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Internal linear inductively coupled plasma (ICP) sources for large area FPD etch process applications

Y.J. Lee, K.N. Kim, B.K. Song, G.Y. Yeom*

Department of Materials Engineering, Sungkyunkwan University, Jangan-Gu Chunchun-Dong 300, Suwon 440-746, South Korea

Abstract

A large area (830 mm × 1020 mm) inductively coupled plasma source with a six internal straight antennas was developed for large area FPD (Flat Panel Display) etch process applications and the effects of magnetic fields employing permanent magnets on the plasma characteristics were investigated. Using six straight antennas connected in series into plasma and though the induction of strong electric field into the plasma by the antennas, high-density plasma on the order of $10^{11}\,cm^{-3}$ could be obtained by applying above 1500 W power to the antennas. By employing the magnetic fields perpendicular to the antenna currents using permanent magnets, improved plasma characteristics such as increase of the ion density and decrease of both electron temperature and plasma potential could be achieved in addition to the stability of the plasma possibly due to the reduction of the electron loss. However, the application of the magnetic field decreased the plasma uniformity slightly even though the uniformity within 10% could be maintained in the 800 mm processing area.

Keywords: Large area plasma; Straight antenna; Inductively coupled plasma; Etching

1. Introduction

In order to achieve the performance required for high-resolution flat panel display (FPD) devices, especially for TFT-LCD of next generation, improved dry etch processes currently indispensable technology for semiconductor industry are required for volume manufacturing and superior critical dimension control [1–3]. The plasma sources developed to date for the production of high-density and large-area plasmas mainly focused on the externally planar ICP sources [4–6]. However, due to its large impedance accompanied by the large antenna size in addition to the cost and thickness of its dielectric material, the conventional ICP systems using an external spiral antenna shows problems in extending the process area.

Currently, to solve these problems, studies on internal ICPs including both loop and straight antenna configurations, where the antenna is inserted into the plasma, are widely reported [7–8]. However, the internal type shows another practical problem such as antenna sputtering and unstable arcing resulting from the high plasma potential, which occurred more frequently when one end of the antenna is grounded and the other end of the antenna is connected to the high-frequency power.

Therefore, in this study, to improve plasma characteristics such as plasma density, plasma uniformity, and plasma potential of internal straight antenna inductively coupled plasma sources with a linear type antenna, magnetic fields employing permanent magnets have been used and the characteristics of the plasma have been investigated and compared with those obtained without the magnets.

2. Experiment

Fig. 1 shows the schematic diagram of the internal type linear inductively plasma source used in the

*Corresponding author. Tel.: +82-31-290-7395; fax: +82-31-290-7410.

E-mail address: gyyeom@yurim.skku.ac.kr (G.Y. Yeom).

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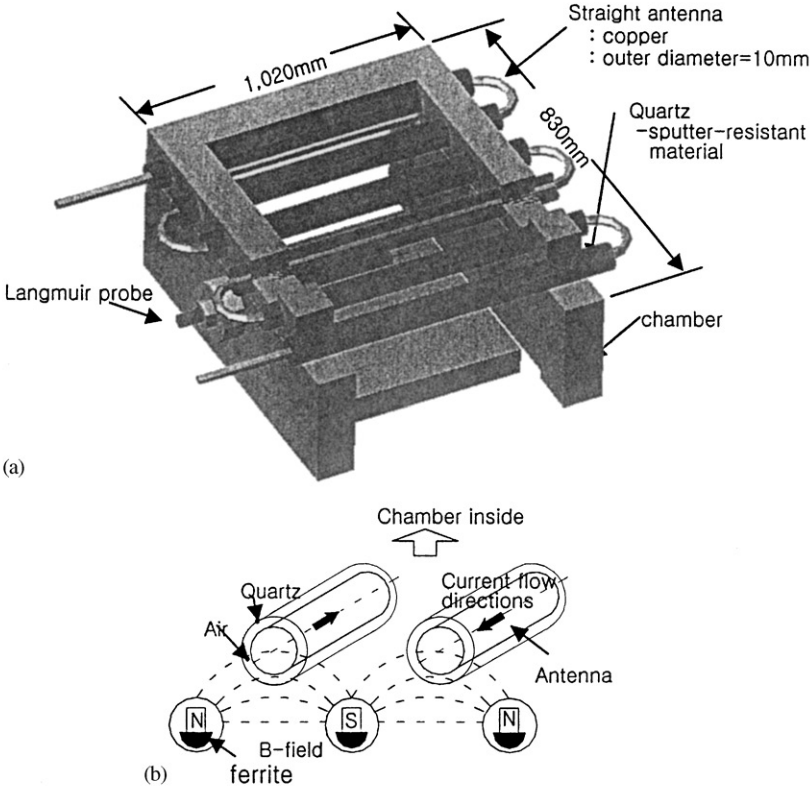

Fig. 1. (a) The schematic diagram of the internal type linear inductive plasma source used in the experiment. (b) Arrangement of the permanent magnets in the source.

experiment. The processing chamber was rectangular shape made of stainless steel with the size of 830 mm × 1020 mm for the application of large-area FPD panel processes. Six linear antennas were embedded in the vacuum chamber and each linear antenna was connected in series as a serpentine type at the outside of the vacuum chamber. The outer diameter of the quartz pipe holding the internal straight antenna conductor was 15 mm and the thickness of the quartz was 2 mm. The antenna was made of 10 mm diameter copper tube. One end of the connected antenna was grounded and the other end was connected to 13.56 MHz rf power to generate inductive discharges.

