HIGH QUALITY SILICON-NITRIDE THIN FILMS GROWN BY
HELIUM PLASMA-ENHANCED CHEMICAL VAPOR DEPOSITION

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Abstract:
Silicon nitride(SiN) films with very high dielectric strength of more than 8MV/cm were successfully deposited on Si wafers using helium plasma-enhanced chemical vapor deposition(He-PECVD) at very low deposition temperature. The quality of the SiN films was much better than that of the SiN films deposited by the conventional PECVD.

Silicon oxynitride(SiON) films with index of refraction varying from 1.46 to 2.0 were also deposited on Corning-7059 glass substrate by controlling the gas flow rate using computer process controller.

1. INTRODUCTION

The silicon oxide(SiO₂), silicon nitride(SiN), or silicon oxynitride(SiON) thin films grown by plasma enhanced chemical vapor deposition(PECVD) have been widely used as insulators or passivation layers for the semiconductor devices or integrated circuits. The PECVD is a low temperature process and it does not degrade the performance of the semiconductor devices or integrated circuits by preventing unwanted diffusion of carriers[1-3].

The refractive index of SiON film grown by PECVD varies from 1.46 to 2.0 according to the oxygen and the nitrogen compositions. The flow rates of reactant gases can be changed by real time control of mass flow controllers so that the PECVD deposited SiON films may have different indices of refraction. By constructing multiple or inhomogeneous SiON layers, it is possible to deposit optical interference coatings such as antirefection(AR) coatings[4,5].

In this research, the improved breakdown field strength of SiN films grown by Helium-PECVD is described. The calibration chart of SiON films grown by conventional PECVD is also described.

2. EXPERIMENTAL

The PECVD with a computer process controller was used to deposit SiN and SiON multiple dielectric layers. The PECVD differs from conventional pyrolitic chemical vapor deposition (CVD) which uses purely thermal activation of the deposition reaction at very high temperatures, typically in excess 800°C. Instead, PECVD uses a plasma to activate or enhance the deposition reactions to produce thin films from flowing reactant gases[6-11]. Therefore, PECVD
can be accomplished at a reduced substrate temperature, typically about 300°C. The physical properties of plasma-deposited films depend on process parameters which modify the plasma properties such as pressure, substrate temperature, power, plasma excitation frequency, and gas flow rates.

A schematic diagram of the SemiGroup 1000 PECVD system, which is used to deposit SiON layers, is shown in Fig. 1. The PECVD reactor has a capacitively coupled, parallel plate configuration in which the top electrode is powered, while the bottom electrode is grounded and heated. The excitation frequency was 13.56 MHz and the substrate temperature of the substrate was set to 300°C. Silane (SiH₄) diluted in helium (2.01% SiH₄ in He), nitrogen (N₂), nitrous oxide (N₂O) diluted in helium (5% N₂O in He), and He gases were the process gases employed for the growth of SiN and SiON layers.

![Schematic diagram of the PECVD system](image)

**Fig. 1 A schematic diagram of the PECVD system.**

2.1 The deposition of SiN films by He-PECVD

The SiN films were deposited on silicon wafers by PECVD. The chamber pressure of 700mTorr, and power density of about 70mW/cm² were used for the deposition of SiN films. The gases used were SiH₄, N₂, and He, and the flow rates were 25sccm, 12.5sccm, and 350sccm, respectively.

The silicon substrate were pretreated with low power He-plasma before the deposition of SiN films for 0, 5, and 10 minutes. The electrical characteristics of the deposited SiN films were measured and compared.

