

Characteristics of inductively coupled plasma with multiple U-type internal antenna for flat panel display applications

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Abstract

In this study, the characteristics of large area internal linear ICP sources of 1020 mm×920 mm (substrate area is 880 mm×660 mm) were investigated using two different types of antennas, that is, a conventional serpentine-type antenna and a newly developed multiple U-type antenna. The multiple U-type antenna showed higher plasma density, higher radical density, and more plasma stability compared to the serpentine-type antenna, and it appears from the higher inductive coupling and less standing wave effect compared to the serpentine-type antenna. Using the multiple U-type antenna, the plasma density of $2 \times 10^{11}/\text{cm}^3$ with the plasma uniformity of 4% could be obtained using 15 mTorr Ar and 5000 W of RF power.

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1. Introduction

For the etching of thin film transistor-liquid crystal display (TFT-LCD) devices, plasma etch processing are replacing wet etch processing due to the many advantages such as better control of critical dimension, better repeatability, less environmental impact, easier automation, etc. Also, as the plasma sources for the dry etching, even though capacitively coupled plasma sources are currently utilized for the etching of TFT-LCD, to improve the throughput of the TFT-LCD device processing, high density plasma sources are preferred compared to conventional capacitively coupled plasma sources due to their higher processing speed.

For the plasma processing of TFT-LCD devices, it is very important to produce a uniform high density plasmas over the extremely large area substrate under a low gas pressure [1–3]. To obtain uniform high density plasmas on the large substrate area, various high density plasma sources have

been recently studied using an array of helicon sources [4], an inductively coupled plasma (ICP) source composed of a large loop [5], ICP sources composed of internal antennas [6–8], etc. Among these various sources, internal-type ICP source is one of the sources that do not require a thick dielectric window on the wall of the processing chamber which is prerequisite for transmitting electromagnetic field to the plasma from the source antennas. Therefore, various internal-type ICPs utilizing serpentine-type antennas have been reported for the applications of large area plasma processing. [6,9–11] However, in the case of TFT-LCD processing, due to the long length of the serpentine-type antenna close to the operating RF wavelength and its high impedance according to the scale-up, it is difficult to overcome the standing wave effect and the plasma instability due to the high antenna voltage as the chamber size becomes larger and larger.

In this study, a novel arrangement of the internal-type antenna (a multiple U-type antenna) for a large-area ICP source, which has little standing wave effect and a low impedance, was studied for the application of the next generation large-area TFT-LCD dry etching and its plasma and electrical characteristics were investigated.

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2. Experiment

Fig. 1 shows the schematic diagram of the experimental apparatus used in the experiment. As shown in the figure, the plasma processing chamber was designed as a rectangular form for flat panel display (FPD) applications and the inner size of the chamber was 1020 mm×830 mm and the substrate holder size was 920 mm×730 mm (the substrate size was 880 mm×660 mm). As shown in Fig. 1(a), in the case of a serpentine-type antenna, five linear antennas were embedded in the vacuum chamber and each linear antenna was connected in series. However, in the case of the multiple U-type antennas investigated in this study, the antenna was consisted of 3 pairs of single U-type antenna as shown in Fig. 1(b). The shape of each single U-type antenna is like open circle, and one side was connected to the radio frequency (RF) power supply while the other side was connected to the ground. The lengths of the serpentine-type antenna and the U-type antenna were 7 m and 2.3 m, respectively. The antenna was made of 10 mm diameter copper tubing with the outside shielded by quartz tubing. The outside diameter of the quartz tubing was 15 mm and the thickness was 2 mm. 13.56 MHz (0–5 kW) RF power was fed to the antenna through a conventional L-type matching network.

The characteristics of the Ar plasma such as plasma density, plasma potential, and plasma uniformity of the

internal-type ICP sources were measured using a Langmuir probe (Hidden Analytical, ESP) located 7.5 cm below the antenna and along the vertical centerline of the chamber. RF root-mean-square (rms) voltages along to the antenna length were measured by a high voltage probe (Tektronix, P6015A) and an oscilloscope. Intensity of oxygen radicals was measured by optical emission spectroscopy (OES, SC Tech. PSM-420). Finally, photoresist was etched using 15 mTorr O₂ and 5000 W of RF power to observe the uniformity of photoresist film etching.

