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Comparison of chlorine- and fluorine-based inductively coupled plasmas for dry etching of $InGaZnO_4$ films

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ABSTRACT

A comparative study of etch characteristics of the $InGaZnO_4$ (IGZO) films has been performed in chlorine- (Cl_2 and BCl_3) and fluorine-based (CF_4 and SF_6) inductively coupled plasmas (ICPs). Higher IGZO etch rates were achieved with chlorine-based discharges due to the higher volatility of metal chloride etch products. The IGZO etch rate was significantly affected by ICP source power and rf chuck power, and maximum etch rates of ~1200 Å/min and ~1350 Å/min were obtained in fluorine-based and Cl_2/Ar discharges, respectively. The etched surface morphologies of IGZO in $10BCl_3/5Ar$ mixtures were better than the unetched control sample. Maximum etch selectivities of 1.4:1 for IGZO over HfO_2, 3.1:1 for IGZO over Al_2O_3, and 1.2:1 for IGZO over yttria-stabilized zirconia were obtained.

1. Introduction

Transparent displays, such as active matrix liquid crystal displays, active matrix organic light emitting diode, and flexible organic light emitting diode, have attracted much attention as an emerging display technology. Oxide semiconductor-based thin film transistors (TFTs) have shown an excellent device performance that can meet the requirements for driving devices of large-area, transparent displays with high resolution and high frame rate [1–5]. Among potential oxide semiconductors, amorphous $InGaZnO_4$ (a-IGZO) is a leading candidate due to its remarkably high electron mobility (10–50 $cm^2/V \cdot s$) and high optical transparency in the visible range of spectrum. It is possible to control the electrical conductivity of the IGZO through the oxygen partial pressure during deposition. Moreover, its ability to be deposited at room temperature allows the use of novel flexible substrates such as plastic or even paper, which can realize low-cost electronics on a very wide range of arbitrary surfaces [6–10].

In order to fabricate a-IGZO TFTs with very fine geometry, a better understanding of appropriate choice of pattern transfer process is essential. Most of previous reports have been focused on the wet chemical etching of IGZO films which generally results in undercut and isotropic sidewall profile. High density plasma etching would be a better alternative to provide high-resolution pattern transfer with high uniformity over a large area. To present, there have been some reports on dry etching of the IGZO films, but mostly employing the chlorine-based plasmas such as Cl_2/Ar, BCl_3/Ar and BCl_3/O_2 discharges [11–15]. Our previous works on dry etching of III–V semiconductors and transparent conducting oxides such as GaN, SiC, GaAs, AlGaAs, InGaP, SnO_2, and ZnO suggests that the use of fluorine-based plasmas also can provide good etch characteristics for IGZO [16–21].

In this work, high density plasma etching of the IGZO films was performed in the chlorine- (Cl_2 and BCl_3) and fluorine-based (CF_4 and SF_6) inductively coupled plasmas (ICPs), and a comparative study of etch characteristics of the IGZO films in these plasma chemistries was conducted. Also, etch selectivity of the IGZO to gate dielectric materials of HfO_2, Al_2O_3 and yttria-stabilized zirconia (YSZ) and mask materials including photoresist, Al and Ni was examined.

2. Experimental details

The ~3000 Å thick IGZO films were deposited by rf magnetron sputtering on SiO_2/Si and quartz glass substrates at room temperature using a 3-inch diameter single target of $InGaZnO_4$. The rf power was 150 W and the working pressure was constant at ~0.8 Pa in a pure Ar ambient. The deposited IGZO films were amorphous as determined by powder x-ray diffraction, and showed optical transmittance of ~80% in the visible range. To determine the etch selectivity of IGZO to gate dielectrics, Al_2O_3, HfO_2 and YSZ films were deposited by rf magnetron sputtering on Si substrates. The rf power was maintained at 150–200 W and the working pressure was ~0.53 Pa. Each film was patterned with photoresist, Al or Ni mask layer. High density plasma etching was performed in a planar ICP source operating at 13.56 MHz

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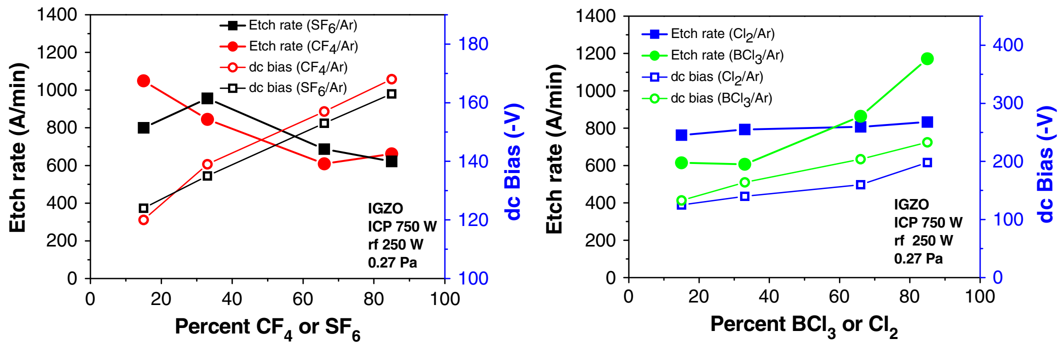

Fig. 1. IGZO etch rates as a function of plasma composition in fluorine- (left) and chlorine-based (right) ICP discharges (750 W source power, 250 W rf chuck power, 0.27 Pa).

