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The electromagnetic shielding effectiveness of indium tin oxide films

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Abstract

Indium tin oxide (ITO) films were deposited on acrylics by low temperature reactive magnetron sputtering. The influence of film thickness on the shielding effectiveness of the films was investigated. The electric conductivity increased with ITO film thickness. This is probably due to the scattering of charge carriers by the external surfaces of thin films which is higher for films with smaller thickness. Results of magnetic moment versus magnetic field suggested that ITO film is basically a non-magnetic material. An increase in reflection loss with film thickness was observed, which was very similar to that observed for the electrical conductivity. The absorption loss was extremely small when compared with the reflection loss and therefore could be neglected when considering the total shielding effectiveness.

Keywords: A. Films; C. Electrical conductivity; C. Magnetic properties; Indium tin oxide

1. Introduction

Indium tin oxide (ITO) films have been extensively used in electronic and photoelectronic applications because of their extremely low electrical resistivity, high transmission to the visible light, high reflection in the infra-red and high absorption in the ultraviolet ranges. The applications of conductive, transparent ITO films include, anti-reflection coatings, display devices, transparent electrodes and photoelectronic devices.

Acrylics have been selected as the substrate material to coat ITO films for specific military applications because of their good impact strength and light weight. In addition, acrylics are transparent to visible light, and can be easily fabricated into complex shapes. The softening temperature of acrylics is less than 80°C, and therefore a low temperature deposition technique such as physical vapor deposition (PVD) is required.

A shield may keep away the electromagnetic radiation and provide protection for specific equipments contained within the shield. The shielding effectiveness of conductive glass and metallic thin films at different frequencies were previously investigated [1,2]. However, there are only few publications discussing the electromagnetic shielding effectiveness of indium tin oxide. In addition, the effects of its film thickness on the shielding of electromagnetic radiation is still not well understood.

In this investigation, the ITO films were deposited on acrylics by low temperature reactive magnetron sputtering. The effects of processing parameters on the deposition rate, lattice parameters, stoichiometric compositions, surface morphology, bonding state, and the electrical and optical properties of films had been previously reported [3–5]. This investigation is a continuation of the previous study and is focused on the influence of film thickness on the shielding effectiveness of ITO films.

2. Experimental procedures

2.1. Sample preparation

The ITO films were deposited on acrylics by reactive d.c. magnetron sputtering. The acrylics (methyl methacrylate) were machined into blocks of 15×15×7 mm, degreased and ultrasonically cleaned in acetone and ethyl alcohol, rinsed in deionized water, and subsequently blown dry in flowing nitrogen before deposition.

The target used in this study was a In–Sn alloy (99.99% purity, Ø3×0.25 in^2) with a composition of 90:10 (wt.%, Plasmaterial Inc., USA). The sputtering was conducted in a mixed Ar–O_2 atmosphere with a

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target-to-substrate distance of 5 cm. A diffusion pump coupled with a rotary pump was used to achieve an ultimate pressure of 1.3×10^{-3} Pa before introducing gas mixtures of argon (20 sccm, 99.9995%, Lien Hwa Gas Co., Hsin Chu, Taiwan) and oxygen (99.999%, Lien Hwa Gas Co., Hsin Chu, Taiwan). The pressure was measured using an ion gauge and a convection vacuum gauge. Two separate mass flow controllers (Hastings HFC-202) were used to monitor the gas flow rates of argon and oxygen.

The target was first sputtered at 1.3 Pa for 10 min in Ar for cleaning purposes. The substrate temperature was maintained at 70°C. An r.f. power supply was used for establishing negative substrate bias. Deposited samples were cooled in Ar atmosphere for 3 h before venting the system.

2.2. Film thickness

Film thickness was measured by an α step (Dektak 3030ST, Surface Texture Analysis System). The deposition rate was calculated from film thickness and deposition time.

2.3. Electrical resistivity

A four-point probe (model RT-7, Napson, Japan) was used for determining the electrical resistivity from the measured current (I), voltage (V) and film thickness. The resolution was controlled to less than 1%.

2.4. Relative permeability

A superconducting quantum interference device magnetometer (SQUID, Model MPMS-7, Qquantum Design, USA) was used for determining M–H curves and relative permeability from a magnetic field of +50 k Oe to −50 k Oe.

3. Results and discussion

The total electromagnetic shielding effectiveness of ITO films is equal to the sum of the reflection loss (R), the absorption loss (A) and a correction factor (B). The correction factor can be neglected for plane waves [6]. The reflection loss and the absorption loss could be expressed as follows [6]:

$$R = 168 + 10\log(\sigma_r/\mu_r f) \quad \text{dB} \tag{1}$$

$$A = 3.34t(f\mu_r\sigma_r)^{1/2} \quad \text{dB} \tag{2}$$

where σ_r is the relative conductivity to copper, μ_r is the relative permeability, f is the frequency, and t is the thickness of the shield in inches.

3.1. Reflection loss

It was previously reported that the ITO films deposited at oxygen flow rate of 6 sccm and under a bias voltage of −60 V had optimum conductivity due to the largest grain size and lower scattering of carriers by the grain boundaries [4]. The samples used for electromagnetic shielding effectiveness calculation were therefore prepared under the above mentioned experimental conditions. The conductivity of films was plotted versus film thickness as shown in Fig. 1. The conductivity had a tendency of increasing with film thickness. This is probably due to the scattering of charge carriers by the external surfaces of thin films with smaller thickness [7]. An optimum conductivity was obtained at thickness of 1 μm. However, some microcracking was observed on the films as the thickness exceeded above 1 μm.

