll-to-roll coating methods using PEDOT-PSS type as a conductive polymer. CP coatings have been fabricated on 2, 5, and 7 mm PET. Transparent conductive polymer film was made on the KTI production line shown in Figure 2.
The Orgacon S300, S305 and S305plus were used as conductive materials. In order to improve process ability of roll to roll coating and environmental stability of coated materials, different kinds of surfactants were included into the formulation. Coating parameters such as dryer temperature, line tension, and line speed were optimized for producing a high quality conductive film.

Optically clear UV hard coated film\(^3,4\) or optical clear anti-fingerprint UV hard coated film was used for conductive polymer coating; the structure is shown in Figure 3.

A hard coating composition includes an oligomer, a monomer, a polymerization initiator, an organic solvent, and some additives. The oligomer and monomers may be urethane acrylates, epoxy acrylates, polyester acrylates, hydroxy ethyl isocyanurate triacrylate, and caprolactone acrylate. The polymerization initiator may be an Irgacure type or Genocure type. In the hard coating composition, the solution has a viscosity of about 5 to 100 cps.
4. Result

PEDOT/PSSA is a water base solution, and it is difficult to get a good adhesion on the PET when R2R coating is conducted. Numerous BYK polymeric additives were tested to adjust formulation for creating a good adhesion on the PET. The conductivity decreased when additive amount was increased. A good adhesion property was observed when 0.2 – 0.5 % of additive was used. Corona treatment of PET helped to create a good adhesion of conductive layer to the PET. It was found that Corona power should be at least 60 Watt.min/m² in order to achieve a good adhesion. It was also found that heat curing energy is one of the main factors controlling the environmental stability of R2R coated conductive layer, and corelation between the factors is shown in Table 1. Using higher heat curing energy in the drying process showed a good environmentally stable conductive layer.

Table 1: Corelation between the Water Resistance and Additive and Heat Parameters

<table>
<thead>
<tr>
<th>Property</th>
<th>Amount of additive</th>
<th>Coating thickness</th>
<th>Dryer temperature</th>
<th>Drying time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water resistivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyzing the formulation and our experimental data, it was found that the effects of coating factors on water resistivity of coated layer can be describe by the equation below.

\[ W = 0.0025 \times A^{1.0} \times H^{1.5} \times T^{2.0} \times R^{1.2} \]

W is water resistivity; A is amount of additive; H is coating thickness; T is dryer temperature; R is retention time in the dryer.

Coating results showed that a good environmental conductive layer was achieved when W was higher than 1.

Optically clear, anti-fingerprint, anti-sparkling UV hard coated film also showed a less visible fingerprint and “easier to wipe off” fingerprint, and less sparkle property.

Novel conductive polymer coated films with higher transmittance and lower resistivity has been made on the Kimoto Tech Inc.’s coating line by developing and optimizing coating formulation and adjusting coating conditions. CP film properties are shown in Table 2.
### Table: 2 Optical and Physical Properties of Conductive Polymer Coated Layer

<table>
<thead>
<tr>
<th></th>
<th>Test Method</th>
<th>UV01ACP400</th>
<th>UV01ACP200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity</td>
<td>Four Point Probe</td>
<td>353 - 357 ohm/sq</td>
<td>200 - 205 ohm/sq</td>
</tr>
<tr>
<td>Water-Resistance</td>
<td>DI water rub test 3 cycles</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>%T</td>
<td>BYK Gardner Haze-gard plus</td>
<td>89.1%</td>
<td>86.1%</td>
</tr>
<tr>
<td>Haze</td>
<td>BYK Gardner Haze-gard plus</td>
<td>0.90</td>
<td>0.84</td>
</tr>
<tr>
<td>Clarity</td>
<td>BYK Gardner Haze-gard plus</td>
<td>99.7</td>
<td>99.7</td>
</tr>
<tr>
<td>Pencil Hardness</td>
<td>Hard Coat layer</td>
<td>&gt;2H</td>
<td>&gt;2H</td>
</tr>
</tbody>
</table>

### 5. Conclusion

The ideal transparent electrode (CP coated film) for flexible displays has been produced at lower cost and with improved flexibility property at the KTI by using roll-to-roll process. The conductive film has been developed for applications requiring a combination of lower resistivity, good water resistivity, and superior flex life, such as flexible display applications. Kimoto’s coating technology improves flexible conductive films by supplementing with consistent glossy/anti-glare surface, hard coated/scratch resistant surface, and attractive appearance. KTI adds value and functionality by applying a variety of proprietary coatings to plastic substrates on one or both sides. We can also provide project coating, toll coating, and other coating services using either KTI or customer supplied specialty substrates via one of our three coaters. KTI has developed hard-coated polyester, polycarbonate material offering excellent impact resistance, optical clarity, excellent abrasion resistance, and weather ability.
References


[3]. Saito Masato; Harada Masahiro; Koyama Masuo; Kimura Takehisa, JP2011085956 A 20110428 [JP2011085956]

[4]. Saito Masato; Koyama Masuo; Kishi Yukio, WO2008108153 A1 20080912 [WO2008108153]

Author’s name and address

Nizamidin Jappar
601 Cana Street
Cedartown, GA 30125, USA
Phone: 770-748-2643
Fax: 770-748-7226
E-mail: njappar@kimototech.com
http://www.kimototech.com