3. Results and discussion

Fig. 2 shows the antenna rms voltage measured along the antenna line from the antenna power input location to the ground location for both the serpentine-type antenna and the multiple U-type antenna for 15 mTorr of Ar and 2000 W of RF power. The possible problems of the serpentine-type internal antenna for the large area application are the standing wave effect due to the long length of the antenna and high capacitive coupling due to the high voltage induced on the antenna caused by high impedance of the antenna. As shown in the figure, in the case of the 7 m serpentine-type antenna, the rms voltage of the antenna measured along the antenna line was changed significantly possibly due to the standing wave effect and the differences

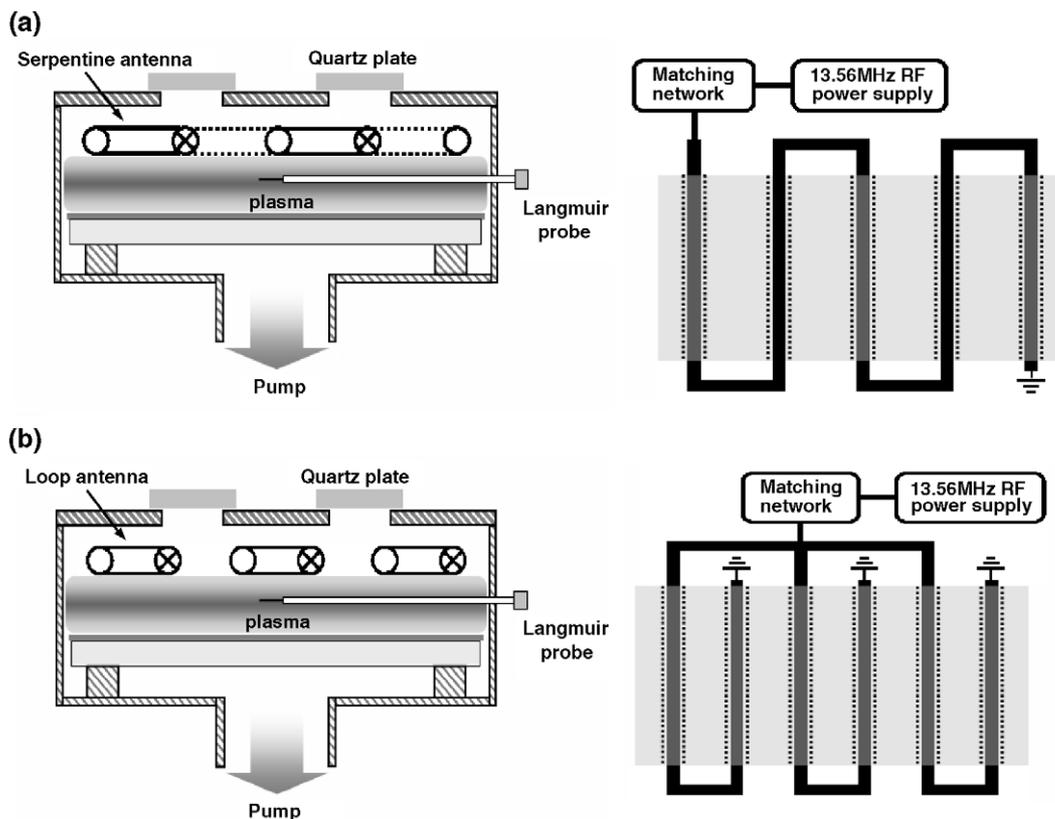


Fig. 1. Schematic diagram of inductively coupled plasma system used in the experiment. (a) Serpentine-type antenna. (b) Multiple U-type antenna.

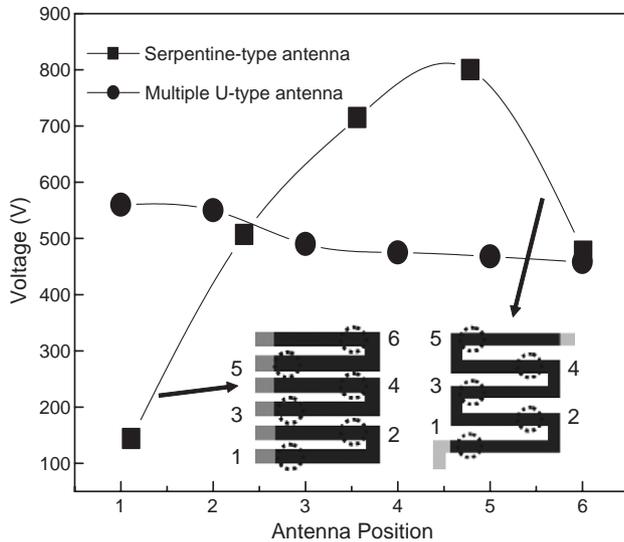


Fig. 2. RF rms voltage distribution of the serpentine-type antenna and the multiple U-type antenna along the antenna line measured by a high voltage probe at 2000 W of RF power and with 15 mTorr of Ar.

