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Preparation of SiOF Films with Low Dielectric Constant by ECR Plasma Chemical Vapor Deposition

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A new technology of interlayer dielectric film formation for multilevel interconnection by ECR plasma CVD has been developed. The technique uses SiF_4 and O_2 as material gases and composition of prepared film is SiOF (Fluorine concentration is about 10 atomic %). By applying rf bias to substrate, deposited film quality is improved. Deposited film has good properties, such as low dielectric constant (3.0), tightly bonded Si-F networks with no OH radicals and high breakdown voltage (6-8MV/cm). Excellent planarization and gap filling without void are also accomplished.

INTRODUCTION

Interlayer dielectric film formation technology is essential for the fabrication of multilevel interconnections for ULSI.

Low temperature deposition has been required for multilevel interconnection interlayer dielectrics because thermal stress affects device characteristics and wiring reliability. Low temperature deposition techniques such as tetra-ethoxy-ortho-silicate chemical vapor deposition (TEOS CVD) [1)-3)] and electron cyclotron resonance plasma CVD (ECR plasma CVD) [4)-10)] have been investigated for this purpose. However, as integrated circuit dimension shrinking, dielectric constants of current interlayer films induce problems such as a signal delay and cross-talk noise. Therefore, deposition processes for low dielectric constant films have been studied [11)-13)].

In this paper, low dielectric SiOF film deposition is proposed by using ECR plasma CVD with SiF_4 and O_2 as material gases. It is reported that deposited SiOF films show low dielectric constant, high breakdown strength, excellent planarization and gap filling without void.

EXPERIMENTAL

The ECR plasma CVD system used in the work is shown in Fig. 1. The system consists of two chambers: a plasma chamber and a reaction chamber. The plasma chamber, which is connected with rectangular wave-guide, works as a microwave cavity resonator (TE_{113}). 2.45GHz microwaves are introduced into the plasma chamber through a microwave window. A magnetic coil is set around the plasma chamber and the magnetic flux density is controlled to be 875Gauss to satisfy the ECR condition. A divergent magnetic field extracts the plasma from the plasma chamber to the reaction chamber.

SiF_4 gas is introduced into the reaction chamber. Oxygen and argon gases are introduced into the plasma chamber.

Film thickness was determined by elipsometry. The etch rates of deposited films were measured using BHF (buffered HF) solution (50%HF : 40%NH_4F = 15 : 85). These etch rates were compared with those of thermally grown silicon oxide. Chemical bonding was investigated by FT-IR. Dielectric constant was determined from Capacitance - Voltage measurement (1MHz) using a MIS (Al / about 1000Å thickness SiOF film / p-Si) diode.

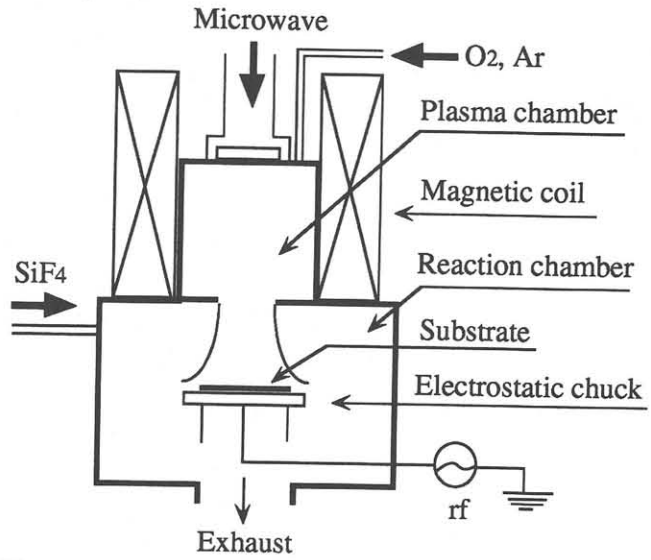

Fig. 1 Diagram of bias ECR plasma CVD system

RESULTS AND DISCUSSION

Fig. 2 shows the deposition rate as a function of SiF_4 gas flow rates. Microwave power is fixed at 2.8 kW. The deposition rates are increasing linearly with SiF_4 gas flow rates and are independent of the substrate chuck temperature. High deposition rate is attained.

Fig. 3 shows the BHF etch rate as a function of SiF_4 gas flow rates. In conventional ECR CVD without both rf bias to the substrate and the substrate heating, the etch rate is three times of that of thermally grown oxide. This film quality is poor. To improve the film quality, heating the substrate at 300°C or applying rf bias to the substrate were performed. The etch rate is dramatically reduced. Thermal energy and/or ion bombardment effect due to rf bias improve the film quality. The film deposited by bias ECR plasma CVD has the excellent quality equivalent to a thermally grown oxide.

