22P027-O

Influence of trench shape of ring-shaped hollow electrode on high-density capacitive coupled plasma
高密度容量結合型プラズマに及ぼすリング状ホロー電極溝形状の影響

Yasunori Ohtsu, Yoshiki Yahata, Johji Kagami*, Yasushi Kawashimo*, Tatsuya Takeuchi* and Tatsuya Misawa
大津康徳，矢羽田祥貴，加々見丈二*，川下安司*，竹内達也*，三沢達也

Department of Electrical and Electronic Eng., Graduate School of Science and Engineering, Saga University
1, Honjo-machi, Saga 840-8502, Japan
佐賀大学大学院工学系研究科電気電子工学専攻　〒840-8502　佐賀市本庄町1
**Shinko Seiki Co., Ltd.*
*神港精機株式会社

Influence of trench shape of ring-shaped hollow electrode on high-density capacitive coupled plasma has been investigated at a wide range of argon gas pressure and various input powers. The trench shapes selected are well-typed, taper-typed, and step-typed ones. It is seen at the lower pressure less than 200mTorr that plasma density for well-typed shape is the highest among three shapes, while for step-typed shape, is the lowest. For the higher pressure more than 200mTorr, plasma density for step-typed shape has the highest value. It was revealed that plasma density for all typed shapes was almost proportional to input power.

1. Introduction

In the microelectronic industry, the parallel-plate radio frequency (RF) plasma source operating at 13.56 MHz is widely used [1]. This is because its geometry is very simple. In especial, capacitively coupled plasma (CCP) source is frequently utilized for dry etching, plasma enhanced chemical vapor deposition and sputtering processes. However, there are the following problems; (1) density and energy of ions can be independently not controlled by external parameters such as power for the dry etching and sputtering process and (2) plasma density is less than 10^9cm^{-3} so that the rates of etching and deposition are very low. This is main problem for RF capacitively coupled plasma. In order to improve this problem, some solutions based on (1) the proposal of dual frequency with high and low frequencies [2] and (2) the high driving frequency [3] such as VHF region have been proposed.

For microelectronics and flat panel displays industries, major uniformity problems in plasma processing are occurred under the plasma excited at higher frequencies. Recently, the large-area capacitive discharge at frequencies higher than the usual industrial frequency of 13.56MHz has been studied numerically [4] and experimentally [5]. From these studies at higher frequency operation, it has been pointed out that standing wave and skin effects can be important limitations for plasma processing uniformity, which cannot be described by conventional electrostatic theory. Since the conventional driving frequency is 13.56 MHz, it will be required to develop high-density and uniform large plasma under the operation of the conventional driving frequency and the simple configuration of geometry.

On the other hand, in our previous studies on plasma source, we have developed the high-density plasma with ring-shaped hollow electrode of well-typed shape[6].

In this paper, influence of trench shape on the high-density capacitive discharge plasma has been investigated in ring-shaped hollow cathode discharge. The plasma parameters of density and temperature of electrons are measured by Langmuir probe at various external conditions of gas pressure and RF input power.

2. Experimental setup

Figure 1 shows a schematic diagram of aluminum cylindrical vacuum vessel with 160 mm in diameter and 200 mm in length. The ring-shaped hollow electrode is mounted as a top electrode along the central axis in the vessel. In the experiment, a base pressure in the vessel is less than 10^{-6} Torr. Ar gas is introduced from 40 to 400 mTorr. The RF power supply of 13.56 MHz was input through a matching box between the RF powered electrode and the grounded vessel. The backside of the electrode is covered by the grounded metal enclosure so as to avoid an additional discharge between the electrode and the grounded chamber. The RF input power is fixed at

50 W corresponding to the RF power density of 0.64 W /cm^2.

Figure 2 shows cross sectional images for three typed shapes selected from well-typed, taper-typed and step-typed trenches.

3. Results and discussion

Figure 3 shows plasma density as a function of Ar gas pressure at RF input power of 50 W. The measured position is at r = 37.5 mm and z = 12 mm under an inlet of trench. It is seen that for the well-typed trench plasma density increases with increasing gas pressure p for p < 200 mTorr and then decreases for p < 400 mTorr. For the taper-typed trench, plasma density raises with gas pressure for p < 200mTorr and then saturates. On the other hand, plasma density increases with increasing gas pressure in the case of the step-typed trench. Therefore, it is found that the well-typed trench has the highest value of plasma density for p < 200 mTorr, while for p > 200 mTorr the step-typed trench gets its maximum value.

