LOW TEMPERATURE DEPOSITION OF SiO_2 FILMS BY ECR

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ABSTRACT

SiO_2 films of high quality have been deposited by Electron Cyclotron Resonance (ECR) at temperatures less than 400 °C. Chemistries of O2 and 25 % SiH_4 in Ar were used. Deposition rates of about 220 Å/minute were obtained, studying films of typical thicknesses of 1100 Å. Characteristics of the films studied include refractive index of 1.467 - 1.477, dielectric strengths of 5.0 - 9.0 MV/cm, dielectric constants of 3.8 - 4.2, and buffered HF etch rates of 19 - 21 A/second. These characteristics were shown to degrade around a deposition temperature of 200 °C, with temperatures on either side of this range yielding better characteristics. Optical emission spectroscopy was also utilized to identify the species present in the plasma.

INTRODUCTION

Plasma enhanced chemical vapor deposition (PECVD) technology usage has been increasing in integrated circuit fabrication as a passivation technique [1]. PECVD allows for growth of films at much lower temperatures than would otherwise be required by conventional CVD techniques. A wide range of control over film composition is also an advantage of PECVD. One technique that has been shown recently to produce high quality SiO_2 films for passivation technology is that of Electron Cyclotron Resonance (ECR) [2-5].

The ECR plasma is generated using microwave frequencies of 2.45 GHz. At this frequency and a uniform magnetic field of 875 G the energy is efficiently transferred to the free electrons. The process is more efficient than conventional radio-frequency (RF) PECVD systems in this transfer of energy to the plasma so that ECR typically operates at 0.1-1.0 mTorr, one or two orders of magnitude lower than RF systems. Also, the plasma density is typically an order of magnitude higher than RF systems [6]. ECR has also been shown as a suitable planarization technology of submicron geometries with high aspect ratios, making it an attractive tool for integrated circuit devices of today [3].

The present work investigates the dependance of certain SiO film characteristics on temperature, with temperatures being less than 400 °C. Characteristics such as dielectric strength, refractive index, and density are discussed.

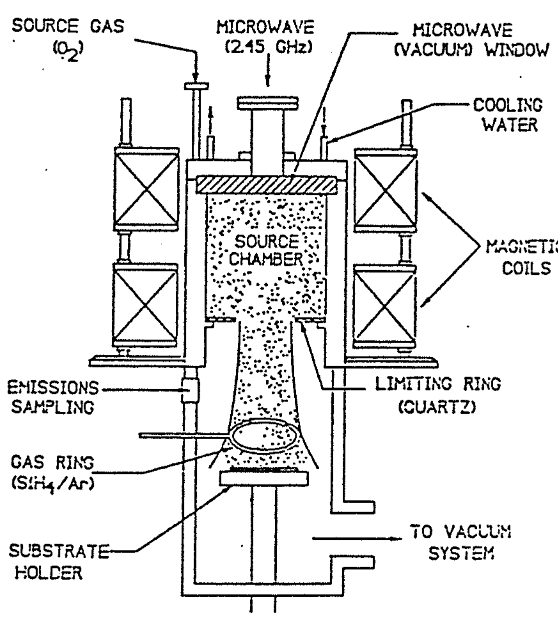
PROCEDURES

A schematic drawing of the ECR system used is shown in Fig. 1. More details on this system can be found elsewhere [4]. The system consisted of a Microscience 906 ECR source attached to an anodized aluminum chamber. A base pressure of 1 X 10^{-6} Torr was achieved by an 880 L/s turbomolecular pump and rough pump package. Oxygen was introduced into the source chamber, while a 25% SiH_4 in Ar mixture was fed through a gas ring located in the proximity of the wafer. The wafers were placed on a molybdenum chuck located 20 cm from the limiting ring of the source. This Mo chuck was electrically isolated from the chamber, resting on a Microscience 1000 heater block. The temperature was monitored by a K-type thermocouple located at the edge of the chuck. Another thermocouple in the center of the heater block fed a signal to a microprocessor based heater controller.

