Extended Abstracts of the 20th (1988 International) Conference on Solid State Devices and Materials, Tokyo, 1988, pp. 65-68

A-4-2

Effects of Magnetic Fields and Excited Plasma Species on Silicon Oxide Film Formation by Microwave Plasma CVD

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By using a microwave plasma deposition system in which distributions of applied magnetic fields can be varied, effects of the ECR position and plasma species on deposition rate and deposited film quality of silicon oxide have been studied. The following results were obtained: Deposition rate increases under the condition in which not only O_2, but also SiH_4 as a material gas, are excited by ECR. High quality film equivalent to thermal SiO_2 film, can be formed when the ECR position is very close to the substrate. The process of forming high quality film is related to highly excited ions transported toward the substrate.

1. INTRODUCTION

Plasma CVD systems utilizing electron cyclotron resonance(ECR) have been developed in order to form high quality films at low temperature and with low damage for fabrication of VLSIs and functional thin film devices.[1)-3)] However, film quality deposited by this method is insufficient and these films can not replace those formed by a conventional thermal chemical reaction. Sometimes, this method has problems with the deposited film, e.g. density decreases as gas flow rate increases or the deposition rate increases. Usually, the ECR position is located in a discharge tube. Excitation levels of the plasma species generated at this position decrease as these species are transported to the substrate, due to energy dissipation and collisions. We felt that to ensure high quality film formation, it was necessary to utilize the excited plasma species adequately. Then an experimental system was manufactured in which the ECR position, i.e. the highest plasma generation position, could be located closer to the substrate by controlling the applied magnetic fields. We examined the effects of locating the ECR position close to the substrate on the deposition rate and the film quality. The electron density and plasma emission spectra were measured in order to investigate effects of plasma condition and species on the film formation.

2. EXPERIMENTAL AND RESULTS

A diagram of the system and representative applied magetic fields are shown in Fig.1. This system has the distinctive feature that magnet coils are set around not only the discharge tube, but also around the reaction chamber. Owing to the additional coils, the ECR position can be moved closer to the substrate and ion species generated are confined so that only radical species can be transported to the substrate. Figure 2 shows dependence of deposition rate and etching rate with a buffered HF solution on the distance from the substrate to the ECR position, under the divergent and cusp magnetic fields. Figure 3 shows the peak position of the IR spectra and the refractive index as a function of the distance from the substrate to the ECR position. Figures 4 and 5 show H radical(H*), O_2^+emission intensities and electron density as a function of the distance.

In comparison of the two cases where the divergent and cusp fields are used, that is, ion species are transported or not transported to the substrate, it is found that 1) the deposition rate is almost constant under each case. Therefore, the deposition rate is dominated by radical species. 2) When the cusp field is used, the etching rate increases and IR peak position shifts to low wave number, that is, density and bond strength of deposited film decrease sharply. Therefore, film quality is dominated by ion species and film quality decreases significantly when ion species are not transported to the substrate.

From the results showing the dependence of measured values on the distance from the substrate to the ECR position, it is found that although the deposition rate is almost constant when the ECR is located upstream from the SiH_4 inlet position, the deposition rate increases sharply when it is located downstream from it. From measurements for H^* emission intensity, it is found that when the ECR position is downstream from the SiH_4 inlet position, SiH_4 is excited by ECR in addition to the usual excitation by the O_2 plasma, so that decomposition efficiency of SiH_4 increases and the deposition rate increases. Although the refractive index is almost constant, the etching rate decreases dramatically and the rate is close to the value of thermal SiO_2, that is, the density becomes higher as ECR is located closer to the substrate. The IR peak position shows that the bond strengh becomes stronger as ECR is located closer to the substrate. Electron density of plasma is independent of the ECR position. From these results, the deposited film quality is independent of the amount of ions transported to the substrate as charge species. On the other hand, emission intensity of O_2^+increases, as ECR is located closer to the substrate. The film quality increases when the amount of excited ion species transported to the substrate is increased by moving the ECR position closer to the substrate.

In order to confirm the above effects of film densification and plasma species at high gas flow rate or at high deposition rate, we examine the dependence of deposition rate and H^* emission intensity on SiH_4 flow rate, and the dependence of etching rate and O_2^+emission intensity on the deposition rate when ECR is located 20 and 310mm from the substrate. These results are shown in Figs. 5-8. In particular, Fig. 7 demonstrates clearly the advantage of moving the ECR position closer to the substrate to form higher density film at a higher deposition rate. It is confirmed that when ECR is located closer to the substrate:
1) The decomposition efficiency of SiH_4 increases and the deposition rate increases.
2) The amount of excited ion species transported to the substrate increases as the deposition rate increases and the film equivalent to thermal SiO_2 can be formed at a high deposition rate. Figure 9 shows step-coverage when ECR is located 20 and 310mm from the substrate. From these results, the coverage is seen to improve markedly, that is, cracks and overhang can not be found, as excited plasma species are utilized adequately by locating the ECR position closer to the substrate.

