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Deposition of a-Si : H films by ECR plasma CVD using large diameter multi-slot antennae

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Abstract

A large diameter electron cyclotron resonance plasma was produced with a multi-slot antenna. The radial profile of the ion saturation current was examined as a function of input microwave power, gas pressure and magnetic mirror coil current to determine the experimental conditions necessary for a large diameter and uniform plasma at low pressure. Furthermore, the deposition of a-Si : H films was attempted onto 8 inch glass substrates using a gas mixture SiH_4–10% He.

Keywords: ECR plasma; Multi-slot antenna; Plasma CVD; Large diameter plasma

1. Introduction

There has been great interest in electron cyclotron resonance plasma (ECR plasma) for plasma processing such as chemical vapor deposition (CVD) and etching because of its high density and adequately high electron temperature. In fact, high deposition rates in CVD experiments using ECR plasmas have been obtained [1–3]. ECR plasmas have much potential for semiconductor processes. However, there are still many problems with ECR plasma processing, in particular the production of a uniform and large diameter ECR plasma. Usually, an ECR plasma is produced by introducing the microwave of the principal mode of the waveguide, TE_{10} or TE_{11}, so it is hard to realize a uniform and large diameter plasma. Recently, industry has requested a large diameter ECR plasma suitable for a wafer 8 inches in diameter. We have produced a large diameter ECR plasma using a multi-slot antenna [4–6] which has the advantage that the plasma diameter does not depend on the frequency of the incident microwave. In order to produce a uniform and large diameter ECR plasma with diameter more than 8 inches, we have made a machine which consists of a chamber 290 mm in inner diameter and a multi-slot antenna 280 mm in diameter. When discussing a large diameter plasma, it is important to specify whether or not a substrate is placed in the chamber, because the plasma and flows are disturbed by the substrate. Here we examined the uniformity of plasma in the presence of a substrate 8 inches in diameter.

Although ECR plasmas provide high deposition rates for CVD, the fabrication of thin films with a large area by ECR plasma CVD has not been reported. This is for the following reasons. Firstly, it is hard to produce a large diameter ECR plasma. Secondly, the physics of ECR plasma CVD is not clear compared with that of a two parallel electrode reactor using r.f. plasmas (13.56 MHz). In this paper, we report experiments on the production of a uniform and large diameter ECR plasma. Furthermore, hydrogenated amorphous silicon (a-Si : H) films were deposited using SiH_4/He plasmas without substrate heating, and the optical band gap of the films was measured, as usual.

2. Experimental

A schematic diagram of the experimental apparatus is shown in Fig. 1. The vacuum chamber was made of stainless steel, 290 mm in inner diameter and 1200 mm in length. An ECR plasma was produced with a multi-slot antenna which was made of stainless steel 280 mm in diameter. The length and width of the slots were 70 mm and 2 mm respectively. The magnetic coil assembly consisted of six coils, four to produce a uniform magnetic field, and two to form the magnetic mirror and control the current for the magnetic mirror I_m. The frequency of the microwave was 2.45 GHz and the power could be varied up to 1000 W. Matching between the microwave circuit and the plasma was done with a stub tuner.

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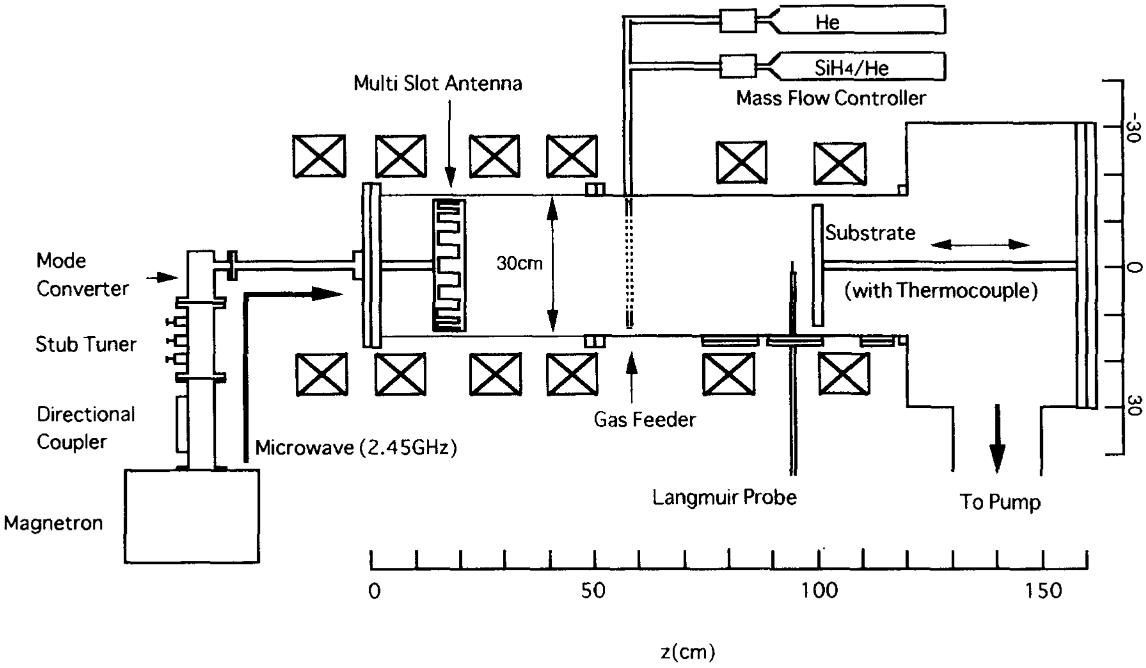

