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Single Step Gap Filling Technology for Subhalf Micron Metal Spacings on Plasma Enhanced TEOS/O_2 Chemical Vapor Deposition System

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A new inter-metal dielectric (IMD) film formation technology for subhalf micron metal to metal space filling has been developed by utilizing C_2F_6 gas on mixed frequency plasma enhanced TEOS/O_2 chemical vapor deposition (PE-TEOS/O_2 CVD) system. Gap filling capability for greater than 2.3:1 aspect ratio of metal to metal spacings was confirmed. Furthermore, it was obtained that those films contain 5~10 atomic % of F, which reduce the dielectric constant of IMD film and is expected to enhance the device performance.

1. Introduction

As the device geometry getting smaller, the requirement for IMD film is more severe, mechanically and electrically. As the result, the IMD process used in advanced semiconductor devices are very complex. Multi-layer structure (PE-CVD~ SOG~ PE-CVD[1~4]), PE-CVD~TEOS/O_3~PE-CVD[5~9]) is widely used with the sacrifice of productivity.

The characterization of PE-TEOS/O_2/NF_3 CVD process has been reported to reduce the void formation and to be simple, single step process.[10~11]) Recently, we have developed PE-TEOS/O_2/C_2F_6 CVD process. By adding C_2F_6 gas to TEOS/O_2 chemistry on PE-CVD system, it was confirmed that the gap filling capability was remarkably enhanced, which can be applied for single step gap filling of subhalf micron metal to metal spacings. So, the IMD process productivity will be greatly improved. In addition, it was obtained that the H_2O content and absorption of the film was maintained as low as that of conventional PE-TEOS/O_2 CVD film. Furthermore, those film contains 5~10 atomic % of F, which reduce the dielectric constant of IMD film and, is expected to enhance the device performance.

In this paper, physical and chemical properties (stress, wet etch rate, FT-IR,SIMS and ESCA) of the PE-TEOS/O_2/C_2F_6 CVD film will be presented and compared to those of conventional PE-TEOS/O_2 CVD film. Also, the result of electrical measurement (I-V, C-V) will be presented, as well as the SEM microphotographs for deposition profile.

2. Experimental

All the CVD experiments were carried out on AMAT Precision-5000CVD system. The system has the parallel plate mixed-frequency PE-CVD configuration.TEOS is fed into process chamber employing He gas as a carrier. In general, (TEOS+He)/O_2 flow rate ratio, high frequency power, pressure, susceptor temperature and electrodes spacing were fixed throughout the experiments.

3. Results and Discussion

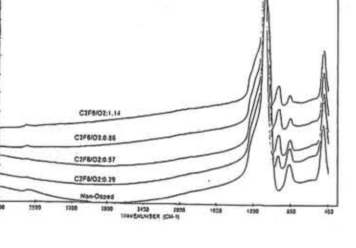
3.1 Optimization of PE-TEOS/O_2/C_2F_6 process

Table 1 shows that the gap filling capability strongly depends on the C_2F_6/O_2 flow rate ratio and low frequency/high frequency (LF/HF) power ratio.

Table 1 Gap filling capability. (Aspect ratio=2.0)

C2F6/O2 Ratio \ LF/HF Ratio	0.75	1.13	1.75	2.75
0.14			VOID	VOID
0.29		VOID	VOID FREE	VOID FREE
0.57	VOID	VOID FREE	VOID FREE	
0.86	VOID	VOID FREE		
1.14	VOID FREE	VOID		

The film characteristics such as F concentration, stress and wet etch rate are also affected by the C_2F_6/O_2 flow rate ratio and LF/HF power ratio as shown in Figs.1-3.



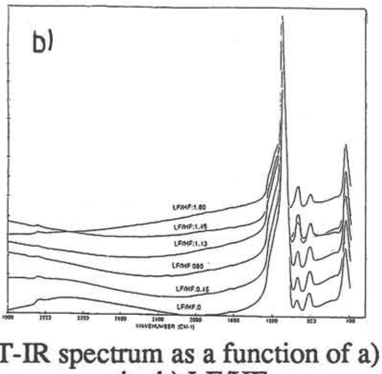


Fig.1 FT-IR spectrum as a function of a) C_2F_6/O_2 flow rate ratio, b) LF/HF power ratio.

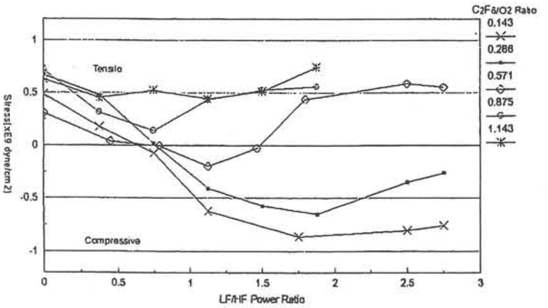


Fig.2 Film stress as the function of C_2F_6/O_2 flow rate ratio and LF/HF power ratio.

