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Plasma Deposited Low k SiCOH Films with Improved Properties Using Nano Imbedded Layers Insertion

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INTRODUCTION

Integration and development of Cu BEOL with PECVD low-K dielectrics with k ~ 2.8 and -3.0 has been reported by our group [1-2, 8] and a number of institutions for the 130, 90 and 65 nm generations [3-7], and has become the predominant path chosen by the industry. In effort to lower the SiCOH ILD dielectric constant, voids had been introduced into the SiCOH film making it become highly porous . As the result, the material also becomes more susceptible to cracking during thick Cu/ILD fabrication. In this paper, we report a simple method to form imbedded nano thickness layer film to enhance the cracking resistance for both plasma deposited SiCOH with low dielectric constants (k~ 2.8) and 2.2 (k~2.2 film has about 30 % porosity). The SiCOH films with k ~2.8 reported here were engineered for the highest levels of mechanical and electrical properties and reliability with simple plasma CVD process chemistry with enhanced bonding structure. This paper focuses on the formation of the imbedded nano layer during the film's deposition and characterization of the high mechanical properties k film with dielectric constant in the range of 2.8 using simple and low cost organosilicon precursor and oxidant. The same evaluation was implemented with the highly porous SiCOH film with k~2.2.

EXPERIMENTAL AND DISCUSSION

The SiCOH films with k ~2.8 were deposited in a production worthy 300 mm plasma CVD system using a commercial ring structured organosilicon precursor. The as-deposited films have good uniformity (1 sigma < 3 %) and uniformed composition across the 300 mm. Table 1 shows typical properties of SiCOH film with dielectric constant in 2.78-2.8 range. Highly porous SiCOH film with k~2.2 were also deposited in the same deposition system at lower temperature (225 degree C) and post deposition process treatment to form porous film.

The as-deposited films were analyzed using Aluminum dots MIS electrical measurement characterization. The film's mechanical properties such as modulus (H), hardness (E), stress, crack velocity and cohesive strength were also measured. Almost all porous and highly porous PECVD SiCOH films generally have higher tensile internal stress (>45 MPa) and are prone to cracking as the thickness increase (>1.2 micron). As the film thickness increase, the film's crack velocity in water (9) also increases significant beyond the acceptable level of ~5x10E-10 m/second. Above this level, the ILD is prone to cracking and peeling especially during packaging processing. Furthermore, plasma deposition process optimization to reduce the film's stress is also tending to reduce the film's modulus and hardness to unacceptable levels for Cu/low k Integration. For SiCOH film, the increased porosity in the film with (k < 2.8) will also increase the cracking velocity (i.e. reduce cracking resistance) beyond the acceptable level at thickness above 1.2 micron.

To address the cracking issues with these films, nanometer scale layers of SiOx or SiOxCy (2-5 nm thick) can be deposited in-situ during the PECVD deposition process between ILD layersr. Nanometer scale layers were imbedded within the ILD as part of the PECVD deposition using the same organosilicon precursor but with higher flow rate of O2 to form a 2-5 nm SiOx or SiOxCy layer within the ILD as shown in Figures 1 and 2. Figure 3 shows a very significant reduction of crack velocity in low k SiCOH film with various imbedded nanometer scale layers. It can be seen that the reduction of crack velocity is proportional to the number of imbedded nanometer scale layer inserted within the ILD. Little change in the overall film stress, modulus and hardness was observed with and without nanometer scale imbedded layers. This result is consistent with the minimal mechanical effect of the thin (~5nm) imbedded nano-layers in the overall thick (~2.2 micron) low k ILD film. FTIR bonding and Auger compositional analysis of the nano imbedded layers showed that the film is oxide like with a low carbon (< 4 atomic %) concentration. Mechanical measurements of thicker (1 um) imbedded layer shows this film have compressive stress (~ 65 MPa,) and much higher modulus (~67 GPa) and Hardness (~7.7 GPa) than the SiCOH ILD film. The imbedded layer also has good electrical properties with high breakdown (~ 9MV/cm), low leakage (<1xE-9 Amp/cm2) and low k value (k~3.2).

The TEM cross section, in Fig 2a, showed a typical structure of ILD with imbedded nano layers with very hard indentation force used in sample preparation that will crack all ILD . However , with normal indentation force in water and moisture (9) that generally will cause cracking in low k ILD. Tthe imbedded nano layer acts as crack stop to prevent the vertical propagation of film cracking and limits the crack to the nano-layer to the upper layer of the ILD, Figure 2b. The same improvement in crack resistance was observed with highly porous and thick plasma CVD SiCOH film with k ~2.2. Figure 4 showed the crack velocity improvement in highly porous low k ~2.2 SiCOH films with nano imbedded layers.

SUMMARY

With the simple insertion of imbedded nano layer during the deposition of plasma deposited porous low k SiCOH film, the cracking resistance of the thick ILD film can be improved significantly without changing modulus and hardness properties. The reduction in cracking will help to facilitate the implementation of thick ILD in Cu/Low k ILD for advanced BEOL.

