The study of silicon etching using the high density hollow cathode plasma system

Jinsu Yoo, Junhoi Lee, U. Gangopadhyay, Kyunghae Kim and Junsin Yi
School of Electrical and Computer Engineering, Sungkyunkwan University
300 Chunchun-dong, Jangan-gu, Suwon, Kyunggi-do, Korea (440-746),
TEL : +82+31 290-7139, FAX: +82+31 290-7179, e-mail : yi@yurim.skku.ac.kr

Abstract

In the paper, we investigated silicon surface microstructures formed by reactive ion etching in hollow cathode system. Wet anisotropic chemical etching technique use to form random pyramidal structure on <100> silicon wafers usually is not effective in texturing of low-cost multicrystalline silicon wafers because of random orientation nature, but High density hollow cathode plasma system illustrates high deposition rate, better film crystal structure, improved etching characteristics. The etched silicon surface is covered by columnar microstructures with diameters form 50 to 100nm and depth of about 500nm. We used SF_6 and O_2 gases in HCP dry etch process. This paper demonstrates very high plasma density of 2×10^{12} cm^{-3} at a discharge current of 20 mA. Silicon etch rate of 1.3 μs/min. was achieved with SF_6/O_2 plasma conditions of total gas pressure=50 mTorr, gas flow rate=40 sccm, and rf power=200 W. Our experimental results can be used in various display systems such as thin film growth and etching for TFT-LCDs, emitter tip formations for FEDs, and bright plasma discharge for PDP applications. In this paper we directed our study to the silicon etching properties such as high etching rate, large area uniformity, low power with the high density plasma.

1. Introduction

The first hollow cathode from an aluminium sheet shaped into a simple retangular tube was used in 1916 by Friedrich Paschen with a helium d.c discharge for study of helium spectral lines.[1] Also, Radiofrequency (r.f.) hollow cathodes were first studied by Horwitz.[2]

Various forms of surface texturing approach have been applied to mc-Si surface including laser structuring,[3,4] mechanical grinding,[5] porous-Si etching ,[6-8] photo-lithographically defined etching,[9] and Reactive Ion Etching (RIE) method.[10] Historical review for RIE texturing of silicon can be found in Sandia report (S.H.Zaidi, SAND2000-0919, Sandia contract #BE-8229, April 2000). In the SF_6/O_2 plasma, SF_6 is the source of active fluorine that etches silicon and O_2 supply oxygen radicals that passivate the surface of the etched silicon structures. An extensive study of SF_6/O_2 RIE in parallel plate reactors was done by Sandia group[11]. We report a successful attempt to form a silicon emitter tips by employing a new hollow cathode discharge in reactive RF sputtering system.

2. Experimental

In experiment, the optogalvanic(OG) signal was monitored the plasma conductivity variation caused by absorption of the radiation at a certain spectral transition of the plasma medium. The OG effect technique was developed for the purposes of laser spectroscopy and has been used in plasma diagnosis; that is, ionization rate, atomic density, translational temperature of the plasma. The experimental setup for measurement of the emission and OG signal is shown schematically in Fig. 1. For the OG signal measurement, the laser beam from a CW single-frequency diode laser (Enviromental Optical Sensor, Inc., Model ECU-2010) was directed axially along the bore of the hollow cathode. The emission and absorption intensity has been btained by a low-noise photo-diode (New Focus Inc., model 1801) that was placed along the axis by detecting the spatially averaged intensity with the help of two identical biconvex lenses (f = 120 nm, diameter of 50.8 mm).

This paper investigated characteristics of a newly developed high density hollow cathode plasma system. Then we applied the HCP system in Si surface etching study. We used SF_6 and O_2 gas for the dry etch of silicon wafer surface. In our experiment, the inductive power was 200 W at 13.56 MHz of RF power. The total pressure (SF_6+O_2) was 50 mTorr and etching time was 5 min. Surface morphology was observed using scanning electron microscope (SEM, philips, XL30FEG). The oxygen partial pressure was maintained less than 10 % of the total chamber pressure.

