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Influence of Precursor Gas on SiGe Epitaxial Material Quality in Terms of Structural and Electrical Defects

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Abstract

We report the comparison of the structural and electrical properties of $Si_{1-x}Ge_x$ epitaxial layers grown with conventional (DCS/GeH_4) and specific precursors (Si_2H_6/Ge_2H_6) combination. The crystalline properties and the presence of electrical defects were investigated by XRD and DLTS measurements. High-order silanes and germanes enable $Si_{1-x}Ge_x$ growth at temperatures as low as 550°C with similar structural material quality compared to DCS/GeH_4 at 615°C. The DLTS results, however, show that vacancy-related complexes are present in the layer grown with Si_2H_6/Ge_2H_6.

1. Introduction

With the downscaling of complementary metal-oxide-semiconductor (CMOS) devices beyond the 10 nm technology node, it is required to reduce thermal budgets during $Si_{1-x}Ge_x$ epitaxial growth for group-IV based devices in order to avoid strain relaxation and unintentional dopant diffusion out of $Si_{1-x}Ge_x$ source/drain stressors, and the strain relaxation of strained Ge (sGe) in sGe/relaxed $Si_{1-x}Ge_x$ multi-stacks for nanowire Ge gate-all-around FETs. In addition, it is known that a Ge reflow is observed in a narrow trench (~20 nm) at 600°C for FinFET structures [1].

In recent reports, high-order silanes and germanes enable to decrease the growth temperature down to 400°C thanks to the low thermal energy for their decomposition [2, 3]. On the other hand, at low temperature growth, there is a potential risk for grown-in point defects such as vacancy-related defects in the layer which lead to a degradation of the device performance.

As a motivation of this study, we investigate the influence of the precursor gas on the epitaxial $Si_{1-x}Ge_x$ quality in terms of structural and electrical defects.

2. Experimental

180 nm-thick *in-situ* As-doped $Si_{1-x}Ge_x$ layers were grown on n-Si(001) substrates using an Intrepid reduced-pressure chemical vapor deposition (RP-CVD) module which is integrated on an ASM Intrepid XPTM 300 mm epi system [4]. Dichlorosilane (DCS), disilane (Si_2H_6), germane (GeH_4), digermane (Ge_2H_6) and arsine (AsH_3) were used as precursor gases for Si, Ge and the n-type As dopant source, respectively. The nominal Ge content was 25%. The growth temperature and growth rate of $Si_{1-x}Ge_x$ were 615°C and 550°C, 6.3 nm/min and 38.2 nm/min for precursor combinations of DCS/GeH_4 and Si_2H_6/Ge_2H_6, respectively. The thickness of the layers is below the critical thickness for strain relaxation [5]. The average carrier concentration in the $Si_{1-x}Ge_x$ layer was estimated to be 0.8-1.5×10^{18} cm^{-3} using capacitance-voltage measurements.

The possible presence of defects was investigated by deep level transient spectroscopy (DLTS). $Si_{1-x}Ge_x$ Schottky diodes were fabricated by depositing circular Au contacts by thermal evaporation. The backside ohmic contacts were formed by InGa eutectic and a piece of In foil. In addition, the layer composition and the degree of relaxation has been measured using X-ray diffraction (XRD). XRD ω-2θ scans and ω-rocking curves of SiGe004 were performed to compare the crystalline properties for each precursor combination. Nomarski microscopy was used to study the surface morphology.

3. Results and discussion

Nomarski microscopy inspections did not show any surface imperfections such as stacking faults, dislocation lines, 3 dimensional island growth or surface roughness for both sets of precursors.

The XRD ω-2θ scans results indicate that the $Si_{1-x}Ge_x$ layers are fully-strained with respect to the underlying Si substrate with an abrupt interface illustrated by the presence of well-defined fringes (Fig. 1a). The FWHM values of the SiGe004 peaks are very similar, 0.0316° for DCS/GeH_4 and 0.0314° for Si_2H_6/Ge_2H_6 (Fig. 1b). Thus, the similar FWHM values prove that there is no pronounced difference in terms of structural material quality.

Figs. 2a and 2b show the DLTS signals at different bias pulses as a function of measurement temperature for DCS/GeH_4 and Si_2H_6/Ge_2H_6, respectively. While no significant peaks appeared for DCS/GeH_4, 2 positive peaks appeared at around 170 and 250 K for Si_2H_6/Ge_2H_6 (Labeled E1, E2, E3 and E4 in Fig. 2b). In DLTS, positive peaks correspond to signals associated with electron traps in the n-type

epi layer. The activation energy extracted from the Arrhenius plots were E_c−0.331 eV (E1), E_c−0.541 eV (E2), E_c−0.304 eV (E3) and E_c−0.452 eV (E4), respectively. According to the literature [6-8], E1, E3, and E4 can be assigned to As-vacancy or di-vacancy or Ge-vacancy. For E2, a little deeper than the other energy levels, can be assigned to oxygen-vacancy structure. It is considered the growth rate for Si_2H_6/Ge_2H_6 might be too high (6 times higher than DCS/GeH_4), then that could cause the introduction of vacancy during growth, especially because of the lower growth temperature.

