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Formation of $AlO_x/GeO_x/Ge$ Gate Stack Structure by Thermal Oxidation

Akira Heya, Naoto Matsuo

Univ. of Hyogo, 2167 Shosha, Himeji, Hyogo, 671-2280, Japan
Phone: +81-79-267-4909 E-mail: heya@eng.u-hyogo.ac.jp

Abstract

$AlO_x/GeO_x/Ge$ gate stack structure have been fabricated using a conventional furnace. In Al(10nm)/Ge(60nm)/quartz substrate, although the overall Al film was oxidized, the Ge film was not oxidized by thermal treatment at 500 °C for 600 s in air. From the X-ray photoelectron spectroscopy spectra of the Al film prepared on GeO_x/Ge/quartz substrate, it is shown that the O atoms in the GeO_x layer moved into the Al film. When the thermal oxidation was separately carried out for Al and Ge films, the $AlO_x/GeO_x/Ge$ gate stack structure with a breakdown voltage of 147.9 V and a leakage current of 6.6×10^{-13} A was obtained.

1. Introduction

Polycrystalline Ge (poly-Ge) film is one of the attractive materials for next generation semiconductor devices because the poly-Ge has a high mobility of 295 cm^2/Vs [1] and a low crystallization temperature of 500 °C [2] in comparison with Si. In Si, a stable and high quality gate insulator (SiO_2) is formed by a thermal oxidation. On the other hand, in Ge, it is known that the issues of GeO_2 are thermal instability and water solubility [3]. Therefore, other insulators such an Al_2O_3 is formed on the GeO_2 to suppress the degradation of GeO_2. In general, the Al_2O_3 films are prepared by atomic layer deposition (ALD) technique. Although it is already reported that high performance poly-Ge FET can be realized by using the ALD Al_2O_3 film, it is considered that the ALD is not suitable for mass production.

Recently, it is reported that the Al_2O_3/GeO_2/Ge substrate gate stack structure can be obtained by using post-deposition oxidation of ultrathin (0.4 - 0.8nm) Al film on Ge substrate [4]. In this study, we have tried to fabricate of the Al_2O_3/GeO_2/Ge film/quartz substrate using a conventional furnace. The oxidation mechanism and electrical property were investigated for development of low-cost method of the gate insulator in Ge thin-film transistors.

2. Experimental

Amorphous Ge (a-Ge) films were deposited on a cleaned quartz substrate by an electron beam evaporation. The acceleration voltage and the emission current of the electron gun were 10 kV and 30 mA, respectively. The deposition rate was 0.12 nm/s. The thickness of a-Ge film was 60 nm. To fabricate the Al_2O_3/GeO_2/Ge gate stack structure, we tried three fabrication process. The fabrication process and the expecting structure are shown in Fig. 1. 10 nm Al film was deposited by a thermal evaporation. The oxidation and crystallization of a-Ge film were carried out using a furnace at 500 °C for 600 s in air. For the oxidation of Al, some samples were heated at 500 °C for 1800 s in the same furnace.

The chemical bond states and depth profiles of Al and Ge atoms were measured by X-ray photoelectron spectroscopy (XPS). For Ar^+ etching, the acceleration voltage was 2 keV every 30 s. To evaluate the electrical property, the Al electrodes with 200 μmϕ in diameter were formed on the prepared sample through a shadow mask. The electrical characteristics were evaluated by I-V measurement at RT in air.

3. Results and discussion

The XPS spectra of samples A, B, and C are shown in Figs. 2 (a), (b), and (c), respectively. In the sample A, the overall Al film was oxidized. When the Al film is oxidized, the thickness should have been increased by 2.6 times from the relationship between density of Al and Al_2O_3. However, the Ge film was not oxidized under this condition. In the sample B, two sevenths of Ge film in film-thickness direction was oxidized by thermal treatment. The Al-O peak was observed in spite of without Al oxidation process. The intensity of Al-O peak at interface between the Al film and Ge film was higher than that of the surface of Al film. This indicates that the O atoms in the AlO_x layer were provided from the GeO_x layer. It is expected the AlO_x/GeO_x Ge gate stack structure can be obtained using O atoms in GeO_x film. However, the 10 nm Al film was not oxidized completely and sharp interface was not obtained by the present condition. It is necessary to control the thickness of GeO_x and Al films and to optimize the thermal oxidation conditions. In the sample C, the 10 nm Al film was oxidized completely by the thermal oxidation for Al film. It is considered that

