Characterization of Ultra-Thin Oxynitride Films by Time-of-Flight Secondary Ion Mass Spectrometry

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Scaling of metal oxide semiconductor devices to and below the 180nm node requires the formation of ultrathin gate oxides. The production of nitrided SiO_2 gate dilectrics at these nodes requires tight control of the processing conditions to provide <2.5nm structures of appropriate N concentration and depth distribution. This paper describes the measurement of N and O concentration depth profiles, as well as the determination of the oxide layer thickness by Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS). The same tool can also readily provide surface metal detection limits between 10^7 and 10^{10} atoms/cm^2 for all elements (except noble gases) from areas of ≤40μm x 40μm in a single analysis without prior chemical processing. The small analysis area makes TOF-SIMS very suitable for lateral mapping of surface metal contaminants on wafers.

A quantitative analysis protocol for measuring N and O concentration profile of sub-3nm oxynitride films by TOF-SIMS was first reported by Douglas, et.al[1]. The method consists of bombarding the surface with Ga^+ primary ions of 1keV impact energy at glancing impact angle ($>70^o$) and measuring the Si_2O^+, Si_2N^+, and Si_2^+ molecular secondary ion intensities as a function of analysis depth. The depth dependent Si_2O^+, Si_2N^+ intensities are normalized by Si_2^+ and converted to a N and O concentration scale. The calibration of these conversion factors was obtained by measuring an oxynitride standard, which was characterized by nuclear activation analysis. It was shown that the measurement provided short and long-term relative standard deviations of <2% for the average depth and concentration of N and O for a 2.13nm oxynitride film. The paper also showed that the measured N concentration profiles were strongly correlated to the processing conditions of the films.

Fig.1 shows an example of TOF-SIMS O and N concentration profiles of an oxynitride film produced by remote plasma doping. The measured oxide thickness was 1.26nm and the N dose was $1.5x10^{15}cm^{-2}$. The depth profile was taken using the measurement protocol described above. Depth and concentration calibration was done using a 1.8nm oxynitride standard film. Fig.2 shows the O and N concentration profile of a 1.65nm oxynitride formed by furnace nitridation. The measured N dose was $7.38x10^{14}cm^{-2}$ and, as expected for these processing conditions, the N peak is shifted toward the Si interface.

This study will focus on the measurement and comparison of O and N concentration profiles and film thickness of sub-2nm oxynitrides, which were processed using a matrix of N doping and anneal conditions. Results of surface metal mapping on wafers will be reported. The correlation of the TOF-SIMS results with XPS dose and film thickness measurements will be discussed.

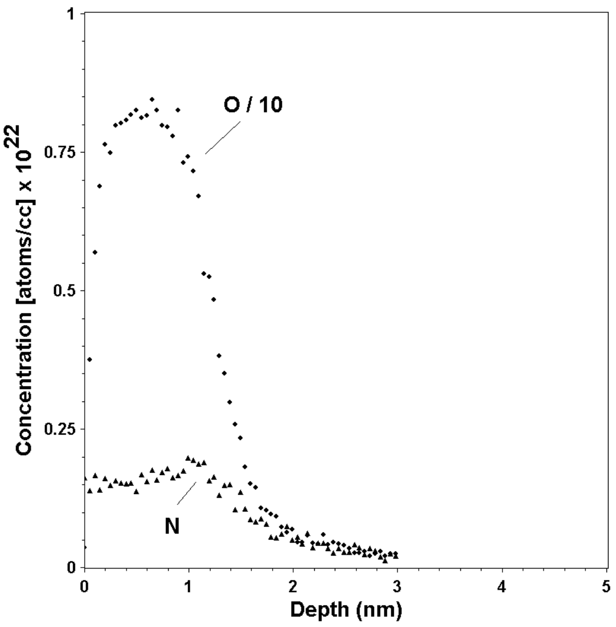

Fig.1: TOF-SIMS N and O concentration depth profiles of a remote plasma doped oxynitride film. Measured SiO_2 thickness: 1.26nm, N-dose: $4.60x10^{14}cm^{-2}$.

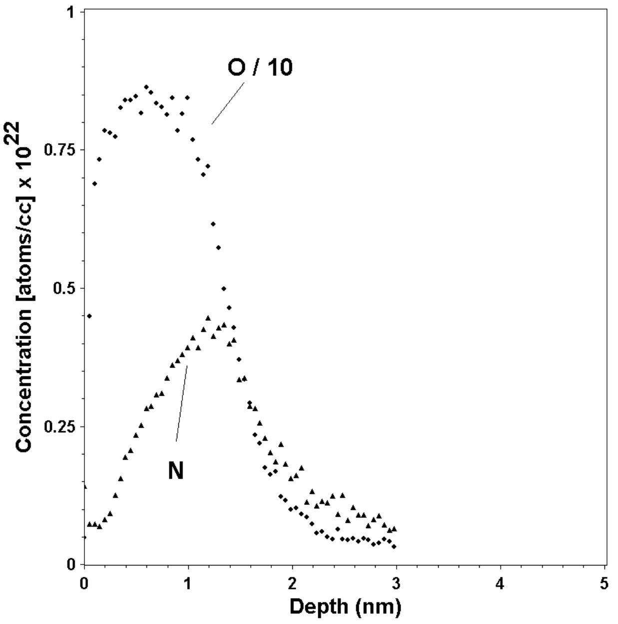

Fig.2: N and O concentration depth profiles of an oxynitride film, formed by furnace nitridation. The TOF-SIMS analysis conditions are identical to those used in Fig.1. Measured SiO_2 thickness: 1.65nm, N-dose: $7.38x10^{14}cm^{-2}$.

1) M.Douglas, S.Hattangady, and K.Eason, J. Electrochem. Soc. **147** (5), 1893-1902 (2000).