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Direct Oxidation of $Si_{1-x}Ge_x$ Layers Using Vacuum-Ultra-Violet Light Radiation in Oxygen

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Oxidation of $Si_{1-x}Ge_x$ films has been carried out by direct photo chemical vapor deposition (direct photo-CVD) directly with activated O_2 induced by Vacuum-Ultra-Violet (VUV) light radiation. The Auger electron spectroscopy profiles show that no Ge-pileup layer at the oxide/$Si_{1-x}Ge_x$ interface is observed after VUV-induced $Si_{1-x}Ge_x$ oxidation process. The X-ray photoelectron spectroscopy analysis of the samples reveals that Si and Ge are oxidized simultaneously in oxidation process and a mixed oxide layer consisting both SiO_2 and GeO_2 is formed. This might be the reason that Ge pileup effect is eliminated in this study.

KEYWORDS: SiGe, photo-CVD, VUV, Auger profile, X-ray photoelectron spectroscopy

1. Introduction

The fabrication of many novel devices has placed strong requirements of the use of new materials such as strained epitaxial $Si_{1-x}Ge_x$ layers. The advantages of the SiGe-base system over other compound semiconductor systems is its compatibility with Si technology and the possibility of very large scale integrated (VLSI) circuits fabrications. Moreover, the hole mobility[1] of SiGe is higher than that of Si. The development of SiGe p-channel metal-oxtde-semiconductor field-effect transistors (p-MOSFETs) allows one to reduce the size of the p-MOSFET in complementary metal-oxide-semiconductor (CMOS) circuit design. Therefore, SiGe-based CMOS circuits can provide a faster switching speed and a larger driving capacity than conventional Si CMOS circuits. However, the limits on the SiGe-based MOS transistors are mainly due to poor gate oxide. There are some difficulties in achieving high quality oxide on a SiGe strained layer.

The wet oxidation and rapid thermal oxidation (RTO)[1,2] of SiGe strained layer in pure oxygen or in steam have not been successful. It will cause Ge to be rejected completely out of the SiO_2 layer to form a Ge-rich layer at the SiO_2/SiGe interface. The resulting Ge-rich layer is responsible for the high fixed oxide charge, interface state densities and poor breakdown characteristics of SiGe-based MOS transistors. It have been shown that the physical characteristics of SiO_2 deposited by direct photo-CVD[3] are close to those of the thermal oxides and the electrical characteristics are acceptable for device applications. The advantage of direct photo-CVD is that it provides an efficient method of energy transfer directly from the excitation source to the reactance gases instead of creating thermal energy. The application of direct photo-CVD can minimize the thermal relaxation since the oxidation layers are grown at low temperature. Surface damages induced by other low-temperature preparation methods, such as plasma CVD and ECR plasma oxidation,[4] can also been avoided. We report the first study of oxidation of $Si_{1-x}Ge_x$ films by direct photo-CVD directly with activated O_2 induced by Vacuum-Ultra-Violet (VUV) light radiation which avoids Ge segregation.

2. Experimental

In this study, the undoped $Si_{1-x}Ge_x$ strained layers were grown at 550°C by ultrahigh vacuum-chemical molecular epitaxy (UHV-CME) technique[5] using Si_2H_6 and GeH_4. 6-in., n-type, 2–7 Ω-cm, Si (100) substrates were subjected to a precleaned process with hydrogen passivation technique.[6] After the precleaning step, the wafers were loaded into the loading chamber and then transferred to the reaction chamber for epitaxial growth. Before the $Si_{1-x}Ge_x$ epilayer growing process, a thin Si buffer layer was grown by introducing 0.2 sccm Si_2H_6 flow into the growth chamber during the heater ramping-up period.

