Transparent conductive films on plastics

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1. Introduction

A transparent conductive film transmits visible light and conducts electricity. It is used commonly as transparent electrodes in liquid crystal displays, electro-luminescence displays, touch panels, solar cells, etc.

Today, the transparent conductive films made from indium oxides and tin oxides have been commercialized. The indium tin oxide (ITO) sputtered film, in particular, has very high transparency and conductivity and necessary patterns can be formed by etching. Because of these desirable properties, this film is most commonly used for making electrode for displays.

Office automation equipment and home appliances are expected to keep growing in diversity and size, and the ITO and other transparent conductive materials are likely to face a more general use in large quantities. These trends are creating a strong demand for the development of a new film forming process in consideration of costs.

Introduced below are transparent conductive films for various resin substrates based on the coated grain dispersion method for easy and inexpensive film formation.

2. Film Forming Methods

Transparent conductive films are formed either by growth or coating method. In the growth method, the film is grown by building the necessary substance on the substrate in a gaseous or liquid phase. Typical examples are the vapor deposition and sputtering commonly used for ITO films. In the coating method, the precursor is applied on the substrate in the form of ultrafine grain, paste, solution, etc., then formed into a thin film mainly by heating. The sol-gel, thermal decomposition, and fine-particle dispersion are the typical examples.

Table 1 compares the characteristics of conductive films formed by various methods. In general comparison, the growth method produces films of high transparency and electric conductivity. But the use of vacuum inevitably requires a large facility and this method is not suited for forming a large film. The coating method is somewhat less desirable in terms of film performance but requires only a simple facility. It allows forming a large film on a complex profile, which makes it an economical film forming method. It must be noted, however, the sol-gel and the thermal decomposition methods require more than coating and drying before an ITO film is formed. They require heat treatment in excess of 300℃ in order to get the necessary electric conductivity, which makes them less feasible for resin substrates. The fine-particle dispersion method can be applied to resin substrates and patterns can be formed by printing without the need for etching.

The fine-particle dispersion method is used in making our transparent conductive films for resin substrates. In this method, the coating material containing conductive filler, etc., dispersed in an organic solution is coated and dried in low temperature. This makes it applicable to various resin substrates (PET film, acrylic, surface treated polycarbonate, etc.). The material may be applied by bar coating, reverse coating, gravure printing, etc. Surface resistance in a wide range ($10^{2\sim10}$Ω/□) can be obtained by heat treatment at around 100℃.

3. Product Features

Our transparent conductive films for resin substrates have the following unique features:

1) Surface resistance can be selected from a wide range of $10^{2\sim10}$Ω/□. (The low resistance in the order of 10^2Ω/□ is the most differentiating factor.)
2) Excellent transparency (transmittance over 80%, haze 5% or lower)
3) Patterns can be formed by gravure printing
4) Unaffected by temperature or humidity and can be used on glass substrates

4. Film Properties

Table 2 shows the characteristics (as formed on substrate) of our transparent conductive films for resin substrates used on PET film. Properties of the PET film used are given below.

Total light transmittance	90.4%
Haze	1.2%
Film thickness	50μm

The table endorses excellent transparency with the transmittance over approximately 80% and haze 5% or lower at all resistances in the $10^{2\sim10}$Ω/□ range.

Figure 1 shows a TEM image of cross section of a 10^4Ω/□ film as an example of transparent conductive films. The pictures shows a dense ITO layer is formed on the PET substrate contributing to the development of stable electric conductivity.

Figure 2 shows the relation between thickness and surface resistance of $10^{2\sim3}$Ω/□ film. Figure 3 shows the relation between thickness and total light transmittance. Figure 4 shows the relation between thickness and haze. They indicate the surface resistance decreased with an increase in the thickness, and a low resistance in the middle order of 10^2Ω/□ was obtained at the thickness of 4μm. The total light transmittance was over approximately 80% and haze 5% or lower.

5. Concluding Remarks

Our transparent conductive films for resin substrates are excellent transparent conductive films with resistances in the $10^{2\sim10}$Ω/□ range. The low resistance films, in particular, make a way for use to make transparent electrodes, etc.

We plan to continue efforts to improve fillers and get more knowledge about the film forming process to develop films of higher density and lower resistance and explore still new applications to maximize the value of the coating type transparent conductive material for easy and inexpensive film formation.

