Extended Abstracts of the 1994 International Conference on Solid State Devices and Materials, Yokohama, 1994, pp. 703-705

PD-4-10

Low Temperature CVD of High Quality SiO_2 Film Using Helicon Plasma Source

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Helicon plasma, a new compact high density plasma source, was investigated for chemical vapor deposition of dielectric oxide. High quality films having low compressive stress of 1-2E9dyne/cm2, lower SiOH content and comparable wet HF etch rate to thermal oxide were obtained. Sub-half micron gaps with high aspect ratio were successfully filled by applying a substrate bias. A combination of biased Helicon plasma CVD and AP TEOS-O3 NSG which has self planarizing characteristics is proposed for planarization without CMP.

INTRODUCTION

Intermetal dielectric formation for advanced devices requires high gap fill capability and high mechanical and electrical reliability. Plasma TEOS CVD and TEOS-O3 AP (Atmospheric Pressure) CVD (1,2) have been widely utilized for half- micron interconnection, however, their film qualities have generated concern about water related reliability issues. High density plasma CVD, such as ECR CVD has been investigated to achieve higher density films with good water blocking (3,4) and gap fill, with simultaneous deposition and sputter etch by applying a substrate bias (5,6).

Other high density plasma sources, such as ICP (inductively coupled plasma), and Helicon wave excited plasma (7,8) have been recently investigated for sub-half micron etching technology (9,10). Helicon plasma has been reported to provide higher density plasma (n=1E12-13/cm3) than ICP and ECR plasma, at lower magnetic field with a simpler structure than ECR plasma. Only a few investigations, however, have been reported for Helicon plasma utilized for chemical vapor deposition.

In this paper, we report a preliminary characterization of SiO_2 films by Helicon plasma CVD at low temperature, less than 300°C, using a SiH_4, O_2 and Ar chemistry. Excellent gap fill of biased Helicon CVD in combination with AP TEOS-O3 NSG which has self-planalizing feature, will be presented for an advanced intermetal dielectric application without chemical-mechanical polish (CMP) planarization.

EXPERIMENTAL

The Helicon plasma source consists of a quartz tube with a double-loop antenna which gives M=0 mode plasma by RF power (13.56MHz), and the substrate is biased by HF power (100KHz). SiH_4 gas is introduced through a gas ring to wafer surface and react s with oxygen and Ar plasma excited in the upper quartz tube as shown in Fig.1. The deposition conditions are listed in Table 1. Film thickness was measured by interferometry. Refractive index by ellipsometry, film stress at room temperature by stress gauge (Ionic System), Fourier transform infrared (FT-IR) spectrum and wet etch rate in 1% HF solution were measured for film characterization. The hydrogen and water desorption from SiH, SiOH and absorbed water in the film were evaluated by Thermal Desorption Spectroscopy (TDS). Gap filling properties for sub-half micron poly-Si spaces were observed by scanning electron microscope (SEM).

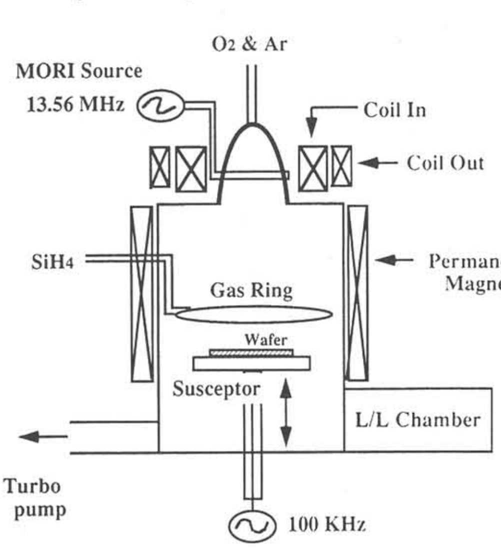

Fig. 1 Apparatus of bias Helicon Plasma CVD

RESULTS & DISCUSSION

Table 1 summarizes the film properties under the listed experimental conditions. Deposition rate was determined mainly by source gas flow and gas ring to wafer distance, denoted as gap in Fig.2, which suggests that the reaction is diffusion limited. The deposition rate decrease and significant drop in wet etch rate with increasing substrate bias is attributed to the densification of the film and simultaneous sputter etch. High density films with low wet etch rate were also obtained at high Helicon source power without substrate bias as shown in Fig.3. This suggests that substantially dense plasma is considered to be formed in Helicon plasma.