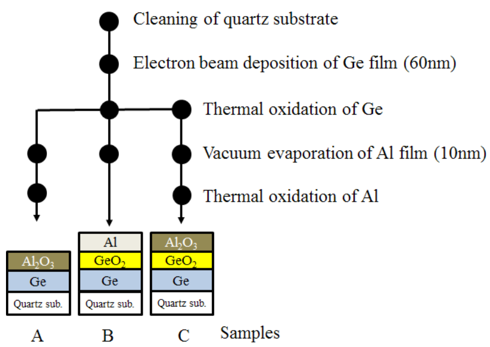
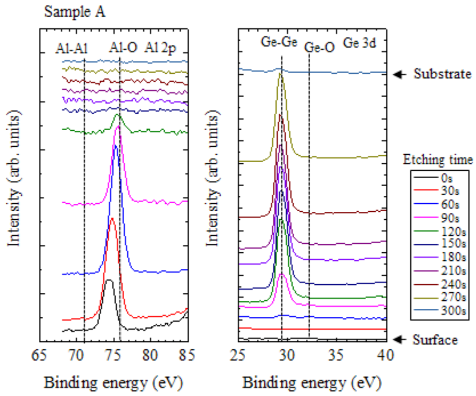
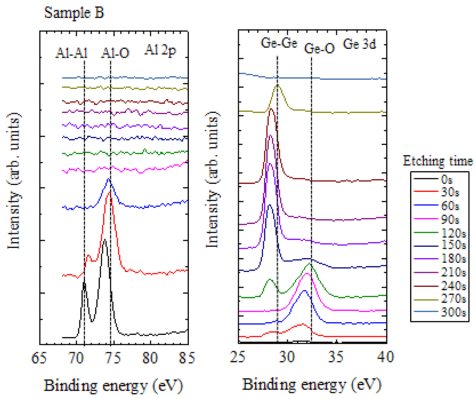


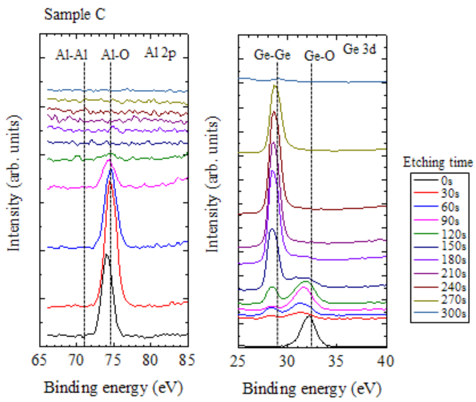
Fig. 1 Process flow of gate stack structure. Cross-sectional view of the prospected sample structures are also shown in bottom part.



(a)



(b)



(c)

Fig. 2 XPS spectra of Al 2p and Ge 3d for the samples A (a), sample B (b), and sample C (c).

the Al film on the Ge film will suppress the oxidation of Ge film. The diffusion coefficient of O atom in Al_2O_3 at 500 °C is estimated to be 7.6×10^{-44} m^2/s [5]. Therefore, both thickness of GeO_x layers of the samples B and C was almost same. It is considered that the thickness of GeO_2 layer have to be controlled by thermal oxidation for Ge. From the XPS depth profile of the sample C, the thickness of Al_2O_3 and GeO_2 layers were estimated to 26 nm and 31 nm, respectively. It has been concluded that the treatment

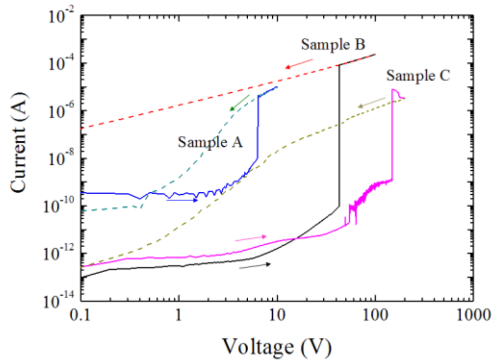


Fig. 3 I-V characteristics of various samples. Solid and dashed line show the voltage sweep of forward and reverse direction, respectively.

Table I. Electrical properties of the gate stack structures.

Samples	A	B	C
V_{BD} (V)	6.4	42.9	147.9
I_{Leak} (A)	2.9×10^{-10}	3.1×10^{-13}	6.6×10^{-13}

time of thermal oxidation for Ge has to be shorter and the Al thickness has to be thinner to obtain thin $Al_2O_3/GeO_2/Ge$ gate stack structure.

The I-V characteristics are shown in Fig. 3. The breakdown voltages (V_{BD}) and the leakage currents (I_{Leak}) at 1V for the samples A, B, and C are summarized in Table I. In the sample A, the breakdown field of the AlO_x film prepared from Al film by thermal oxidation was estimated to be 1.6 MV/cm by assuming the AlO_x thickness of 26 nm. This breakdown field was smaller than the bulk Al_2O_3 (13 MV/cm) and ALD Al_2O_3 (7 MV/cm). In the sample B, the V_{BD} was increased to 42.9 V by formation of the GeO_2 layer. Furthermore, in the sample C, the V_{BD} was increased to 147.9 V. It is expected that the two step oxidation is used as the fabrication of $Al_2O_3/GeO_2/Ge$ gate stack structure.

4. Conclusions

1) The overall Al film in the Al(10nm)/Ge(60nm)/quartz substrate was oxidized by the thermal treatment at 500 °C for 1800 s in air. However, the underlayer Ge film was not oxidized under present conditions because the diffusion coefficient of O atom in Al_2O_3 is small.

2) In the $Al/GeO_x/Ge$ structure, the O atoms were provided from the GeO_2 layer to the Al film without post treatment.

3) The $AlO_x/GeO_x/Ge$ gate stack structure was obtained by two-step oxidation using a conventional furnace.

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