Japanese Journal of Applied Physics
Vol. 43, No. 7A, 2004, pp. 4373–4375

Characteristics of Parallel Internal-Type Inductively Coupled Plasmas for Large Area Flat Panel Display Processing

Kyong Nam KIM, Young June LEE, Seung Jae JUNG and Geun Young YEOM

Department of Materials Engineering, Sungkyunkwan University, Suwon 440-746, Korea

(Received October 13, 2003; accepted February 27, 2004; published July 7, 2004)

The development of a large-area high-density plasma source is desired for various plasma processes from microelectronics fabrication to flat panel display (FPD) device fabrication. In this study, using a parallel internal-type (double comb-type) inductively coupled plasma source having the size of 1020 mm × 830 mm, high density plasmas on the order of 2.2×10^{11} cm^{-3} could be obtained with Ar at 5000 W inductive power. Plasma uniformity on the substrate in the size of 920 mm × 730 mm decreased with the increase in inductive power and was about 8% when the inductive power was 5000 W. When SF_6 was used to etch SiO_2 using the source, the SiO_2 etch rate higher than 2000 Å/min with an etch uniformity of about 6% could be obtained at 5000 W inductive power, −350 V bias voltage, and 15 mTorr operating pressure.
[DOI: 10.1143/JJAP.43.4373]

KEYWORDS: large-area plasma, etching, Langmuir probe, inductively coupled plasma, uniformity, parallel internal-type antenna

1. Introduction

In the semiconductor device processing and flat panel display (FPD) manufacturing processes, plasma processes are widely employed.[1–3] In the case of the etching process of FPD devices, to achieve the performance required for high resolution devices of next-generation TFT-LCD, improved large-area dry etch processes utilizing high-density plasmas will be required for increased throughput and superior critical dimension control. The plasma etching sources developed to date for the production of high-density and large-area plasmas are mainly focused on the externally planar inductively coupled plasma (ICP) sources.[4–6] However, due to its large impedance with the scale-up to larger areas and the cost and thickness of its dielectric material, the conventional ICP equipment using an external spiral antenna show problems in extending the process area.[7]

One of the solutions to above problems is to use internal-type inductively coupled plasmas.[8] Currently, various internal-type ICPs utilizing serpentine-type antennas have been reported for the applications of large-area FPD processing[9–11] and semiconductor processing.[12] However, in the case of FPD processing, due to the large long serpentine-type antenna close to operating rf wavelength and its high impedance, it is difficult to remove the standing wave effect and the plasma instability as the chamber size increases.

Therefore, in this study, a novel arrangement of the large-area internal-type antenna (double comb-type antenna) ICP source which does not have the standing wave effect and a high impedance was studied for the application of the next generation large-area FPD dry etching, and plasma characteristics and etch characteristics such as etch rates and etch uniformity were investigated.

2. Experiment

Figure 1 shows a schematic diagram of the internal-type ICP system and the arrangement of the internal-type antenna used in the experiment. As shown in the figure, the plasma processing chamber was designed as a rectangular form for FPD applications and the inner area of the chamber was 1020 mm × 830 mm. Five parallel antennas were embedded in the vacuum chamber and the antennas were connected to the rf power supply alternatively from the opposite ends as shown in Fig. 1. The other ends of the antennas were connected to the ground, therefore, a double comb-type internal antenna was formed. As the antenna material, copper tubing with a diameter of 10 mm was used and the outside of the copper tubing was enclosed by a 15 mm diameter and 2 mm-thick quartz tubing. A rf power of 13.56 MHz (0–5 KW) was fed to the antenna through a conventional L-type matching network.

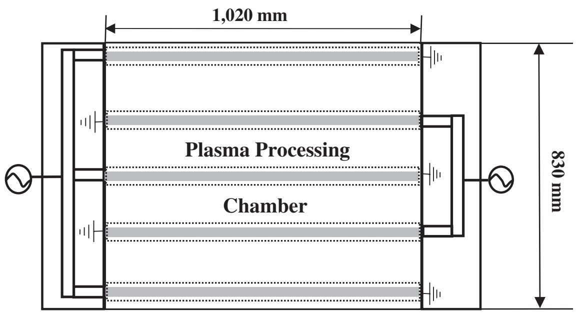

Fig. 1. Schematic diagram of the double comb-type internal ICP system used in the experiment.