2.2 The deposition of SiON films by the conventional PECVD

The SiON films were deposited on the Corning-7059 substrates by the conventional PECVD. The chamber pressure of 500mTorr, and power density of about 165mW/cm² was used for the deposition of SiON films. The gases used were SiH₄, N₂, and N₂O. The N₂O is exceedingly reactive, compared to N₂, so that small variations of the N₂O flow rate result in large variations in the refractive index of the film. For this reason, the flow rates of SiH₄ and N₂ (as well as other deposition parameters such as RF power, chamber pressure, and substrate
temperature) were kept constant using the SemiGroup programmable microprocessor; only the \( \text{N}_2\text{O} \) flow rate was subject to real time control by the computer process controller. The calibration chart which shows the index of refraction and the deposition rate as a function of \( \text{N}_2\text{O}/\text{N}_2 \) flow rate ratio was constructed.

3. RESULTS AND DISCUSSIONS

3.1 The SiN films grown by He-PECVD

The silicon substrate were pretreated with low power He-plasma before the deposition of SiN films. The average dielectric strengths of the SiN thin films deposited on Si substrates without He-plasma pre-treatment and with 5 or 10 minutes of He-plasma pre-treatment were 3MV/cm and 8MV/cm, respectively. There were no big differences in the dielectric strength between the SiN films with 5 minutes of He-plasma pre-treatment and 10 minutes of He-plasma pre-treatment.

It seems that the very high quality plasma oxide was formed on the Si substrate during the He-plasma pre-treatment. The base pressure of the PECVD chamber was 5mTorr and it is clear that the dissociation of water molecule remained in the PECVD chamber under He-plasma caused the deposition of high quality silicon dioxide film on the surface of the Si substrate. The very thin silicon dioxide deposited on the surface of the bare Si substrate in a self-limiting manner during the He-plasma pre-treatment was believed to have increased the dielectric strength of the SiN films grown by He-PECVD.

![Image](attachment:fig2.png)

Fig. 2 The Current - Voltage characteristics of SiN films grown by He-PECVD.

![Image](attachment:fig3.png)

Fig. 3 The Capacitance - Voltage characteristics of a SiN film grown by He-PECVD.
3.2 The SiON films grown by the conventional PECVD

Generation of a calibration chart is a first requirement for the fabrication of multiple or inhomogeneous dielectric layers. A large number of homogeneous SiON layers with different compositions were grown on Si substrates by varying the N₂O/N₂ flow rate ratio; then the refractive indices and thicknesses of these SiON films were measured by ellipsometry. A calibration chart was constructed by plotting the refractive indices and deposition rates as a function of the N₂O/N₂ flow rate ratio as shown in Fig. 4 (a) and (b), respectively.

![Graphs](image)

Fig. 4.1 SiON calibration chart. (a) Refractive index, and (b) deposition rate as a function of N₂O/N₂ flow rate ratio.

The dynamic range of the index of refraction of a SiON layer varies from approximately 1.46 for SiO₂ to 2.0 for SiN. The minimum deposition rate of SiON films varies from about 93 Å/min. for SiN growth to 214 Å/min. for SiO₂ growth. The flow rate ratios and deposition rates are selected according to the desired composition and thickness of the dielectric layer. The optical thin film is then synthesized by specifying the flow rate of the N₂O and the deposition time by writing a process control program using the computer process automation system which controls the deposition in real-time.

4. CONCLUSION

The SiN films with very high dielectric strength were successfully deposited on Si wafers using He-PECVD at very low deposition temperature. The average dielectric strengths of the SiN thin films deposited on Si substrates without He-plasma pre-treatment and with 5 or 10 minutes of He-plasma pre-treatment were 3MV/cm and 8MV/cm, respectively. One of the possible applications of high quality SiN films grown by He-PECVD on a He-plasma pretreated Si substrate at low temperature includes the gate insulator of the field emitter devices.

Silicon oxynitride(SiON) films with index of refraction varying from 1.46 to 2.0 were deposited on Corning-7059 glass substrate by controlling the gas flow rate using the computer process controller. Using SiON layer, multilayer or inhomogeneous AR coatings for field emission display can be constructed on the Corning-7059 glass substrate so that the contrast ratio of the FED can be improved.

References