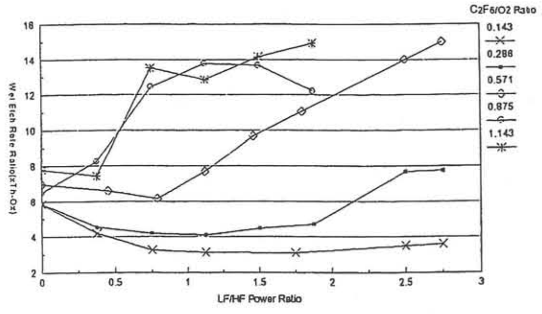


Fig.3 Wet etch rate as the function of C_2F_6/O_2 flow rate ratio and LF/HF power ratio.

There exists an optimal C_2F_6/O_2 flow rate ratio and LF/HF power ratio. In the following experiments, we consider C_2F_6/O_2=0.57 and LF/HF=0.89 as the optimal process condition.

3.2 Characteristics of PE-TEOS/O_2/C_2F_6 CVD film

Fig.4 shows the SIMS spectrum for F concentration and depth profile analysis in PE-TEOS/O_2/ C_2F_6 CVD film.

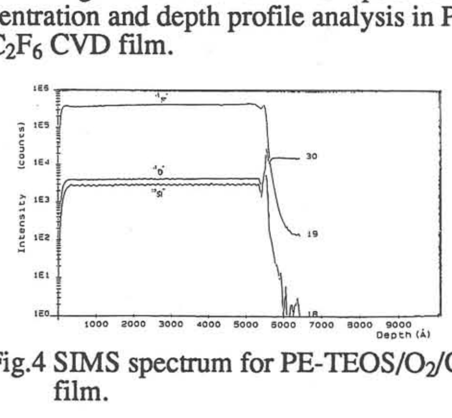


Fig.4 SIMS spectrum for PE-TEOS/O_2/C_2F_6 CVD film.

Fig.5 shows the XPS spectrum for chemical bond analysis in PE-TEOS/O_2/C_2F_6 CVD film.

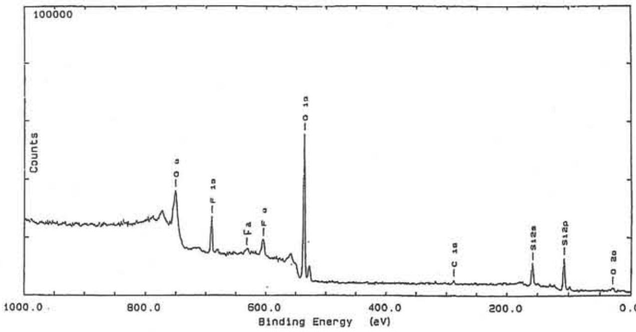


Fig.5 XPS spectrum for PE-TEOS/O_2/C_2F_6 CVD film

It is obtained that approximately 7.4% of F atoms are uniformly distributed, and those F atoms are bonded to Si atoms in PE-TEOS/O_2/C_2F_6 CVD film.

TDS spectrum for H_2O desorption analysis is shown in fig.6 , and also, the film properties are summarized in table 2 as a comparison to Thermal-TEOS/O_3 CVD and PE-TEOS/ O_2 CVD films .

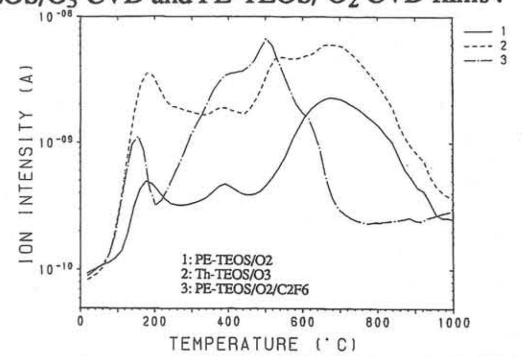


Fig.6 TDS spectrum for PE-TEOS/O_2/C_2F_6 CVD film

Table 2 Properties of PE-TEOS/O_2/C_2F_6 CVD film.

	PE-TEOS/O2	Th-TEOS/O3	PE-TEOS/O2/C2F6
Wet Etch Rate (/Thermal Ox.: 6:1 BOE)	2.0	3.6	4.7
Stress (E9Dyne/cm2)	1.3 Compressive	4.0 Tensile	0.2 Compressive
Refractive Index	1.46	1.45	1.41
Dielecteic Constant	4.2	5.3	3.9
Leak Current (A:3MV/cm)	7.0E-12	1.0E-09	4.0E-08

It is obvious that the PE-TEOS/O_2/C_2F_6 CVD film has such an strong advantage that dielectric constant is lowest among the 3 films compared. On the other hand, it has some disadvantages such as weakness in dielectric leakage and H_2O desorption comparing to the PE-TEOS/O_2 CVD film. In the next section, we present one approach to supplement these disadvantages.

