I-2-2
Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp1043-1044

Impact of Sn incorporation on Epitaxial Growth of Ge Layers on Si(110) Substrates

°Shohei Kidowaki[1], Takanori Asano[1], Yosuke Shimura[1],
Noriyuki Taoka[1], Osamu Nakatsuka[1], and Shigeaki Zaima[1]
[1] Graduate School of Eng., Nagoya Univ., Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan.
Phone: +81-52-789-3819, FAX: +81-52-789-2760, E-mail: nakatuka@alice.xtal.nagoya-u.ac.jp

1. Introduction

Ge(110) is an attractive candidate for channel material in next generation metal-oxide-semiconductor field effect transistors (MOSFETs). Because Ge(110) has about 3.2 and 3.0 times higher mobilities than Si(001) for hole and electron, respectively. The development of heteroepitaxial growth technique of Ge layers on Si(110) is required for electronic device applications. However, the heteroepitaxial growth of $Si_{1-x}Ge_x$ and Ge layers on a Si(110) substrates is generally difficult compared to the epitaxial growth on a Si(001) substrate. It is known that the growth twins and microtwins defects are formed in an $Si_{1-x}Ge_x$ epitaxial layer grown on Si(110) with gas-source molecular beam epitaxy (GS-MBE) [1]. In the case of an epitaxial Ge growth on Si(110) with reduced pressure chemical vapor deposition, high temperature growth employed two-phased growth method (at 400°C and above 670°C), high temperature heat treatment (830°C), and thick film (> 500nm) are required in order to reduce the density of threading dislocations [2].

We consider that such a difficulty is due to the difference of surface structure between (001) and (110) substrates. There is an anisotropic structure on Si(110) surface; which is an anisotropic up-and-down terrace structures with a width of about 2.5 nm ("16×2"), in contrast to 2×1 dimer structure of Si(001) surface [3]. Here, we focus on the effect of Sn incorporation to control the surface structure. In vapor deposition of Sn on Si(110) surface, it is reported that the "16×2" surface structure changes to flatter terraces of Si(110)-Sn "7×2" at an Sn coverage of 0.4 monolayer (ML) [3]. Recently, we reported that the epitaxial growth of a uniform $Ge_{1-x}Sn_x$ layer on a Ge(110) substrate at a growth temperature of 150°C without growth twin defects [4],[5]. In this study, we investigated the impact of Sn incorporation on the crystalline structures of a Ge epitaxial layer grown on a Si(110) substrate. We found the improvement of crystalline quality of Ge epitaxial layers on Si(110) with Sn incorporation.

2. Experimental

After cleaning an n-type Si(110) wafer, a $Ge_{1-x}Sn_x$ layer was grown on the substrate with solid-source MBE method at a temperature of 200°C. Ge and Sn were deposited with Knudsen cells. The target Sn composition was ranging from 0.0% to 3.0%. The detail growth conditions are summarized in Table 1. The *in-situ* observation of the surface reconstruction structure was performed with reflection high energy electron diffraction (RHEED). The composition of substitutional Sn atoms and the strain-structure of $Ge_{1-x}Sn_x$ layers were estimated with x-ray diffraction two dimensional reciprocal space mapping (XRD-2DRSM).

3. Results and discussion

Fig. 1(a)-1(f) show *in-situ* RHEED patterns during the growth of Ge and $Ge_{0.969}Sn_{0.031}$ layers on Si(110). In the case of the Ge/Si(110) sample, the two dimensional (2D) growth is observed at the initial stage (Fig. 1(a)). After the growth of 10 min, the formation of twins defects is observed (Fig. 1(b) and 1(c)). On the other hand, in the case of the $Ge_{1-x}Sn_x$/Si(110) sample, the 2D growth is also observed at the initial stage (Fig. 1(d)). However, the three dimensional (3D) growth is observed at the growth time over 10 min and we can find no formation of twin defects (Fig. 1(e)). Then, 2D growth is observed again at the end of the epitaxial growth (130 min) (Fig. 1(f)).

