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Characteristics of a Large-Area Plasma Source Using Internal Multiple U-Type Antenna

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In this study, an internal-type antenna (multiple U-type antenna) was used as a large-area (1,020 mm × 830 mm) inductively coupled plasma (ICP) source, and the electrical characteristics, such as the voltage, current, phase, *etc.*, of the antenna and the characteristics of the Ar plasma were investigated. In addition, using the ICP source with multiple U-type antenna, the etching characteristics, such as the etch rates and etch uniformities, of the photoresist on a large-area substrate (880 mm × 660 mm) were investigated using an O_2 plasma. The plasma density obtained with the multiple U-type antenna was about 2×10^{11} /cm^3 at an rf power of 5000 W and an Ar pressure of 15 mTorr. When the photoresist was etched using the ICP source, an etch rate of about 0.54 μm/min with an etch uniformity of 7 % over the entire substrate area was obtained for an O_2 pressure of 15 mTorr, an rf power of 5000 W, and a dc bias voltage of −100 V.

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I. INTRODUCTION

Large-area plasma source technology, which is widely used for the deposition and etching of microelectronic thin films, is becoming more and more important in the fields of flat panel display (FPD) device processing and semiconductor device processing, due to the decrease in the critical dimension of the FPD device which allows for, a lower environmental impact compared to wet etch processing, *etc.* [1–4].

Among the various plasma sources, inductively coupled plasma (ICP) sources are particularly promising for microelectronic device processing [5,6]. Since they do not depend upon large voltages to ignite the plasmas through the powered radio frequency (rf) antenna, the plasma potentials and the electron temperatures in the inductive plasmas are considerably lower than those found in capacitively coupled rf plasmas. Currently, the etching and deposition processes for flat panel displays, such as thin film transistor-liquid crystal displays (TFT-LCDs), are performed using conventional parallel plate capacitively coupled plasmas [6–12]. High-density plasmas are preferred, instead of capacitively coupled plasmas, due to the higher processing speed and better step coverage that they provide; however, difficulties are encountered in obtaining uniform plasmas over extremely large-area substrates.

In this study, the use of an internal-type ICP source with multiple U-type antennas as a large area plasma source was investigated, and its plasma and electrical characteristics were investigated using a Langmuir probe and an impedance probe, respectively. Also, the etch characteristics of the photoresist (PR), such as the etch rates and etch uniformities on a large area substrate (880 mm × 660 mm), were investigated using the multiple U-type antenna, and its potential for commercialization was assessed.

II. EXPERIMENTS

Figure 1 shows a schematic diagram of the ICP source with multiple U-type antennae as internal ICP sources installed in a 1,020 mm × 830 mm rectangular chamber for use in TFT-LCD processing. The substrate area was 880 mm × 660 mm. As Figure 1 shows, in the case of the multiple U-type antennae, six linear antennaes were inserted in the chamber, and the left sides of the antenna were alternatively connected to the matching network and ground while the right sides of the antennae were connected in groups of two to form three U-type antennae. The linear antennaes were made of 10 mm diameter copper tubing covered by quartz tubing with an outside diameter of 15 mm and a thickness of 1 mm. A 0 ∼ 5-kW 13.56-MHz inductive power supply was used, and the substrate was biased using a 0 ∼ 2-kW 12.56-MHz rf power supply. The substrate was maintained at

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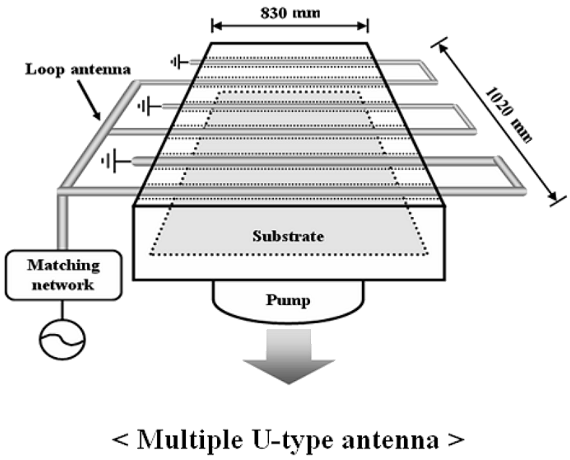

Fig. 1. Schematic diagram of the multiple U-type ICP system used in the experiment.

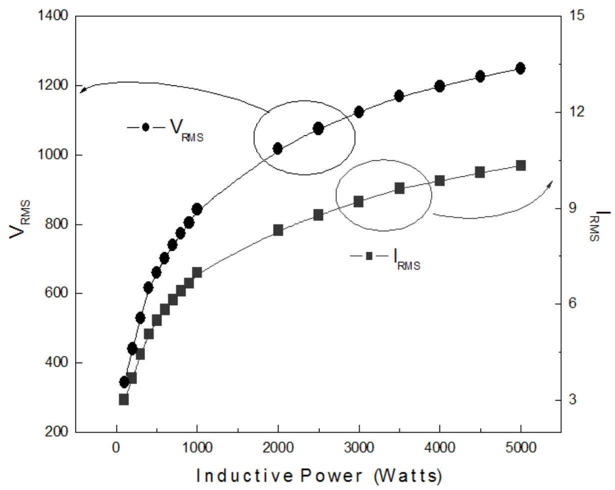

Fig. 2. RF rms voltage & current measured by using an impedance analyzer between the matching box and the multiple U-type antenna as a function of the inductive power at an Ar pressure of 15 mTorr

room temperature. The Ar plasma characteristics of the internal-type ICP sources were measured using a Langmuir probe (Hiden Analytical Inc., ESP) located 7.5 cm below the antenna and at the centerline of the chamber. The electrical characteristics of the antenna, such as the root-mean-square (rms) current and voltage, the phase, *etc.*, were measured using an impedance probe (MKS Inc.).