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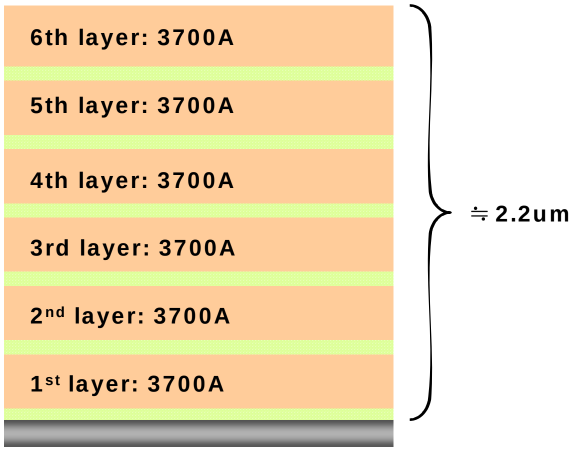
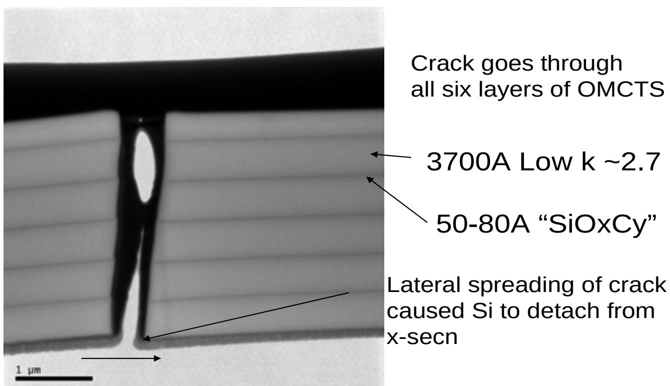


Fig.1. Typical Nano Imbedded Structure with equal ILD thickness

	SiCOH (k=2.8)
k (at R.T.)	2.78
Modulus [GPa]	9.2
Hardness[GPa]	1.04
Adhesion to SiC(N,H) [J/m2]	3.85*
Porosity [%]	22*
Averaged pore diameter [nm]	1.2 – 1.3*
Vbd [MV/cm]	> 8

Table 1. Typical Low-k (`2.78) SiCOH film properties.



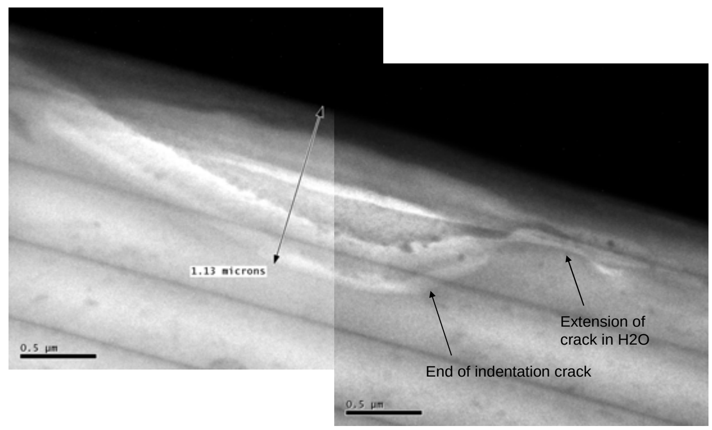


Fig. 2a and 2b. Typical TEM profiles of nano imbedded layers in low k ILD with hard indention force used for test and sample preparation (2a) . With normal indentation force, nano layer limits the end of normal indention crack and its extension in water and moisture to upper most ILD layers (2b) .

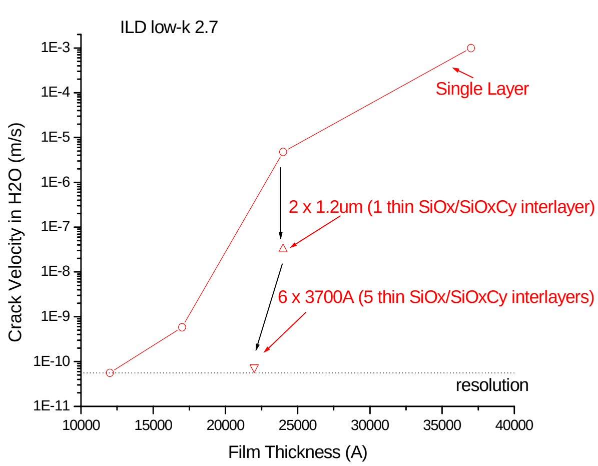


Fig.3. Reduction of Crack velocity with nano imbedded layer in typical SiCOH film with k ~2.78

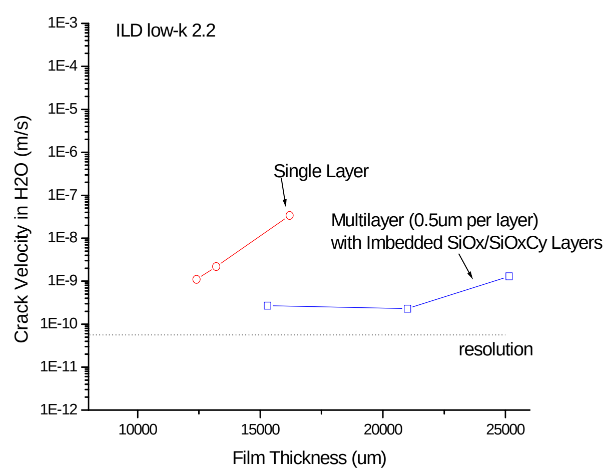


Fig.4. Reduction of Crack Velocity with nano imbedded layers in typical porous SiCOH film with k ~2.2

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