Characteristics of linearly Extended Inductively Coupled Plasmas with Magnetic Fields

Young Joon Lee , Kyung Nam Kim , Byoung Kwan Song, and Geun Young Yeom
Department of Materials Engineering, Sungkyunkwan University, Suwon, Korea, 440-746
Phone : +82-31-299-6562 , E-mail : sdpark74@mail.skku.ac.kr

Abstract

A large-area (830mm× 1,020mm) inductively coupled plasma source with a six internal straight antennas was developed for large area FPD etch process applications and the effects of magnetic fields employing permanent magnets on the plasma characteristics were investigated. By employing the magnetic fields perpendicular to the six straight 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 800mm processing area.

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] The plasma sources developed to date for the production of high-density and large-area plasmas mainly focused on the externally planar ICP sources. [2-4] 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. [5] 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. Experimental

The processing chamber was rectangular shape made of stainless steel with the size of 830mm×1,020mm 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 15mm and the thickness of the quartz was 2mm. The antenna was made of 10mm diameter copper tube. One end of the connected antenna was grounded and the other end was connected to 13.56MHz rf power to generate inductive discharges.

Magnetic field effects perpendicular to current carrying antennas permanent magnets having 3,000G on the magnet surface were used. Figure 1 shows the arrangement of the permanent magnets in the source. 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 17cm and 5cm below the straight antenna.

3. Results and discussion

Figure 2 shows the effect of rf power to the antenna,

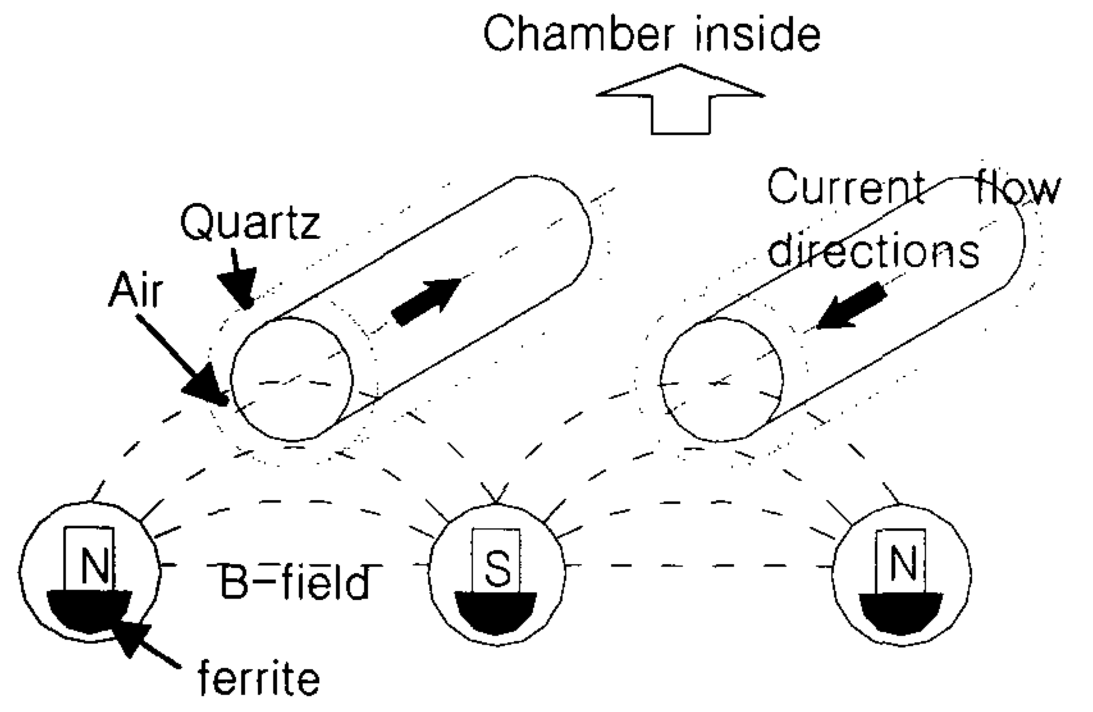

Figure 1. The arrangement of the permanent magnets in the source.

and the magnetic field on the ion density and the electron temperature measured by a Langmuir probe using Ar at 15mTorr and rf power from 600 to 2000Watts. Six internal linear antennas were connected in series as a serpentine type. The total length of the antenna was 7.89m and the distance between the adjacent linear antennas was 11.4cm. The ion density was measured 17cm below the antenna. As shown in the figure, the increase of rf power to the antenna increased the ion density almost linearly. At 2000Watts of rf power and 25mTorr Ar, the ion density obtained without the magnetic field was about $6.5x10^{10}cm^{-3}$.