Dielectric constant is shown in Fig. 4. Applying thermal energy or ion bombardment effect to the substrate, the dielectric constant is reduced. Especially, the dielectric constant is nearly equal to 3 by using bias ECR plasma CVD. Tightly bonded Si-F structure generated by ion bombardment is expected to have lower polarizability than Si-O structure. It is suggested that it results in obtaining low delelctric films.

Fig. 5 shows a FT-IR spectrum. Si-F bond absorption peak is observed at around $930cm^{-1}$. Fluorine concentration in this film is about 10 atomic % (measured by RBS: Rutherford Back Scattering spectroscopy). Because of hydrogen free deposition in this process, any absorption peaks of neither Si-OH nor H-OH are observed at around $3650cm^{-1}$ and $3400cm^{-1}$, respectively.

For evaluating Si-F bond stability, pressure cooker test (PCT) was performed for 100 hours under the condition of 120°C and 85% humidity. Fig. 6 shows the Si-F bond absorption ($930cm^{-1}$) spectra of FT-IR before and after PCT. The Si-F bond absorption did not change even after PCT. This result indicates that fluorine atoms are tightly bonded to silicon atoms.

The breakdown strength histogram is shown in Fig. 7. The SiOF films have high breakdown strength of about 6 - 8 MV/cm. This is high enough for a practical interlayer dielectric film.

Gap filling and planarization were investigated. Fig. 8 shows a SEM photograph of the cross-sectional view of the SiOF film deposited on the 0.35μm space pattern (aspect ratio is about 3.8). Excellent planarization and gap filling without void are accomplished.

CONCLUSION

We have deposited SiOF films with low dielectric constant by ECR plasma CVD. The

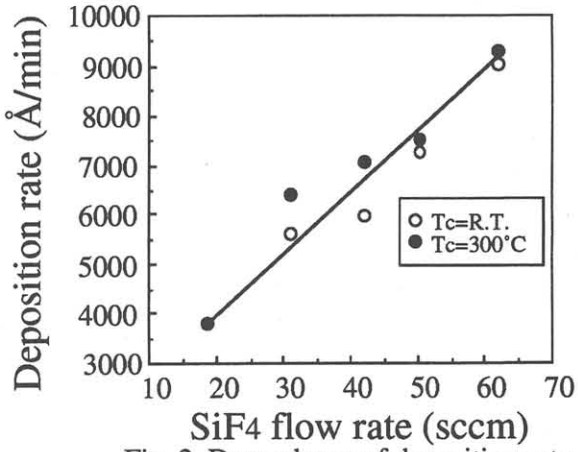

Fig. 2 Dependence of deposition rate on SiF_4 flow rate.
O_2:Ar=80:43 sccm
Microwave power=2.8kW, rf power=0W

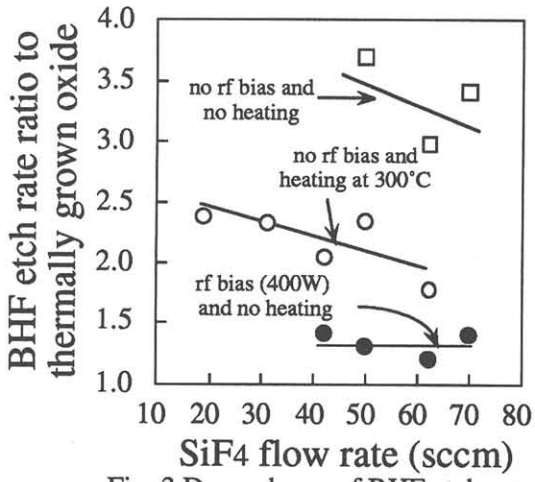

Fig. 3 Dependence of BHF etch rate ratio on SiF_4 flow rate.
O_2:Ar=80:43 sccm
Microwave power=2.8kW

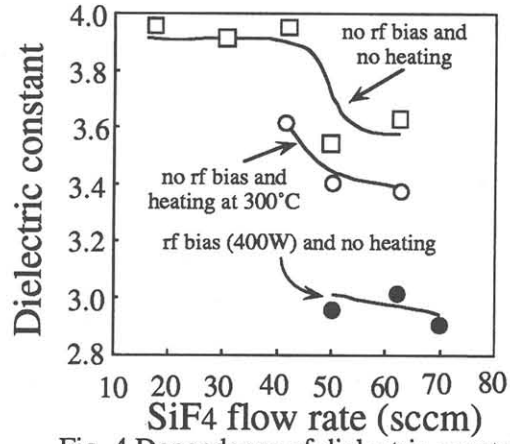

Fig. 4 Dependence of dielectric constant on SiF_4 flow rate.
O_2:Ar=80:43 sccm
Microwave power=2.8kW

SiOF films have low dielectric constant (about 3.0), high breakdown strength (6 ~ 8 MV/cm), low etch rate equivalent to a thermally grown oxide, and tight Si-F bonds. Further, the SiOF films reveal excellent planarization and gap filling without void. This SiOF film can be used as interlayer dielectric films for ULSI.

