Large Area Plasma Characteristics using Internal Linear ICP (Inductively Coupled Plasma) Source for the FPD processing

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Abstract

In this study, the characteristics of large area internal linear ICP sources of 1,020mm×920mm (substrate area is 880mm×660mm) were investigated using a multiple linear antennas with U-type parallel connection. Using the multiple linear antennas with U-type parallel connection, a high plasma density of 2 $\times 10^{11}/cm^3$ and a high power transfer efficiency of about 88% could be obtained at 5kW of RF power and with 20mTorr Ar. A low plasma potential of less than 26V and a low electron temperature of 2.6~3.2eV could be also obtained. The measured plasma uniformity on the substrate size of 4th generation (880mm×660mm) was about 4%, therefore, it is believed that the multiple linear antennas with U-type parallel connection can be successfully applicable to the large area flat panel display processing.

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.

2. Result

Figure 1 shows the schematic diagram of the experimental apparatus used in the experiment.

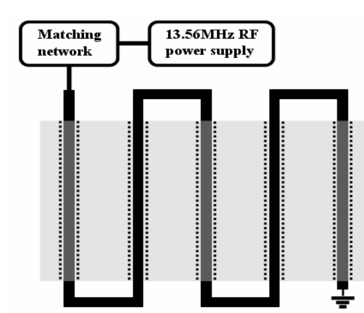

Figure. 1(a)

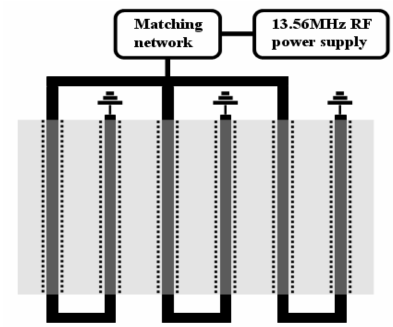

Figure. 1(b)

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 1,020mm × 830mm and the substrate holder size was 920mm × 730mm (the substrate size was 880mm × 660mm). As shown in Figure 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 Figure 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 7m and 2.3m, respectively. The antenna was made of 10mm diameter copper tubing with the outside shielded by quartz tubing. The outside diameter of the quartz tubing was 15mm and the thickness was 2mm. 13.56MHz (0~5KW) 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 (Hiden Analytical Inc., ESP) located 7.5cm 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 15mTorr O_2 and 5000W of RF power to observe the uniformity of photoresist film etching.

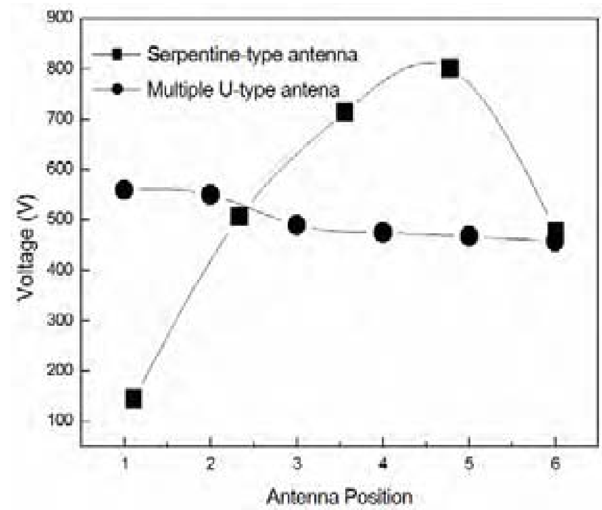

Figure. 2

Figure 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 15mTorr of Ar and 2000W 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 meter 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 in the voltage were as high as 650V. However, in the case of the 2.3 meter U-type antenna, due to the short length of the antenna line, the rms voltage differences measured along the antenna line were about 100V, therefore, they were significantly lower than those by the serpentine-type antenna.