Finally, in order to investigate the etch characteristics of the ICP sourced with multiple U-type antennae, we used a 3-μm-thick PR covered glass as the sample, and we investigated the etch rates and the etch uniformities of the PR on a substrate area of 880 mm × 660 mm were investigated for an O_2 pressure of 15mTorr. The PR etch rates were measured using a step profilometer (Tencor Inc., Alpha-step 500).

III. RESULTS AND DISCUSSION

Figure 2 shows the rms voltage and current of the ICP source with multiple U-type antennae measured as a function of the inductive power for an Ar pressure of 15mTorr by using an impedance probe. The impedance probe was located between the matching network and the antenna. The increase in the rms voltage on the antenna, which occurs with increasing inductive power, can increase the sheath voltage near the quartz tubing. Therefore, contamination of the substrate can be induced by sputtering the quartz tubing. The DC voltage induced on the quartz tubing is related to the capacitance ratio and the rms antenna voltage (V_a) by

$$V_{DC} \propto \frac{C_i}{C_i + C_s} V_a,$$

where V_{DC} is the DC voltage induced on the quartz, C_i is the capacitance between the antenna and the quartz surface, and C_s is the capacitance between the quartz surface and the plasma.

Therefore, the increase in the DC voltage induced on the quartz tubing is linearly related to the rms antennae voltage. In Figure 2, even though the rms voltage increased with increasing inductive power, the rate of increase gradually decreased, possibly indicating a low degree of contamination caused by the induced DC voltage on the quartz tubing. In fact, in the case where a linear-type ICP using a "serpentine-type antenna" is employed, the length of the antenna becomes comparable to the operating rf wavelength, causing the standing wave effect, which induces a high voltage and voltage distribution at the antenna position (not shown). However, in the case of multiple U-type antennae, this problem does not arise, due to the parallel arrangement. Therefore, the induced voltage of the serpentine-type antenna was found to be much higher than that of the ICP source using multiple U-type antennae under the same processing conditions [3]. The rms current flowing on the antenna is related to the induction of the magnetic field required to generate the ICP; therefore, the observed increase in the rms current with increasing inductive power is believed to be related to the increase in the plasma density with increasing inductive power.

In general, the plasma conductivity (σ) is proportional to the plasma density ($\sigma \propto n_e$) and the plasma impedance is related to the efficiency of the power transfer to the plasma. To estimate the plasma impedance ($Z = Z_r + iZ_i, Z_r$ being the plasma resistance and Z_i being the plasma reactance), the rms antenna voltage, current, and phase shift φ (power factor, cosφ) between the antenna voltage and the current were measured, and the plasma impedance was indirectly calculated from the

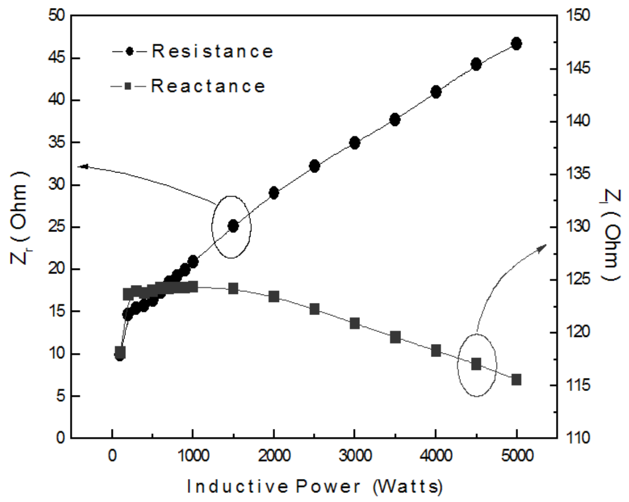

Fig. 3. Plasma impedance measured using an impedance analyzer as a function of the inductive power at an Ar pressure of 15 mTorr.

