

# Ultrashallow depth profiling by using SIMS and Ion Scattering Spectroscopy

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In recent years there is a growing demand of high depth resolution profiles, for example to characterize interfaces reactions, multilayer structures in magnetic recording heads, ultra-shallow dopant distributions and ultra-thin gate dielectrics structures in complimentary metal-oxide semiconductor (CMOS) devices.

SIMS is widely employed for dopant depth profiling in semiconductor layers and devices, providing accurate measurements of dopant distributions over concentrations from  $1 \times 10^{13}$  to  $1 \times 10^{21} \text{ cm}^{-3}$ . On the other hand, quantitative analysis for thin layer structures is a challenging task because of matrix effect. Attempts have been made to overcome the matrix effect using the detection of  $\text{MCs}^+$  secondary ions sputtered by bombardment with  $\text{Cs}^+$  primary ions [1,2], but basic studies showed that  $\text{MCs}^+$  ion yield depend in a complex manner on the sample material and the bombardment conditions [3,4]. Even though the severe problems of quantitative analysis by SIMS with  $\text{Cs}^+$  were documented in a recent review [5,6], work on the characterization of thin layers has been continued using  $\text{MCs}^+$  SIMS. In particular,  $\text{MCs}^+$  SIMS has been used for nitrogen depth profiling in gate oxide layers (“oxynitride”), assuming or claiming that the matrix effect is sufficiently small. As an alternative approach,  $\text{SiN}^+$  and  $\text{Si}_2\text{N}^+$  detection using oblique bombardment of low-energy  $\text{O}_2^+$  has been investigated [7,8]. However, accuracy of the depth profiles is not clear. Recently, another ion bombardment technique, a high-resolution Rutherford backscattering spectroscopy (HRBS) system using a magnetic spectrometer has been developed, which enable us to measure depth profiles with monolayer resolution. HRBS is also used for the characterization of gate dielectrics, oxynitride and high- $K$  layers.

In this study, SIMS and HRBS were employed for depth profiling of nitrogen in ultra thin gate oxide layers, where nitrogen was incorporated at Si-SiO<sub>2</sub> interfaces and at the SiO<sub>2</sub> top surface, respectively. SIMS depth profiling was done using the  $\text{MCs}^+$  mode and the oblique  $\text{O}_2^+$  bombardment mode. The aim of this study was twofold, (i) to explore the depth resolution under the different ion bombardment techniques, SIMS and HRBS and (ii) to improve the accuracy in ultra-shallow depth profiling.

From the measured depth profiles, we observed a large difference in the nitrogen distributions at the SiO<sub>2</sub> top surface. The  $\text{SiN}^+$  and  $\text{Si}_2\text{N}^+$  signals by the oblique  $\text{O}_2^+$  bombardment mode were extremely sensitive to the nitrogen concentration at the SiO<sub>2</sub> top surface. The profiles measured by the other techniques showed unreasonable distributions. It is conceivable that a large transient distorted the surface profile in  $\text{MCs}^+$  mode and the damages due to high energies of  $\text{He}^+$  bombardment shifted the nitrogen distribution at the top surface.

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