Table 1. Deposition conditions and film properties

Reactant gases	O2, SiH4 and Ar
Gas pressure	6 -- 30mTorr
Helicon power	0.5 -- 2.0KW
Bias power	0 -- 500W
Substrate temperature	25 -- 300°C
Deposition rate	300 -- 2000Å/min
Refractive index	1.45 -- 1.75
Film stress	1 -- 2E9dyne/cm2
Wet etch rate ratio to th. oxide	< 3 with bias

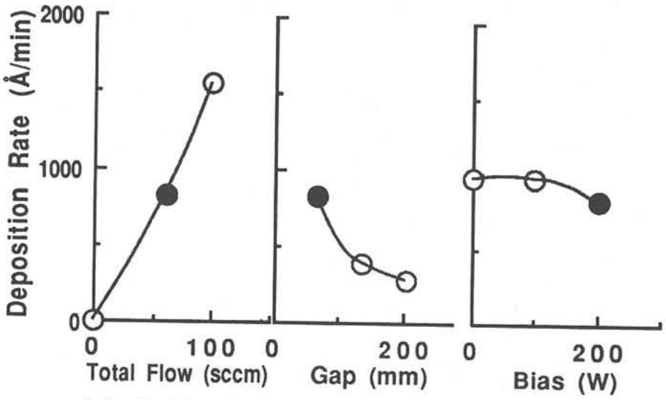

Fig.2 Dependence of deposition rate
●; standard condition.

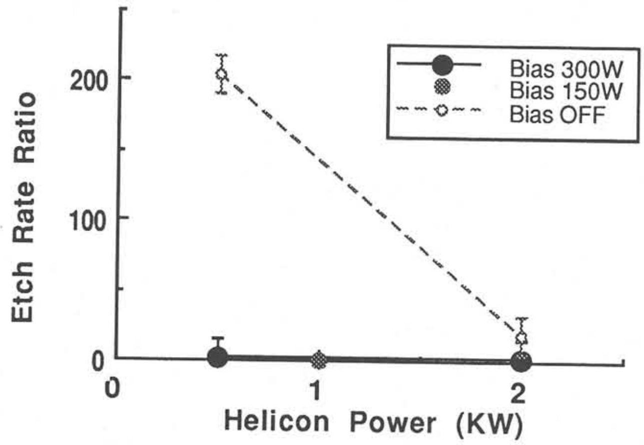

Fig. 3 Dependence of wet etch rate.

Low compressive stress films of 1-2E9dyne/cm2, and stable films with no significant stress change by water absorption in ambient air, were obtained by substrate bias and at higher Helicon source power as shown in Fig.4.

Film properties such as film composition and chemical bonding structure evaluated by refractive index as shown in Fig.5, and by FT-IR spectrum as shown in Fig.6 were strongly dependent on O_2 and SiH_4 gas flow ratio. Higher SiH_4 gas flow gives a higher refractive index film with higher SiH content. The absorption peaks associated with SiH stretching band at about 2260cm-1 and SiO band in the structure of $HSiO_3$ at about 880cm-1 were observed. Very low wet etch rate, less than of thermal oxide, at higher SiH_4 would indicate that Si rich film is formed in an oxygen starved condition. Higher O_2 gas flow gives comparable refractive index and FT-IR spectrum to thermal SiO2 of stoichiometric film. SiOH containing films having the absorption peak associated with OH stretching band in the structure of SiOH at about 3650cm-1 were formed at excess oxygen conditions. The films of comparable wet etch rate, containing very low SiOH and SiH were obtained at around 1.3 O_2/SiH_4 gas flow ratio. Hydrogen from SiH and water desorption from SiOH were observed at temperature higher than 400°C and 600°C respectively as shown in Fig.7. Loosely absorbed water evolving at lower temperature was negligible except in the films deposited at low Helicon power without substrate bias.

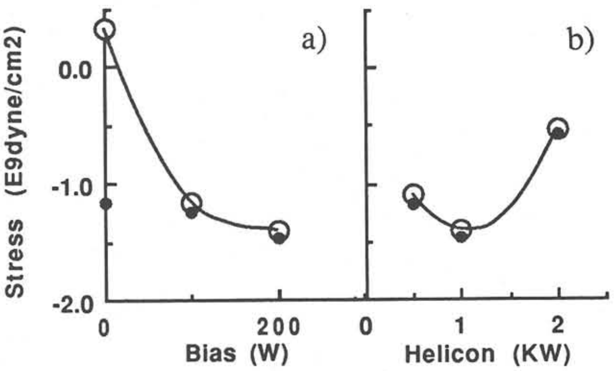

Fig.4 Dependence of film stress
o; as deposition, •; 3 weeks exposed in air.
a) Helicon; 1KW, b) Bias; 200W.