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 $8.2x10^{10}cm^{-3}$ at 2000Watts of rf power and 25mTorr Ar, therefore, the obtained ion density was close to $10^{11}cm^{-3}$. These ion densities were measured at 17cm below the antenna and, when the ion density was measured 5cm below the antenna, the ion density was increase two times in general. Therefore, by applying more than 1500Watts 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.

Also, as shown in the figure 2, the electron temperature was in the range from 2 to 4.5eV and the increase of rf power slightly decreased the electron temperature. 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 without the magnetic field appears to be related to the increased loss of the electron.

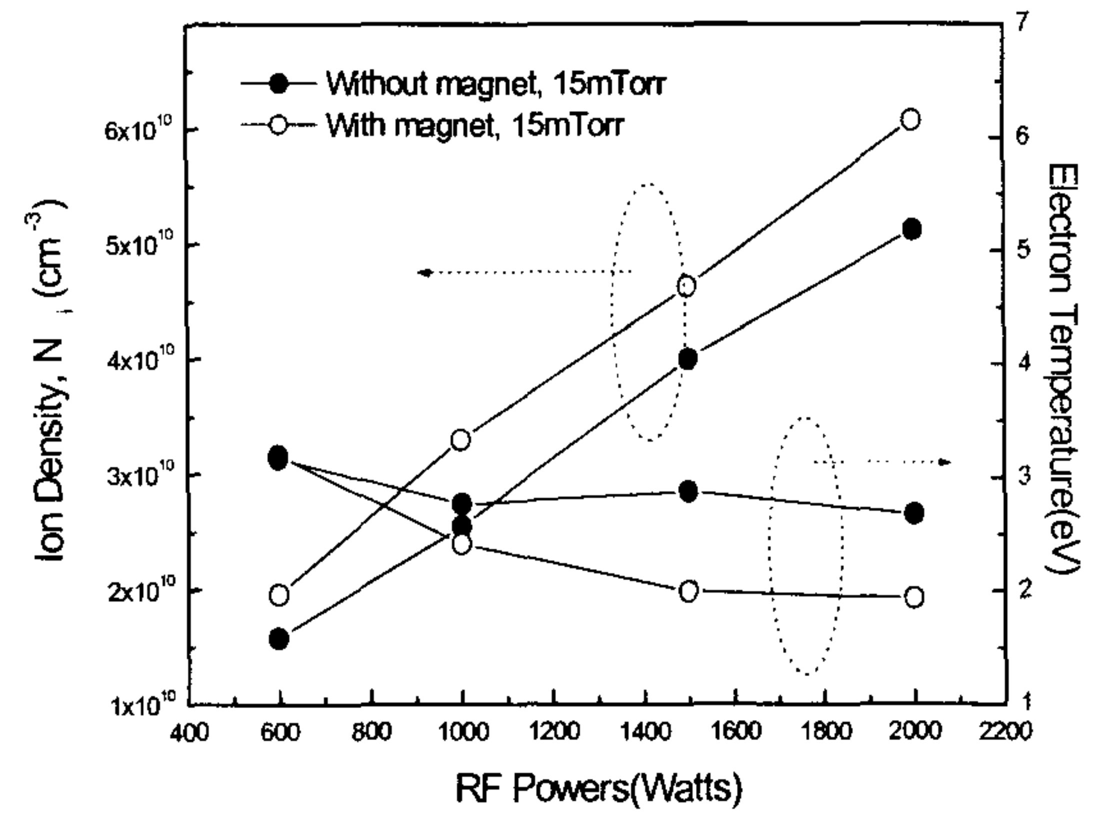

Figure 2. The effect of rf power to the antenna and the magnetic field on the ion density and the electron temperature measured by a Langmuir probe using Ar, at 15mTorr and rf power from 600 to 2000Watts.

