Development of Internal linear Inductively Coupled Plasma Sources for Large Area Flat Penal Display Processing

Jong Hyeuk Lim, Jung Kyun Park, Kyong Nam Kim, and
Geun Young Yeom*

Department of Materials Science and Engineering, Sungkyunkwan University,
Suwon, Kyunggi-do, 440-746, S. Korea
TEL:82-31-299-6562, e-mail: gyyeom@skku.edu.

Abstract

An inductively coupled plasma source with internal-type linear inductive antennas named as "multiple U-type antenna" was developed for the substrate size of 2,300mm × 2,000mm. High density plasmas on the order of 1.18×10^{11} *㎝*$^{-3}$ *could be obtained and the RF power of 8kW with good plasma stability.*

1. Introduction

Inductively coupled plasma (ICP) sources have been widely investigated as effective tools for microelectronic device processing. In addition, due to their geometric simplicity and ability to produce uniform high density plasma, the ICP sources have been also widely investigated for the large-area plasma processing applied to flat panel displays(FPDs) among the high density plasma sources such as ICP [1,2], electron cyclotron resonance (ECR) plasma [3], helicon plasma [4], etc.

For FPDs, as the substrate size increases, due to the extremely large size of the substrate, obtaining high plasma uniformity at high plasma density over the substrate area becomes more important. Currently, as the conventional antenna for ICP sources, external spiral-type antennas located on the top of the dielectric window are generally used to obtain uniform and high density plasmas. However, as the processing area is increased, conventional ICPs having the external spiral antenna show some problems such as a large voltage on the antenna, and the increased thickness of dielectric window, etc. [5] When the large voltage is induced on the spiral antenna, capacitive coupling to the plasma with a low power transfer efficiency and unstable impedance matching can be resulted. In addition, the increase of dielectric window thickness causes the deterioration of the power transfer efficiency from the antenna to the plasma in addition to the increase of manufacturing cost. [1,5] Also, the long antenna length can exhibit a standing wave effect which results in unstable and non-uniform plasmas. [6] To reduce the standing wave effect with increasing antenna length, various configurations of the internal-type antenna having low impedances have been investigated by a few researchers. [7,8]

In this work, we present an internal-type ICP source that enables large-area (2,300 mm × 2,000 mm) plasma generation. As the internal-type antenna, a multiple U-type antenna array, where, the antenna was composed of four pairs of single U-type antenna connected in parallel, was used and its electrical characteristics and the plasma characteristics were investigated to study the possibility of overcoming standing wave effect and large antenna voltage on the antenna. In some cases, for the uniform distribution of current to each U-type antenna, variable capacitors were connected and their effects on the plasma characteristics were also investigated.

2. Experimental

The experimental setup of the internal ICP system used in this study is schematically shown in Figure 1. The processing chamber has a rectangular shape with the size of 2,750mm × 2,350mm for the application of large-area FPD processing and the substrate size was 2,300mm × 2,000mm (larger than 7th generation substrate: 2200mm × 1870mm). As shown in Figure 1, the multiple U-type antenna was consisted of four pairs of U-type antennas connected in parallel and one side of the antenna was connected to a 10kW 13.56MHz RF power generator through a L-type matching network while the other side was connected to ground directly or to ground through a variable capacitor. To investigate the characteristics of the plasmas, a Langmuir probe (Hiden Analytical Inc., ESP) was installed at 19cm below the antenna and at the center of the chamber.(total height of the processing chamber: 650mm) The electrical properties of the internal antenna were measured by an impedance analyzer (MKS Inc) located between the matching box and the antenna.

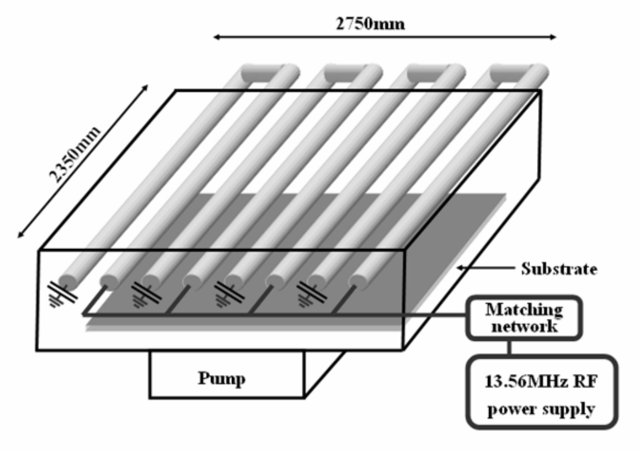

Fig. 1. Schematic diagram of an internal ICP source with the multiple U-type antenna.

3. Results and discussion

Figure 2 shows the characteristics of the plasma measured at the center of the chamber as a function of RF power at 15mTorr of Ar for the antennas connected to ground directly (grounded antenna) and the antennas connected to ground through a variable capacitor (floated antenna). Figure 2 shows the plasma density measured using a Langmuir probe as a function of RF power for the grounded antenna and the floated antenna. As shown in the figure, as the RF power is increased from 1kW to 8kW, the plasma density is increased almost linearly for both the grounded antenna and the floated antenna. However, the floated antenna shows a little higher plasma density compared to the grounded antenna and, at 8kW RF power, a high density plasma of about 1.18×10^{11} cm^{-3} could be obtained for the floated antenna.