Films of approximately 1100 Å were deposited over five minutes with an O_2 flow of 140 sccm and a 25% SiH_4/Ar mixture flow of 56 sccm, a pressure of 1.4 mTorr, a microwave power of 450 W and a temperature range from room temperature to 400°C. Film thicknesses were measured by ellipsometry and by Nanospec. Al/Si/SiO_2/Al structures were used for measuring the breakdown voltage and the dielectric constant. Optical emissions spectroscopy was performed using a Sofie Instruments SD-20 Spectrum Analyzer, with a monitoring position of 5 cm above the wafer.

FIGURE 1.

A schematic of the ECR system.



ANALYSIS AND DISCUSSION

Preliminary depositions were performed to find conditions which would yield films of near stoichiometric structure, having an index of refraction of 1.46. The flow of oxygen was kept constant at 140 sccm, while the SiH_4/Ar flow was varied from 42 to 126 sccm. The results are shown in Fig. 2. The deposition rate increases from about 200 Å/minute to almost 500 Å/minute with the increase of SiH flow examined. The index of refraction, however, also increased to a value as high as 1.8, indicating a silicon rich oxide film. The conditions for the temperature dependance experiment were chosen from these results as being an O flow of 140 sccm and SiH_4/Ar flow of 56 sccm, yielding an index of refraction close to that of thermal oxides.

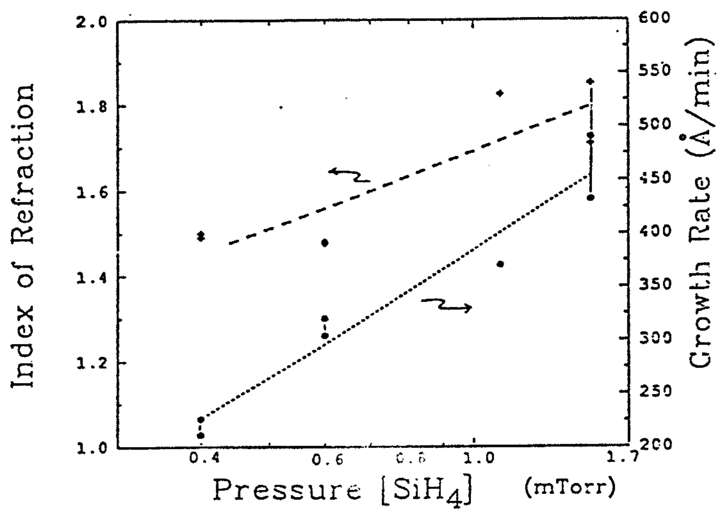


FIGURE 2: The refractive index and growth rate as a function of SiH /Ar partial pressure O_2 pressure is constant at 0.5 mT, and microwave power is 450 W.

Fig. 3 is an optical emissions spectra of a plasma of these gas flows, covering a wavelength range of 200 - 750 nm. Peaks have been identified as being those of atomic oxygen, hydrogen, silicon, and argon, as well as bonds of SIH, SiO and Si_2. A reaction equation has been proposed by Lucovsky et al. [7] for the process of SiO_2 deposition by SIH_4 and O_2 chemistries in a remote PECVD system. This equation is given as follows:

$$O_2^* + SiH_4 \longrightarrow SiO_2 + H_2O + H_2$$

where O_2^* is a neutral oxygen metastable. This metastable is not detectable by optical emissions spectroscopy, however.

The results of the temperature variation study seems to suggest that this may not be the only major reaction of the film growth process, or that it is affected by thermal activation in some way. Fig. 4 is a graph showing the relationship of the index of refraction, dielectric strength, and buffered HF etch rate to the temperature of the deposition.

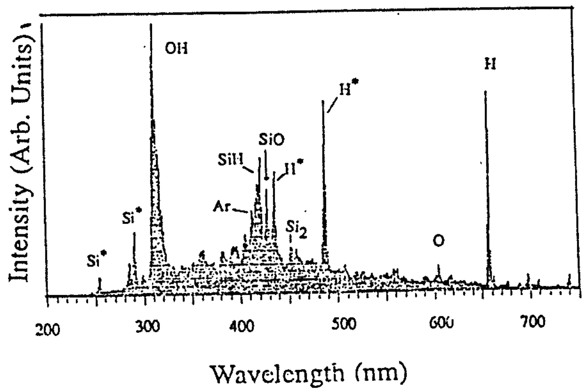


FIGURE 3: Optical Emissions Spectra of O_2 and SiH_4/Ar ECR plasma. O_2 flow is 140 sccm, and SiH_4/Ar is 56 sccm.

