Surface Analysis of Thermally Growth Ge Oxide on Ge (100)

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***Abstract*—The understanding of Ge oxidation is utmost importance in order to form the good quality dielectric/Ge interface in fabricating Ge Metal Oxide Semiconductor Field Effect Transistor (MOSFETs). In addition, the mechanism of Ge oxidation is still under intensive studies. For Silicon oxidation, Deal and Grove Model have been accepted to explain the Si Oxidation mechanism. The purpose of this paper is to report the mechanism of Ge oxidation at two different temperatures, 375 and 490°C and the detail of Ge oxide composition at Ge oxide/Ge interface. After wet chemical cleaning with HCl, the thermal oxidation was performed at temperature 375 and 490°C at atmospheric pressure. The thickness and composition of Ge oxide were measured with spectroscopic ellipsometry and x-ray photoelectron spectroscopy, respectively. It was observed that the *n* value extracted from a log-log plot of oxidation time versus oxide thickness was dependent on the oxidation temperature. The oxygen-deficient region was formed during thermal oxidation of Ge and the electronic states of suboxide component were observed in the region within 2.3eV above the top valence band. The novelty of this work is to investigate the kinetics oxidation of Ge and evaluate the composition of oxide layer after thermal oxidation that becomes useful information for the development of Ge MOSFETs.**

***Index Terms*—Germanium; Oxidation; X-Ray Photoelectron Spectroscopy**

I. Introduction

GE has been regarded as a promising channel material for metal-oxide-semiconductor (MOS) field effect transistors (FETs) because it has higher carrier mobility than Si [1]-[2]. One of the most critical issues for developing Ge MOS FETs includes controlling the MOS interface and minimizing the defect state densities in the gate dielectric and at the dielectric/Ge interface [3]-[5]. Therefore, a better understanding of the Ge surface oxidation mechanism is quite important for fabricating a high-quality dielectric/Ge interface. As for the thermal stability of the GeO_2/Ge interface, there has been a report on the change in oxide network to generate Ge mono-oxide (Ge^{2+}) near the substrate interface by using vacuum annealing at 300ºC (~10^{-8} Torr) and thermal desorption of Ge oxide by further increasing the annealing temperature [6]. In addition, a thermal desorption spectroscopy (TDS) analysis of GeO_2/SiO_2 and GeO_2/Ge structures also has shown that GeO desorption was not derived from the decomposition of GeO_2 itself but from its reaction with a Ge substrate [4]. It is also confirmed that the desorption of GeO leads to the deterioration of the surface and interface of GeO_2/Ge systems and degrades the electrical characteristics, which places a large hysteresis on the C-V characteristics of MIS capacitors [7]- [8].

For Ge oxidation, the desorption process must be taken into account during the oxidation process. In fact, it was reported that the parabolic constant is not proportional to the partial pressure of oxygen for the oxidation of Ge for the thermal oxidation of Ge at 550°C with different oxygen pressures [9], which is contradictory to the thermal oxidation model for the Si oxidation proposed by Deal and Grove [10].

In contrast to Ge oxidation, there is no oxidation model that has been accepted. Therefore, the detailed mechanism of Ge surface oxidation is a great importance to develop oxidation model in detail. In this paper, the kinetics oxidation between high temperature and low-temperature oxidation is investigated in detail by using spectroscopic ellipsometry (SE) and high-resolution x-ray photoelectron spectroscopy (XPS).

II. Experimental Procedures

P-type Ge (100) with a resistivity of 10Ω·cm was used in this work. Before thermal oxidation, the wet chemical cleaning was performed as similar in our previous research work [11]-[12]. In this cleaning, the wafer was dipped in 15% H_2O_2 after dipping in deionized water. Then the wafer was dipped in the 30 % HCl. After the wet chemical cleaning, a GeO_2 layer was grown at 375 or 490°C in a dry oxygen ambience (O_2 gas flow rate: 4.0L/min) at atmospheric pressure. The oxide thicknesses were determined by using spectroscopic ellipsometry (SE) at wavelengths ranging between 192 and 1000 nm. The XPS measurement was used to characterized the chemical bonding features of the thermally grown Ge oxide with photoelectron take-off angles of 30° and 90° using monochromatized AlKα (1486.6 eV) radiation. From the Ge 3d core-line spectra, the oxidation states in thermally grown Ge oxide and in the region near the Ge oxide/Ge interface were evaluated. The valence band offset in Ge oxide/Ge (100) system was determined by the onset of the valence band.

III. Results and Discussion

Ge oxide growth on Ge (100) at 375°C and 490°C with the oxidation time were evaluated from spectroscopic ellipsometry (SE) as shown in Figure 1. Both oxidations were performed under atmospheric pressure in dry oxygen ambience. In this graph, the n value is the slope which is extracted in the log-log plot that indicates the oxidation rate. The slope of oxidation at the temperature of 490°C increases about three times of the oxidation slope for oxidation temperature of 375°C. The increases of slope indicate that the oxidation and the desorption rate may be enhanced during Ge