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Dry etch properties of IZO thin films in a CF_4/Ar adaptively coupled plasma system

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ABSTRACT

In this study, we investigated to the etch characteristics of indium zinc oxide (IZO) thin films in a CF_4/Ar plasma, namely, etch rate and selectivity toward SiO_2. A maximum etch rate of 76.6 nm/min was obtained for IZO thin films at a gas mixture ratio of CF_4/Ar (25:75%). In addition, etch rates were measured as a function of etching parameters, including adaptively coupled plasma chamber pressure. X-ray photoelectron spectroscopy analysis showed efficient destruction of the oxide bonds by ion bombardment, as well as accumulation of low volatile reaction products on the surface of the etched IZO thin films. Field emission Auger electron spectroscopy analysis was used to examine the efficiency of ion-stimulated desorption of the reaction products.

1. Introduction

Indium zinc oxide (IZO) thin films are a wide band gap transparent conducting oxide that has provoked a great deal of interest recently due to their many potential applications. IZO thin films allow for the fabrication of devices with a low operating voltage, and the design of such devices will lead the way to the next generation of display technologies based on transparent and flexible devices. IZO thin films have also attracted a great deal of attention because of their excellent optical transmission, high conductivity, chemical stability, thermal stability and low compressive stress. Among the various patterning techniques used for the IZO thin films, plasma etching is preferred, because it allows for high resolution pattern transfer for optoelectronic device structures [1–8].

Although the growth characteristics of IZO thin films have been well optimized, an efficient pattern transfer process remains to be developed. Among the various patterning techniques, the dry etching process has several advantages over the conventional wet etching process, including high resolution and easy process automation. Moreover, there have been only a few studies of dry etching of IZO thin films using the adaptively coupled plasma sources favored by modern microelectronic technology. As a result, the influence of the process parameters on the etch rate of IZO thin film has not been sufficiently explored, and thus the etch mechanism of IZO thin film remains unclear.

In this work, we investigated the etch characteristics of IZO thin film deposited using an adaptively coupled plasma (ACP) system. The etch characteristics of the IZO thin film were investigated in the terms of the selectivity of IZO to SiO_2 as a function of the etch chemistry. The chemical reactions on surface of the etched IZO thin film were investigated by X-ray photoelectron spectroscopy (XPS). Field emission Auger electron spectroscopy (FE-AES) was used for elemental analysis on surface of the etched IZO thin film. The morphologies of the etched IZO thin films were investigated using Scanning Probe Microscopy (SPM).

2. Experimental

The IZO thin films used in this work were deposited by atomic layer chemical vapor deposition (Evertek, Plus-100). For low-temperature processing, an IZO target with a composition ratio of In:Zn = 2:2 (atomic ratio) was chosen, the gas ratio was fixed at 15% O_2 in an Ar and O_2 mixture, and the RF power was 200 W. The deposition temperature of the IZO films was 15 °C, and the final thickness of the IZO films was approximately 120 nm. The ACP etch system consisted of an APTC SELEX 200, as shown in Fig. 1. Multi-spiral coils and a bushing were connected to a 12.56-MHz RF power generator and located above a thick horizontal ceramic window. The plasma source exhibited the characteristics of the inductively coupled plasma and capacitively coupled plasma, as well as its own characteristics. The basic properties and process performance of the plasma source have previously described [9].

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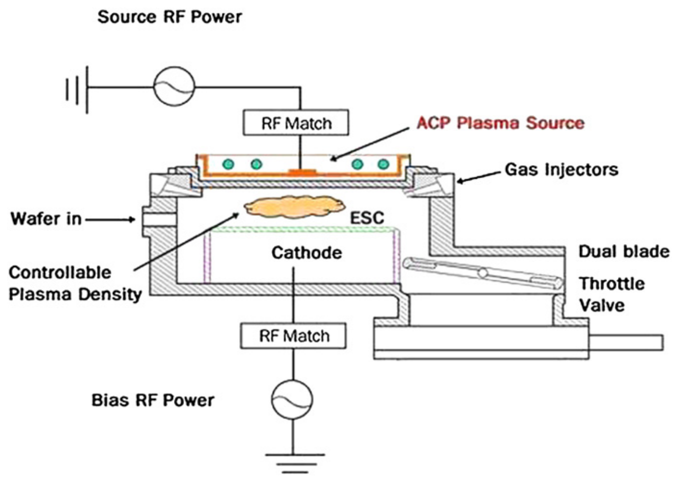

Fig. 1. Adaptively coupled plasma system.

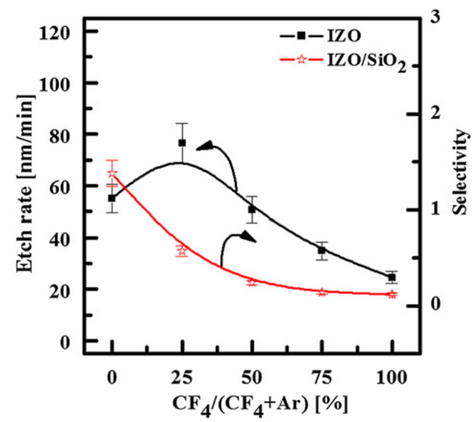

Fig. 2. The etch rate of the IZO thin film and the selectivity of IZO to SiO_2 as a function of the CF_4/Ar gas mixture ratio.