Fig. 1. Schematic diagram of the experimental apparatus.

The gas used was He, and the pressures ranged from 1×10^{-4} to 5×10^{-4} Torr. Hydrogenated amorphous silicon films were deposited onto Corning 7059 glass substrates by flowing SiH_4 gas diluted with He gas. As is well known, the uniformity of deposited films is influenced by the uniformity of the gas stream. So, we used a circular tube along the wall of the chamber as a gas feeder. The gas spouted from several holes of the tube to the center.

In this experiment, the substrate which was not heated intentionally was placed at 85 cm from the multi-slot antenna ($Z = 100$ cm), and was kept at floating potential. The diameter of the substrate holder was 270 mm, which enabled a wafer 8 inches in diameter to be held. Plasma parameters were measured with cylindrical Langmuir probes in front of the substrate. The electron densities were determined from the ion saturation current, the accuracy of which was confirmed with a microwave interferometer of 8 mm in previous experiments [5]. The electron temperatures were determined from the best fit curve for the Langmuir probe characteristics, where the distribution function of the electron was assumed to be a single maxwellian. The thickness and the optical band gap were measured with a spectrophotometer using a well known formula by Tauc [7].

3. Results and discussion

At first, in order to determine the optimum conditions for the production of a large diameter plasma, the radial profile of the ion saturation current density I_{is} was examined as a function of pressure, microwave power and current I_m to produce a magnetic mirror. Fig. 2 shows the radial profile of the ion saturation current density of He plasma for different gas pressures, where the input power of the microwave was 200 W. As is seen in Fig. 2, a relatively uniform profile over 20 cm in diameter was obtained at a certain gas pressure. Here, the ion saturation current density is large near the wall of the chamber, owing to the fact that the electric field near the multi-slot antenna is large [6]. Fig. 3 shows the radial profile of the ion saturation current density for different input microwave powers, where I_m was 90 A and the gas pressure was 2×10^{-4} Torr. When the microwave power is increased, the ion saturation current density increases, as seen in Fig. 3.

Axial magnetic field configurations are illustrated in Fig. 4(a). The smaller I_m is, the larger the magnetic mirror ratio is, that is, confinement by the magnetic mirror field is expected. Fig. 4(b) shows the radial profile of the ion saturation current density for different magnetic coil currents I_m, where the input microwave power and the gas pressure were 200 W and 2×10^{-4} Torr respectively. When I_m is small, the ion saturation current density is high, owing to the effect of confinement by the magnetic mirror field. When I_m is 110 A, the ion saturation current density at the center is low, which is due to decreases in the mirror ratio, as seen in Fig. 4(a). The radial profile of the floating potential V_f at a microwave power of 300 W is shown in Fig. 5, which indicates that V_f is comparatively uniform except near the chamber wall; therefore, the space potential is considered to be uniform.

