Carbon doped silicon oxides (SiOCd) deposited by plasma enhanced chemical vapor deposition (PECVD) is currently being used in interconnect applications requiring dielectric constant $k < 3$. Trimethylene silane (3MS) is a relatively new organosilane source for SiOCd deposition. Its advantages include ease of handling and the possibility of depositing both the low-$k$ dielectric and the low-$k$ barrier material from the same source [1]. In this paper, we describe an in-depth study of the plasma deposition of SiOCd from 3MS with the aim of obtaining better understanding of structure-property relationships and limitations for this low-$k$ material. In particular, it will be shown that for certain plasma conditions, SiC crystallites were found to be embedded within the SiOCd oxide matrix.

SiOCd films were deposited using a 3MS/O$_2$ plasma at 13.56 MHz in a two chamber PECVD cluster tool. The precursor flow rate ratio (FR), substrate temperature, chamber pressure and radio frequency (RF) power density were varied systematically and several series of samples were deposited onto (100) p-type Si wafers. The structure and composition of the deposited SiOCd films were comprehensively characterized by X-ray photoelectron spectroscopy (XPS), X-ray diffraction/refractivity (XRD/XRR), Fourier transform infra-red spectroscopy (FTIR), atomic force microscopy (AFM) and room temperature photoluminescence (RT-PL).

At constant substrate temperature, pressure and RF power, the dielectric constant of SiOCd does not change significantly with source gas FR. Typical carbon content determined from XPS (excluding H) is ~20 at.%. FTIR spectra showed that the bonding consists primarily of Si-$\equiv$O and Si-C bonds. The ratio of Si-C to Si-O bonds, however, increases with increasing RF power density for the pressure range studied (fig. 1). XRD analysis revealed further the presence of a crystalline phase within the SiOCd (fig. 2) and this is identified to be SiC from published literature [2]. The structure of the deposited SiOCd can be described as consisting of a SiO$_2$ like phase which is amorphous and an embedded SiC like phase which is microcrystalline. The morphology of the SiC phase was studied by AFM. In general, this phase appeared as distinct faceted protrusions from an otherwise homogeneous surface. Statistical analysis of AFM images was performed to characterize the size distribution of these crystallites.

The optical properties of the SiC phase embedded within SiOCd was further investigated by steady state RT-PL using a 361nm near UV laser radiation. Two main emission bands at visible wavelengths were observed at 2.5-2.6 eV and 2.8-2.9 eV. These emission lines were attributed to D$_2$ centres in the crystalline SiC-like phase [3]. The intensities of both bands decreased nearly exponentially with RF power density but the linewidth remained practically constant.

The presence of a SiC like phase also affected the electrical properties and in particular, the defect spectrum of these SiOCd samples. Two types of test structures were fabricated for electrical characterisation. Current-voltage measurements on the sandwich structures showed rectifying characteristics. Since the substrate is p-type, the SiOCd exhibited n-type conductivity. Additional dark capacitance-voltage measurements showed that the depletion region is associated with the SiOCd/Si interface. Capacitance deep level transient spectroscopy measurements was then used to determine the electron defect state distribution, N(E) up to 0.7eV below the conduction band bottom. Distinct peaks in the N(E) distribution could be identified for samples deposited at 4 Torr and the defect densities increased with RF power density. These peaks correspond to previously identified defect levels in SiC and may have reliability implications for SiOCd in interconnect applications.

References

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