Figures 2(a) and 2(b) show cross-sectional dark field transmission electron microscopy (TEM) images of Ge and $Ge_{0.969}Sn_{0.031}$ layers grown on Si(110) under the weak beam condition with a diffraction vector **g**=[002]. As shown in Fig. 2(a), the crystalline structure of the Ge layer is very poor. We can see many growth twins defects and stacking faults and tilting a lattice plane in the Ge layer seriously occurs. As a result, the TEM image of the layer is not uniform and very dark. In contrast, the crystallinity of the $Ge_{1-x}Sn_x$ layer is significantly improved. The formation of growth twins is effectively suppressed, while there are observed a few stacking faults and threading dislocations.

Figures 3(a) and 3(b) show XRD-2DRSM around 620 and 33 3 Bragg reflections with the incident x-ray directions of [1 10] and [001], respectively, for the $Ge_{0.969}Sn_{0.031}$/Si(110) sample. The substitutional Sn content was estimated to be 3.1% and the degrees of strain relaxation along [110] and [001] directions were estimated to be 96.4% and 93.7%, respectively. The full width half maximum (FWHM) of both the 2θ-ω scan and ω rocking curve around the (220) plane for Ge and $Ge_{1-x}Sn_x$ layers are summarized in Table I. FWHMs of the $Ge_{1-x}Sn_x$ layers are smaller than that of the Ge layer. These results indicate that the $Ge_{1-x}Sn_x$ layers has a superior crystallinity compared to the Ge layer on Si(110).

Figure 4 shows the degree of strain relaxation in $Ge_{1-x}Sn_x$ layers as a function of the substitutional Sn composition. The strain of Ge and $Ge_{1-x}Sn_x$ epitaxial layers is almost completely relaxed. However, the degree of strain relaxation of the Ge layer shows anisotropic structures. On the other hand, the strain of the $Ge_{1-x}Sn_x$ layer is more isotropically relaxed. Sn incorporation into Ge leads to the isotropic strain relaxation with suppressing the anisotropic structures in the Ge epitaxial layer.

4. Conclusions

We investigated the impact of the Sn incorporation on the epitaxial growth of a Ge layer on a Si(110) substrate. The Sn incorporation effectively improves on the crystalline quality of a Ge epitaxial layer on Si(110). The Sn incorporation suppresses the formation of growth twins, stacking fault even in the low temperature growth at 200°C. In addition, the Sn incorporation also enhances the isotropic strain relaxation of a Ge layer on Si(110).

Acknowledgements

This work was partly supported by a Grant-in-Aid for Specially Promoted Research (No. 22000011) from the MEXT of Japan.

References

[1] K. Arimoto *et al*., Solid-State Electron. **53**, 1135 (2009).
[2] V. H. Nguyen *et al*., Thin Solid Films **520**, 3222 (2012).
[3] T. An *et al*., Surf. Sci. **576**, 165 (2012).
[4] Y. Shimura *et al*., Appl. Phys. Exp. **5**, 015501 (2012).
[5] T. Asano *et al*., Thin Solid Films, *submitted*.

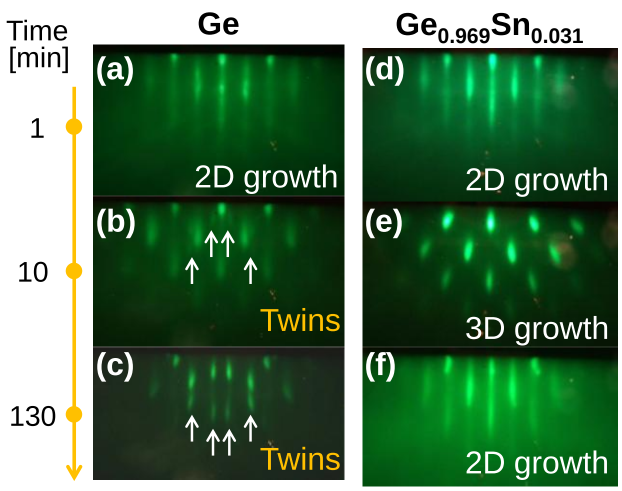

Fig. 1 RHEED patterns during the growth of (a)-(c) Ge and (d)-(f) $Ge_{0.969}Sn_{0.031}$ epitaxial layers on Si(110) substrates.