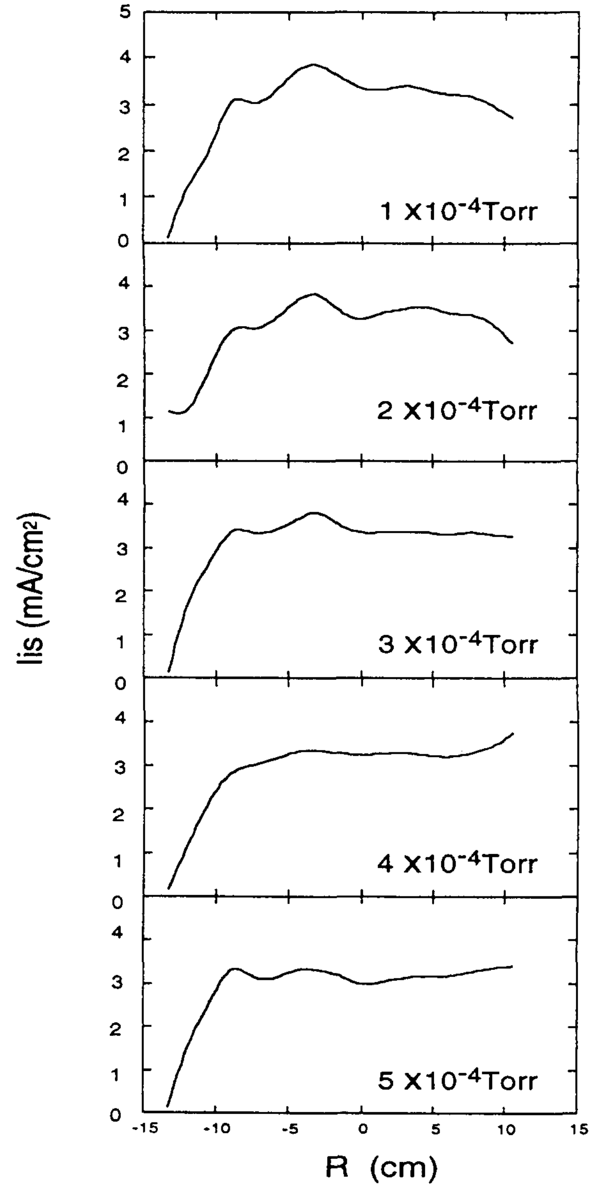

Fig. 2. The dependence of the ion saturation current density profile on the gas pressure where the input microwave power is 200 w. The substrate was set at $Z = 100$ cm ($I_m = 60$ A).

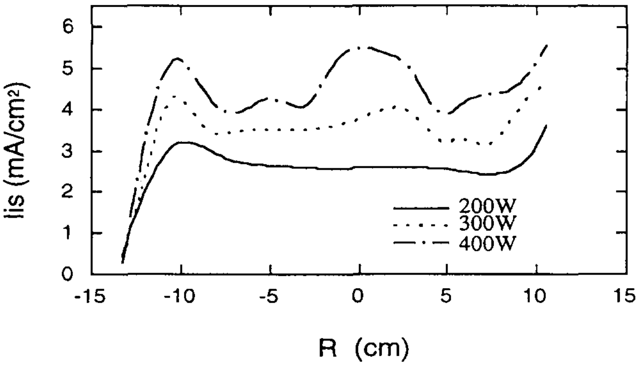

Fig. 3. The dependence of the ion saturation current density profile on the input microwave power at 2×10^{-4} Torr. The substrate was set at $Z = 100$ cm ($I_m = 90$ A).

An axial profile of the ion saturation current density was measured to examine how effective ECR is for plasma production. Fig. 6 shows the axial profile of the ion saturation current density; the points A and B in this figure correspond to the ECR points on the axis. The electron temperatures and densities at the measuring points $Z = 30$ cm, 70 cm and 95 cm in Fig. 6 were 9.9, 10.8, 12.0 eV and 1.6×10^{10}, 4.0×10^{10}, 5.0×10^{10} cm^{-3} respectively. It has been proposed [8] that an ECR plasma using a multi-slot antenna is produced only at the first ECR point, A. However, as seen from above results, the plasma density increases after the first ECR point, which is not explained by the above model. Fig. 6 suggests that the plasma was produced at the second ECR point, B, as well as the first ECR point, A. The incident microwave was transferred to the whistler mode, which propagated and produced the plasma at the second ECR point. Furthermore, the ion saturation current density decreased rapidly outside the magnetic mirror field ($Z > 107$ cm).

As described before, the plasma density of 5×10^{10} cm^{-3} was obtained at 2×10^{-4} Torr. Therefore, the degree of ionization amounts to more than 1%, which means that a multi-slot antenna is an efficient antenna for ECR plasma production.

Under comparatively high gas pressure (2×10^{-3} Torr) and high microwave power (1000 W), radial uniformity of the ion saturation current density within 3% over 20 cm in diameter was achieved [9]. In the present experiments, the production of ECR plasma and deposition of the films were carried out at lower gas pressures ((1–5) $\times 10^{-4}$ Torr) to investigate the effect of ECR plasma for CVD. Thus, a comparatively high density and high electron temperature of plasma were obtained at low power and low pressure with a multi-slot antenna because of the ECR effect.