Magnetic field effects perpendicular to current carrying antennas permanent magnets having 3000 G on the magnet surface were used. Plasma characteristics such as, plasma density, plasma uniformity, and plasma potential of internal straight antenna inductively coupled plasma sources were measured using the Langmuir probes (Hiden Analytical Inc., ESP) located on the sidewall of the chamber. The Langmuir probe was installed 17 cm and 5 cm below the straight antenna. The Ar gas was used to monitor the above-mentioned plasma characteristics.

3. Results and discussion

Fig. 2(a) shows the effect of rf power to the antenna, operation pressure, and the magnetic field on the ion density measured by a Langmuir probe using Ar from 5 to 25 mTorr and rf power from 600 to 2000 W. Six internal linear antennas were connected in series as a serpentine type. The total length of the antenna was 7.89 m and the distance between the adjacent linear antennas was 11.4 cm. The ion density was measured 17 cm below the antenna. As shown in the figure, the increase of rf power to the antenna increased the ion density almost linearly and the increase of Ar operation pressure from 5 to 25 mTorr also increased the ion density. At 2000 W of rf power and 25 mTorr Ar, the ion density obtained without the magnetic field was about $6.5 \times 10^{10}\,cm^{-3}$.

As shown in Fig. 2(a), the application of the magnetic field perpendicular to the electric field generated by the antenna current generally increased the ion density about 50%. The maximum ion density obtained with the magnet was about $8.2 \times 10^{10}\,cm^{-3}$ at 2000 W of rf power and 25 mTorr Ar; therefore, the obtained ion density was close to $10^{11}\,cm^{-3}$. These ion densities were

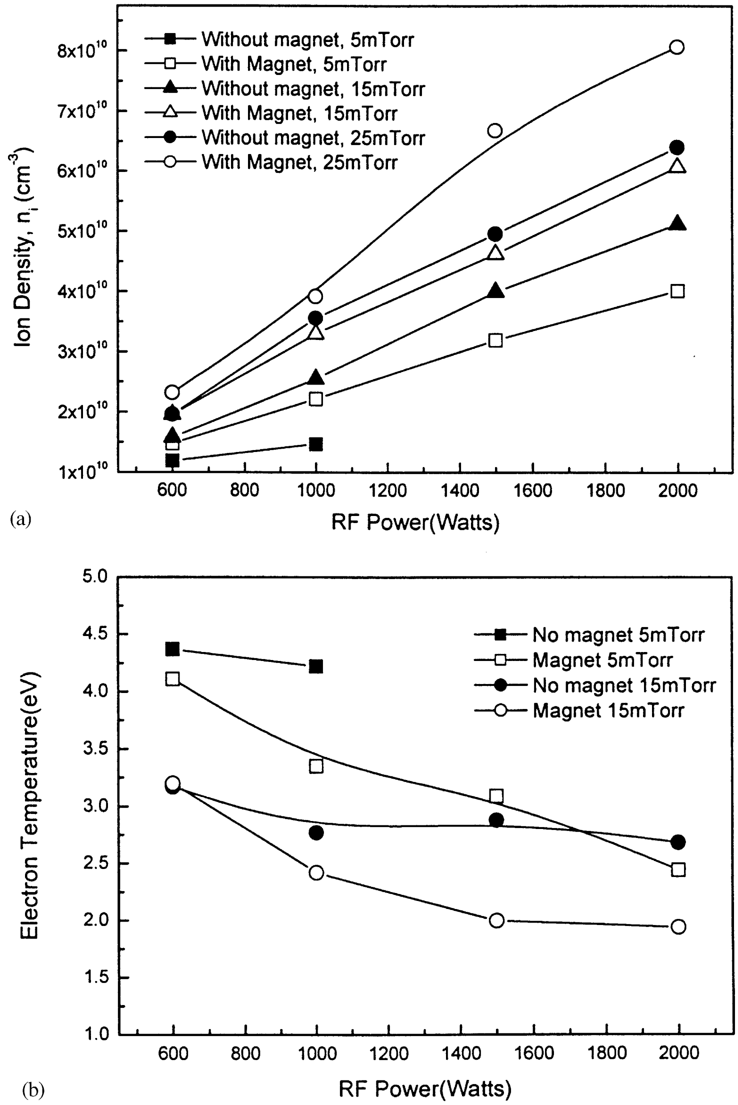

Fig. 2. The effect of rf power to the antenna, operation pressure, and the magnetic field on the ion density measured by a Langmuir probe using Ar from 5 to 25 mTorr and rf power from 600 to 2000 W. Six internal linear antennas were connected in series as a serpentine type. The total length of the antenna was 7.89 m and the distance between the adjacent linear antennas was 11.4 cm. The ion density was measured 17 cm below the antenna.