Figure 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 5000W using 15mTorr Ar and O_2, respectively, for the serpentine-type antenna and the multiple U-type antenna. The plasma density was measured about 7.5cm below the antenna and at the center of the chamber and 775nm of optical emission line was used for the intensity of oxygen radicals

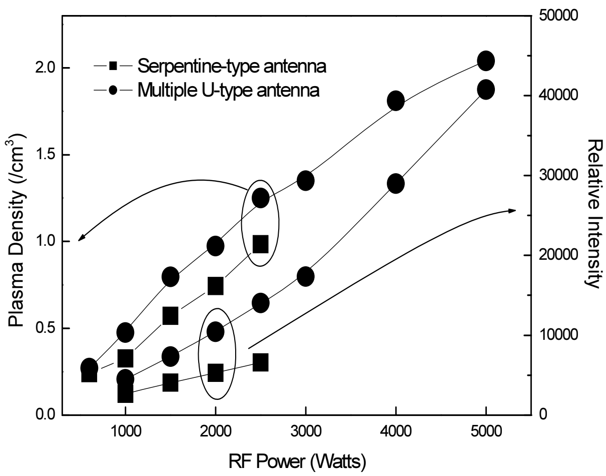

Figure. 3

. 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 5000W of RF power, the plasma density of about $2\times10^{11}/cm^3$ could be obtained. However, in the case of the serpentine-type antenna, the plasma became unstable above 2500W 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 2500W of RF power. At 2500W 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.

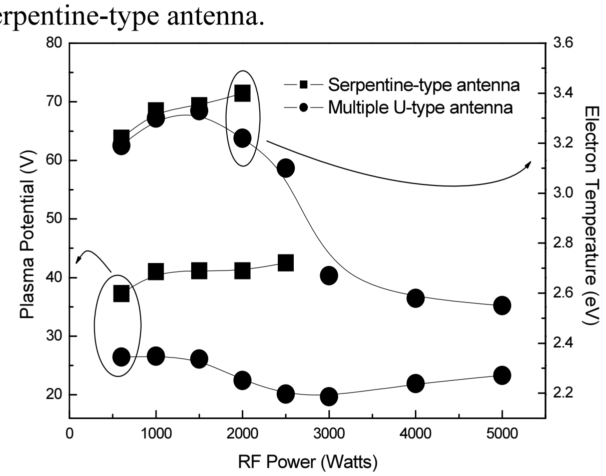

Figure. 4

Figure 4 shows the plasma potentials and electron temperatures measured as a function of RF power at 15mTorr 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 7.5cm 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 2500W, the plasma potential was continuously increased from 37V to 42V, however, in the case of the multiple U-type antenna, the plasma potential started at a lower voltage of 26V at 600W compared to that of the serpentine-type antenna and, with the increase of RF power, it was decreased to about 20V at 3000W and almost saturated. The electron temperature also showed the similar trend. As shown in the figure, the electron temperature was increased about 0.2eV from 3.2eV at 600W to 3.4eV at 2000W for the serpentine-type antenna, however, it was decreased about 0.7eV from 3.2eV at 600W to 2.5eV at 5000W for the multiple U-type antenna. The higher plasma potentials and higher electron temperatures for the serpentine-type 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 2500W. Also, in the figure, significant decrease of plasma potential and electron temperature appears to occur between 1500 to 3000W 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 -60V for 15mTorr of Ar and the results are shown in Figure 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.

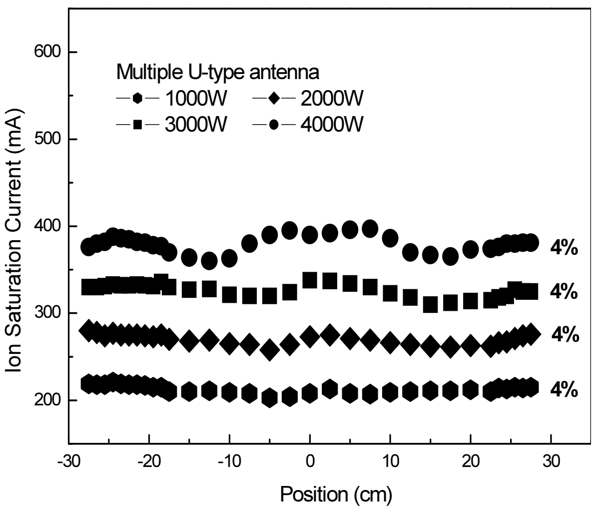

Figure. 5

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 $\times 10^{11}/cm^3$ at 5000W 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.

3. Acknowledgements

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

4. References

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