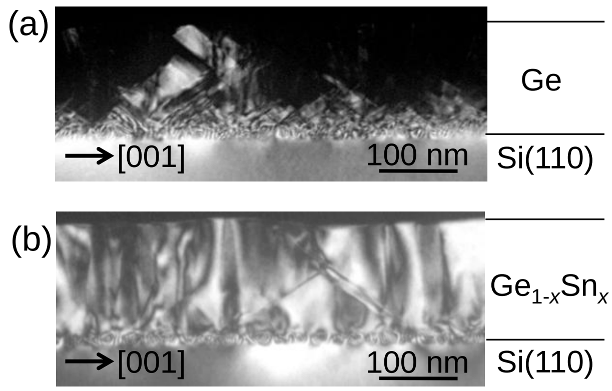

Fig. 2 Cross-sectional TEM (dark field) images of (a) Ge and (b) $Ge_{0.969}Sn_{0.031}$ layers grown on a Si(110) under the weak beam condition with diffraction vector g=[002] and incident direction [$\bar{1}$10].

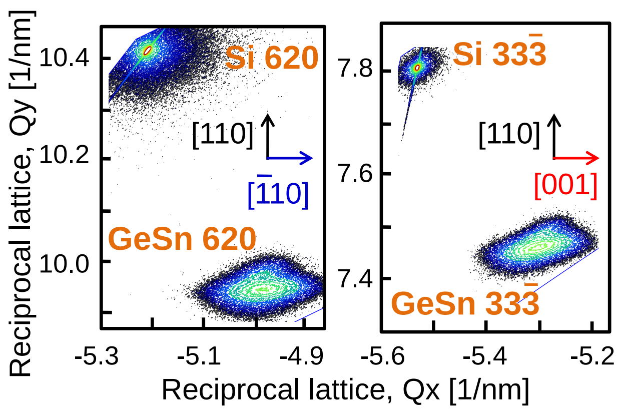

Fig. 3 XRD-2DRSM around Si (a) 620 and (b) 33$\bar{3}$ Bragg reflections for the $Ge_{0.969}Sn_{0.031}$/Si(110) sample.

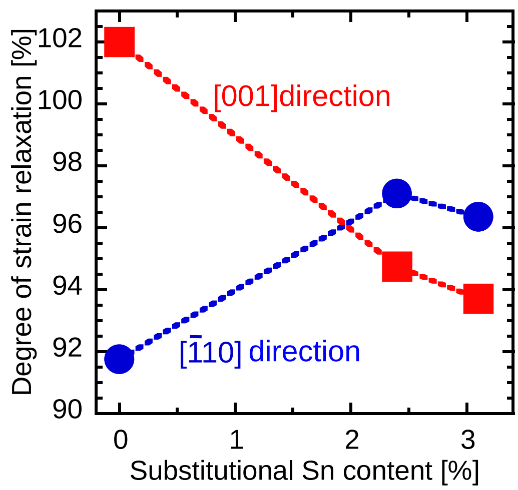

Fig. 4 Degree of strain relaxation for Ge/Si(110) and $Ge_{1-x}Sn_x$/Si(110) samples as a function of the substitutional Sn content. DSR was estimated from XRD-2DRSM.

Table I The summary of the growth conditions and crystallinity estimated with XRD for Ge and $Ge_{1-x}Sn_x$ layers on Si(110).

	Growth temperature [°C]	Growth time [min]	Film thickness [nm]	FWHM 2θ-ω [deg.]		FWHM ω-rocking [deg.]	
				[110]inc.	[001]inc.	[110]inc.	[001]inc.
Ge			145	1.0	1.15	0.68	0.75
$Ge_{0.976}Sn_{0.024}$	200	130	164	0.63	0.71	0.23	0.23
$Ge_{0.969}Sn_{0.031}$			167	0.58	0.59	0.25	0.25