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Dry etching characteristics of ITO thin films deposited on plastic substrates

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Abstract

The dry etching characteristics of indium-tin-oxide (ITO) films deposited on plastic substrates were studied using Ar/CH_4 magnetized inductively coupled plasmas (MICP). When conventional inductively coupled plasmas (ICP) were used, the etch rates of ITO films were generally low. However, by using both the multidipole magnets and the axial electromagnets around the chamber wall of ICP, high ITO etch rates > 250 nm/min could be obtained at 90% Ar/10% CH_4 with the etch selectivity over photoresist higher than that of the ICP. Atomic force microscopy (AFM) measured as a function of Ar/CH_4 showed smoother etched ITO surfaces for most of the etch conditions except for high CH_4 conditions such as 70% Ar/30% CH_4 which generate hydrocarbon polymer on the etched ITO surface. The surface composition characterized using x-ray photoelectron spectroscopy (XPS) showed preferential losses of ITO components depending on the etch gas composition. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: ITO; Plastic substrate; MICP; Etching

1. Introduction

Indium tin oxide (90% In_2O_3:10% Sn; ITO) thin films on glass substrates are more widely used as transparent electrodes in selective heat mirrors, anti-reflection coatings, solar cells, gas sensors, and flat panel displays [1,2]. To reduce the weight of the flat panel display devices, plastic substrates which result in significantly lighter devices with an ability to tolerate greater impact may be used in the near future. Additionally, practical organic electroluminescent devices (OLEDs) require ITO deposits on plastic substrates [3,4].

Currently, ITO films are patterned by wet etching methods, however, the wet etching methods tend to produce different ITO etch rates depending on the deposition methods in addition to isotropic etching and selective grain-boundary etching. Therefore, it may not be suitable for the fabrication of fine patterns required for next generation display devices [5]. Recently, many researches have carried out studies on the dry etching of ITO, however, most studies on ITO dry etching are limited to the films deposited on the glasses [6] and the dry etching of ITO films on plastic substrates have not been investigated. Therefore, dry etching characteristics of ITO films on the plastic substrate were observed in this study for the application of flat panel devices. The etch characteristics were compared with those obtained by conventional ICP.

2. Experiment

In this study, ITO thin films were etched using a magnetized inductively coupled plasma etching apparatus described in detail elsewhere [7]. A square array of magnet housing made of anodized aluminum was installed inside of the chamber to hold permanent magnets having 3000 G on the magnet surface, and the magnets were arranged in the housings to form a magnetic cusp. For the magnetic cusping, 16 pairs of

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magnets were inserted in the anodized aluminum housings. Separate (500 mm × 500 mm) square-shaped Helmholtz type axial electromagnets (15 G) were also installed around the chamber.

ITO films used in this experiment were deposited using oxygen ion beam-assisted evaporation on both the glass and the polycarbonate (PC) to the thickness of 400 nm and showed the resistivity of $4 \sim 5 \times 10^{-4}$ Ω cm. ITO etchings were performed as a function of gas combination of Ar/CH_4 ratio while other etch parameters such as rf power, pressure, and bias voltage were fixed at 500 W, 0.67 Pa and −200 V respectively. Etch rates were determined by stylus profilometry of feature depths after the removal of the photoresist masked on the film. Atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS) were also used to investigate the root-mean-square roughness and the near-surface stoichiometry, respectively, before and after the etching of ITO films.

3. Results and discussion

Fig. 1 shows the etch rates of ITO deposited on polycarbonate substrates and their etch selectivities over photoresist for MICP and ICP as a function of Ar/CH_4. As shown in the figure, the ITO etch rates by MICP were approximately three times higher than those by ICP for the same etch conditions, and the etch selectivities were also generally higher for the etching by MICP. The etch rates as a function of Ar/CH_4 gas combination showed a maximum at 90% Ar/10% CH_4 with the increase of CH_4 for both ICP and MICP and a further increase of CH_4 rapidly decreased the ITO etch rates. The maximum etch rate obtained with MICP was 270 nm/min with the etch selectivity over photoresist approximately 1.3.

