Robust ultrathin (20-25 nm) trilayer dielectric low k Cu damascene cap for sub-30 nm nanoelectronic devices.

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Introduction

Plasma Enhanced Chemical Vapor Deposited (PECVD) low k Silicon Carbon Nitride (SiCNH) has become the predominant dielectric Cu diffusion cap chosen by the industry. The integration and development of a bilayer dielectric Cu cap with k ~4.0 for 45/32 nm CMOS Back End of Line (BEOL) has been previously reported by our group [1-3]. Upon UV cure exposure used in processing porous SiCOH ILD in sub-32 nm CMOS BEOL, most low k SiCNx dielectric cap will convert from compressive to tensile stress. Thus, this stress conversion tends to induce the cracking in multi layer BEOL structures impacting the device reliability. This paper reports the development and optimization of robust trilayer PECVD silicon nitride/low k cap SiNx/SiNy/SiCNz dielectric film with k~-4.0 that remain compressive post UV cure of the p-SiCOH and its implementation in a multilevel structure of sub-32nm CMOS BEOL. The properties of the trilayer cap film were optimized for low k, oxidation and Cu diffusion barrier, and robust post UV cure mechanical properties. The trilayer cap layers are: 1) an ultrathin (1-1.5 nm) bottom silicon nitride deposited with silane (SiH_4) /ammonia (NH_3) precursors at low RF plasma power to minimize plasma damage to porous pSiCOH; 2) a middle ultrathin (3-7 nm) dense silicon nitride prepared with same precursors but at high RF power to produce a film with high compressive stress film; 3) a third thicker (10-25 nm) top layer low k SiCNH with low nitrogen concentration (~4 at. %) deposited with Trimethyl Silane (TMS) + NH_3. The new robust trilayer cap retains high compressive stress after exposure to UV cure and was successfully implemented in a multilevel 22nm BEOL structures.

Experimental and Discussion

The three layers of the trilayer cap films were deposited sequentially in a commercial 300 mm PECVD system using SiH_4+ NH_3 and TMS+ NH_3 at 350C using a 13.56 MHz RF power supply. The first two SiNx/SiNy layers were deposited from SiH_4+ NH_3 precursors, and the third layer was deposited from TMS+NH_3. Blanket cap structures were exposed to UV cure at 350C to evaluate the film's stress change post UV cure. Films were characterized by using various electrical measurements of MIM/MIS structures. Nano-indentation for modulus (E) and hardness (H), four points bending method for adhesion to Copper (Cu) metal, Fourier Transformed Infrared (FTIR) spectroscopy, Secondary Ion Mass spectroscopy (SIMS), Rutherford Back Scattering (RBS) and hydrogen forward scattering (HFS) methods were used to measure the cap film's properties, composition and bonding structure.

The first two cap layers are silicon nitride SiNx/SiNy films deposited at low and high rf plasma power to form a high stable compressive stress (k ~6.8-6.9, E~150 MPa, Stress~1200 MPa compressive) part of the trilayer cap. The top third layer is a carbon-rich SiCNH film deposited with k value around 3.3 to reduce overall effective k. The trilayer overall robust mechanical and post UV cure compressive stress provide excellent stability in multi-layer BEOL Cu-ultralow k interconnect structures. SIMS analysis showed that the initial 1.5 nm bottom SiNx layer deposited at low rf plasma power cause no plasma damage to ultra low k (k~2.2) pSiCOH film. The implementation of the ultrathin (20 nm) trilayer low k cap into 22 nm ground rule BEOL CMOS structures (Figure 1) results in ~ 4% reduction in wiring capacitance, low electrical leakage, and enhanced stress stability as compared to those of last generation bilayer (26 nm) low k cap (1).

Summary

Robust ultrathin (20 nm) trilayer low k SiNx/SiNy/SiCNH dielectric Cu caps (k ~4.0-4.2) with post UV cure compressive stress were developed and integrated into 22nm CMOS BEOL devices. The new cap reduces device's capacitance (~ 4 %) and enhances stress stability in Cu-ULK structures.

Acknowledgment

This work was performed by the Semiconductor Alliance Teams at various IBM Research and Development facilities.

References

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Figure 1- TEM of typical 22nm CMOS BEOL structures with 20 nm trilayer SiNx/SiNy/SiCNH cap structure (k~4) with 4% capacitance reduction (CR plot) compared to optimal 26.2 nm bilayer cap.