A three dimensional simulation of inductively coupled plasma sources for TFT fabrications

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Recently, high-resolution display devices are widely used in TV, monitor and mobile devices. The number of pixels in ultra-high definition (UHD) devices are 4 or more times that of the usual high definition (HD) (1080p) ones [1, 2]. For higher resolution with a brighter screen, display devices need a thin film transistor (TFT) with fine design rule and a high mobility semiconductor material.

For the high mobility semiconductor materials, poly-Si or oxide semiconductors are adopted. For these materials, the SiO_x is used for a dielectric layer instead of the usual SiN_x. Therefore, high-density plasma sources are required in the dry etching process for silicon-oxide film.

Because it is not difficult to obtain a high density ($\geq 10^{17}/m^3$), a good uniformity ($\leq$ 5 %) at low pressure ($\leq$20 mTorr), ICP reactors are used for etching and deposition in these devices. Inductively coupled plasma reactors are widely used for etching or deposition processes in the microelectronics industries. In the fabrication processes of semiconductor devices, most discharge characteristics in plasma simulation can be obtained by assuming azimuthal symmetry, and plasma simulation in semiconductor processes have only been studied for small sizes ($\leq$ 500mm). However, for the fabrication processes of display devices such as TFT-LCD or AMOLED, a three dimensional studies are inevitable due to the absence of symmetry.

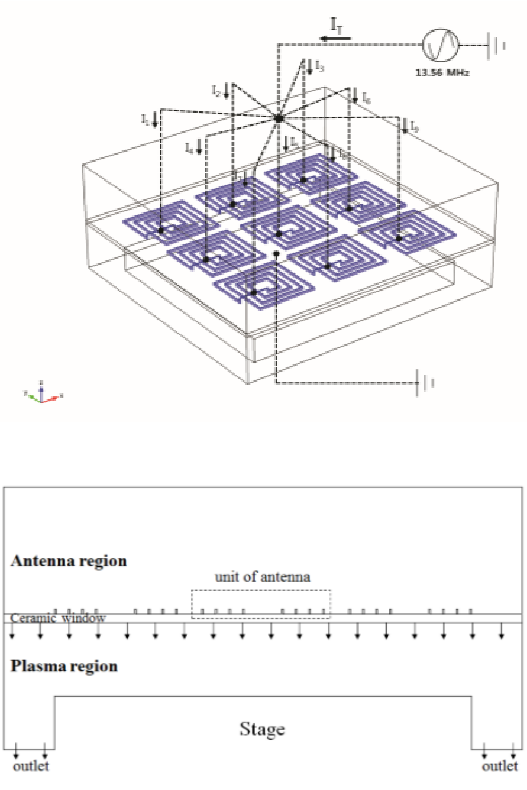

Figure 1: *(a) Schematic diagram of 8th G chamber and (b) cross sectional view in the yz plane*

The substrate size of the 8th generation is 2200×2500 mm and the process chamber is rectangular. This means that the process chamber has a large volume and no symmetry. Thus, a high cost for the experiment is inevitable to find process conditions. Plasma parameters are significant to find out optimized process conditions. Therefore, plasma discharge simulation may be an effective way for finding process conditions.

To apply these methods in display device processes, a large area without symmetry should be considered. In this paper, we developed a three dimensional 8th generation ICP simulation based on a fluid model without symmetry. CF_4/O_2 discharge was used to study the etching process of SiO_x film. Three dimensional profiles of electron density, electron temperature, ion densities, and radical densities are investigated.

The simulation chamber is shown in fig.1. The antenna consists of 9 units. Each unit has a 4-turn coil. The input current (13.56MHz) flows through each antenna unit. A gas inlet is located beneath the ceramic window and an outlet is outside the stage.

The usual equation set for fluid description and ICP discharge are used for simulation [3, 4]. CF_4/O_2 chemical reactions are used from the data in ref [5, 6, 7]. The default process conditions are pressure in 20 mtorr, flow rate in 4000 sccm. The ratio of $(CF_4/(CF_4+O_2))$ is 0.1, 0.5, 0.7 and 0.9.