The higher ITO etch rates obtained with MICP appear to be from the higher ionization and dissociation rates obtained by the application of the axial magnetic field to ICP as described elsewhere [7]. The application of multipole magnets inside the chamber appears to contribute in increasing the etch uniformity rather than increasing the etch rates. In a previous study on the polysilicon etch rates, by the application of multidipole magnets in addition to the axial magnets, the polysilicon etch uniformity was improved from 5.5% to 3% on the 18 cm × 18 cm substrate [8]. The increase of ITO etch rate with the addition of 10% CH_4 to Ar appears to be from the formation of volatile etch products such as In $(CH_3)_x$ and Sn $(CH_3)_y$ during the ITO etching in addition to the sputtering by Ar. However, the rapid decrease of ITO etch rate with the further increase of CH_4 percent in Ar/CH_4 suggests the formation of carbon related residue on the etched surface.

When the ion current density was measured as a function of CH_4 in Ar/CH_4 using a Langmuir probe, the increase of CH_4 decreased the ion current density in the Ar/CH_4 plasmas, therefore, the ion flux (sputter effect) to the ITO surface decreased with the increase of CH_4. The maximum ITO etch rate shown with 90% Ar/10% CH_4 appears to be from appropriate combined effects of chemical reaction and sputtering of non-volatile surface residue.

In addition to the ITO deposited on polycarbonate (0.5 mm in thickness), ITO thin films deposited on the glass (0.7 mm in thickness) were also etched using MICP and the results are shown in Fig. 2 for the same etch condition in Fig. 1. The ITO deposited on the glass showed lower etch rates compared to that deposited on the polycarbonate. In our experiment, the

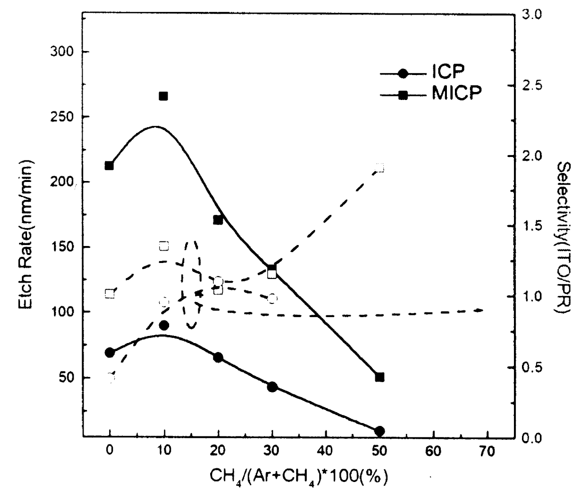

Fig. 1. Etch rates of ITO deposited on polycarbonate and their etch selectivities over photoresist as a function Ar/CH_4 for ICP and MICP. Process conditions: 500 W of inductive power, −200 V of bias voltage, and 0.67 Pa of operation pressure.

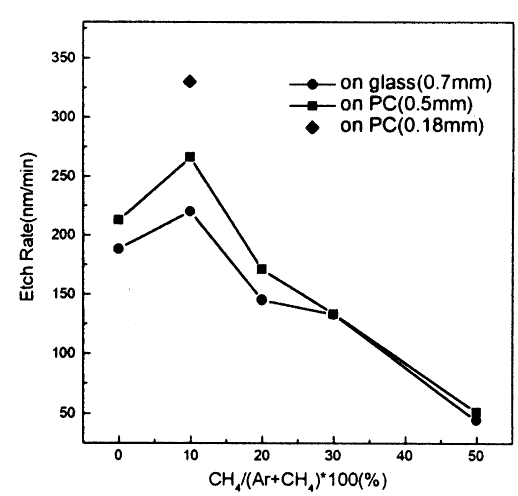

Fig. 2. Etch rates of ITO as a function Ar/CH_4 for both glass and plastic substrates in MICP. Process conditions: 500 W of inductive power, −200 V of bias voltage, and 0.67 Pa of operation pressure.