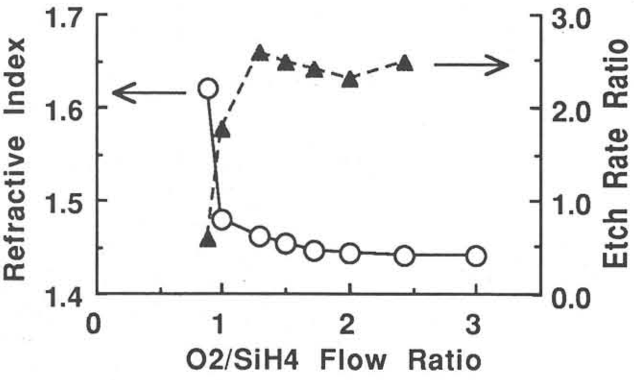

Fig.5 Dependence of Refractive Index and Etch rate ratio to therm. oxide.

Figure 8 shows the deposition rate ratio of AP TEOS-O_3 NSG on Helicon plasma CVD films versus Bare Si. TEOS-O_3 NSG has been reported to show dependency on substrate material, which causes deposition rate, surface morphology and step coverage differences.(11). The deposition rate ratio of TEOS-O_3 NSG on Helicon plasma CVD film was controlled to almost unity by the O_2 and SiH_4 gas flow ratio.

Sub-half micron gap fill was successfully achieved by substrate bias as shown by SEM in Fig.9. The sputtered edges affecting the subsequent metalization can be planarized by the deposition with good step coverage, such as AP TEOS-O_3 NSG, which has self-planarizing characteristics, thus avoiding CMP process which is susceptible to mechanical damage and water intrusion.

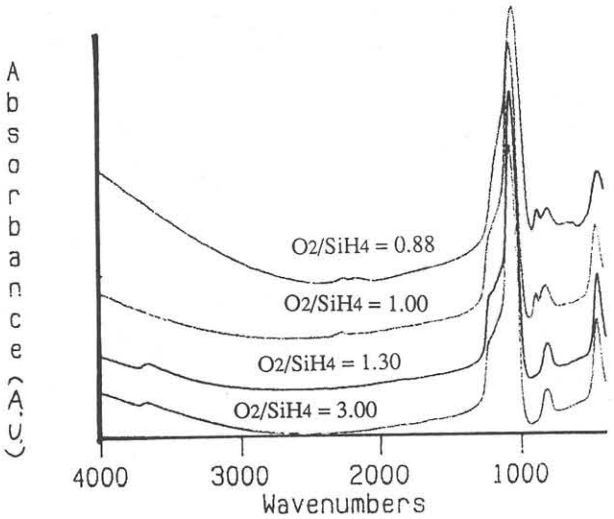

Fig.6 FT-IR spectra at various O2/SiH4 ratio.

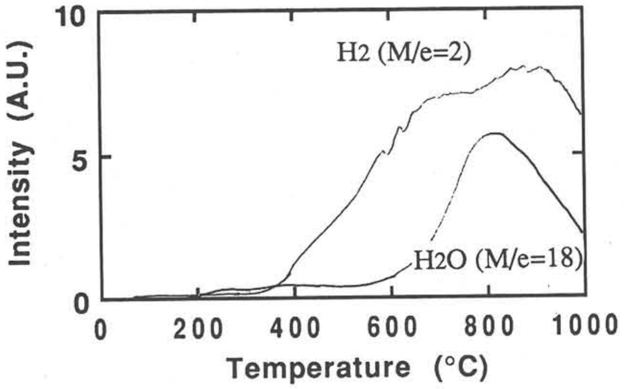

Fig.7 TDS spectra of water and Hydrogen.