Hydrogenated amorphous silicon (a-Si:H) films were deposited onto glass substrates by introducing SiH_4 to the He plasma. The deposition time was 1 h, and the flow rates of He and SiH_4 were 18 and 2 standard cm^3 min^{-1} respectively.

The radial profile of film thickness was measured to investigate the conditions necessary for the deposition of uniform films with a large area. Fig. 7 is the radial profile of the film thickness for different microwave powers, where the pressure was 2×10^{-4} Torr. As seen in Fig. 7, the most uniform thickness profile of the film is obtained under the same conditions which give a uniform ion saturation current. Figs. 3 and 7 show that the thickness increases when the ion saturation current density increases, except at $R \leq -4$ cm. When the input power is increased, the thickness also increases. The radial profile of the thickness of a-Si:H films deposited at 200 W is less uniform than that of the ion saturation current density, as seen from Figs. 3 and 7. These results mean that radical reactions play an important role in

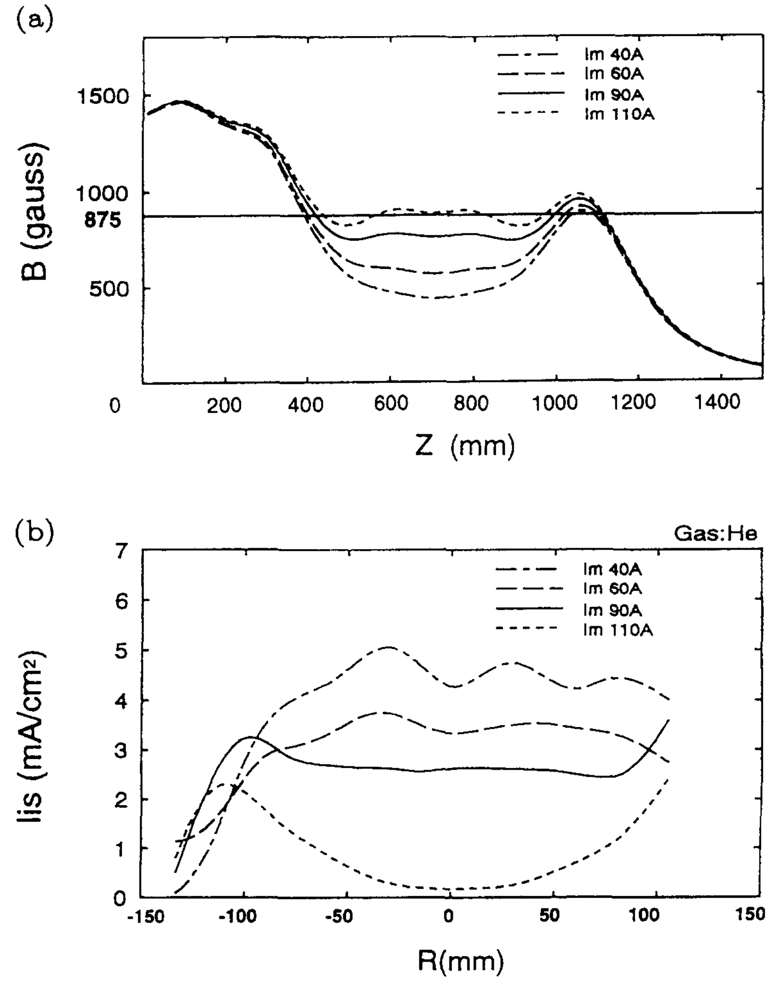

Fig. 4. (a) The axial profile of magnetic fields at the center, for I_m of 40, 60, 90 and 110 A. (b) The dependence of the ion saturation current density profile on magnetic field configurations. The input microwave power and the gas pressure are 200 W and 2×10^{-4} Torr respectively. The substrate was set at $Z = 100$ cm.

