Study of Ge/Ge-oxide and Ge/Ge-oxide/high-k-oxide interfaces for microelectronic applications

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Introduction

Microelectronic Engineering recent trends concern the replacement of SiO_2 with high-k dielectrics as well as the possible substitution of Si with high-mobility substrates such as Ge [1]. The poor interface quality of Ge/High-k oxides can be improved by the insertion/creation of an optimum passivation layer [2]. The growth of a passivation layer leads to a significant improvement of the electrical response of Ge-based MOS devices [3]. Different plasma techniques have been proposed in the last years for Ge oxidation [3].

In this study, stable and easily controllable Germanium oxide layers were grown on p- Ge substrates by plasma technique. The purpose of the present work is to study the effect of plasma treatment on the p-Ge surfaces as well as to investigate the chemical structure, stability and thickness of the Ge / Ge-oxide / high-k oxides interfaces by X-Ray Photoelectron Spectroscopy.

Experimental

Initially Ge substrates were exposed to plasma treatment (30 mTorr of N50 molecular oxygen, 50 sccm, 13.56 MHz, 45-50 W as it was measured on the generator readout display) for time intervals increasing from 5 to 180 s. Then the samples were introduced (*ex-situ*) in an ultra-high vacuum system equipped with an EA-11 hemispherical electron energy analyser, and an X-ray dual anode source for XPS analysis. The XP spectrum revealed the growth of stable GeO_2 layer after plasma treatment. The thickness of this layer increases (exponentially-like as a function of the time of exposure to O_2 plasma) from 1 nm to 3.2 nm, exhibiting saturation after 60 s.

On the top of the passivation layer, ultrathin high-k oxide films (i.e. Al_2O_3 and/or HfO_2) were deposited on different plasma-treated p-Ge (100) substrates, by means of Atomic Layer Deposition (ALD). With this technique the deposition of ultra-thin layers at relative low temperatures can be achieved. The high-k films were deposited at a nominal thickness of 3 nm at 200°C (Al_2O_3) and 250°C (HfO_2). The stoichiometry, thickness, and stability of the interface layers (GeO_2, HfO_2 and Al_2O_3) were investigated by XPS.

Figure 1 shows schematically the different preparation stages of the investigated interfaces.

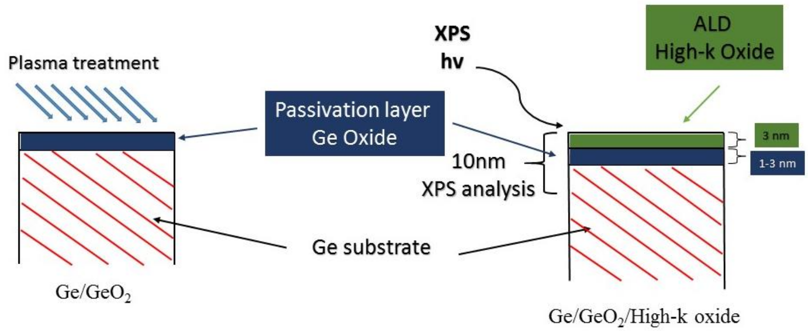

Fig.1: Conceptual view of the Interface structures

Figure 2 compares the Ge 3d XPS of the plasma-treated Ge substrate without and with Al_2O_3 on the top. Two main peaks, located at 29.5 eV and ~33.0 eV, are identified. The Ge 3d peak, after correction for electrostatic charging using C1s at 285.0 eV, appears at a binding energy of 29.5 eV, whereas the observed energy shift of the GeO_2 peak in respect to the elemental Ge^0 peak is ~3.2eV. The thickness of the oxidized Ge layer was obtained from the XPS intensity ratio Ge^0 3d / Ge^{ox} 3d.

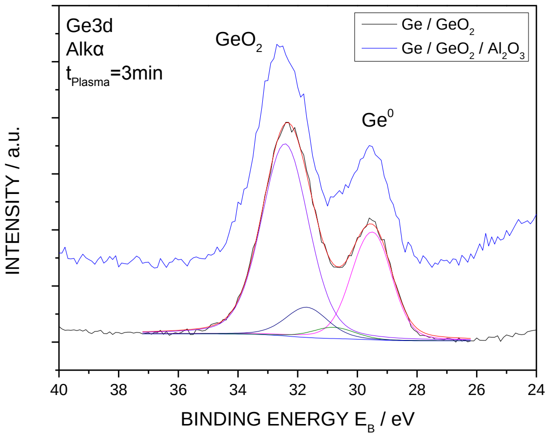

Fig.2: Ge 3d XPS peak of plasma-treated Ge substrate, with Al_2O_3 on the top.

Figure 3 compares the Ge 3p XPS of the plasma-treated Ge substrate without and with HfO_2 on the top. The peak was fitted with two doublets due to spin orbit, corresponding to Ge^o and GeO_2. First doublet appears at a binding energy of 121.7 eV whereas the observed energy shift of the GeO_2 peak in respect to the elemental Ge^0 peak is ~2.9 eV. In this case, the thickness of the oxidized Ge layer was obtained from the XPS intensity ratio Ge^0 3p doublet/ Ge^{ox} 3p.

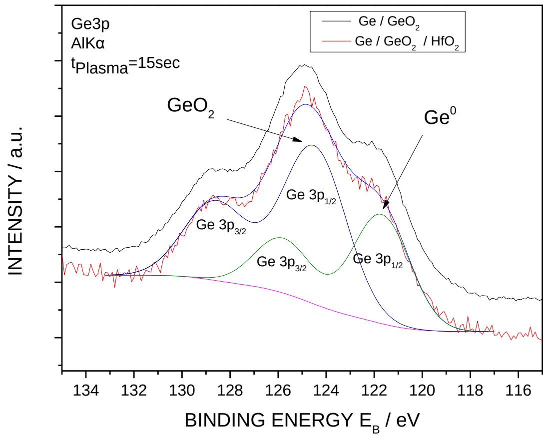

Fig.3: Ge 3p XPS peak of plasma-treated Ge substrate, with HfO_2 on the top.

As it is obvious from both spectra, the Ge oxide remains unchangeable after ALD-deposited high-k oxides. No chemical interaction, degradation or diffusion has been observed.
In summary, plasma treatment of p-Ge surfaces creates a stable ultra-thin passivation layer which in combination with ALD of high-k oxides can form stable and abrupt interfaces.

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