Table 1 Comparative characteristics of conductive films

Coating Method	Cost of Equipment	Cost of Coating	Transparency	Electric Conductivity	Substrate	Patterning
Sputtering	High	High	High	High	Plastics/Glass	Etching
Vapor Deposition	High	High	High	High	Plastics/Glass	Etching
Sol-Gel	Low	Medium	High	High	Glass only	Etching
Thermal Decomposition	Low	Medium	High	High	Glass only	Etching
Fine-particle Dispersion	Low	Low	Medium	Low	Plastics/Glass	Printing

Table 2 Characteristics of our transparent conductive films

Film	10^2Ω/□	10^3Ω/□	10^4Ω/□	10^7Ω/□
Surface Resistance / Ω・□$^{-1}$	5×10^2	3×10^3	2×10^4	2×10^7
Total Light Transmittance / %	78	87	88	86
Haze / %	5.0	5.0	2.4	0.9
Thickness / μm	4.0	1.0	1.0	1.0

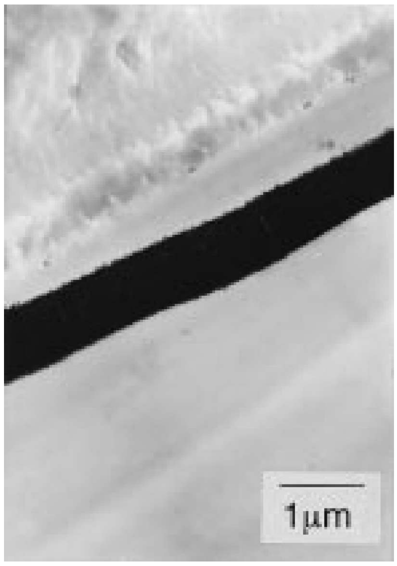

Fig. 1 TEM image of cross section of 10^4Ω/□ film

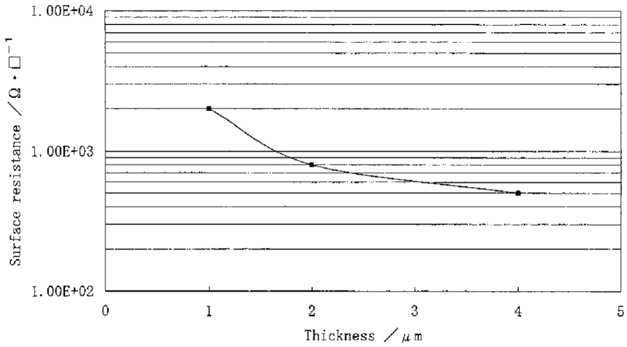

Fig. 2 Thickness vs. surface resistance of $10^{2\sim3}$Ω/□ film

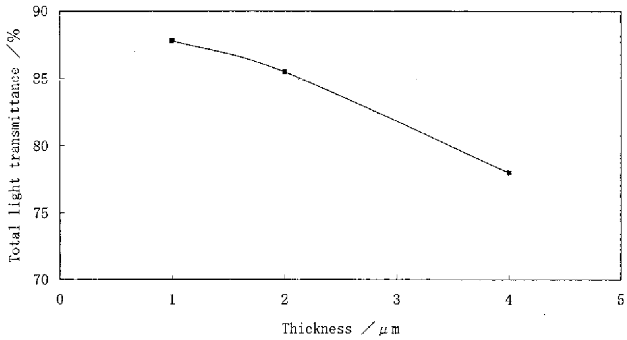

Fig. 3 Thickness vs. total light transmittance of $10^{2\sim3}$Ω/□ film

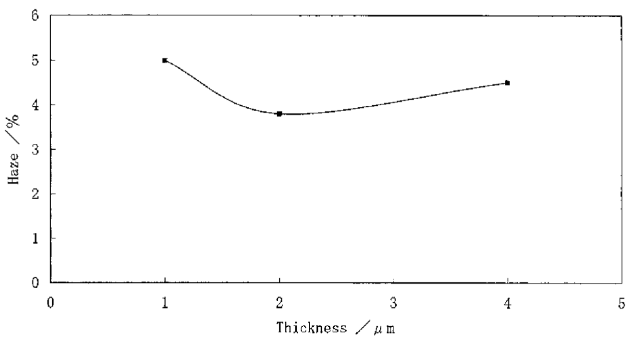

Fig. 4 Thickness vs. haze of $10^{2\sim3}$Ω/□ film