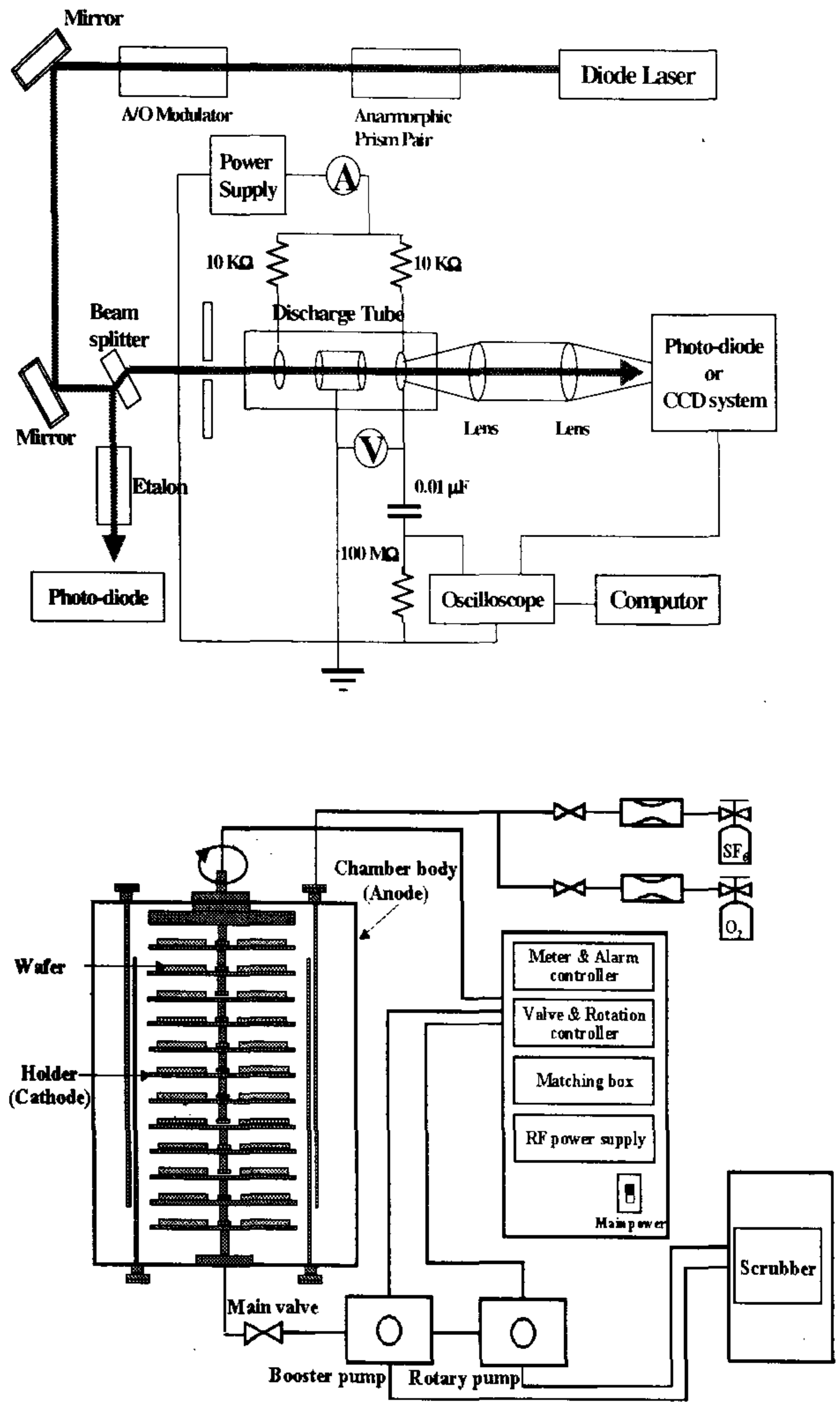


Fig. 1. Experimental setups (top) plasma diagnosis system and (bottom) HCP silicon etching system.

3. Results and discussion

Fig. 2. shows the emission intensity of a hollow cathode in function of positions of the discharge in the radial direction. Since the buffer gas fills the discharge space uniformly, the spatial emission distributions of buffer gas atoms approximately show the characteristic of the spatial distribution of electrons in the discharge. Therefore, the electron density is almost uniform and decrease linearly as approaching to the cathode wall. Hence, the hollow cathode represents a unique source of dense and stable plasma in negative glow region. At the same power, the hollow-cathode exhibits a plasma density one to two orders of magnitude higher than of conventional planar electrodes. The magnitude of OG signal exhibited a certain dependence on positions of hollow cathode in the radial direction.