In addition to the above results, it is found that electrical characteristics, that is breakdown voltage and surface electron density, can be improved by controlling the ECR position closer to the substrate.

3. REFERENCES

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2) T.Watanabe, K.Azuma, M. Nakatani, K.Suzuki T.Sonobe and T.Shimada; Jpn.J.Appl.Phys.25 (1986) 1805.
3) H.Kawaharada, K.S.Mar and A.Hiraki; Jpn.J. Appl.Phys.26(1987) L1032.

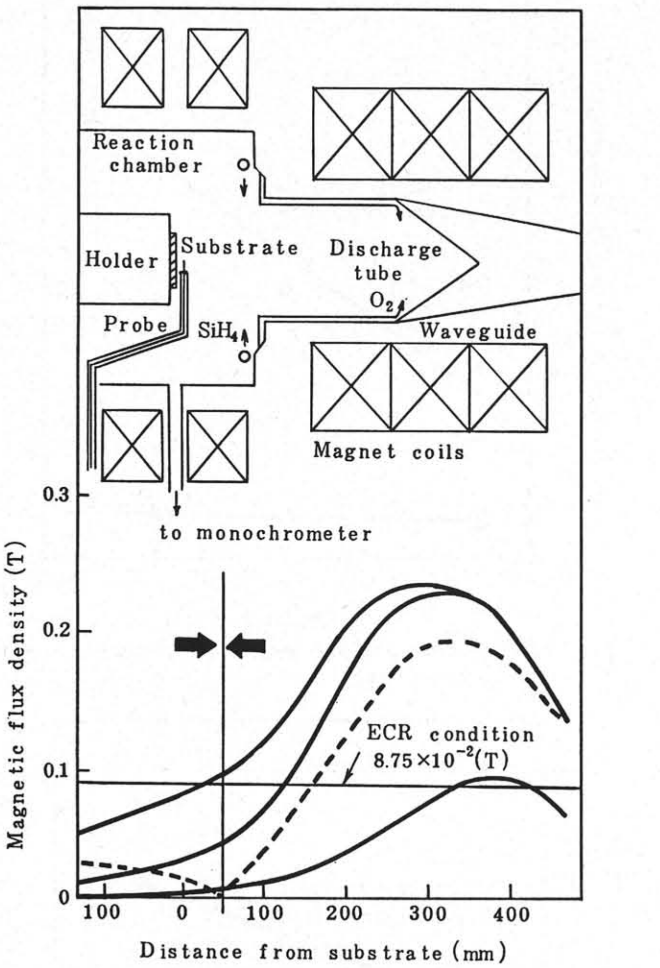

Fig.1 Diagram of the microwave plasma CVD sysytem and representative applied distributions of magnetic flux densities on the central axis. Solid and dashed lines indicate the divergent and cusp magnetic fields. Heavy arrows indicate the magnetic forces on the cusp magnetic field.

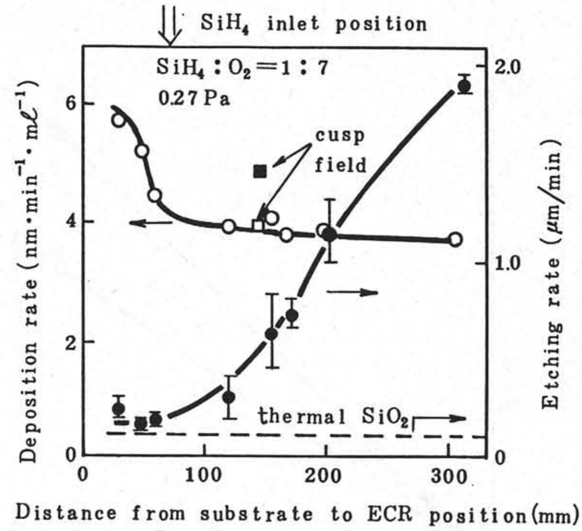

Fig.2 Dependence of the deposition rate(○,□) and the etching rate of deposited film(●,■) on the distance from substrate to ECR position, under the divergent and cusp fields.