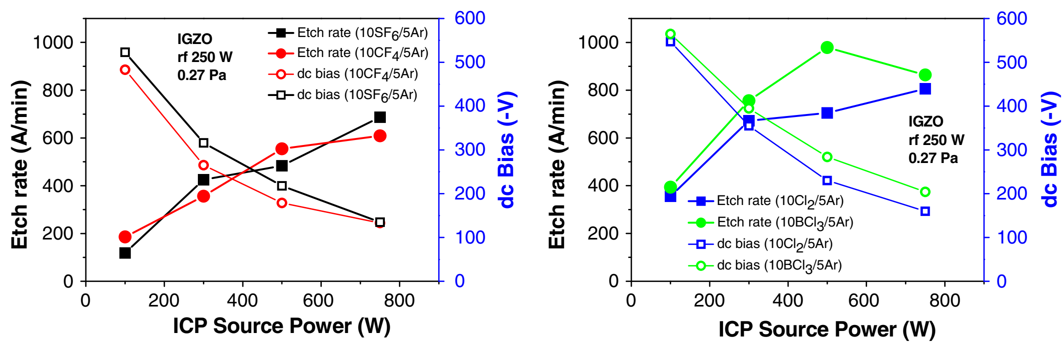

Fig. 2. IGZO etch rates as a function of source power in fluorine- (left) and chlorine-based (right) ICP discharges (250 W rf chuck power, 0.27 Pa).

and with a power up to 1000 W, and the samples were thermally bonded to a Si carrier wafer that was mechanically clamped to a He backside-cooled, rf-powered (13.56 MHz, up to 450 W) chuck. Chlorine- and fluorine-based (Cl_2, BCl_3, CF_4, and SF_6) ICPs were employed to etch the IGZO and gate dielectric films, and the total gas load was fixed at 15 standard cubic centimeters per minute. After removal of the mask the material etch rate, etch selectivity and surface morphology were characterized by stylus profilometry measurements, field-emission scanning electron microscopy (Hitachi S4700, operating voltage 15 kV) and atomic force microscopy (AFM, PSIA SE100, non-contact mode).

3. Results and discussion

Fig. 1 shows the IGZO etch rates as a function of plasma composition in chlorine- (Cl_2/Ar and BCl_3/Ar) and fluorine- (CF_4/Ar and SF_6/Ar) based discharges at fixed source power (750 W), rf chuck power (250 W) and presser (0.27 Pa). The dc bias increases in all chemistries as percentage of halogen compounds increases because of the electronegative character of chlorine and fluorine, which indicates that ion density decreases under these conditions. In CF_4/Ar and SF_6/Ar discharges, the IGZO etch rates generally decrease as the concentration of CF_4 or SF_6 in the discharges increases. This suggests that the etching of IGZO under these conditions is limited by the physical bombardment. As CF_4 or SF_6 content in the discharges increases, a fluorinated selvedge layer is accumulated on the surface and removal of this layer by ion bombardment is not efficient with the lowered ion density. The IGZO etch rate is not affected by the content of Cl_2 in Cl_2/Ar mixtures. On the contrary, the IGZO etch rate increases continuously with the BCl_3 percentage, indicating the neutral-to-ion ratio under these conditions is maintained within the range of optimal values that provide sufficient chlorine surface coverage and reaction, and subsequent etch product desorption. The maximum etch rate of ~1200 Å/min was obtained at 85% BCl_3 content.

The effect of ICP source power on the IGZO etch rates at fixed plasma composition and rf chuck power is shown in Fig. 2. In fluorine-based and Cl_2/Ar ICP discharges, the IGZO etch rates increase monotonically

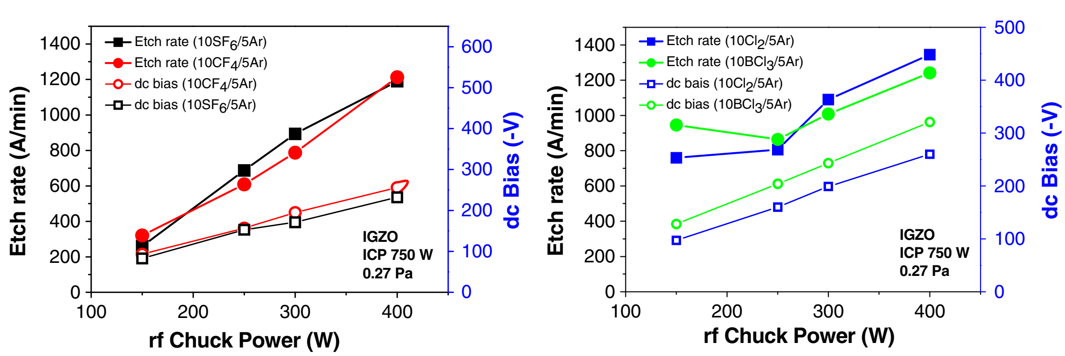

Fig. 3. IGZO etch rates as a function of rf chuck power in fluorine- (left) and chlorine-based (right) ICP discharges (750 W source power, 0.27 Pa).