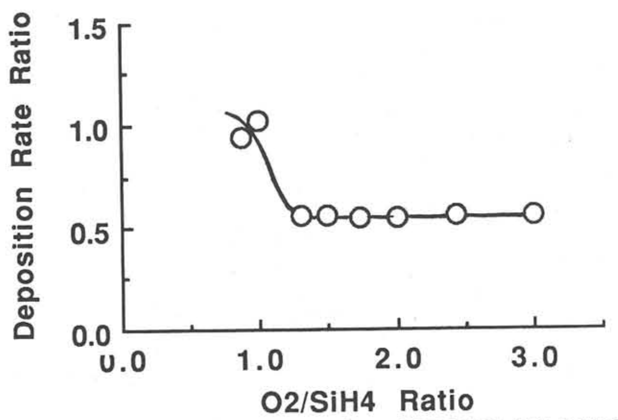

Fig.8 Deposition rate ratio of TEOS-O3 NSG on Helicon plasma CVD film versus Si.

CONCLUSION

Helicon plasma, a new compact high density plasma source, was investigated for chemical vapor deposition of intermetal dielectric oxide. The resultant high quality films, filling high aspect ratios, establish Helicon plasma CVD as a promising process for future next generation sub-half micron devices.

REFERENCES

(1) K. Fujino, Y. Nishimoto, N. Tokumasu, and K. Maeda, J. Electrochem. Soc., Vol. 137, No.9, p.2883 (1990).
(2) Y. Takata, A. Ishii, M. Matsuura, A. Ohsaki, M. Iwasaki, J. Miyazaki, N. Fujiwara, J. Komori, T. Katayama, S. Nakao, and H. Kotani, Proc. IEEE VMIC Conf., p.13 (1991).
(3) K. Machida, N. Shimoyama, J. Takahashi, Y. Takahashi, E. Arai, and N. Yabumoto, Proc. IEEE VMIC Conf., p. 103 (1993).
(4) M. Doki, H. Watatani, S. Okuda, and Y. Furumura, Proc. IEEE VMIC Conf., p. 235 (1994).
(5) C. Chiang, D. B. Fraser, and D. R. Dension, Proc. IEEE VMIC Conf., p. 381 (1990).
(6) B. Fowler, D. Stark, J. Xie, P. McDonald, R. Carpio, and S. Akbar, SPIE Vol. 2090 Multilevel Interconnection p. 203 (1993).
(7) F. F. Chen, Plasma Physics and Controlled Fusion, Vol. 33, No. 4. p.339 (1991).
(8) T. Shoji, Y. Sakawa, S. Nakazawa, K. Kadota and, T. Sato, Plasma Sources Sci. Technol. 2, p.5 (1993).
(9) R. W. Boswell and R. K. Porteous, J. Appl. Phys. 62 (8), 3123 (1987).
(10) A. J. Perry, D. Vender, and R. W. Boswell, J. Vac. Sci. Technol. B9 (2), p.310 (1991).
(11) K. Fujino, Y. Nishimoto, N. Tokumasu, and K. Maeda, J. Electrochem. Soc., Vol. 138, No. 2, p.550 (1991).

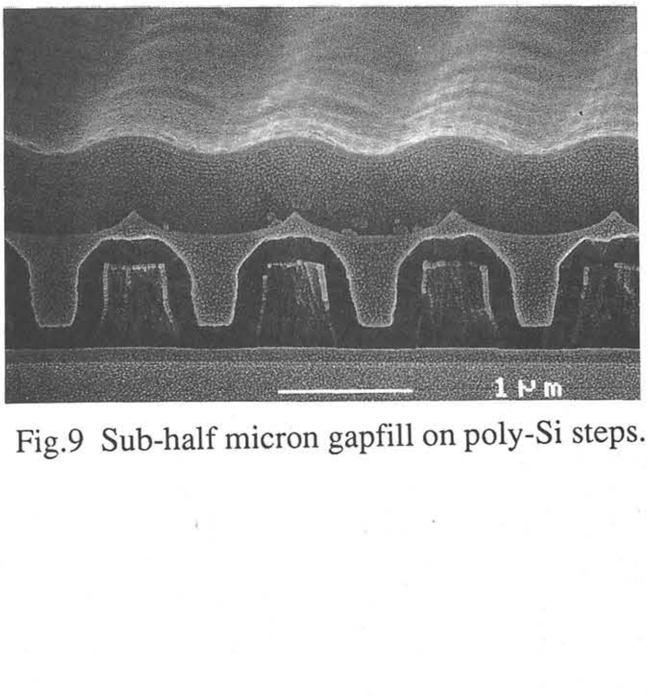

Fig.9 Sub-half micron gapfill on poly-Si steps.