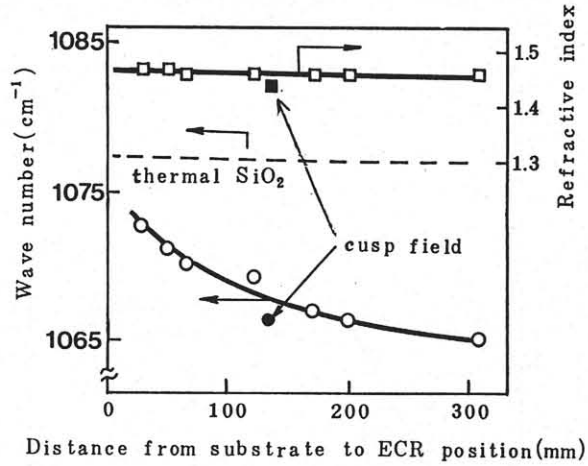

Fig.3 Dependence of the peak position of the Si-O stretching mode for deposited film(○,●) and the refractive index(□,■) on the distance from substrate to ECR position.

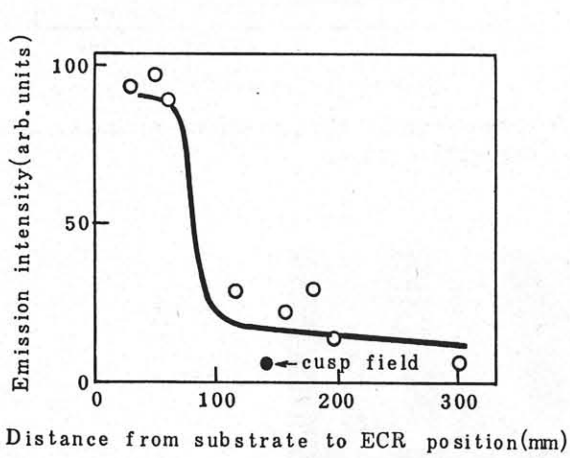

Fig.4 Dependence of the emission intensity of H_α line on the distance from substrate to ECR position.

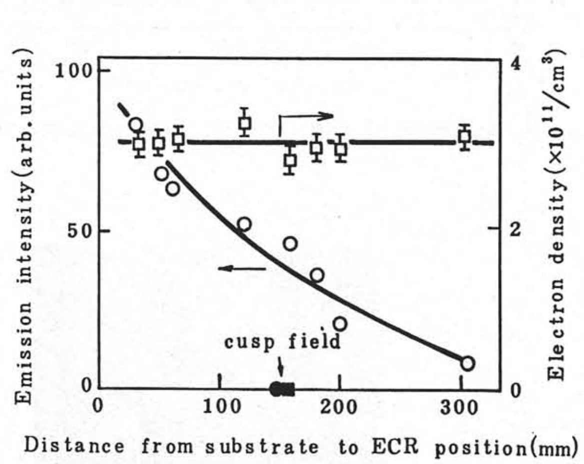

Fig.5 Dependence of the emission intensity of O_2^+ 560nm line(○,●) and the electron density measured for He plasma(□,■) on the distance from substrate to ECR position.

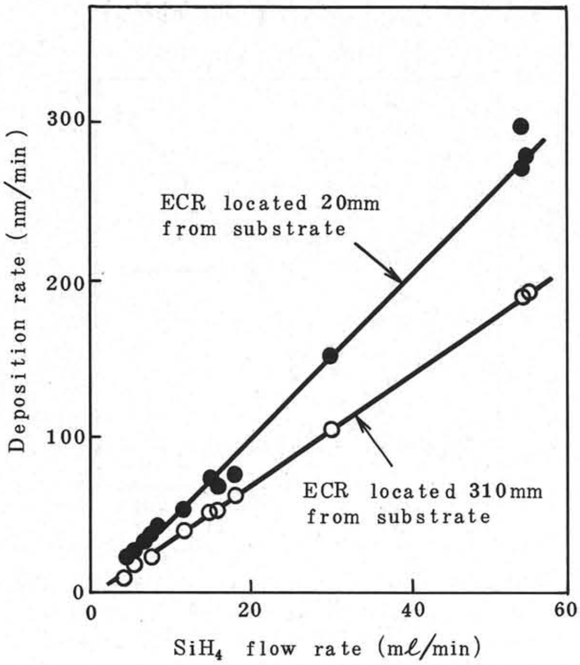

Fig.6 Dependence of the deposition rate on SiH_4 flow rate.