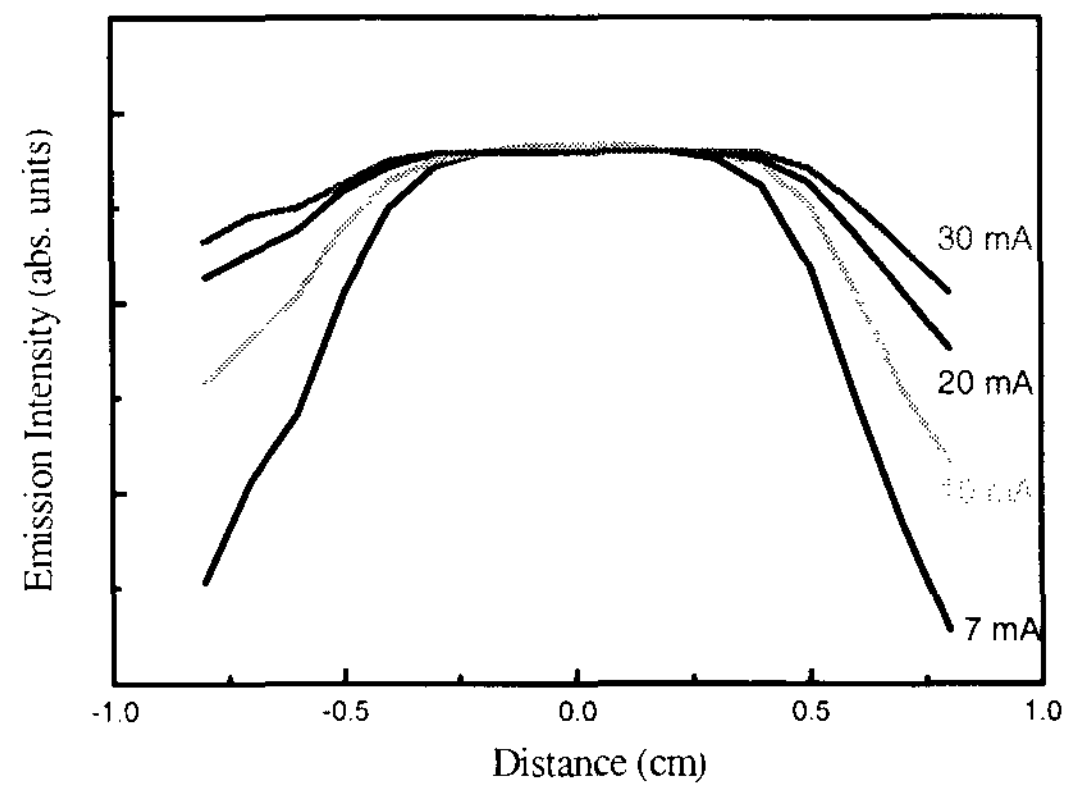


Fig. 2. The radial profile of the emission intensity of a hollow cathode system. The decrease of this signal corresponds to the decrease of electron density.

The spatial distribution of magnitude of OG signal across the diameter of a hollow cathode are shown in Fig. 3. In order to explain the higher OG signal magnitude by us in the cathode wall than in the center, it is necessary to consider the electron density distribution. The electron density is higher and uniform in the center than in the cathode wall as shown Fig 2. At the cathode wall, where the electron density is lower, the ionization rate by electron impact is negligible. So, the OG signal has maximum amplitude in the cathode wall and it decreases by one order of magnitude in the center. The OG signal has minimum of constant value in the center. The effect due to the incresaed collision ionization rate at center of tube because electron density is higher and uinform. Hence, the hollow cathode represents a unique source of dense and uniform plasma.

To estimate the plasma density, the absorption spectra have been measured. Fig. 4 shows the plasma density as a function of the discharge current. The density was ranged from 10^{11} to 10^{12} cm^{-3}. The HCP system generated plasma ion density up to $2x10^{12}cm^{-3}$. This high ion concentrations expected to yield high deposition rates and to give high etch rates for a display system fabrication.