Plasma characteristics, such as plasma density and plasma uniformity of the internal-type antenna ICP sources, were measured using a Langmuir probe (Hiden Analytical Inc., ESP) located 7.5 cm below the antenna and along the vertical centerline of the chamber. Photoresist (PR) and SiO_2 were used to investigate the etch characteristics. The PR used in this experiment was AZ1512 and spin-coated about 1.2 μm on the glass substrate and, in the case of SiO_2, 1 μm-thick SiO_2 was deposited by e-beam deposition on the silicon substrate. To determine the etch rates and etch uniformities of PR and SiO_2, a water-cooled large-area substrate holder was installed 5 cm below the source and connected to a separate rf power supply (12.56 MHz, 0–2 KW) through a separate matching network to supply bias voltages to the substrate. An operating pressure of 15 mTorr of Ar was used to characterize plasma characteristics. In the case of etching of PR, oxygen and SF_6 at 15 mTorr were used, and for SiO_2 etching, SF_6 in the range from 15 to 100 mTorr was used. Etch rate and etch uniformity were

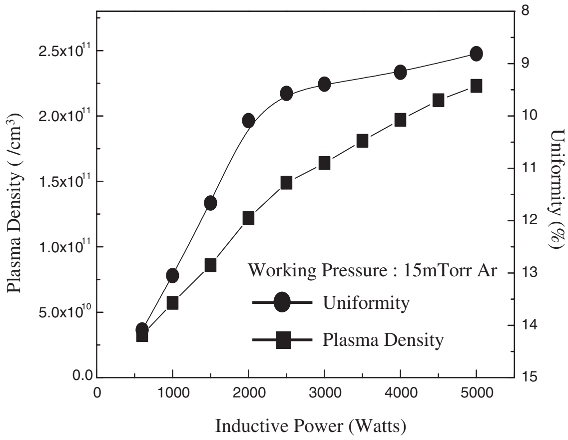

Fig. 2. Ar ion density measured by a Langmuir probe at 7.5 m below the antenna and its uniformity along the centerline of the substrate width (920 mm × 730 mm) as a function of inductive power from 600 to 5000 W for 15 mTorr Ar.

estimated by measuring the step heights of the sample along the substrate centerline before and after etching with a stylus profilometer (Tencor Alpha-step 500).

3. Results and Discussion

Using the double comb-type internal antenna, inductively coupled plasmas were generated and their effects on plasma density and uniformity were investigated at 15 mTorr Ar. Figure 2 shows the effect of rf power to the double-comb linear antenna on Ar plasma density and uniformity measured by the Langmuir probe. The rf power varied from 600 to 5000 W. The Langmuir probe was located 7.5 cm below the antenna and scanned vertically along the centerline of the substrate width (the substrate size area was 920 mm wide × 730 mm long). Therefore, the probe was scanned across the antenna line which was considered to show a poor uniformity compared with that along the antenna line. As shown in Fig. 2, the increase in rf power to the antenna increased the plasma density almost linearly without saturation. When the rf power was higher than 2000 W, the plasma density was higher than $1 \times 10^{11}/cm^3$ and, when the applied rf power was 5000 W, the plasma density was about $2.2 \times 10^{11}/cm^3$. Therefore, it is considered that high-density plasmas can be obtained using the double comb-type internal ICP source used in the experiment. Figure 2 also shows the uniformity of plasmas measured along the centerline of the substrate and, as shown in the figure, the plasma uniformity improved with the increase in rf power from about 14% at 600 W to about 8% at 5000 W. When plasma uniformity was measured along the centerline of the substrate, plasma density was generally showed a flat profile in the middle section of the source and rapidly decreased at the edge of the source. However, when the rf power was high, the uniform plasma area increased due to the spreading of the plasma to the edge of the chamber. Therefore, the improvement in plasma uniformity by increasing the ICP rf source power appears associated with the spreading of the plasma to the edge of the substrate.