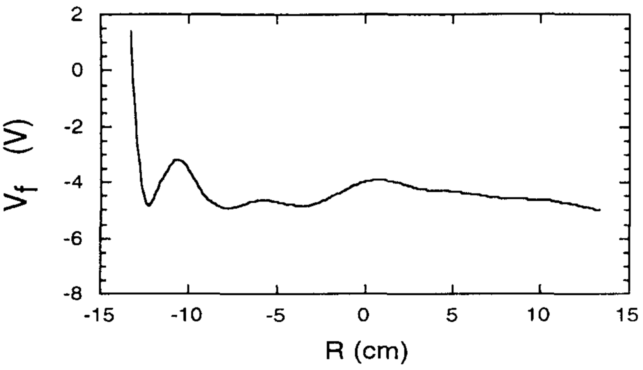

Fig. 5. The radial profile of the floating potential V_f for an input microwave power and gas pressure of 300 W and 2×10^{-4} Torr respectively. The substrate was set at $Z = 100$ cm ($I_m = 60$ A).

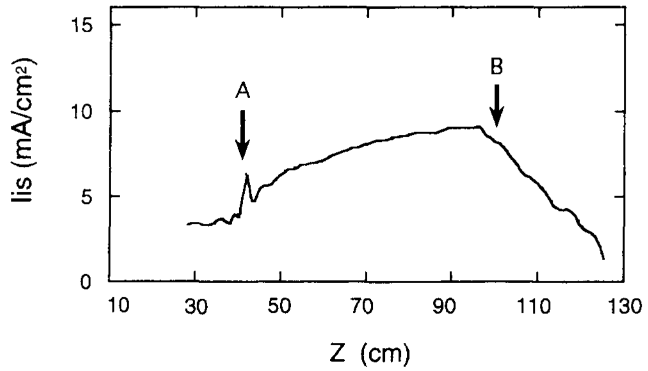

Fig. 6. The axial profile of the ion saturation current density, for an input microwave power and gas pressure of 300 W and 2×10^{-4} Torr respectively ($I_m = 60$ A).

the uniformity of the films. The control of radicals will be necessary for uniform deposition of films. The deposition rate is estimated from the thickness and the deposition time. The average deposition rate was 2 Å s^{-1} which is of the same order as that obtained using a conventional ECR plasma [1], where the flow rate of SiH_4 was 2 standard cm^3 min^{-1}. If the ratio of SiH_4 gas to He gas is increased, the deposition rate will increase further.

The optical band gap, which is an important property

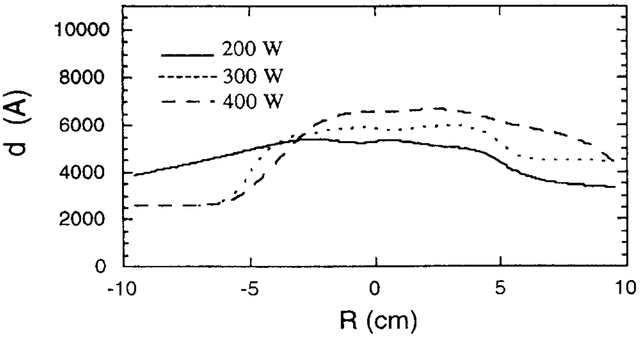

Fig. 7. The radial profile of the thickness *d* of a-Si:H films for input microwave powers of 200 W, 300 W and 400 W, and gas flow rate of 20 standard cm^3 min^{-1}.

of a-Si:H films, was measured using Tauc's formula. The average value of the optical band gap of these films was about 2.1 eV. The optical band gap will decrease if the substrate is heated; this is the subject of future work.

References

[1] S. Mastuo and M. Kiuchi, *Jpn. J. Appl. Phys.*, *22* (1983) L210.
[2] M. Kitagawa, K. Setsune, Y. Manabe and T. Hirao, *Jpn. J. Appl. Phys.*, *27* (1988) 2026.
[3] Y. Nakayama, M. Kondoh, K. Hitsuishi and T. Kawamura, *Jpn. J. Appl. Phys.*, *29* (1990) 1801.
[4] G. Lisitano, R.A. Ellis, Jr., W.M. Hooke and T.H. Stix, *Rev. Sci. Instrum.*, *39* (1968) 295.
[5] Y. Kawai and K. Sakamoto, *Rev. Sci. Instrum.*, *53* (1982) 606.
[6] A. Yonesu, Y. Takeuchi, A. Komori and Y. Kawai, *Jpn. J. Appl. Phys.*, *27* (1988) 1482.
[7] J. Tauc, in J. Tauc (ed.), *Amorphous and Liquid Semiconductors*, Plenum, London, 1974, P. 159.
[8] Y. Suetsugu and Y. Kawai, *Jpn. J. Appl. Phys.*, *23* (1984) 1101.
[9] Y. Ueda, M. Tanaka, S. Shinohara and Y. Kawai, *Proc. 7th Symp. on Plasma Science for Materials, Tokyo, 1994*, in press.