The hollow cathode effect is satisfied by the relation[6] of $2d_s < W < \lambda_{en}$, where d_s, W and λ_{en} are sheath thickness in the trench, trench width and electron-neutral mean free path, respectively. The influence of trench-shape on plasma density as a function of gas pressure is mainly ascribed by the relation between W and λ_{en}. This is because the mean free path is inversely proportional to gas pressure.

It was also found that plasma density increased proportionally with increasing RF input power for all typed trenches. This results indicates that the ring-shaped hollow cathode RF discharge proposed is very useful for the stable plasma processing sources.

4. Conclusions

The influence of trench-shape on high-density plasma production has been investigated in ring-shaped hollow cathode RF discharge. It is found that for the lower gas pressure the well-typed trench is the highest value of plasma density, while for the higher gas pressure the step-typed trench is attained to be high-density plasma.

Acknowledgments

This work was partially supported by Grant-in-Aid for Scientific Research (C) (23540577).

References

[1] S. J. Fonash: IBM J. Res. Develop. **43** (1999)103.

[2] T. Makabe and Z. Lj. Petrovic: Appl.Surf.Sci., **192** (2002) 88.

[3] M. Tanda, M. Kondo, A. Matsuda: Thin Solid Films **427** (2003)33.

[4] M. A. Lieberman, J. P. Booth, P. Chabert, J. M. Rax and M. M. Turner: Plasma Sources Sci. Technol. **11** (2002)283.

[5] S Rauf, K Bera and K Collins: Plasma Sources Sci. Technol. **17** (2008)035003.

[6] Y.Ohtsu and H.Urasaki: Plasma Sources Sci.Technol. **19**(2010) 045012.

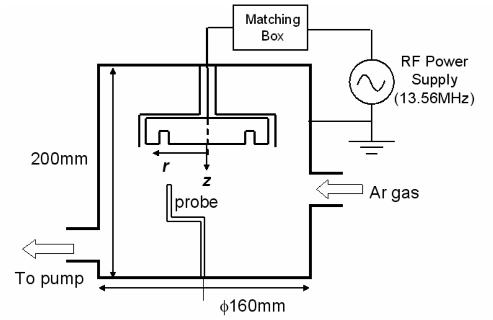

Fig.1. A schematic diagram of experimental setup.

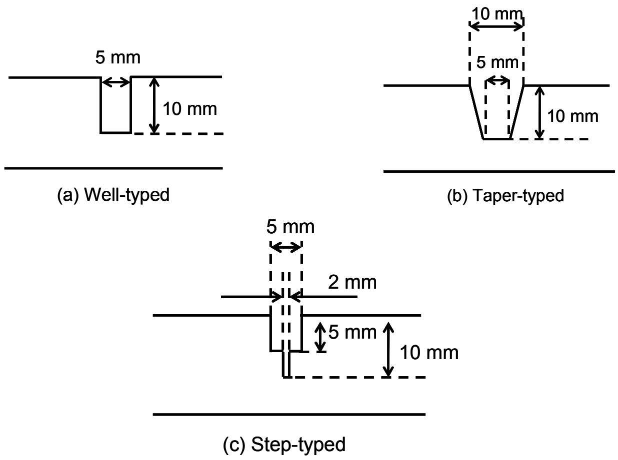

Fig.2. Structures of three typed trenches selected, where (a) the size for the well-typed trench is 5 mm width and 10 mm depth, (b) for the taper-typed trench, the widths of the inlet and the bottom are 10 and 5 mm, respectively and the depth is 10 mm, (c) the step-typed trench has a large trench with 5 mm width and 5 mm depth and a small trench with 2 mm width and 5 mm depth.

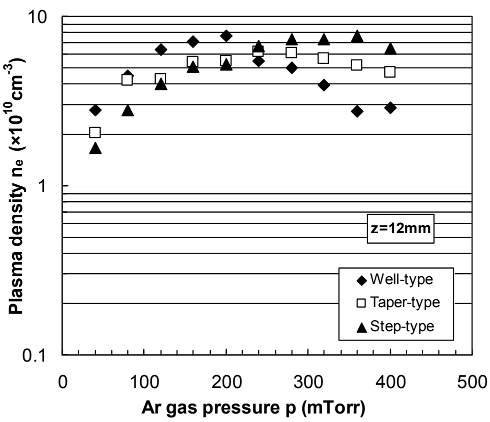

Fig.3. Plasma density as a function of Ar gas pressure at fixed RF input power of 50 W.