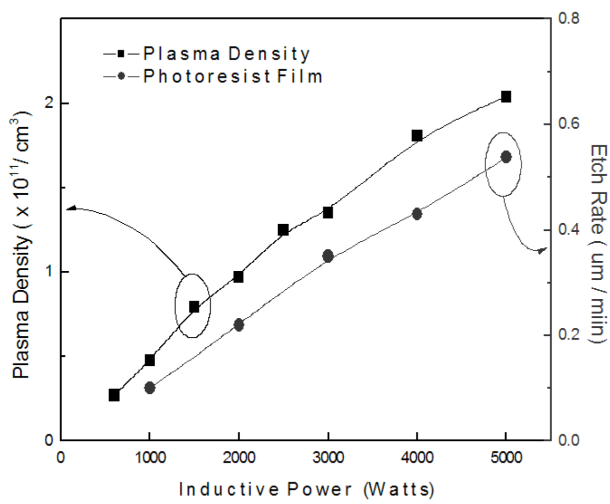

Fig. 4. Ar plasma density measured by using a Langmuir probe at 7.5 m below each antenna for the multiple U-type antenna as a function of the inductive power from 600 W to 5000 W at an Ar pressure of 15 mTorr. For the PR etching, an O_2 pressure of 15 mTorr was used, and a dc bias voltage of -100 V was applied to the substrate. The substrate was maintained at room temperature.

following equation:

$$Z_r = \left(\frac{V_{rf}}{I_{rf}}\right)\cos\varphi, \qquad Z_i = \left(\frac{V_{rf}}{I_{rf}}\right)\sin\varphi.$$

As the inductive power was increased from 100 W to 5000 W, cosφ was increased from 0.08754 to 0.34489 (not shown). Using the measured voltage, current, and phase shift as functions of the inductive power for an Ar pressure of 15 mTorr, we calculated Z_r and Z_i [13,14], and the results are shown in Figure 3. As the figure shows that the increase in the inductive power resulted in an increase in the value of Z_r and in a decrease in the value of Z_i, which corresponds to an increase in the efficiency of the power transfer from the antenna to the plasma. When the power transfer efficiency was calculated from the above data, even though the value measured at 100 W was about 90 %, it increased with increasing inductive power, and the power transfer efficiency measured at 5000 W was as high as 98 % (not shown).

Figure 4 shows the plasma density measured using a Langmuir probe as a function of the inductive power for an Ar pressure of 15 mTorr. As this figure shows, the plasma density increased almost linearly with increasing inductive power, and a high plasma density of about 2 10^{11} /cm^3 could be obtained at an inductive power of 5000 W. Figure 4 also shows the PR etch rate measured as a function of the inductive power using O_2 at a pressure of 15 mTorr instead of Ar. The etch rate was measured at the center of the substrate which was located 5 cm below the antenna. The substrate was biased at -100 V by using a 12.56-MHz rf power supply. The PR etch rate increased almost linearly with increasing inductive power, in a manner that was similar to the increase in the plasma density, and showed a value of about 0.54 μm/min at an inductive power of 5000 W.

For the successful commercialization of the plasma source in the field of flat panel display device processing, the process uniformity should be less than 15 % over the entire substrate area. To investigate its conformity with this requirement, we etched a PR-covered glass substrate with dimensions of 880 mm × 660 mm by using an O_2 pressure of 15 mTorr, an inductive power of 5000 W, and a dc bias voltage of -100 V, and the etch results are shown in Figure 5. As this figure shows, the etch uniformity over the substrate area was about 7 %. Therefore, excellent uniformity could be obtained using the ICP source with multiple U-type antennae studied in this experiment.

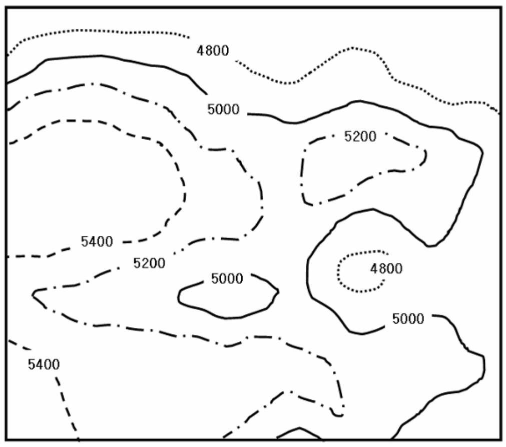

Fig. 5. Etch uniformity of PR on glass with a substrate area of 880 mm × 660 mm measured at an inductive power of 5000 W, a dc-bias voltage of –100 V, and an O_2 pressure of 15 mTorr by using an internal-type ICP source with a multiple U-type antenna.

IV. CONCLUSIONS

In this study of the possible use of an internal-type ICP source with multiple U-type antennae as a next generation large-area plasma source for flat panel display device processing, the characteristics of the plasmas and the electrical characteristics of the source were investigated. The rms antenna voltage induced on the antenna was considerably lower than that induced on the other types of antennae; therefore, low sputtering of the quartz surface covering the antenna and low contamination of the substrate were to be expected. When the power transfer efficiency was estimated by means of an impedance probe, a value of about 98 % was obtained at an inductive power of 5000 W. At an rf power of 5000 W and an Ar pressure of 15 mTorr, the plasma density obtained with the plasma source was about 2×10^{11} /cm^3 ,and when the PR was etched, an etch rate of about 0.54 μm/min with an etch uniformity of 7 % on a substrate area of 880 mm × 660 mm was obtained using an O_2 pressure of 15 mTorr, an rf power of 5000 W, and a dc bias voltage of −100 V.

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