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Etching characteristics of multiple U-type internal linear inductively coupled plasma for flat panel display

Seung Jae Jung*, Kyong Nam Kim, Geun Young Yeom

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

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Abstract

In this study, internal type antennas such as a multiple U-type antenna and a serpentine-type antenna were used for the large area (1020 mm×830 mm) inductively coupled plasma (ICP) source and their plasma characteristics of Ar were investigated. In addition, using the multiple U-type antenna, the etching characteristics such as etch rates and etch uniformities of photoresist on the large area substrate (880 mm×660 mm) were investigated using O_2 plasma. The multiple U-type showed about 25% higher plasma density compared to the serpentine-type antenna due to the shorter antenna length and higher inductive coupling. The plasma density obtained with the multiple U-type antenna was about 2×10^{11} /cm^3 at 5000 W of RF power and 15 mTorr Ar. When photoresist was etched using the multiple U-type antenna, the etch rate of about 5385 Å/min with the etch uniformity of 7% on the substrate area could be obtained using 15 mTorr O_2, 5000 W of RF power, and −100 V of dc bias voltage.

Keywords: Dry etching; Plasma; Langmuir

1. Introduction

Plasma etching which is widely applied to the patterning of electronic materials is becoming more and more important processing in the flat panel display device processing due to the decrease of the critical dimension of the device, less environmental impact compared to wet etch processing, etc. [1–3]. Currently, plasma etching is performed in the processing of flat panel displays such as thin film transistor–liquid crystal displays (TFT–LCDs) using conventional parallel plate capacitively coupled plasmas. High-density plasmas are preferred instead of the capacitively coupled plasmas due to the higher processing speed, better step coverage, etc., however, they tend to show difficulties in obtaining uniform plasmas on the extremely large area substrates.

Recently, various large-area high-density plasma sources have been developed for the application to large area TFT–LCD processing. Among the various high-density plasma sources, inductively coupled plasma (ICP) sources are more widely investigated due to the easier physics involved in the source, easier scalability to large area, etc. [4–6]. One of the ICP sources studied for the application to the TFT–LCD processing is the internal ICP source using serpentine-type antenna. However, this serpentine-type antenna tends to show a standing wave effect and plasma instability when traveling wave is not launched [7–9] due to the long length of the antenna, and the launching the traveling wave is also known to have some problems in the matching.

In this study, multiple U-type antenna was investigated for the internal large area ICP source and its characteristics were compared with the serpentine-type antenna without utilizing the traveling wave. Also, the etch characteristics of photoresist (PR) such as etch rates and etch uniformities on the large area substrate (880 mm×660 mm) were investigated using the multiple U-type antenna for possible commercialization.

* Corresponding author. Tel.: +82 31 290 7395.
E-mail address: jungsj@skku.edu (S. Jae Jung).

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2. Experiment

Fig. 1 shows the schematic diagrams of the serpentine-type antenna and the multiple U-type antenna as the internal ICP sources installed in the 1020 mm×830 mm rectangular chamber for the application to TFT–LCD processing. The substrate area was 880 mm×660 mm. As shown in the figure, in the case of the serpentine-type antenna, five linear antennas were inserted in the chamber and the antennas were connected in series to form a 7-m-long serpentine. One end of the serpentine antenna was connected to the matching network of the power supply and the other end was connected to the ground. In the case of the multiple U-type antenna, six linear antennas were inserted in the chamber and the left sides of the each antenna were connected to the matching network and ground alternatively while the right sides of the each antennas were connected in a group of two to form three U-type antennas as shown in the figure. The linear antennas were made of 10-mm diameter copper tubing and the outside of the copper tubing was covered by 15-mm outside diameter and 1-mm-thick quartz tubing. As the power supply, 0–5 kW 13.56 MHz was used and the substrate was biased using 0–2 kW 12.56 MHz RF power supply. The substrate was maintained at room temperature.