Direct photo-CVD using O_2 was used for the oxidation process. In using direct photo-CVD to grow thin films,[7,8] it is most important to select the proper light source with a radiation spectrum matching the absorption spectra of the reactance gases. In this study, we used a deuterium (D_2) lamp as the excitation source, since it is capable of strong ultra violet (UV) and vacuum-ultra violet (VUV) radiation. Therefore, the D_2 lamp is a suitable light source that can effectively excite O_2. A D_2 lamp with a window, which is made of MgF_2, was placed on the top of the chamber to provide UV and VUV light to excite and dissociate the reactance gases. Prior to the oxidation process, the wafer was cleaned by the RCA method[9] including a HF-dip to remove the native oxide. Low temperature oxide was grown at 200°C with 150 Watts D_2 lamp radiation. In VUV-induced oxidation process, O_2 was activated by VUV light radiation. The $Si_{1-x}Ge_x$ epilayer was surrounded by not only O_2 molecular, but also atomic oxygen (O) and ozone (O_3). Atomic oxygen and ozone are much unstable and active than oxygen moleculasr, and the oxidation of $Si_{1-x}Ge_x$ epilayers may take place in the ambient.

The Ge mole fraction and thickness of $Si_{1-x}Ge_x$ epilayers were evaluated by double crystal X-ray rocking curves.[10] The thickness of the $Si_{1-x}Ge_x$ epilayers were well below the critical thickness for $Si_{1-x}Ge_x$ epitaxial growth. The Ge mole fraction of the 50-nm thick $Si_{1-x}Ge_x$ epilayers were kept at 0.12 and 0.16 in this study. Some $Si_{1-x}Ge_x$ epilayers of the samples were capped on the top side with a 6 nm Si cap layer to form a $Si_{1-x}Ge_x$-buried channel structure. The analysis of Auger electron spectroscopy (AES) was used to determine the

composition and distribution of surface films for individual elements after oxidation process. X-ray photoelectron spectroscopy (XPS) analysis was used to investigate the chemical structure of the oxide flms.

3. Results and Discussions

Figure 1 shows the AES depth profiles of the $Si_{0.88}Ge_{0.12}$ epilayer without Si cap layer after VUV induced oxidation process for 12 h at 200°C. The surface layer was sputtered etch using 1 keV Ar^+ ions in 120 nA and the AES signals were recorded continuously. It can be used to determine the distribution of Si, Ge and O elements after VUV induced oxidation. The thicknesses of the oxide layers are around 1–1.5 nm in this study. In the depth profiles, we can find that Ge does not pile up at the oxide/$Si_{0.88}Ge_{0.12}$ interface and is uniformly distributed due to low temperature process. In the previous research on rapid thermal oxidation (RTO) of SiGe layers, Nayak *et al.*[11] reported that the Ge distribution at the interface can be described by a concentration-dependent diffusivity of Ge in the epilayer. The distribution is changed at high temperature (>750°C) due to high diffusivity of Ge. Thus Ge segregation does not occur in the VUV induced oxidation process of $Si_{1-x}Ge_x$ films at the temperature as low as 200°C.

The XPS analysis of the samples with a strained $Si_{0.84}Ge_{0.16}$ epilayer exposed in the VUV induced oxidation environment for 3 h were carried out to investigate the chemical structure of oxide films. The signal spectra of these samples both with and without a Si cap layer are shown in Fig. 2. As shown in Fig. 2(a), no Ge signal is found in the $Si_{0.84}Ge_{0.16}$ sample with a Si cap layer after oxidation process. As contrasted with Fig. 2(a), Figure 2(b) shows that the Ge element exixts in the $Si_{0.84}Ge_{0.16}$ sample without a Si cap layer after oxidation process. From Figs. 2(a) and 2(b), we can conclude that the Ge element may exist in the oxide film of the $Si_{0.84}Ge_{0.16}$ sample without a Si cap layer after oxidation process. The line shape and binding energy of the XPS spectra provide information about the film stoichiometry and the presence of suboxide phases in the film. Figure 3