Using the double comb-type antenna, SiO_2 and PR were etched and their etch rates were determined as a function of inductive power for 15 mTorr SF_6 and −300 V of dc-bias voltage and the results are shown in Fig. 3. As shown in the figure, the etch rates of SiO_2 and PR increased with the increase in inductive power almost linearly and, at 5000 W inductive power, the PR etch rate reached 3700 Å/min and the SiO_2 etch rate reached 1700 Å/min. Therefore, PR etch rate was higher than SiO_2 etch rate probably due to the chemical reaction of PR with abundant fluorine atoms in the SF_6 plasma.

At 5000 W inductive power, −300 V dc-bias voltage, and 15 mTorr SF_6, the etch rates of SF_6 and PR were also determined as a function of working pressure to improve etch rates and the results are shown in Fig. 4. Similar to the results in Fig. 3, the etch rates of PR were higher than those of SiO_2 at the pressure range investigated. However, as shown in the Fig. 3, the etch rates of both PR and SiO_2 were increased with the increase in working pressure until 50 mTorr and a further increase in working pressure decreased the etch rates. The maximum PR and SiO_2 etch rates were 6000 Å/min and 2800 Å/min, respectively. The initial increase in etch rates with the increase in working pressure appears related to the increase in plasma density and

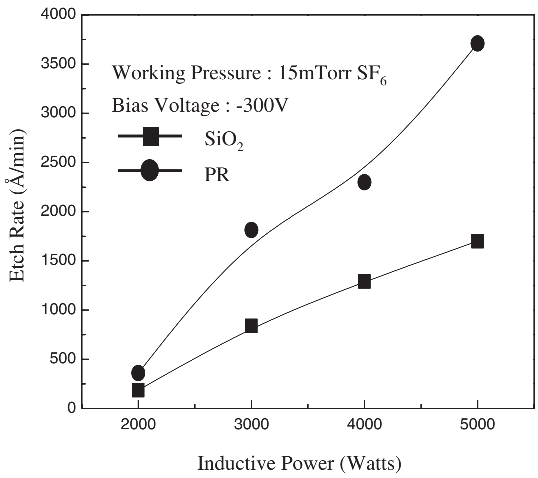

Fig. 3. Etch rates of SiO_2 and PR as a function of inductive power for 15 mTorr Ar and −300 V of dc-bias voltage.

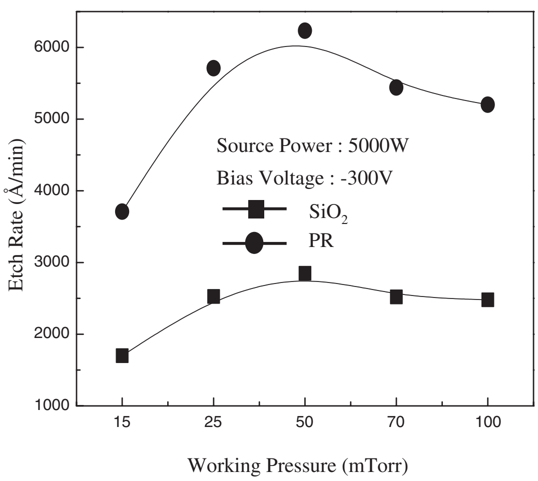

Fig. 4. The etch rates of SiO_2 and PR as a function of working pressure for SF_6, 5000 W inductive power, and −300 V dc-bias voltage.