3.3 Application of PE-TEOS/O_2/C_2F_6 CVD film

One approach to supplement the poor film properties of Thermal-TEOS/O_3 CVD film is to form the stacked structure, which is practically used for device application of the Thermal-TEOS/O_3 CVD film. We applied the same concept for PE-TEOS/ O_2/C_2F_6 CVD film. An advantage of PE-TEOS/ O_2/C_2F_6 CVD process is to be able to combine non

C_2F_6 process without any requirement for hardware change.

Fig.7 shows the TDS spectrum for water desorption analysis of the PE-TEOS/O_2~PE-TEOS/O_2/C_2F_6~PE-TEOS/O_2 CVD films, triple layer stacked structure.

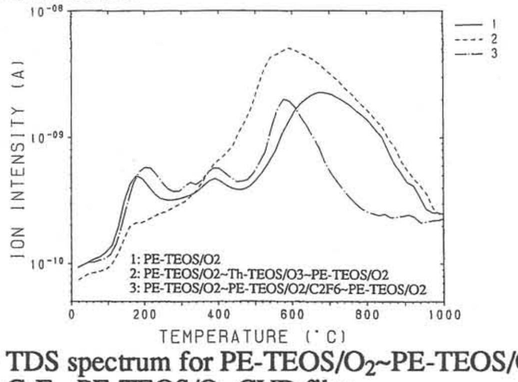


Fig.7 TDS spectrum for PE-TEOS/O_2~PE-TEOS/O_2/C_2F_6~PE-TEOS/O_2 CVD film.

It was obtained that the H_2O desorption was greatly reduced by the stacked structure. It seems that the H_2O desorption spectrum traces that of PE-TEOS/O_2 CVD film at low temperature regime (<600 C) and PE-TEOS/O_2/C_2F_6 at high temperature regime (>600 C), and as the result, total H_2O desorption is even lower than that of PE-TEOS/O_2 CVD film.

Other film characteristics are summarized in table 3.

Table 3 Characteristics of PE-TEOS/O_2~PE-TEOS/O_2/C_2F_6~PE-TEOS/O_2 CVD film.

	PE-TEOS/O2	PE-TEOS/O2 Th-TEOS/O3 PE-TEOS/O2	PE-TEOS/O2 PE-TEOS/O2/C2F6 PE-TEOS/O2
Stress (E9Dyne/cm2)	1.3 Compressive	1.5 Tensile	0.6 Compressive
Dielecteic Constant	4.2	4.3	3.6
Leak Current (3MV/cm)	7.0E-12	1.3E-11	1.1E-11

The weakness in film stress and dielectric leakage is also supplemented by the stacked structure. Further more, the dielectric constant is even lower comparing to that of single PE-TEOS/O_2/C_2F_6 CVD film.

As shown in fig.8, even with this stacked structure, we could achieve the gap filling of 0.7um height/0.3um width (aspect ratio>2.3) of metal to metal spacings on flat oxide surface.

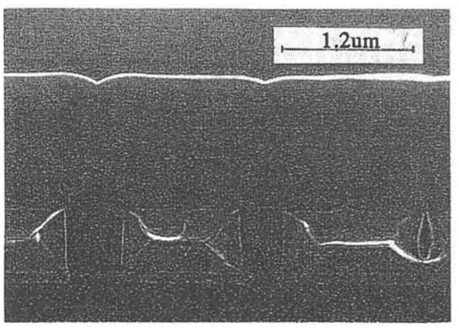


Fig.8 SEM microphotographs of PE-TEOS/O_2~PE-TEOS/O_2/C_2F_6~PE-TEOS/O_2 CVD film over metal lines on flat oxide surface

4. Summary

By utilizing C_2F_6 gas in PE-TEOS/O_2 CVD system, single step gap filling of 0.7um height/0.3 um width metal to metal spacings has demonstrated on AMAT Precision-5000CVD system. Gap filling capability of PE-TEOS/O_2/C_2F_6 CVD process strongly depend on the C_2F_6/O_2 flow Rate ratio and LF/HF power ratio. PE-TEOS/O_2/C_2F_6 CVD film contains approximately 7.4% of F atoms, and the F atoms are bonded to the Si atoms and uniformly distributed in the film. As the result, the film has such a strong advantage as lower dielectric constant. On the other hand, the film is weak in dielectric leakage and H_2O desorption. However, those weakness is supplemented by PE-TEOS/O_2~PE-TEOS/O_2/C_2F_6~PE-TEOS/O_2 CVD stacked film structure. The stacked structure also further enhances lowering the dielectric constant, and still remain good gap filling capability.

5. References

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