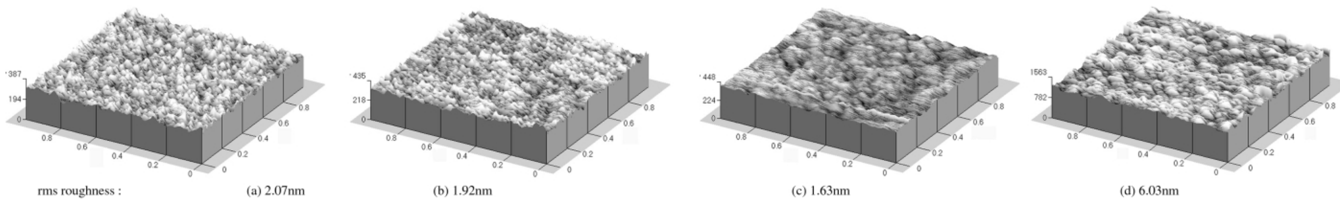

Fig. 3. AFM data showing the surfaces of ITO on polycarbonate as deposited: (a) and after the etching with; (b) 90% Ar/10% CH_4; (c) 80% Ar/20% CH_4; and (d) 70% Ar/30% CH_4. Process conditions: 500 W of inductive power, −200 V of bias voltage, and 0.67 Pa of operation pressure.

deposited ITO thin films were amorphous regardless of the substrate. Therefore, the difference in the ITO etch rates depending on the substrate obtained in Fig. 2 appears to be from the differences in the thickness of the substrate. When an ITO thin film deposited on 0.18 mm thick plastic was etched, and the highest ITO etch rate of approximately 330 nm/min could be obtained at 90% Ar/10% CH_4. Therefore, a higher ITO etch rate appears to be obtained for a thinner dielectric substrate.

Using AFM, the surface roughness of the ITO deposited on polycarbonate was investigated after the dry etching of ITO in MICP using various Ar/CH_4 gas combinations and the results are shown in Fig. 3. This concludes that after the etching of ITO using Ar/CH_4, the surface roughness was decreased until 20% CH_4 was added to Ar. However, the use of high CH_4 conditions such as 70% Ar/30% CH_4 increased the roughness of the etched surface. The decrease of surface roughness at lower CH_4 conditions appears to be related to the dependence of sputter etch rate on the incident ion angle. Therefore, sharper features are etched faster than flat features and it results in the decrease of surface roughness after the etching. However, if there is any micromasking on the surface, it will be rougher after the etching due to the selective etching of the surface. The increased roughness at the high CH_4 conditions such as 70% Ar/30% CH_4 appears to be from the micromasking of the etching surface by carbon related etch residues remaining on it.

The change of ITO composition during the etching was investigated using XPS and the results are shown in Table 1 for various Ar/CH_4 gas combinations. We see that the increase of CH_4 percent in Ar/CH_4 increased the preferential loss of Sn and O of ITO. The loss of Sn and O relative to In appears to be from the high vapor pressure of CO_x and Sn $(CH_3)_y$ compared to In $(CH_3)_x$. The surface residue formed on the surface is under investigation.

Table 1
Surface compositions and their ratios such as Sn/In and (In + Sn)/O measured by XPS for the ITO thin films etched in MICP

Sample	In	Sn	O	Sn/In ratio	O/(In + Sn)
Control	40.8	4.1	55.1	0.100	1.22717
100% Ar	42.6	2.9	54.5	0.068	1.1978
90% Ar/10% CH_4	46.6	3.1	50.3	0.066	1.01207
80% Ar/20% CH_4	46.5	2.8	50.7	0.060	1.0284
70% Ar/30% CH_4	50.1	2.4	47.6	0.048	0.90667

4. Conclusions

In this study, dry etch characteristics of ITO thin film deposited on polycarbonate substrates were studied using Ar/CH_4 magnetized inductively coupled plasmas. The ITO etch characteristics by MICP were compared with those by conventional ICP.

The use of MICP increased the ITO etch rates approximately three times compared to those obtained by conventional ICP. The etch selectivity was also improved. The increase of CH_4 in Ar/CH_4 up to 10% increased the ITO etch rates for both MICP and ICP, however, the further increase of CH_4 decreased the ITO etch rates. The maximum etch rate obtained was 270 nm/min with the etch selectivity of approximately 1.3. The roughness of the surface was decreased after the etching except for high CH_4 conditions.

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