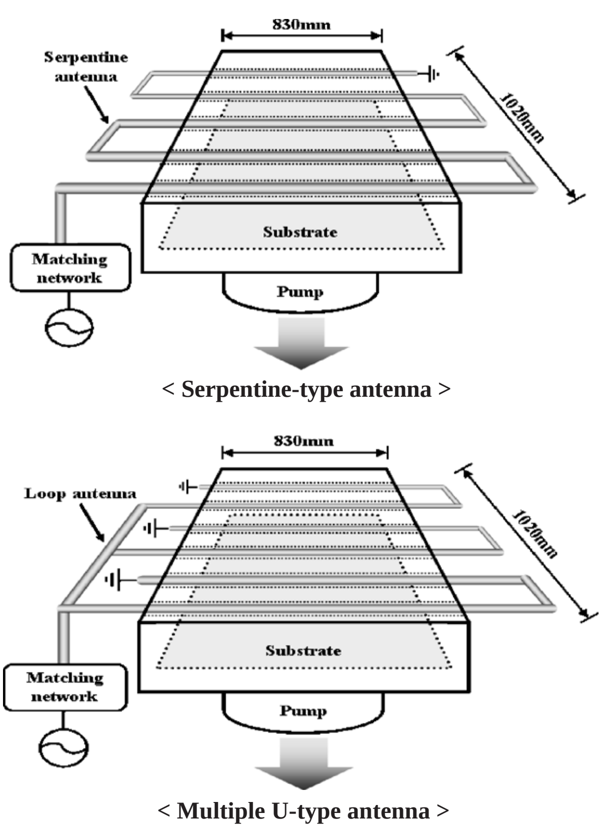

Fig. 1. Schematic diagrams of the serpentine-type antenna and the multiple U-type antenna as the internal ICP sources installed in the 1020 mm×830 mm rectangular chamber for the application to TFT–LCD processing.

The plasma densities of the ICP sources with the serpentine-type antenna and the multiple U-type antenna were measured with a Langmuir probe (Hiden Analytical, ESPION) by locating the probe tip 7.5 cm below the antenna and the center of the chamber using 15 mTorr Ar. In the case of O_2 plasmas, as an estimation of oxygen ion densities of the ICP sources with the both type antennas, ion current densities were measured by the Langmuir probe by biasing the probe at −60 V. Oxygen atomic density was estimated by Ar actinometry by the addition of 5% Ar to O_2 plasmas and taking the ratio of oxygen atomic emission intensity at 776 nm to Ar atomic emission intensity at 707.2 nm measured using optical emission spectroscopy (OES, SC Tech., PCM420).

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

3. Results and discussion

Fig. 2 shows the plasma density of 15 mTorr Ar and the ion current density of 15 mTorr O_2 measured as a function of RF power from 600 to 5000 W using a Langmuir probe for the serpentine-type antenna and the multiple U-type antenna. As shown in the figure, in the case of Ar plasma density, the increase of RF power increased the plasma density for both the serpentine-type antenna and the multiple U-type antenna, however, the multiple U-type antenna showed about 25% higher plasma ion density compared to the serpentine-type antenna at 2500 W of RF power. At 5000 W of RF power, the Ar plasma density obtained with the multiple U-type antenna was about $2\times10^{11}/cm^3$. For the ion current density measured for 15 mTorr O_2 as the estimation of oxygen plasma density, the multiple U-type antenna also showed the 18%–36% higher ion current density compared to the serpentine-type antenna as shown in the figure. The higher Ar plasma density and the higher oxygen ion current density obtained for the multiple U-type antenna appear related to the higher inductive coupling obtained for the modified type antenna. In fact, when the antenna voltages and impedances were measured using an impedance probe (V–I probe), the multiple U-type antenna showed a lower voltage and compared to the serpentine type antenna at a given RF power due to the shorter length of the antenna (not shown). That is, the higher plasma density appears to be obtained for the multiple U-type antenna by the higher electromagnetic field to the plasma generated by the higher antenna current and lower antenna voltage.

Fig. 3 shows the atomic density of oxygen estimated by Ar actinometry for 15 mTorr O_2 measured as a function of

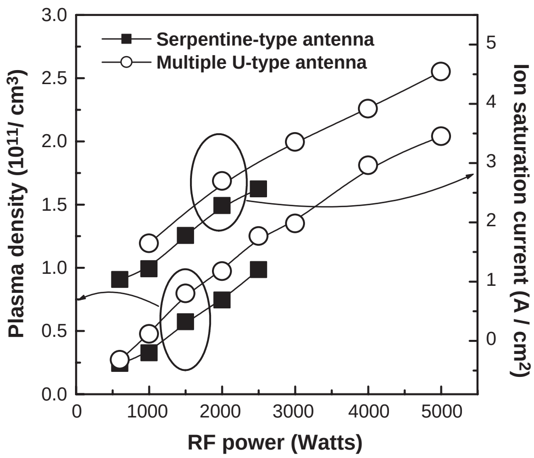

Fig. 2. Plasma density of 15 mTorr Ar and ion saturation current of 15 mTorr O_2 measured by a Langmuir probe at 7.5 m below the antenna and the center of the chamber as a function of RF power from 600 to 5000 W.