in the voltage were as high as 650 V. However, in the case of the 2.3 m U-type antenna, due to the short length of the antenna line, the rms voltage differences measured along the antenna line were about 100 V, therefore, they were significantly lower than those by the serpentine-type antenna.

Fig. 3 shows the Ar plasma density measured by a Langmuir probe and intensity of oxygen radicals measured by OES as a function of RF power from 600 to 5000 W using 15 mTorr Ar and O₂, respectively, for the serpentine-type antenna and the multiple U-type antenna. The plasma density was measured about 7.5 cm below the antenna and at the center of the chamber and 775 nm of optical emission

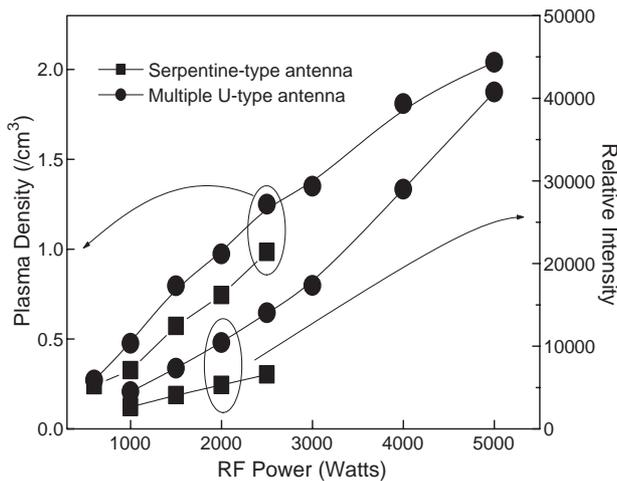


Fig. 3. Ar ion density measured by a Langmuir probe at 7.5 m below the each antenna and the relative optical emission intensity of oxygen atom (775 nm) measured using optical emission spectroscopy for the multiple U-type antenna and the serpentine-type antenna as a function of inductive power from 600 to 5000 W at 15 mTorr Ar.

line was used for the intensity of oxygen radicals. As shown in the figure, the multiple U-type antenna showed higher plasma density and higher intensity of oxygen radicals compared to those by the serpentine-type antenna. In the case of the multiple U-type antenna, the plasma density and intensity of oxygen radicals were increased almost linearly with the increase of RF power and, at 5000 W of RF power, the plasma density of about $2 \times 10^{11}/\text{cm}^3$ could be obtained. However, in the case of the serpentine-type antenna, the plasma became unstable above 2500 W of RF power possibly due to the high voltage induced on the antenna, therefore, the plasma density and intensity of oxygen radicals could not be measured above 2500 W of RF power. At 2500 W of RF power, the multiple U-type antenna showed about 25% higher plasma density and about 100% higher intensity of oxygen radicals compared to the serpentine-type antenna.

Fig. 4 shows the plasma potentials and electron temperatures measured as a function of RF power at 15 mTorr of Ar using the Langmuir probe for the serpentine-type antenna and the multiple U-type antenna. The plasma potentials and electron temperatures were also measured 7.5 cm below the antenna and at the center of the chamber. As shown in the figure, in the case of the serpentine-type antenna, with the increase of RF power from 600 to 2500 W, the plasma potential was continuously increased from 37 V to 42 V, however, in the case of the multiple U-type antenna, the plasma potential started at a lower voltage of 26 V at 600 W compared to that of the serpentine-type antenna and, with the increase of RF power, it was decreased to about 20 V at 3000 W and almost saturated. The electron temperature also showed the similar trend. As shown in the figure, the electron temperature was increased about 0.2 eV from 3.2 eV at 600 W to 3.4 eV at 2000 W for the serpentine-type antenna, however, it was decreased about 0.7 eV