The profiles of electron density, CF_3^+, CF_2^+ and F^+ in the stage are shown in fig.2. CF_3^+ is dominantly produced by the collision between electron and feedstock CF_4. CF_2^+ is produced by the electron impact reaction of CF_3 and CF_4. As the difference of reaction rate constant, CF_3^+ has a better uniformity than CF_2^+ distribution. F^+ is produced by the collision between the electron and CF_x. As a result,

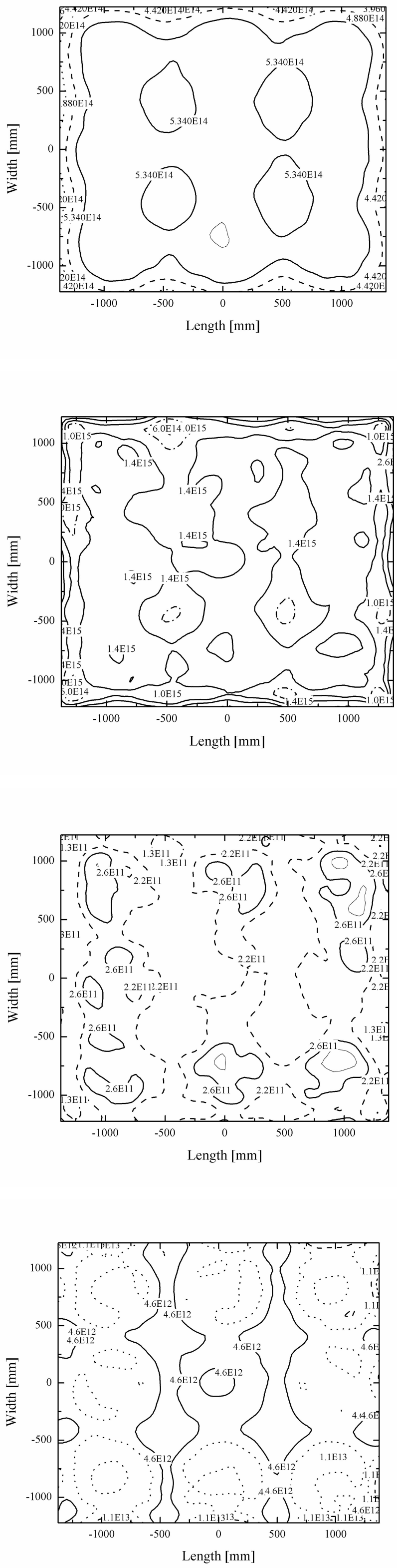

Figure 2: *Distributions of (a)electron density, (b)*CF_3^+*, (c)*CF_2^+ *and (d)*F^+

F^+ has a higher density than CF_2^+ and CF^+. The ions and neutrals coming to the substrate result in the etch rate of SiO_2 film. From the fluxes of ions and neutrals on the substrate, it is possible to obtain the uniformity of etch rate beside the average etch rate.

Fig.3 describes electron density, major radicals (CF_4, CF_3, CF_2, CF and F) and major ions (CF_3^+, CF_2^+, CF^+ and F^+) depending on CF_4/O_2 ratio. The addition of O_2 mole fraction decreased total neutral and positive ions. However, despite the increase of O_2 ratio, neutral fluorine has a region in which number density increases. F is produced to destroy CF_x radicals by O atom. Therefore, the F number density is increased [8].

The etch rate of SiO_2 is known for relying on $\Gamma_{neutral}/\Gamma_{ion}$. This relation may or may not valid for SiO_x film, but this relations is an useful guideline. The result like fig.4 was obtained by calculating $\Gamma_{neutral}/\Gamma_{ion}$ on substrate surface. The ratio of each species may increase or decrease, but the total ratio is important in etch rate. The ions move to the substrate by drift and diffusion. The neutrals are slower than the ions because they have diffusion only, but the ion-neutral collisions increase the velocity of neutrals. The ions and neutrals collide with the films on the substrate that there are two kinds of reactions which are physical sputtering and chemical reactions. As is well known, the simulataneous reactions increase the etch rate of film on the substrate. Since the physical sputtering and etching by chemical reactions are proceeded at the same time by ion and neutral flux, it is possible to obtain such a result [9].

