Characterization of Phosphorus Redistribution near Si-SiO_2 Interfaces

Ruey-Dar Chang (張睿達)[1], Meng-Ju Huang (黃孟茹)[1], Wan-Ting Su (蘇皖亭)[1], and Tun-Wen Pi (皮敦文)[2]

[1]**Department of Electronic Engineering, Chang Gung University, Taoyuan, Taiwan**
[2]**National Synchrotron Radiation Research Center, Hsinchu, Taiwan**

The junction depth in metal-oxide-semiconductor field effect transistors (MOSFETs) becomes very shallow with the scaling-down of the gate length. Mechanisms associated with dopant redistribution near Si-SiO2 interfaces need to be verified. Dopant clustering occurs when the dopant concentration exceeds the solid solubility of dopant in silicon. Moreover, dopant clustering with point defects has been shown to degrade dopant activation during junction formation [1]. Unfortunately, these complex reactions of phosphorus are not well understood. In order to identify the mechanisms, analysis methodology for measuring phosphorus near the surface is developed based on X-ray photoelectron spectroscopy (XPS).

<100>-oriented p-type wafers were used. Phosphorus was doped by using $POCl_3$ as the source or by ion implantation. $POCl_3$ doped wafers and implanted samples after laser annealing were analyzed. Surface oxide of the samples was removed by dilute HF or in-situ annealing in the ultra-high vacuum chamber. The in-situ annealing was performed by applying an electric current on the sample. The photon energy of X-ray is 170 eV.

The XPS spectra of Si 2P show that all samples in initial condition at room temperature (RT) still have native oxide. Therefore, high temperature (HT) conditions were created by applying a high electric current on each sample to evaporate the surface oxide. However, the HT treatment can also cause phosphorus redistribution. Figure 1 shows the spectra obtained from POCl3 doped sample. The P 2p become stronger after HT treatment. Figure 2 exhibits the XPS results from the P-implanted sample. The P 2p signal decays after HT treatment. Since the phosphorus profile in the low-energy implanted sample is much sharper than that in the POCl3 doped sample. The decay of P signal in the implanted sample might be due to phosphorus diffusing out of the sample region. Figures 3 and 4 show the spectra of laser anneal samples after HF dip for 11 and 45s, respectively. The Si 2p signal indicates that HT does not totally remove the oxide in the sample dipped for 11s. Oxide in the sample dipped for 45s is almost removed after HT. The P 2p signal is still observed after HT treatment in laser-anneal samples. This implies that laser annealing changes the phosphorus behavior.

In summary, high resolution XPS spectra were obtained using X-ray generated from synchrotron radiation. XPS was demonstrated to measure phosphorus in ultra-shallow junctions. XPS spectra revealed different phosphorus behaviors between samples under different process conditions.

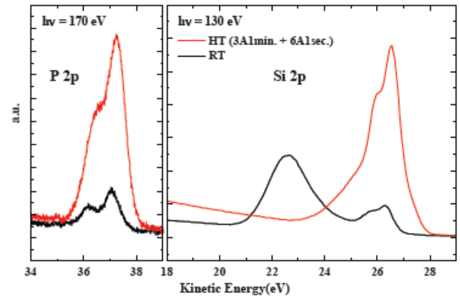

Fig. 1: XPS spectra obtained from $POCl_3$ doped sample.

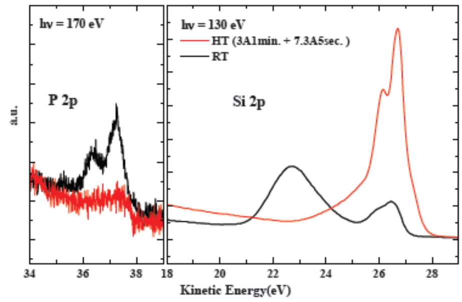

Fig. 2: XPS spectra for low-energy phosphorus implanted sample.

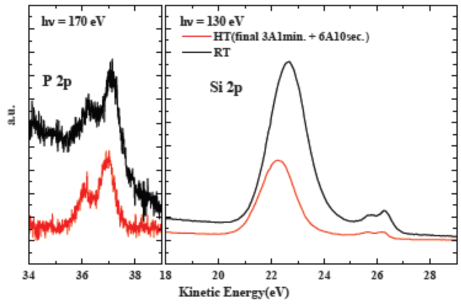

Fig. 3: XPS spectra for laser annealed samples after HF dip for 11 s.

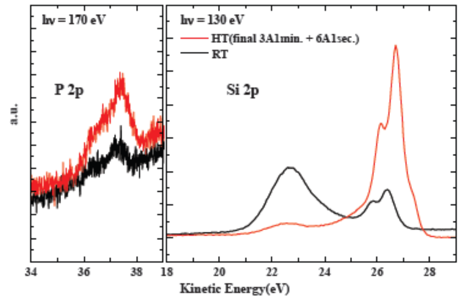

Fig. 4: XPS spectra for laser annealed samples after HF dip for 45 s.

Reference

[1] G. Mannino, N. E. B. Cowern, F. Roozeboom, and J. G. M. van Berkum, Appl. Phys. Lett. **76**, 855 (2000).