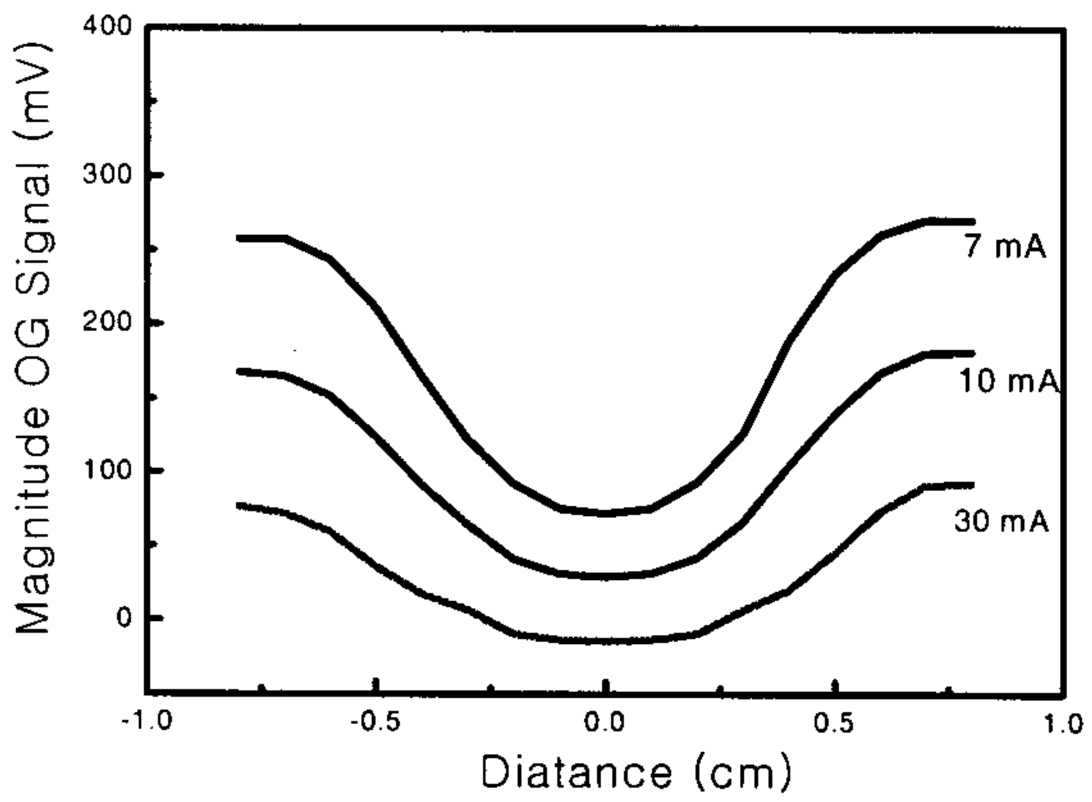


Fig. 3. The magnitude of OG signal at various positions of hollow cathode in the radial direction.

