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Optical and structural properties of metal-dielectric near-infrared cutoff filters for plasma display panel application

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Abstract

Electromagnetic interference shielding and near-infrared cutoff filters for plasma display panel application were designed and fabricated by radio frequency magnetron sputtering. Three types of the filters were prepared: the basic structure of type A consisted of [TiO_2|Ti|Ag|TiO_2]; type B, of [TiO_2|ITO|Ag|TiO_2]; type C, of [TiO_2|ITO|Ag|ITO| TiO_2]. Ti and ITO layers deposited on Ag layers were employed as barriers to prevent the oxidation and the diffusion of Ag film into the adjacent oxide layers. Optical, electrical, chemical, and structural properties were investigated, and the result shows that the filters with the ITO barrier layers provided an enhancement in transmittance in the visible owing to a lower absorption of ITO layers than Ti layers. Type C filter showed better optical and electrical performances and smoother surface roughness than Type B and C filters: the average sheet resistance was as low as 1.51 Ω/□ (where □ stands for a square film), the peak transmittance in the visible was as high as 78.2 %, and the average surface roughness was 1.48 nm.

Keywords : Near-infrared cutoff filter, Barrier layer, Sputtering, Sheet resistance

1. Introduction

Recently metal-dielectric multi-layers have been used as a near infrared (NIR) cutoff filter in a plasma display panel (PDP) system as well as on a sheet of solar control glass in the architectural and automotive industries. The NIR filter should not only shield the hazard electromagnetic (EM) waves resulting from the micro-plasma discharges in the PDP, but also block the NIR waves, which may induce a malfunction in an electronic appliance [1-3].

It is known that the basic period of NIR cutoff filters consists of [oxide layer| barrier layer| metal layer| base layer| oxide layer]. For a metal layer, a thin Ag film of 10~20 nm thickness used to be selected, because the electrical conductivity and the transmittance in the visible are higher than other noble metal films at the same thickness [4,5].

As a barrier layer, a very thin metal layer of ~1 nm thickness, such as Ti, Ta, Ni, Fe, W, etc., can be inserted between the oxide and the Ag layers in order to protect the Ag film from oxidation and disruption owing to the backfilled oxygen gases, which are needed for formation of an oxide layer in the case of reactive sputtering. Even though the barrier layer is indispensable for chemical and structural stability, the metal barrier layer can result in a significant decrease in the visible transmittance owing to the absorption of a metal film [3,4].

In this study we employed an indium tin oxide (ITO) film as an alternative for a metal barrier layer, because it is transparent and conductive and can be deposited without the backfilled oxygen gases. We also

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employed the ITO film as a base layer to improve the interface smoothness and conductivity of the filter [6,7].

In this study we investigated the effect of Ti and ITO films as the barrier and the base layers in the performance of the NIR cutoff filters, and characterized the optical, electrical, structural, and chemical properties of the three types of NIR cutoff filters by using the various analytical tools.

2. Designs and Experimentals

The basic structure of [oxide layer| barrier layer| metal layer| base layer| oxide layer] was repeated twice for a lower transmittance in the NIR and a lower sheet resistance, and the thickness of each layer was adjusted for higher transmittance in the visible. The optimized designs for the three types of filters are as follows:

Type A: [air|TiO_2(24)|Ti(2)|Ag(18)|TiO_2(48)
|Ti(2)|Ag(13)| TiO_2(24)|glass|air];

Type B: [air|TiO_2(17)|ITO(10)|Ag(18)|TiO_2(43)
| ITO(10) |Ag(13)|TiO_2(23)|glass|air];

Type C: [air|TiO_2(18)|ITO(8)|Ag(18)|ITO(13)|TiO_2(34)
|ITO(8)|Ag(15)|ITO(8)|TiO_2(20)|glass|air];

in which the number in parenthesis indicates the thickness of each layer in nm.

Ag films were thicker than 13 nm, because they were discontinuous and insulated electrically under 12 nm thickness from the previous experiments [1,4]. A RF-magnetron sputtering method was used to deposit Ag, Ti, ITO, and TiO_2 films [2,8]. BK7 glasses and Si wafers were employed as substrates for optical, chemical, structural, and electrical analyses.

The optical constants and thicknesses of metal and oxide films were determined by variable angle spectroscopic ellipsometry (VASE). Optical spectra of the filters were measured by a spectrophotometer to study the optical properties of the filters and the sheet resistances were determined by a four-point probe method to study the electrical properties. Also Auger electron spectroscopy (AES), and Atomic force microscopy (AFM) were employed to examine the chemical and structural properties.

3. Results and Discussion

3.1 Optical Property

As shown in Fig. 1, the transmittance of filter Type C in the visible (400~600 nm), in which ITO films were used as a barrier layer as well as a base layer, is the highest, while that of filter Type A with a Ti film as a barrier layer is the lowest. The peak transmittances of the filters in the visible are 72.2 % for Type A, 75.5 % for Type B, and 78.2 % for Type C. Also the NIR cutoff ability of Type C is the best among the filters, because the transmittance (reflectance) in the NIR is the lowest (the highest) in the longer wavelength than 800 nm. It indicates that the transparent conductive ITO layers can effectively improve the optical properties of the filters.

On the other hand, it is found that, as shown in Fig. 2, the measured transmittance of filter Type C in the visible is lower by 5~8 % than the simulated one, while that of Type A with the Ti barrier is in good agreement with the simulated one. In Type B with the ITO barrier layers a similar discrepancy was measured.