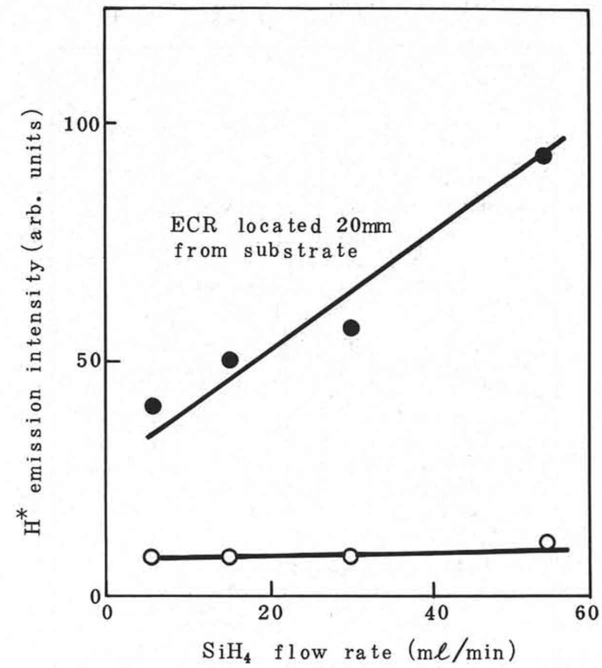

Fig.7 Dependence of the emission intensity of H^* on SiH_4 flow rate.

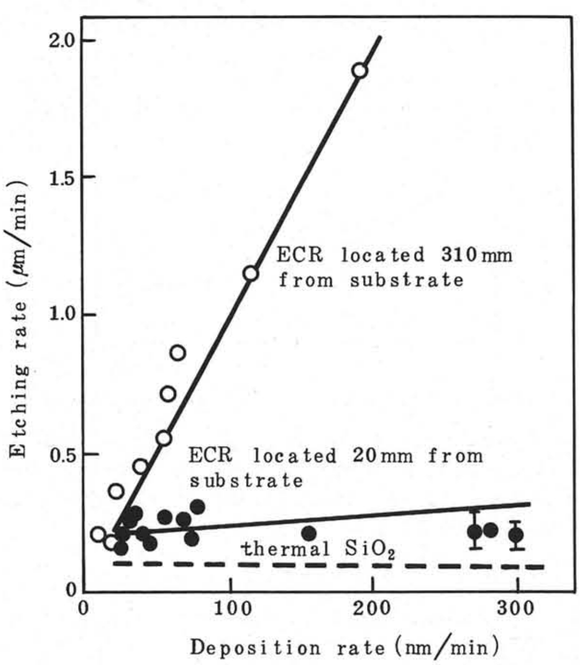

Fig.8 Dependence of the etching rate on deposition rate.

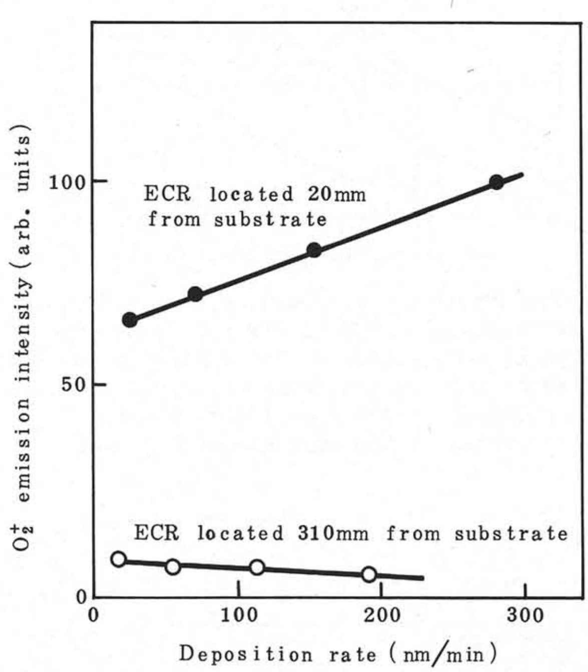

Fig.9 Dependence of the emission intensity of O_2^+ on deposition rate.

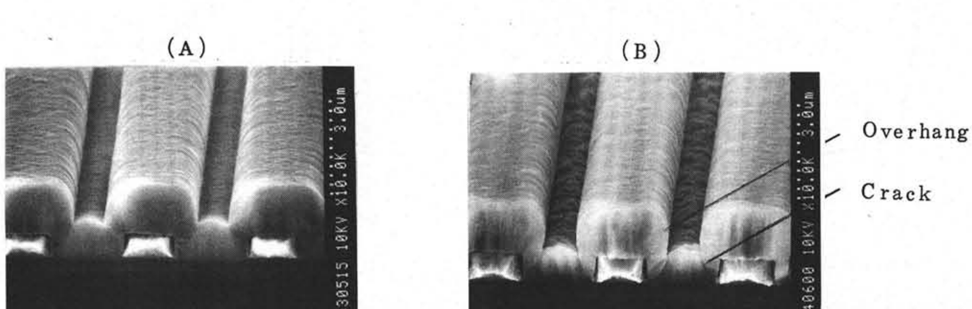

Fig.10 SEM photographs for surfaces deposited on Al pattern. (A) and (B) indicate surfaces deposited when ECR is located 20 and 310mm.