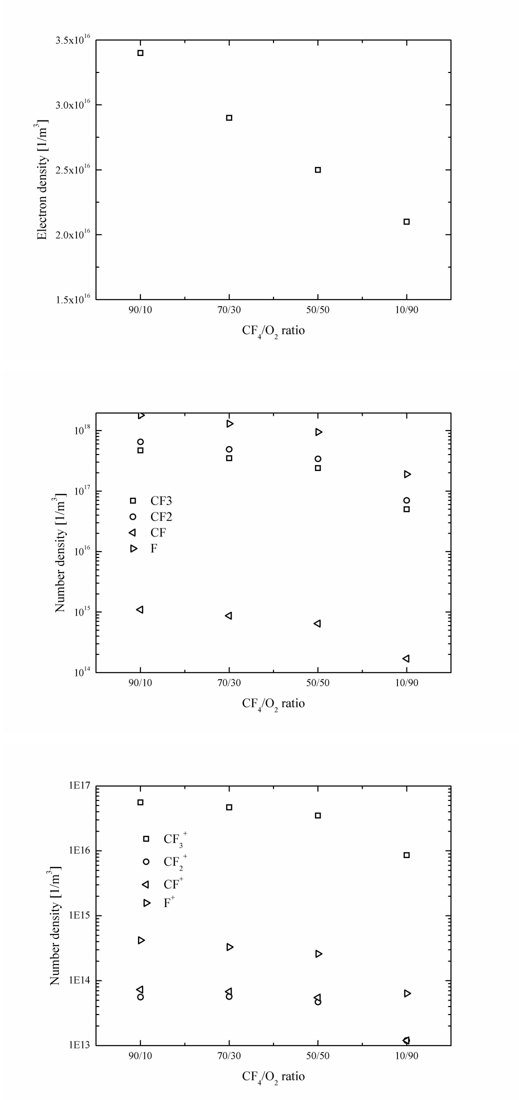

Figure 3: *Electron density, radicals and ions for* CF_4/O_2 *ratio*

In summary, a three dimensional ICP simulation with CF_4/O_2 discharge is conducted for an 8th generation plasma chamber in display device process. The profiles of radicals, ions and flux which is related to SiO_x etch rate can be obtained. These reults may be used for the prediction of etch rate or uniformity. However, the detailed etching mechanism SiO_x film (not SiO_2 film) are not well known. Therefore, to obtain reasonable predictions, the simulation results are expected to apply to process by matching the experiment result.

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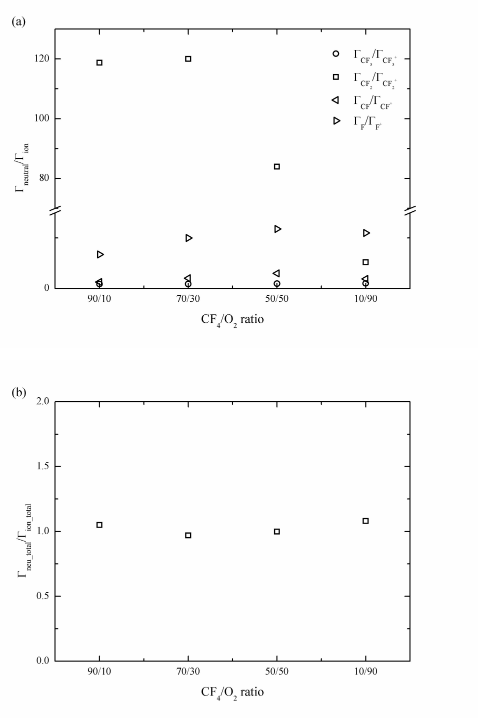

Figure 4: $\Gamma_{neutral}/\Gamma_{ion}$ *on substrate*

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