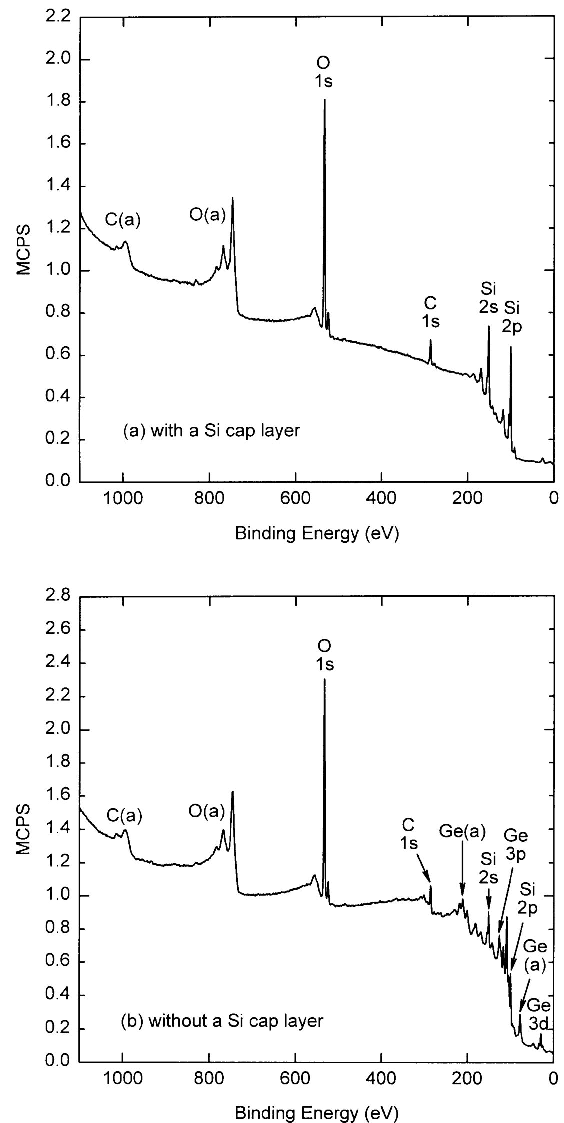

Fig. 2. The signal spectra of the $Si_{0.84}Ge_{0.16}$ epilayers both (a) with and (b) without a Si cap layer after VUV induced oxidation process for 3 h.

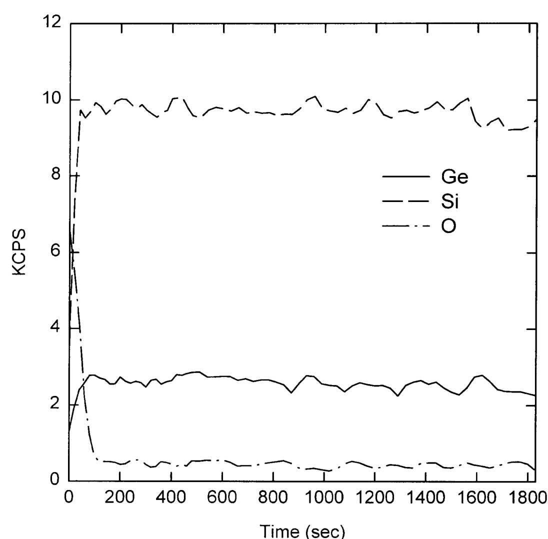

Fig. 1. The AES depth profiles of the the $Si_{0.88}Ge_{0.12}$ epilayer without Si cap layer after VUV induced oxidation process for 12 h at 200°C.

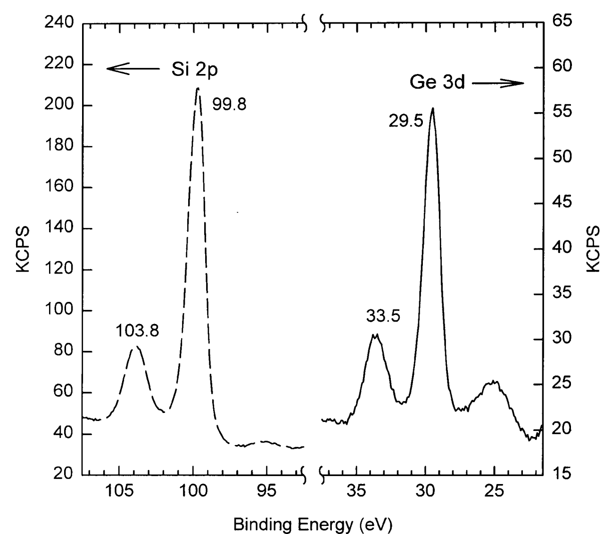

Fig. 3. The XPS signals in the Si 2p and Ge 3d regions of the $Si_{0.84}Ge_{0.16}$ epilayer without a Si cap layer after VUV induced oxidation process for 3 h.

