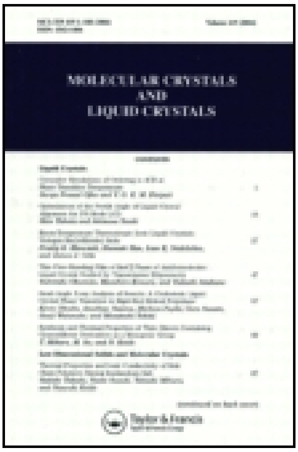

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Transparent Multi-layer Conductive Electrode Film Prepared by DC Sputter Deposition and its Flat Panel Display Application

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Version of record first published: 29 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 377, pp. 41-44

1058-725X/02 $12.00 + .00
DOI: 10.1080/10587250290088492

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Multi-layer conductive electrode films to be used as a substrate for a plastic liquid crystal display (LCD) were prepared by the DC magnetron roll-to-roll sputtering method. The conductive layer is consisted of three layers, ITO/Ag/ITO, ITO/APC/ITO and SnO_2/Ag/ITO, on the polymer substrate. The multi-layered conductive electrode has sheet resistance of about 5-8 Ω/square, optical transparency of 85-88 % at 550 nm, and appropriate gas permeability. In particular, the ITO/APC/ITO structured electrode shows about 5-10 % higher transmittance at 600-800 nm ranges than structures of SnO_2/Ag/ITO and ITO/Ag/ITO.

Keywords: Multi-layer thin film, Plastic LCD, Sputtering

INTRODUCTION

Recently, thin polymer films have been used as a substitute for the typical glass substrate in mobile LCD panels because polymer films are superior to the glass panels in lightness and durability. The plastic substrates used for the flat panel displays (FPDs), which are virtually unbreakable and can be bent and twisted, have only one sixth the weight of a glass substrate. Plastic substrates have essentially the same structure as glass substrates, but the difference is the panel material. In general, the possible candidates are highly transparent polyimide (PI), polyethersulfonic acid (PES), poly(ethylene terephthalate) (PET), and polycarbonate (PC) films, and etc.[1,2]. For the conductive electrode layer, indium tin oxide (In_2O_3-SnO_2; ITO) has been widely used as the highly transparent conductive and semi-conductive materials for display and photo-voltaic devices. At present, ITO films with a low resistivity of the order of 10^{-4} Ωcm with stable electrical, optical, and mechanical properties are generally used for practical applications. With a glass substrate, ITO sputtering is possible at high temperatures above 200 ℃, but that is hardly the case with plastic substrate, which deforms and decomposes at such elevated temperature. However, commercially available ITO conductors on various polymer films still show about 60 Ω/square or a little less resistance [3]. But, for the plastic film display, especially LCD, the sheet resistance of conductor is required at least 10 Ω/square. In general, it has been reported that the multi-layer conductive electrode having the sandwich structure of oxide/metal/oxide is the most suitable system for plastic film LCD applications [4].

In this study, we report the polymer-based multi-layer conductor (ITO/Ag/ITO, ITO/APC/ITO and SnO_2/Ag/ITO) on the polymer substrate (Arton®; trade name of JSR), which has been treated with hard coat and gas barrier layers, for the plastic film display panel.

EXPERIMENTAL

The experiments were carried out using an ULVAC Coating Technology's DC magnetron Sputter [5-7]. It is an experimental system for rolling up a web substrate of 100 mm in effective width. Targets (ITO, SnO_2; SnO_2 target is composed of SnO_2:Sb_2O_3 = 9:1 weight ratio, silver, and APC; APC target is composed of Ag:Pd:Cu = 98:0.9:1.1 weight ratio) are used with the 12.7 cm x 20.3 cm size. Sputter deposition was carried out at a pressure of 10^{-3}-10^{-5} torr with a DC power, and sputtering gas was a mixture of Ar, N_2, and O_2. As a base substrate, Arton® (trade name of JSR) films which has been treated with hard coat and gas barrier layers was used. The thickness of the film was 0.1 mm to meet stiffness requirements. The optical transmittance of the film was measured with an UV spectrophotometer. Sheet resistance was used the 4-point probe method.