Figure 3 shows the plasma potential and electron temperature of the plasmas measured for the condition shown in Figure 2. As shown in the figure, the plasma potential is generally decreased with the increase of RF power for both the grounded antenna and the floated antenna, and the grounded antenna shows a higher plasma potential compared to the floated antenna at a given power. The increase of RF power also decreases the electron temperature for both antennas as shown in the figure and the floated antenna also shows a lower electron temperature compared to the grounded antenna. For, 8kW of RF power and 15mTorr Ar, the grounded antenna shows the plasma potential of about 36V and the electron temperature of about 2.96eV while the floated antenna shows the plasma potential of about 28V and the electron temperature of about 2.89eV. The decrease of plasma potential and electron temperature with increasing RF power is believed to be related to the increase of inductive coupling to the plasma compared to capacitively coupling and, the increase of plasma density with the increase of RF power shown in Figure 2 is also believed to be related to not only the increase of power input to the plasma but also to the increase of inductive coupling by the antenna to the plasma. The lower plasma potential and the lower electron temperature shown for the floated antenna compared to those for the grounded antenna decrease possible contamination to the substrate by decreasing the energy of the charged particle to the chamber wall, electrodes, etc.

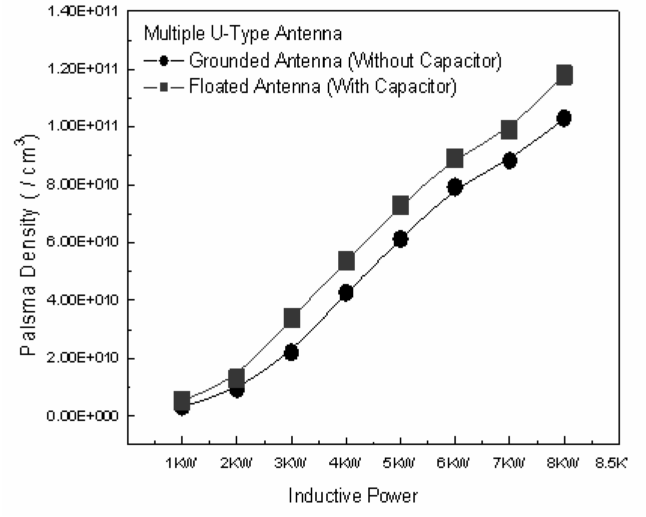

Fig. 2. Ar$^+$ ion density measured by a Langmuir probe at 19cm below the antenna as a function of RF power for the grounded antenna and the floated antenna.

Figure 4(a) and (b) show the RF RMS voltage measured for 5kW of RF power and for 15mTorr O_2 at the each U-type antenna input location along the chamber wall using a high voltage probe for the grounded antenna and floated antenna, respectively. As shown in Figure 4(a), the antenna input voltage measured along the chamber wall is not uniform for each U-type antenna of the grounded type possibly

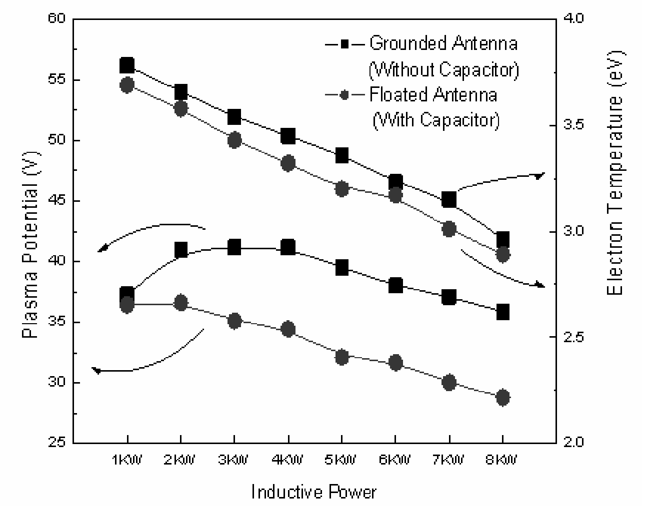

Fig. 3. Plasma potential and electron temperature calculated as a function of RF power for both antennas. RF input power to the antennas was varied from 1kW to 8kW and the operation pressure was maintained at 15mTorr of Ar.

due to the difficulty in maintaining the same antenna length for four U-type antennas from the power input to ground. By adding a variable capacitor between the ground and each U-type antenna line and, by varying the capacitance from 300pF ~ 400pF, relatively uniform voltage distribution on each antenna as shown in Figure 4(b) can be obtained. Also, as shown in Figure 4(b), by adding the capacitor, lower antenna voltages are obtained on the each antenna for the floated type. The more uniform and lower antenna voltage obtained by the floated antenna is believed to be related to formation of uniform impedance for each antenna.