A typical plot of magnetic moment versus magnetic field of ITO films with a thickness of 5000 Å is shown in Fig. 2. A line with negative slope, without evident magnetic hysteresis loop was observed which suggested a non-magnetic material. The relative permeability could therefore be assumed as 1 [8].

Assuming an infinite film under plane waves at 1 GHz, the reflection loss of ITO films with different thickness could be calculated from Eq. (1) as shown in Fig. 3. A trend of increase in reflection loss with film thickness was observed. Similar observations were reported by Weck who investigated the plane-wave shielding effectiveness of vacuum deposited metallic thin films and reported a trend of increase in shielding effectiveness with film thickness [1]. The sensitivity of effectiveness is a function of test frequency [1].

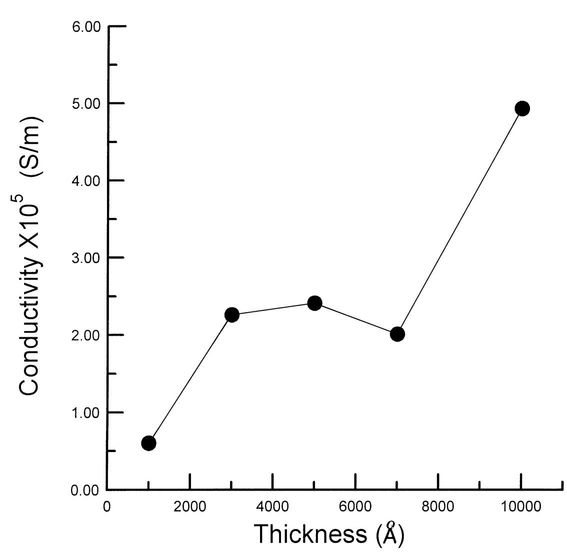

Fig. 1. A plot of the electric conductivity versus film thickness. Samples were deposited at an oxygen flow rate of 6 sccm and under a bias voltage of −60 V.

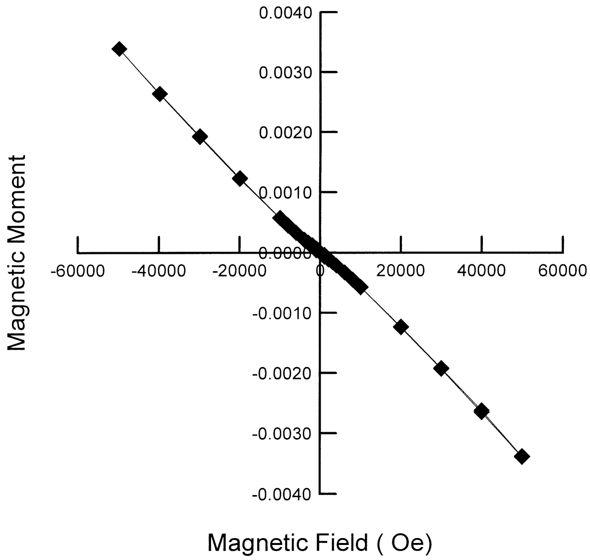

Fig. 2. A plot of the magnetic moment versus magnetic field. The thickness of ITO films was 5000 Å.

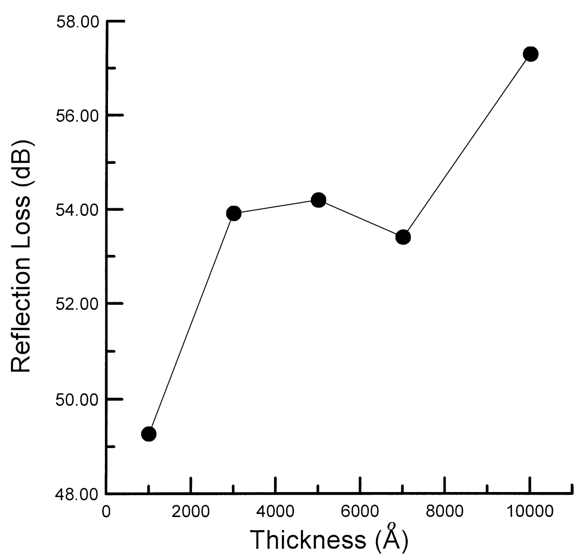

Fig. 3. The calculated reflection loss as a function of the film thickness.

It is interesting to note that the trend of change in reflection loss as a function of ITO film thickness (Fig. 3) was very similar to that of conductivity (Fig. 1). Kaynak studied the shielding effectiveness of conducting polypyrrole films and also reported significant increase in shielding effectiveness because of the increase in conductivity [9]. Similar results regarding the influence of conductivity on the shielding and reflection characteristics were also reported by Lasitter [2] and Chu [10] although different substrates such as the conductive glass or fiber were used.

3.2. Absorption loss

An absorption loss of less than 1 dB was calculated from Eq. (2) at 1 GHz with film thickness from 0.1 to 1 μm. The absorption loss was extremely small in comparison with the reflection loss discussed in Section 3.1 and therefore could be neglected since the total shielding effectiveness is equal to the sum of the absorption loss (A) and the reflection loss (R). The shielding effectiveness of ITO films can therefore be represented simply by the reflection loss as shown in Fig. 3.

4. Summary and conclusions

1. The electric conductivity increased with the ITO film thickness. This is probably due to the scattering of charge carriers by the external surfaces of thin films is higher for films with smaller thickness. Results of magnetic moment versus magnetic field suggested that ITO film is basically a non-magnetic material.
2. A trend of increase in reflection loss with film thickness was observed. This trend was very similar to that of electric conductivity.
3. The absorption loss was extremely small in comparison with the reflection loss and therefore could be neglected when considering the total shielding effectivess.

Acknowledgements

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