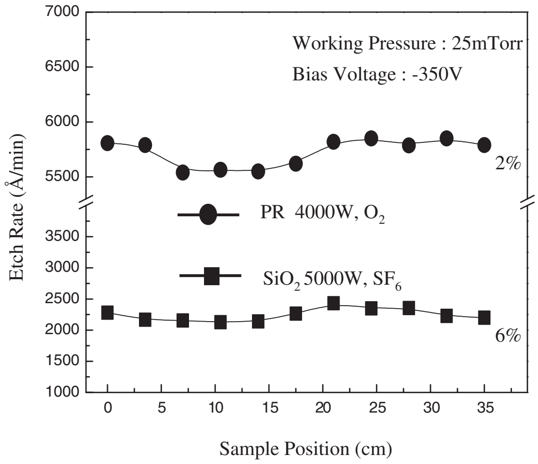

Fig. 5. Etch uniformity of SiO_2 and PR in SF_6 and O_2 plasmas, respectively measured along the centerline of the substrate width. Bias voltage was -350 V and working pressure was 25 mTorr. For PR and SiO_2 etch uniformities, the inductive power of 4000 W and 5000 W were used respectively.

dissociated species such as fluorine atoms by increased ionization and dissociation. However, the decrease in etch rates with a further increase in working pressure appears related to the decreased efficiency of inductive coupling due to the increased collision of energetic electrons with gas atoms. In Fig. 4, by increasing the working pressure up to 50 mTorr, we were able to obtain SiO_2 etch rates higher than 2000 Å/min which is generally acceptable for the FPD processing. However, it is considered that a much higher SiO_2 etch rate can be obtained by applying an inductive power higher than 5000 W because the power density applied to unit area is much lower than that for typical reactive ion etching.

For the etching of large-area FPD devices, the etch uniformity on the substrate area is important. Therefore, etch uniformities of PR and SiO_2 were investigated along the substrate from the center to the edge of the substrate (in the same direction as shown in Fig. 2) using O_2 and SF_6, respectively, the results of which are shown in Fig. 5. The inductive powers were 4000 W for PR and 5000 W for SiO_2, dc-bias voltage was -350 V, and the working pressure was 25 mTorr. As shown in the figure, the uniformity of PR etch rate obtained using O_2 plasma was about 2% and that of SiO_2 etch rate was about 6%. Compared with the results of plasma uniformity shown in Fig. 2, the etch uniformities of SiO_2 and PR were better than the plasma uniformity. Therefore, using the double-comb type internal antenna, SiO_2 etch rates higher than 2000 Å/min can be obtained with the etch uniformity about 6%. In general, the etch uniformity of large area commercial TFT-LCD dry etchers should be less than 10% and the etch selectivities of SiO_2 and Si_3N_4 over PR should be higher than 1.0. Therefore, the etch uniformity obtained in our experimental equipment is believed excellent but the etch selectivities of SiO_2 over PR are lower than 0.4, and different gas combinations need to be studied to improve etch selectivities of SiO_2 over PR as the next step.

4. Conclusions

In this study, the effect of double comb-type internal antenna applied to 1020 mm × 830 mm rectangular ICP on the characteristics of plasma such as plasma density and uniformity were investigated using Ar. Also, the etch rates and etch uniformities of SiO_2 and PR were investigated along the centerline of the substrate width (920 mm wide × 730 mm long) using O_2 and SF_6.

By increasing the inductive power up to 5000 W, the increase in plasma density and the improvement of plasma uniformity could be obtained. At 5000 W inductive power, the plasma density was about $2.2 \times 10^{11}/cm^3$ while the plasma uniformity measured 7.5 cm below the antenna was about 8%. SiO_2 etch rates were also increased with the increase in inductive power and, by using 5000 W of inductive power and 15 mTorr SF_6, 1700 Å/min was obtained. By increasing the working pressure up to 50 mTorr, the SiO_2 etch rate increased to 2800 Å/min. The etch selectivities of SiO_2 over PR were lower than 0.4 in general for the SF_6 plasma, possibly due to the abundant fluorine atoms in the SF_6 plasma. The etch uniformities of PR and SiO_2 measured along the substrate were higher than 6%.

Acknowledgments

This work was supported by National Research Laboratory (NRL) Program of the Korea Ministry of Science and Technology.

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