RF power from 1000 to 5000 W for both the serpentine-type antenna and the multiple U-type antenna. As shown in the figure, the measured oxygen atomic density was also 80%–100% higher for the multiple U-type antenna, therefore, more oxygen atomic density in addition to the higher ion density is believed to be obtained by the higher dissociation of oxygen at the same RF power by using the multiple U-type antenna. Fig. 3 also shows the PR etch rate as a function of RF power for 15 mTorr O_2 plasma generated by the ICP source with the multiple U-type antenna. The substrate was biased at −100 V and was maintained at room temperature. As shown in the figure, the PR etch rate increased almost linearly with the increase of RF power due to the increase of oxygen ion density and oxygen atomic density in the plasma. The PR etch rate obtained at 5000 W of RF power was about 5385 Å/min.

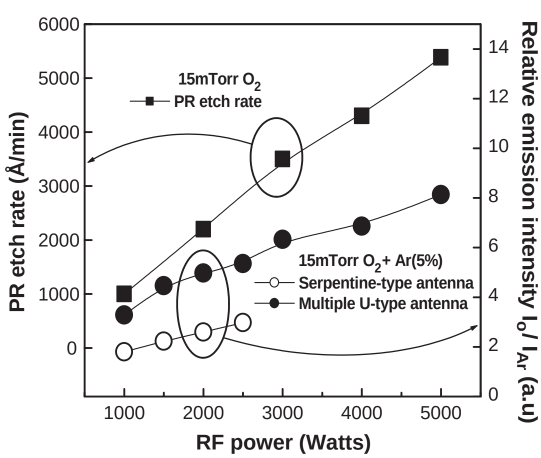

Fig. 3. Relative oxygen atomic density estimated by Ar actinometry for the serpentine-type antenna and the multiple U-type antenna and PR etch rate for the multiple U-type antenna as a function of RF power from 1000 to 5000 W at 15 mTorr O_2. For the PR etching, −100 V of dc bias voltage was applied to the substrate. The substrate temperature was maintained at room temperature.

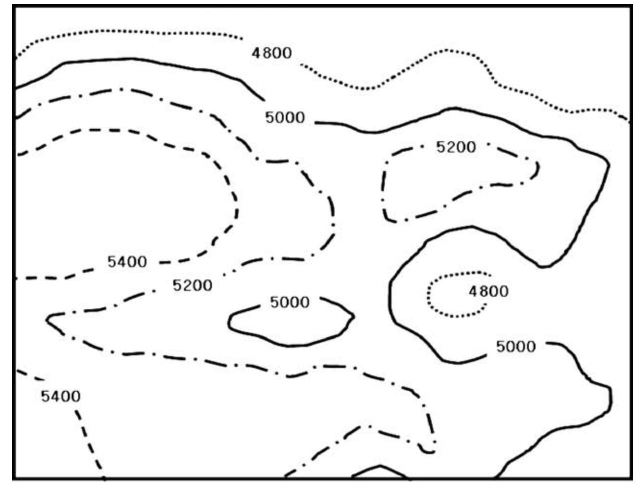

Fig. 4. Etch uniformity of PR on glass on the substrate area of 880 mm×660 mm measured at 5000 W of RF power, −100 V of dc bias voltage, and 15 mTorr of O_2 for the ICP source with the multiple U-type antenna.

To use the ICP source with the multiple U-type antenna for the large-area TFT–LCD processing, not only the high etch rates but also the high etch uniformities should be maintained. To investigate the uniformity of the PR etching, a PR-coated glass substrate covering the substrate area of 880 mm×660 mm was used and the etch uniformity over the substrate area was measured and the result is shown in Fig. 4. The PR etch condition was the same as the condition in Fig. 3 for the PR etching. As shown in the figure, using the multiple U-type antenna, an excellent PR etch uniformity of about 7% with the etch rate of about 5385 Å/min could be obtained.

4. Conclusions

In this study, as the application to a large area TFT–LCD etch processing, an internal ICP source with a multiple U-type antenna was developed and its plasma characteristics were compared with the internal ICP source with a serpentine-type antenna. Also, PR etch characteristics were investigated for the multiple U-type antenna.

The multiple U-type antenna showed lower antenna voltage and higher stability compared to the serpentine-type antenna due to the lower impedance of the multiple U-type antenna caused by the shorter antenna length. Due to the higher inductive coupling caused by the higher current induced on the antenna, about 25% higher plasma density and about 100% higher radical density could be obtained for the ICP source with the multiple U-type antenna. Using the ICP source with the multiple U-type antenna, the plasma density of about $2\times10^{11}/cm^3$ could be obtained at 5000 W of RF power and 15 mTorr Ar. When PR was etched using the ICP source with the multiple U-type antenna, the PR etch rate of about 5385 Å/min with the etch uniformity of about 7% on the substrate area of 880 mm×660 mm could be obtained. It is believed that the internal type ICP source using the multiple U-type antenna can be commercially applicable to the large area TFT–LCD processing.

Acknowledgments

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