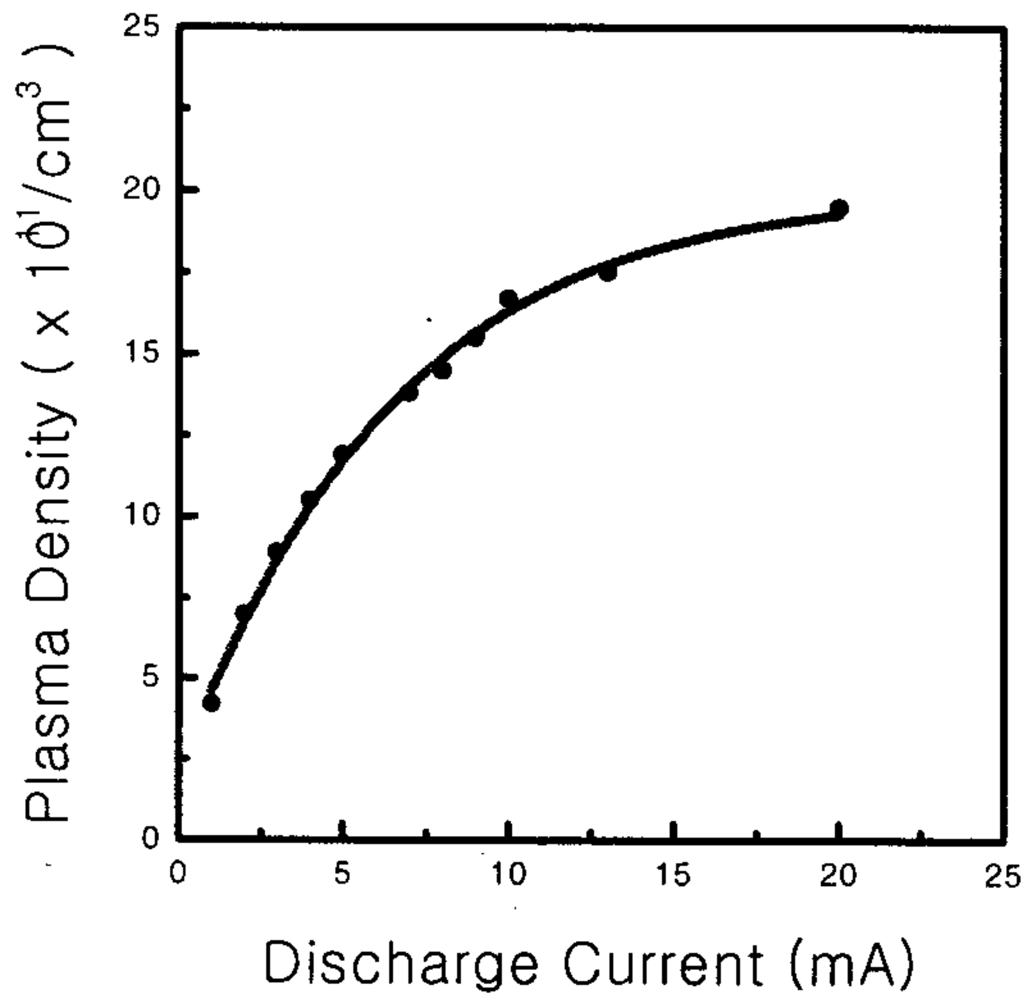
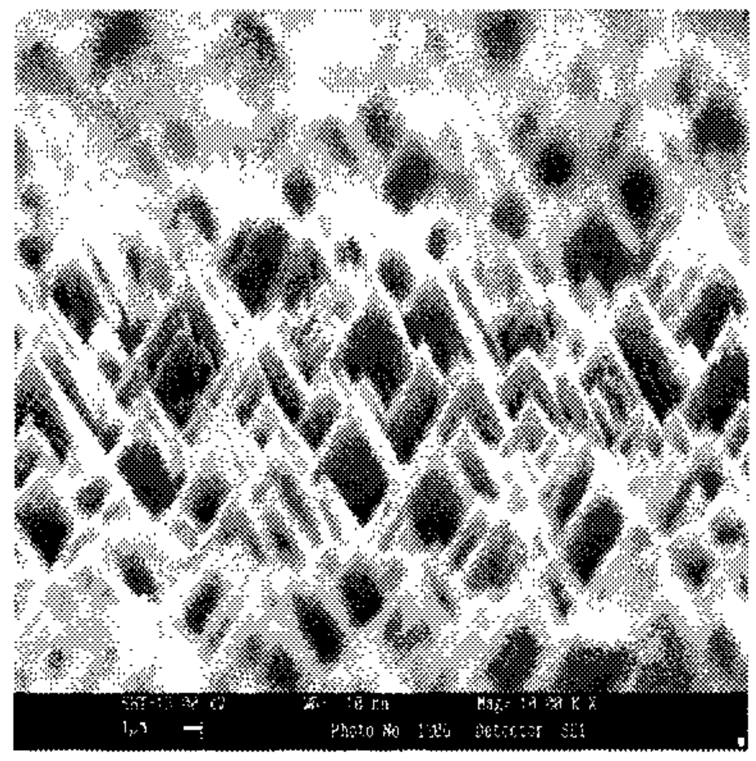
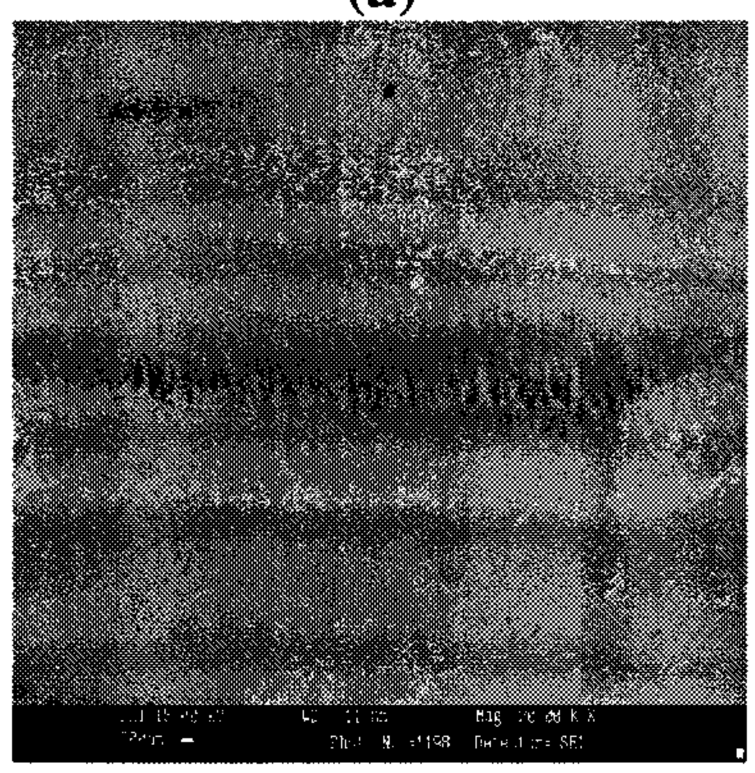