RESULTS AND DISCUSSION

We show deposition results of the three-layered conductors having the sandwich structures (ITO/Ag/ITO, ITO/APC/ITO and SnO_2/Ag/ITO) among the ITO, APC and SnO_2 in Figs. 1. The deposition of ITO was carried out at 0.35-kW power, 1.0 x 10^{-3} torr, O_2 gas flow rate of 6 SCCM, and the dynamic rate was 6.7 nm m/min. The sheet resistance of ITO film strongly depends on film thickness. The film thickness dependence of the resistance was related with the decreased mobility by decreasing the thickness up to 160 nm. According to the Minami et al. [8], the mobility correlates to the crystallinity of ITO film. The depositions of Ag and APC were carried out at 0.35-kW power, 1.2 x 10^{-3} Torr, and the dynamic rates were 17.4 and 18.8 nm m/min, respectively. The sheet resistance of Ag and APC films also strongly depends on film thickness as like as ITO. The sheet resistance was below 10 Ω/square at above 10 nm thick. The deposition of SnO_2 was carried out at 0.35-kW power and 1.0 x 10^{-3} torr, the dynamic rate was 6.7 nm m/min. The sheet resistance of a 100 nm thick SnO_2 was about 10^7-10^8 Ω/square. The SnO_2 film was also used as the oxide layer of inner side of multi-layer conductive electrode having the sandwich structure of oxide/metal/oxide system with ITO. In general, the structure of ITO/Ag/ITO system has been known as the conductive electrode for plastic LCD. In this paper, we newly propose the ITO/APC/ITO and SnO_2/Ag/ITO systems. The Ag and APC were used as the conductive metal layer. The ITO of top layer in the sandwich structure functions as a protection layer of metal and also acts as a part of anti-reflection layer, which increases the transparency to light. The ITO and SnO_2 of under layer in the sandwich structure serves as nucleation modifacation layer of Ag or APC metal, and also protects diffusion of materials from metal layer to barrier layer.

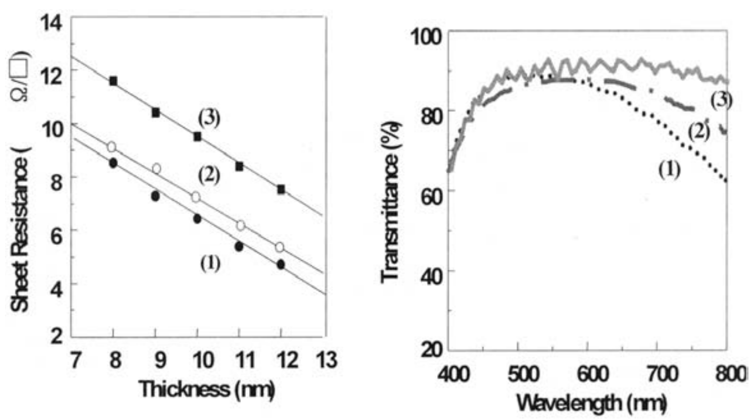

Fig. 1. Sheet resistance (left) and light transmittance (right) as a function of thickness of metal in the multi-layer structures; (1) ITO(45 nm)/Ag/ITO (45 nm), (2) SnO_2(45 nm)/Ag/ITO(45 nm), and (3) ITO(45 nm)/APC/ITO(45 nm).

Figures 1 (left) shows the sheet resistance as a function of thickness of Ag and APC in the sandwich structures consisting of ITO(45 nm)/Ag/ITO (45 nm), ITO(45 nm)/APC/ITO(45 nm), and SnO_2(45 nm)/Ag/ITO(45 nm). The thickness of metal alone was varied from 8 nm to 13 nm. It was found that the sheet resistances were decreased almost linearly with increasing the thickness of metal, which reached less than 8 Ω/square at 10 nm thickness. In particular, the ITO/APC/ITO structured electrode shows about 2-3 Ω/square higher sheet resistance than structures of SnO_2/Ag/ITO and ITO/Ag/ITO. The thickness of oxide layers is fixed at 45 nm because the transmittance is highest when ITO or SnO_2 thickness is in the range between 40 nm and 50 nm. The transmittance spectra have also been measured at between 400 nm and 800 nm, and the results shown in figure 1 (right). The multi-layered conductive electrode has optical transparency of 85-88 % at 550 nm. In particular, in the case of ITO/APC/ITO, the transmittance at 600-800 nm ranges shows about 5-20 % higher than structures of SnO_2/Ag/ITO and ITO/Ag/ITO at the same thickness. As the electrodes for the plastic panel of FPDs applied to SVGA or higher definition, the sheet resistance less than 10 Ω/square is required and light transmittance should be higher than 85 % at 550 nm of light wavelength. Especially, photo characteristic is a very important factor. Such sandwich structure of the conductor, however, bears another inevitable issue, which is how it can be patterned. Since the chemical etching method using the photo lithographic technique can not remove the multiple layers of the conductor at once, a dry etching method using an IR laser can be applied to pattern the electrode lines [4]. All materials comprising of the plastic LCD cell are carefully selected for low-temperature usage, and the processing conditions of the materials are properly determined.

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