When the grounded antenna is used, due to the non-uniform voltage of the antenna across the chamber, non-uniform plasma across the processing chamber could be estimated by etching photoresist covering the substrate area (not shown). However, by using the floated antenna, more uniform plasma across the chamber could be estimated. Figure 5 shows the photoresist etch uniformity measured by etching photoresist for the floated antenna at 5kW RF power and 15mTorr O_2 gas using 2-μm thick photoresist coated glass covering the substrate area of 2,300mm × 2,000mm. The etch uniformity of photoresist film was performed with O_2 gas due to the high etch photoresist etch rate compared to Ar gas and the operation with O_2 gas did not show significant differences compared to that with Ar gas. As shown in the figure, using the floated antenna, about 11% of etch uniformity, therefore, possibly the plasma density of about 11% could obtained on the substrate size of 2,300mm × 2,000mm.

4. CONCLUSIONS

In this study, as the application to the plasma processing of large-area FPD (substrate size of 2,300mm × 2,000mm: larger than 7th generation glass), an internal-type antenna composed of multiple U-type antennas was used as the ICP source and the electrical characteristics of the antenna and the plasma characteristics were investigated. Also, by connecting a variable capacitor in the range from 300~400pF at the end of the each U-type antenna line, the effect of the capacitor on the electrical characteristics of antenna and the plasma characteristics was compared. The results showed that, by connecting the capacitor to the antenna (floated antenna), lower RF RMS antenna voltage, higher RF RMS antenna current, and higher power transfer efficiency could be obtained resulting in higher plasma density, lower plasma potential, and lower electron temperature of the plasma. By using the floated antenna, at 8kW of RF power and 15mTorr Ar, the plasma density of about 1.07×10^{11} cm^{-3} could be obtained at 19cm below the antenna and at the center of the chamber. The capacitance of the capacitors connected at the end of the U-type antenna needs to be optimized to obtain uniform antenna voltage along the chamber wall, and, when the photoresist was etched using 15mTorr O_2 and at 5kW of RF power after the optimization of capacitance of the capacitor, about 11% etch uniformity of photoresist could be obtained over the substrate area of 2,300mm × 2,000mm.

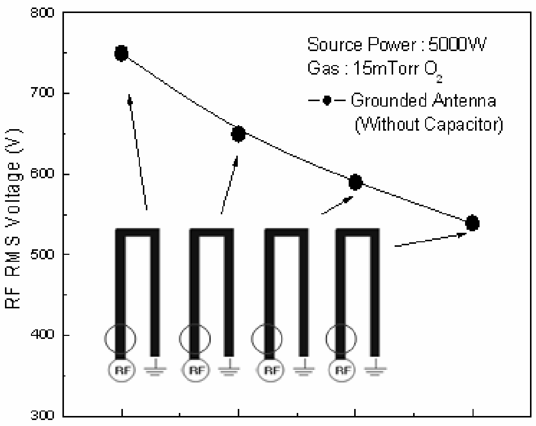

Fig. 4(a). RF RMS voltage on the multiple U-type antenna measured by a high voltage probe at an

inductive power of 5kW and an O_2 pressure of 15mTorr for the grounded antenna

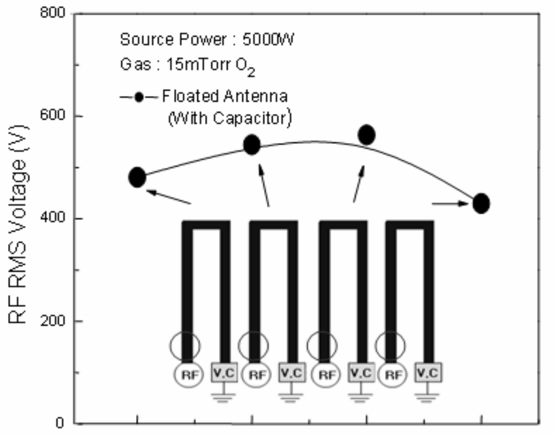

Fig. 4(b). RF RMS voltage on the multiple U-type antenna measured by a high voltage probe at an inductive power of 5kW and an O_2 pressure of 15mTorr for the floated antenna.

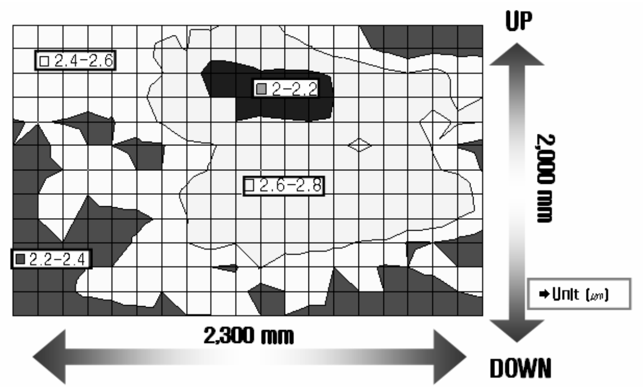

Fig. 5. Etch uniformity of photoresist film on the substrate area of 2,300mm × 2,000mm measured at 5kW RF power and 15mTorr O_2. (Unit is μm)

5. References

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