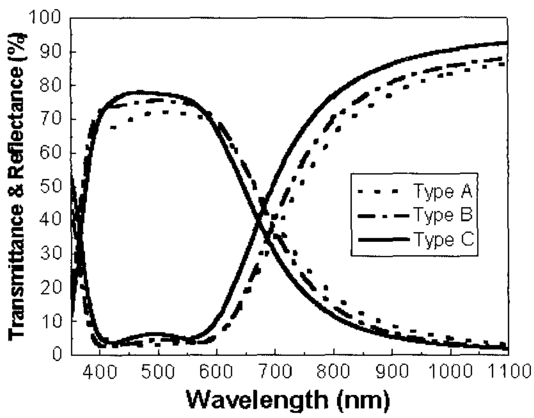

Fig. 1. Measured transmittances and reflectances of sputtered filters.

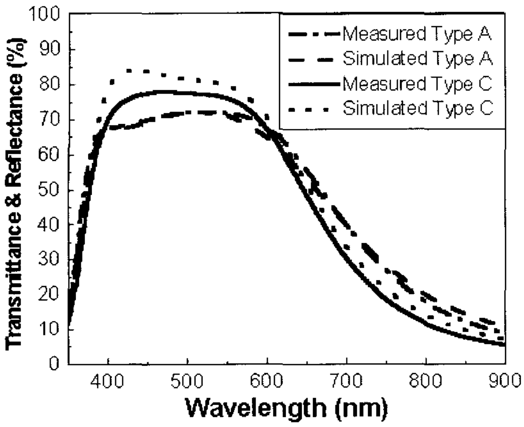

Fig. 2. Measured and simulated transmittances for Type A and C filters.

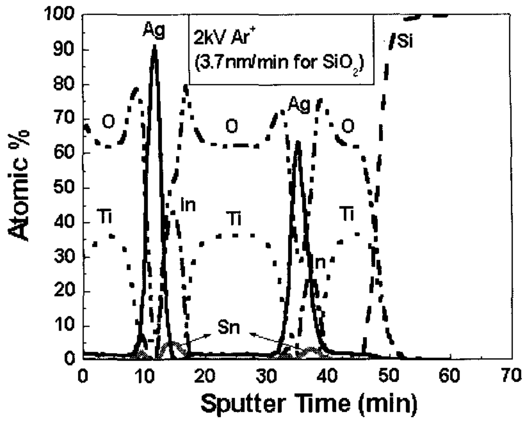

Fig. 3. AES depth profile of Type C filter.

3.2 Structural and chemical properties

To investigate the spectral discrepancy between the measured and the simulated transmittances of Type B and C shown in Fig. 2, Auger electron spectroscopy (AES) was performed to investigate the depth profile of elements for filter Type C.

In Fig. 3, indium (In) peaks of ITO barrier layers deposited on the TiO_2 layers are much lower than those below the TiO_2 layers. It suggests that the ITO barrier layers are partially disrupted during the reactive sputtering process of the upper TiO_2 films, so that the intermixed layers of TiO_2 and ITO are formed, resulting in a loss of light at the intermixed layers.

Four oxygen peaks of about 80 % are shown at the boundaries of TiO_2 and ITO layers: however, they are artificial, resulting from the AES measurement, and the superposition of Ti and In raw signals in AES caused higher O peaks than there should be.

Also the Rutherford backscattering spectrometry (RBS) for type B and C filters could not separate In and Ag elements clearly, because the elemental numbers of In and Ag are too close in the periodic table.

The RMS surface roughness values of the filters by AFM are 4.83 nm for Type A, 1.75 nm for Type B, and 1.48 nm for Type C, respectively. It is found that not only the ITO barrier layers, but also the ITO base layers are effective on smoother surfaces [3,5].

3.3 Electrical property

Sheet resistance ($R_\square$) was measured by a four-point probe method to evaluate the shielding ability of the filters against the emission of RF waves, resulting from the gas discharge at a working voltage of 100~200 V in the PDP. Shielding efficiency (*SE*) is inversely proportional to sheet resistance as in the following equation (1),

$$SE = 200 \log \frac{k}{D f R_\square} \quad \text{(dB)}$$

where *D* is the distance between the radiation source and shielding side of a glass and *f* is the frequency of the EM field to be shielded. The constant of *k* depends on the frequency. If *D* of 6 mm, $R_\square$ of 2 Ω/□, and *f* of 10~30 MHz, are applied, k is given by 3.3×10^9 and *SE* becomes 86.2 dB.

Emissivity (ε), which is proportional to sheet resistance, is widely used as an alternative term for expressing the shielding efficiency. The empirical formula for ε may be found in the references [1,3], and thus ε of NIR cutoff filters should be low [9].

The sheet resistances of Type A, B, and C were 1.56, 1.64, and 1.51 Ω/□, respectively, and satisfy the regulation for residential use (regulation B: 1~2 Ω/□

[10]. Then ε and *SE* of the three filters are around 0.02 and 88 dB at *f* of 10~30 MHz and *D* of 6 mm. It seems that Type C shows lower sheet resistance owing to effectively thicker Ag and ITO films than in Type A and B filters.

4. Conclusions

We have designed and fabricated three types of NIR cutoff filters with the enhanced optical and electrical performances for PDP application.

The average visible transmittance of each filter was higher than 65 %, and the filters with ITO barrier layers showed higher visible transmittance and better NIR cutoff ability than that with Ti barrier layers. The sheet resistances of the three filters were lower than 2 Ω/□. The surface roughness of the filters with ITO barrier layers was smaller than that with Ti.

It was found that the intermixed layers exist between TiO_2 and ITO barrier layers, and filter Type C with ITO barrier and base layers represents the best performance among the three filters: the peak transmittance was 78.2 %; the sheet resistance was 1.51 Ω/□; the RMS surface roughness was 1.48 nm.

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