measured at 17 cm below the antenna and, when the ion density was measured 5 cm below the antenna, the ion density was increase two times in general. Therefore, by applying more than 1500 W of rf power, we were able to identify the formation of high-density plasmas having ion density higher than 10^{11} cm^{-3}. The increase of ion density by the application of the magnetic field appears to be from the helical motion of the electrons; therefore, from the increase of electron-neutral collision frequency by increasing the path of electron length and from the decrease of electron loss by decreasing its mobility. In fact, the applied magnetic field was configured so that energetic electrons accelerated by the induced E field have $E \times B$ force, therefore, to be more efficiently confined [9–10]. Also, at 5 mTorr, the operation of the source was unstable without the magnetic field and frequent arcing could be observed at high rf power conditions above 1500 W. However, after the application of the magnetic field, no such instabilities could be observed.

Fig. 2(b) shows the effect of rf power to the antenna, operation pressure, and the magnetic field on electron temperature measured by a Langmuir probe using Ar from 5 to 15 mTorr and rf power from 600 to 2000 W.

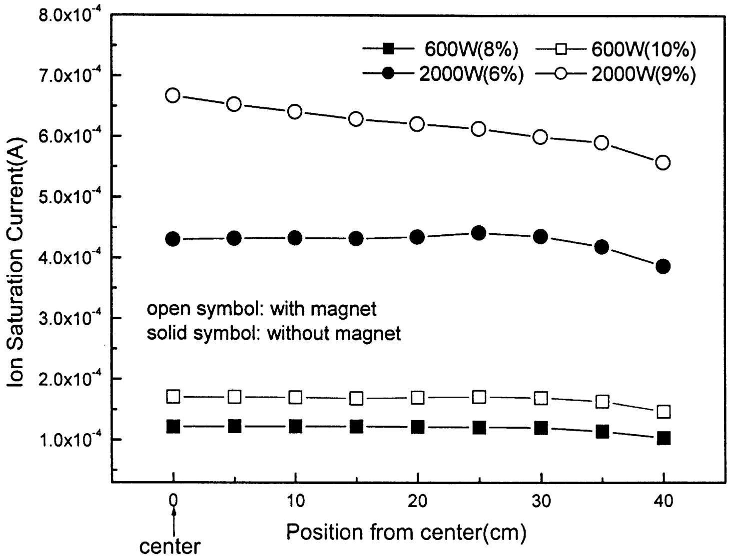

Fig. 3. Ion saturation current measured by the Langmuir probe at 5 cm below the antenna as a function of position of the chamber along the antenna line and with/without magnetic field. The rf power to the antenna was 600 and 2000 W and the operation pressure was 15 mTorr Ar.

As shown in the figure, the electron temperature was in the range from 2 to 4.5 eV and the increase of rf power slightly decreased the electron temperature and the increase of operation pressure decreased the temperature, too. The application of the magnetic field also decreased the electron temperature. If electron loss is increased by the decrease of electron-neutral collision frequency, electron temperature should be increased to maintain the plasma. The increase of electron temperature at the lower operation pressure and without magnetic field appears to be related to the increased loss of the electron. Plasma potentials were also measured and were in the range from 25 to 45 eV and the increase of rf power and the increase of operational pressure also decreased the plasma potential, in general, while the application of the magnetic field did not show the significant change (not shown).

Fig. 3 shows the ion saturation current measured by the Langmuir probe at 5 cm below the antenna as a function of position of the chamber along the antenna line. The ion saturation current was used as the measure of plasma density. The rf power to the antenna was 600 and 2000 W and the operation pressure was15 mTorr Ar. As shown in the figure, the increase of rf power to the antenna from 600 to 2000 W not only increased the plasma density but also improved the plasma uniformity possibly due to the change from capacitively coupling mode to inductively coupling mode of the plasma. Along the 40 cm from the center of the chamber, 6% of plasma uniformity was obtained at 2000 W of rf power without the magnetic field. When the magnetic field was applied, the increase of rf power also increased plasma density and improved the plasma uniformity. The application of the magnetic field further increased plasma density along the chamber position as observed in Fig. 2(a); however, the plasma uniformity was somewhat degraded even though the plasma non-uniformity was still less than 10%. We believe that, by optimizing the magnetic field configuration, the plasma uniformity can be further improved.

4. Conclusions

In a large-area (830 mm × 1020 mm) internal linear type inductively coupled plasma source has been developed and the effects of rf power to the antenna, operation pressure, and static magnetic field on the plasma characteristics were investigated. The magnetic field supplied by the permanent magnets was configured perpendicular to the induced electric field by the antenna current to confine the electron motion. The increase of rf power and operation pressure increased the plasma density and decreased electron temperature, and using the developed source, the plasma density higher than $10^{11}\,cm^{-3}$ could be obtained by applying above 1500 W of rf power. The application of the magnetic field increased plasma density about 50% and decreased electron temperature possibly due to the reduction of the electron loss. The application of the magnetic field also increased the stability of the plasma; however, the plasma uniformity was slightly decreased even though the uniformity was maintained within 10%.

Acknowledgements

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