All three graphs show a degradation of characteristics at around 200 °C. Between room temperature and 200°C the index of refraction increases from 1.467 to 1.477. With a further increase in temperature to 400°C the value drops back down closer to that of stoichiometric thermal oxides. The refractive index is often used as an indicator of film quality, and the other two curves show this clearly. The dielectric strength goes from 9.0 MV/cm at room temperature down to 5.0 at 200°C, and back up to 7.0 MV/cm at 400°C. These values are all in the range of typical thermal oxide values.

The density of the films is related to the etch rate of the film. Films were etched in a buffered HF (BHF) solution yielding etch rates of 19 - 21 Å/second, showing a density close to that of thermal oxides, which had an etch rate of 15.5 Å/second in the solution. It is unclear what the degradation of the characteristics at 200 °C is resulting from without further analysis of the film structure, perhaps using infrared spectroscopy or Rutherford backscatter techniques. These techniques might indicate a higher hydrogen content of the films at 200°C, or maybe an oxide film of a higher Si content.

There was no detectable growth rate dependance on temperature; however, this was dismissed due to the usage of manual operation of the ECR system at a high growth rate (ie. operator timing errors). The dielectric constant of the films was determined by capacitance measurements of capacitor structures, with values falling in a range of 3.8 to 4.2, with thermal oxide having a value of 3.9. Uniformities were measured to be typically +/- 4% across 3 inch wafers; however, the intention of these depositions was not high uniformity, and it might be noted that this ECR system has been shown to be capable of high uniformity deposition of up to +/- 3% on 200 mm wafers [8].

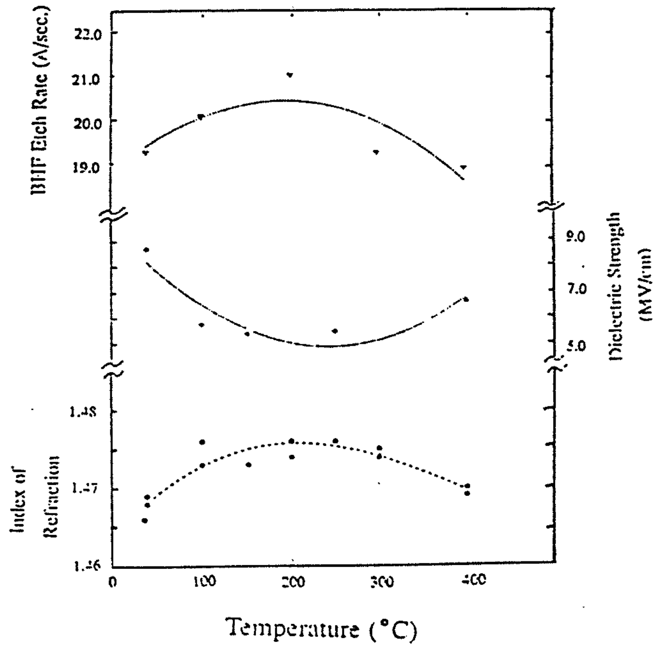


FIGURE 4: Dependance of refractive index, dielectric strength, and buffered HF etch rates on temperature.

CONCLUSION

An ECR plasma stream system was utilized to deposit high quality SiO_2 films at temperatures of 40 - 400°C. The film quality was noted to degrade at temperatures around 200 °C, with temperatures above and below this area showing better film characteristics. This degradation may be due to the inclusion of hydrogen in the films, or to deposition of Si rich films at that temperature. This can not be determined without further analysis of the film structures. Characteristics of the films include a refractive index of 1.466 - 1.477, a dielectric strength of 5 - 9 MV/cm, a BHF etch rate of 19 - 21 Å/second (compared to thermal oxide of 15.5 Å/second) and a dielectric constant of 3.8 - 4.2.

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