Fig. 4. Plasma density as a function of discharge current.

The SEM pictures of silicon surface on c-Si and mc-Si substrates are shown in Fig. 5(a) and Fig. 5(b) respectively. From these pictures, we have found that silicon surface is a silicon surface covered by a lot of columnar microstructures. The columnar microstructures have diameters from 50 to 100 nm and depth of about 500 nm. The region of technological conditions was very narrow to have good uniformity for large area silicon surface.



(a)



(b)

Fig. 5. SEM photographs of top view of (a) c-Si and (b)mc-Si surfaces. Hollow cathode RIE parameters: SF_6/O_2 partial pressure ratio 2.5; texturing time 20 Min; pressure 50 mTorr for plasma glowing condition; RF power 200 Watt per one hollow cathode glow.

4. Conclusion

In this paper, we investigated the characteristics of a newly developed HCP system and then directed the system application to silicon surface etching. The HCP system generated plasma ion density up to 10^{12} cm^{-3}. We obtained silicon etch rate of 1.3 μs/min. at a low input power of 200 W. This paper presented the HCP system application in FED emitter tip generation. However, our experimental results are expected to be used in wide range of display systems because of the HCP capability of high plasma generation at a low discharge power less than 200 W.

5. Acknowledgements

Research was supported in part by the Advanced Electric Energy Technology Research Center (AIERC).

6. References

[1] F. Paschen, Ann. Phys. (Leipzig), 58 (1916) 731.

[2] C. M. Horwitz, Appl. Phys. Lett., 43 (1993) 977.

[3] P. Fath, G. Wileke, E. Bucher, J. Szlufcik, R.M. Murti, K. De Clercq, J. Nijs, R. Mertens, Proc. of the 24th IEEE Photovoltaic Specialists Conference (1994) 1347-1350.

[4] U. Kaiser, M. Kaiser and R. Schindler, Proc. of the 10th EC Photovoltaic solar energy conf. (1991) 293-294.

[5] S. Narayanan, Ph.D. Thesis, University of New South Wales, May, 1989.

[6] M. Lipiñski, P. Panek, Z. Šwiatek, E. Beltowska, R. Ciach, Solar Energy Materials and Solar Cells, 72 (2002) 271-276.

[7] R. Guerrero-Lemus, C. Hernández-Rodríguez, F. Ben-Hander, J. M.Martínez-Duart, Solar Energy Materials and Solar cells 72 (2002) 495-501.

[8] M.Saadoun, H.Ezzaouia, B.Bessaïs, M.F.Boujmil, R.Bennaceur, Solar Energy Materials and Solar cells 59 (1999) 377-385.

[9] S. Winderbaum, O. Reinhold, F.Yun, Solar Energy Materials and Solar Cells, 46 (1997) 239-248.

[10] Y.Inomata, K.Fukui, K.Shirasawa, Solar Energy Materials and Solar cells, 48, Part- II (1997) 237-242.

[11] D.S. Ruby, W.K. Schubert, J.M. Gee, S.H. Zaidi, U.S. patent No. 6091021.