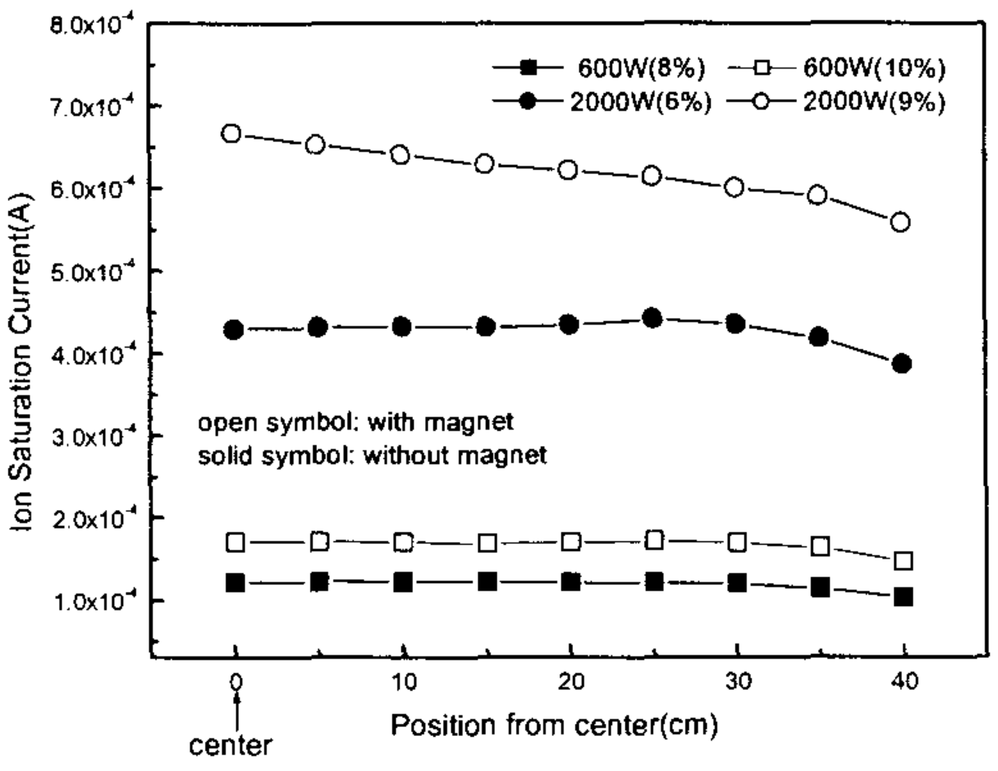

Figure 2. Ion saturation currents measured by the Langmuir probe at 5cm below the antenna as a function of position of the chamber along the antenna line and with/without magnetic field. Rf power to the antenna was 600Watts and 2000Watts and the operation pressure was 15mTorr Ar.

Figure 3 shows the ion saturation current measured by the Langmuir probe at 5cm 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. Rf power to the antenna was 600Watts and 2000Watts and the operation pressure was 15mTorr Ar. As shown in the figure, the increase of rf power to the antenna from 600Watts to 2000Watts 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 40cm from the center of the chamber, 6% of plasma uniformity was obtained at 2000Watts 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 Figure 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. Conclusion

In a large-area (830mm×1,020mm) internal linear type inductively coupled plasma source has been developed and the effects of rf power to the antenna, 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 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 1,500Watts 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 %.

5. Acknowledgements

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

6. References

[1] F. Mendoza, B. Sarette, D. McReynolds, B. Richardson, and J. Holland, Semiconductor International, June 143 (1999)

[2] J. Yu, D. Shaw, P. Gonzales, G.J. Collins, J. Vac. Sci. Technol. A, 13(3) 871 (1995)

[3] P.W. Lee, S.S. Kim, S.H. Seo, C.S. Chang, H.Y. Chang, T. Ichiki, and Y. Horiike, Jpn. J. Appl. Phys., 39 L548 (2000)

[4] M.H. Khater and L.J. Overzet, J. Vac. Sci. Technol. A, 19 (3) 785 (2001)

[5] Y. Wu and M.A. Lieberman, Appl. Phys. Lett., 72 777 (1998)