shows the XPS signals in the Si 2p and Ge 3d regions of the $Si_{0.84}Ge_{0.16}$ epilayer without a Si cap layer after VUV induced oxidation process for 3 h. We can find that parts of Ge element were also oxidized in addition to Si element from the shift of the core level binding energy during chemical bonding. The chemical shift of the core level in the Ge 3d region from 29.5 eV to 33.5 eV corresponds to the formation of Ge^{4+} while that in the Si 2p region from 99.8 eV to 103.8 eV corresponds to the formation of Si^{4+}. These imply the existence of GeO_2 in the oxide layer in addition to SiO_2. The main peaks at 29.5 eV and 99.8 eV come from the $Si_{0.84}Ge_{0.16}$ epilayer for the sake of very thin oxide layer. In order to verify the behavior of Ge element in oxidation process, $Si_{0.88}Ge_{0.12}$ epilayers without a Si cap layer were oxidized with different oxidation time (3 h, 6 h and 12 h) for XPS analysis. The subpeak intensity which corresponds to Ge^{4+} increases gradually from 26.32, 26.98 to 28.35 KCPS with oxidation time. In the mean time, the main peak intensity in the Ge 3d region decreases gradually from 55.1, 52.36 to 49.56 KCPS which may be due to the increase of the oxide thickness. So it is obviously that the quantity of oxidized Ge element increases with increasing oxidation time. Hence, the XPS analysis reveals that Si ans Ge are oxidezed simultaneously in oxidation process and a mixed oxide layer consisting SiO_2 and GeO_2 is formed. This might be one of the reason that Ge-pileup effect is eliminated in this study.

4. Conclusions

Oxidation of $Si_{1-x}Ge_x$ films has been carried out by direct photo-CVD directly with activated O_2 induced by Vacuum-Ultra-Violet (VUV) light radiation. The Auger electron spectroscopy profiles shows that no Ge-pileup layer at the oxide/$Si_{1-x}Ge_x$ interface is observed in VUV-induced $Si_{1-x}Ge_x$ oxidation process. The X-ray photoelectron spectroscopy analysis of the samples reveals that Si and Ge are oxidized simultaneously in oxidation process and a mixed oxide layer consisting both SiO_2 and GeO_2 is formed. No Ge pileup effect is obseved in this study.

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1) D. K. Nayak, K. Kamjoo, J. S. Park, J. C. S. Wo and K. L. Wang: IEEE Trans. Electron Devices **39** (1992) 56.
2) D. K. Nayak, K. Kamjoo, J. S. Park, J. C. S. Wo and K. L. Wang: Appl. Phys. Lett. **56** (1990) 66.
3) C. T. Lin, S. J. Chang, D. K. Nayak and Y. Shiraki: Jpn. J. Appl. Phys. **34** (1995) 72.
4) P. W. Li and E. S. Yang : Appl. Phys. Lett. **63** (1993) 2940.
5) G. W. Huang, L. P. Chen, T. C. Chou, K. M. Chen, H. C. Tseng, W. C. Tsai and C. Y. Chang: J. Appl. Phys. **81** (1997) 205.
6) T. G. Jung, C. Y. Chang, T. C. Chang, H. C. Lin, T. Wang, W. C. Tsai, G. W. Huang and P. J. Wang: Jpn. J. Appl. Phys. **33** (1994) 240.
7) Y. Toyoda, K. Inoue, M. Okuyama and Y. Hamakawa: Jpn. J. Appl. Phys. **326** (1987) 835.
8) J. D. Lin, Y. K. Su, S. J. Chang, M. Yokomaya and F. Y. Juang: J. Vac. Sci. & Technol. A **12** (1993) 7.
9) K. Koyama, M. Hiroi, T. Tatsumi and H. Hirayama: Appl. Phys. Lett. **57** (1990) 2202.
10) S. H. Li, P. K. Bhattacharya, R. Malik and E. Gulari: J. Electron. Mater. **22** (1993) 793.
11) D. K. Nayak, J. S. Park, J. C. S. Woo, K. L. Wang and I. C. Ivanov: J. Appl. Phys. **76** (1994) 982.