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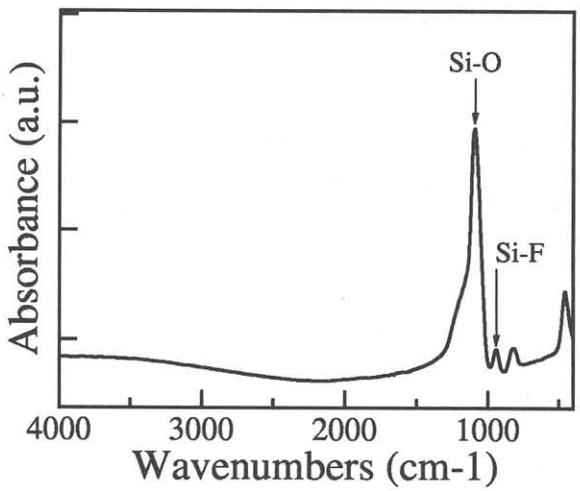

Fig. 5 FT-IR spectrum

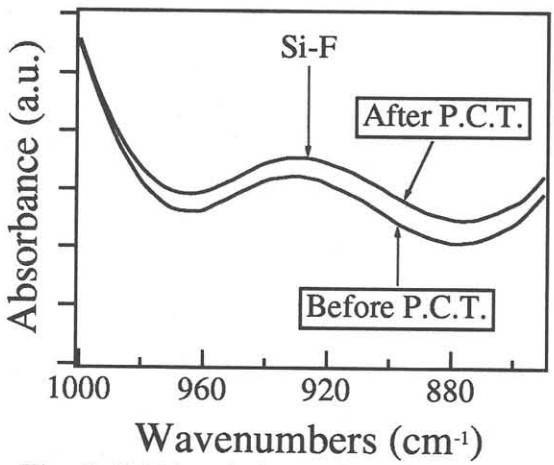

Fig. 6 Si-F bond absorption spectra of FT-IR before and after PCT
Microwave power=2.8kW, rf power=400W
SiF_4:O_2:Ar=62:80:43 sccm

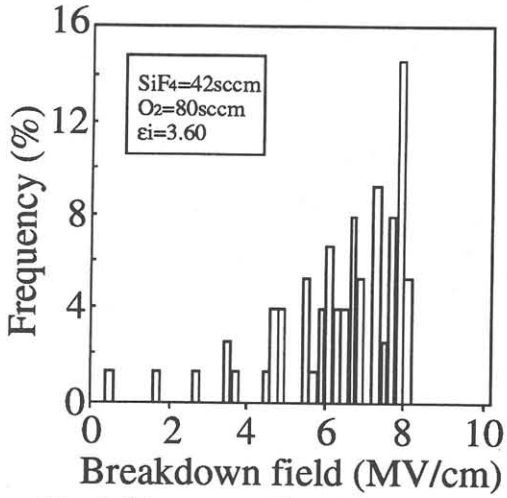

Fig. 7 Histogram of breakdown strength.
Microwave power=2.8kW
Chuck temperature=300°C

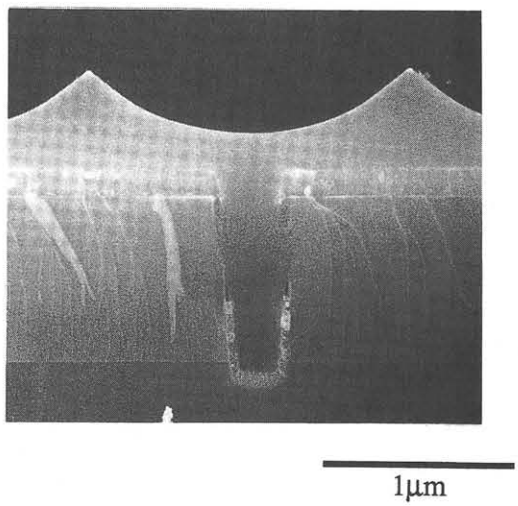

Fig. 8 SEM photograph of the cross sectional view of SiOF deposited on the 0.35μm space pattern. (aspect ratio is about 3.8)