4. Conclusions

We investigated the crystalline and electrical properties of epitaxial $Si_{1-x}Ge_x$ layers (x~0.25) grown with each precursor combination of DCS/GeH_4 and Si_2H_6/Ge_2H_6. High-order Si and Ge precursors enable $Si_{1-x}Ge_x$ growth at low temperature with similar structural material quality as for standard DCS/GeH_4. The DLTS results, on the other hand, indicate that vacancy-related deep level point defects are present for Si_2H_6/Ge_2H_6.

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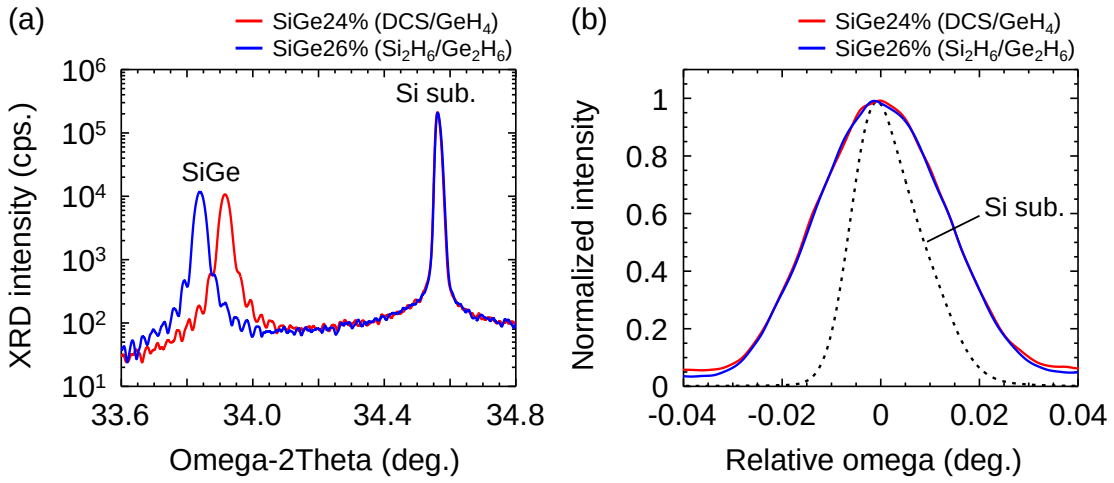

Fig.1 (a) XRD ω-2θ scans and (b) ω-rocking curves of $Si_{1-x}Ge_x$/Si samples.

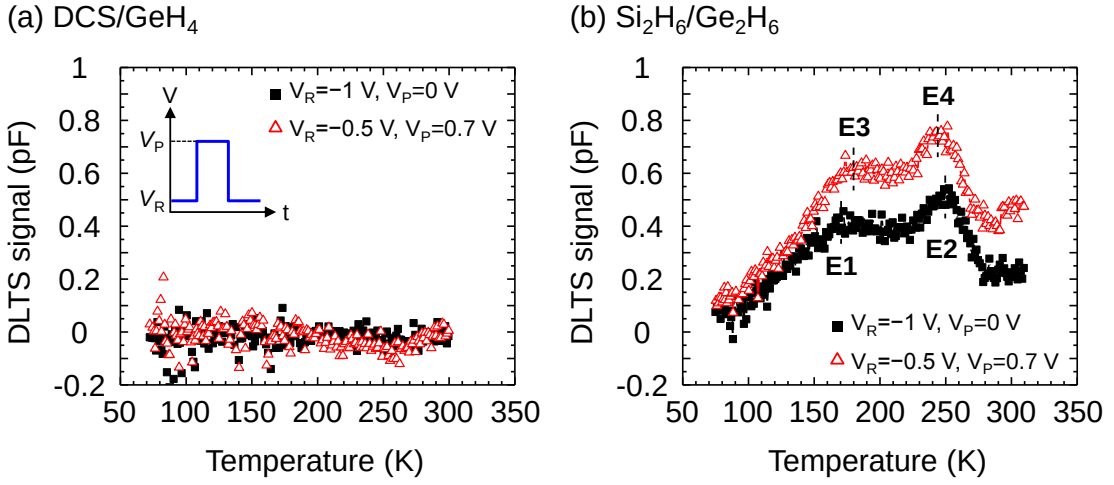

Fig.2 DLTS signals at different bias pulses as a function of measurement temperature for (a) $Si_{0.76}Ge_{0.24}$ (DCS/GeH_4) and (b) $Si_{0.74}Ge_{0.26}$ (Si_2H_6/Ge_2H_6).