The IZO thin films were etched in various conditions to determine the etching characteristics in a CF_4/Ar gas mixture. For these experiments, the source power, bias power, process pressure and substrate temperature were 400 W, 100 W, 0.013 mbar and 45 °C, respectively. In addition, the plasma etching of the IZO thin films was investigated using a source power of 200–600 W, a bias power of 10–200 W, and a process pressure of 0.008–0.019 mbar at various ratios of CF_4/Ar. The etch rate was measured by a surface profiler (KLA Tencor, α-step 500). Surface analysis of the etched IZO thin films processed with the various etch chemistries was performed by X-ray photoemission spectroscopy (SIGMA PROBE, Thermo VG Scientific). The spectra were plotted by counting the photoelectrons at kinetic energy intervals of 0.1 eV. Detailed information of the inner region of the IZO thin films was obtained by spectra recorded at 90°. All of the samples for the XPS and FE-AES analysis consisted of bare IZO thin films without any photoresist patterns and the size of the samples was 1×1 cm^2. FE-AES (Microlab 310-D, Thermo VG Scientific), which is a surface sensitive spectroscopic technique, was used for the elemental analysis of the etched surface. Further, the surface images of the etched IZO thin films were confirmed by SPM (Dimension 3100, Veeco).

3. Results and discussion

To determine the etch characterization of the IZO thin film in the ACP system, the etch rate of the IZO thin film and the selectivity of IZO to SiO_2 were systematically investigated using various etch chemistries. Fig. 2 shows the etch rate of the IZO thin film and the selectivity of IZO to SiO_2 as a function of the CF_4/Ar gas mixing ratio when the total flow rate was maintained at 100 sccm. The other process conditions of source power, bias power, process pressure, and substrate temperature, were maintained at 400 W, 100 W, 0.013 mbar, and 45 °C, respectively. A comparison of the etch rates of the IZO thin film in pure Ar (55.2 nm/min) and pure CF_4 (24.6 nm/min) plasmas showed that the physical sputtering mechanism was more effective than chemical etching. The maximum etch rate of the IZO thin films was 76.6 nm/min and the selectivity of IZO to SiO_2 was 0.57 at a $CF_4/(CF_4 + Ar)$ gas mixing ratio of 25%. The selectivity of IZO to SiO_2 decreased from 1.38 to 0.12 as the $CF_4/(CF_4 + Ar)$ gas ratio changed from 0 to 100% due to the deposition of Si–O, Si–F or Si–O–F etch by-products at low vapor pressure. These results confirmed that fluorine interacted with the SiO_2 thin film and produced a blocking layer, resulting in a decreased etch rate of materials [10,11]. Thus, between $CF_4/(CF_4 + Ar)$ gas mixing ratio of 0–25%, the etch rate of the IZO thin film increased, while the selectivity of IZO to SiO_2 decreased. It is well known that fluorine components react with IZO thin films to form highly-volatile by-products such as InF_3 (melting point: 1170 °C) and ZnF_2 (melting point: 872 °C) [12]. The comparison of the etch rate in pure CF_4 and Ar demonstrated that ion bombardment plays an important role in the etching process. Therefore, the etching mechanism may be assumed to be ion-assisted etching, while the role of ion bombardment includes physical sputtering as well as ion-stimulated desorption of volatile reaction products. In the case of the physical sputtering of IZO thin films, we expect the contribution of this pathway to be much higher compared to that of the ion-assisted chemical reaction. In the $CF_4/(CF_4 + Ar)$ plasma, increasing the CF_4 content up to 25% increased the etch rate via two different mechanisms: (1) acceleration of the chemical reaction that has been explained by the ion-stimulated desorption of the reaction products and (2) a decrease in the contribution of physical sputtering. When CF_4 content exceeded 25%, the etch rate began to decline due to interruption of the chemical reaction, indicating that, for a given range of experimental conditions, the physical etch pathway is more effective than the chemical reactions [13].

Fig. 3 shows the etch rate of IZO thin film and the selectivity of IZO to SiO_2 as a function of the source power in the CF_4/Ar plasma. As the source power applied to the ACP coil was increased from 200 to 600 W, the etch rate of the IZO thin films increased from 58.8 to 95 nm/min, while the selectivity of IZO to SiO_2 decreased from 0.72 to 0.34. This behavior of etch rates with increasing input power may

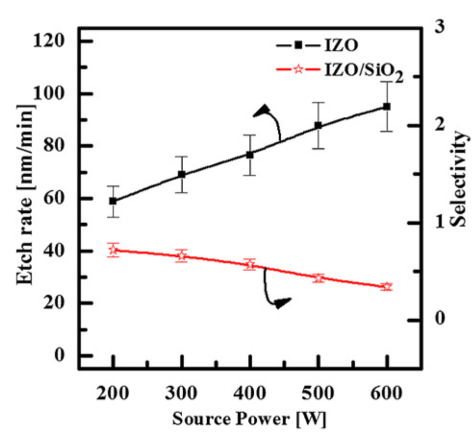

Fig. 3. The etch rate of the IZO thin film and the selectivity of IZO to SiO_2 as a function of source power.