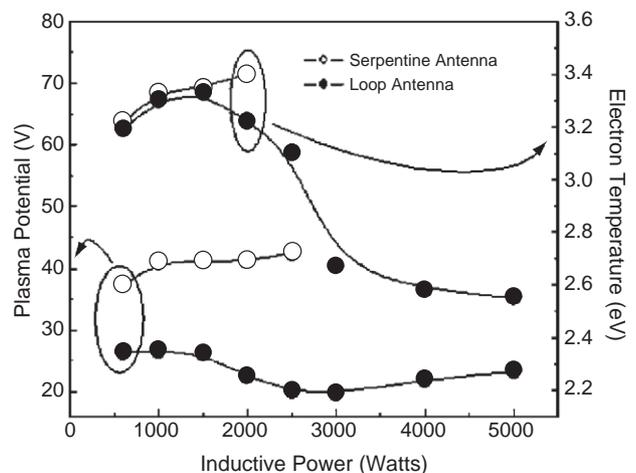


Fig. 4. Plasma potentials and electron temperatures of the serpentine-type antenna and the multiple U-type antenna measured using a Langmuir probe as a function of RF power from 600 to 5000 W at 15 mTorr Ar.

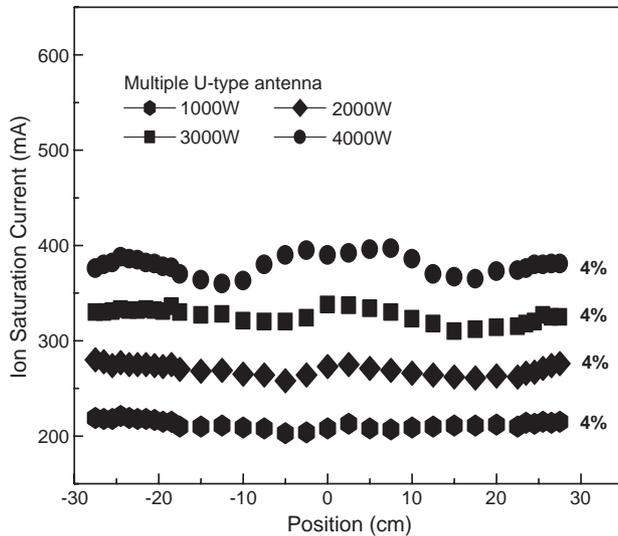


Fig. 5. Plasma uniformity of the multiple U-type antenna measured 7.5 cm below the antenna as a function of RF power from 1000 to 4000 W with 15 mTorr Ar. Ion saturation current measured using a Langmuir probe biased at -60 V was used as the estimation of plasma density.

from 3.2 eV at 600 W to 2.5 eV at 5000 W for the multiple U-type antenna. The higher plasma potentials and higher electron temperatures for the serpentine-type antenna compared to the multiple U-type are believed to be related to the higher antenna voltage induced on the antenna and higher capacitive coupling. They also appear to be the origin of the plasma instability of the serpentine-type antenna at the RF power higher than 2500 W. Also, in the figure, significant decrease of plasma potential and electron temperature appears to occur between 1500 and 3000 W for the multiple U-type antenna and it appears related to the transition from more capacitively coupling to the more inductive coupling.

Using the multiple U-type antenna, plasma uniformity was estimated as a function of RF power by measuring ion saturation current along the vertical centerline of the chamber using the Langmuir probe biased at -60 V for 15 mTorr of Ar and the results are shown in Fig. 5. As shown in the figure, the increase of RF power increased the ion current density due to the increase of plasma density, however, the plasma uniformity was maintained about 4% for all of the conditions, therefore, excellent plasma uniformity could be obtained with the multiple U-type antenna.

4. Conclusions

In this study, plasma characteristic of a newly developed multiple U-type internal linear antenna was compared with those of conventional serpentine-type antenna as the application to internal ICP source for large area TFT-LCD processing. The multiple U-type antenna showed a negligible standing wave effect and lower antenna voltage compared to the serpentine-type antenna due to the shorter antenna length and lower impedance, respectively. The multiple U-type antenna also showed a high plasma density of about $2 \times 10^{11}/\text{cm}^3$ at 5000 W of RF power and good plasma stability possibly due to the low plasma potential and low electron temperature obtained with the multiple U-type antenna. The plasma uniformity of the multiple U-type antenna measured along the vertical line of the chamber was about 4%. It is believed that the internal ICP source using the multiple U-type antenna can be applied to various plasma processing of large area TFT-LCDs which require uniform and high density plasmas.

Acknowledgments

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