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Ge / SiGe Multi Quantum Well Fabrication by Using Reduced Pressure Chemical Vapor Deposition

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Abstract

10 cycles of 15 nm thick $Si_{0.2}Ge_{0.8}$/15 nm thick Ge multi quantum well (MQW) on SiGe virtual substrate (VS) with 85% - 100% Ge content is fabricated to investigate the influence of strain on the $Si_{0.2}Ge_{0.8}$/Ge MQW growth. In the case of $Si_{0.2}Ge_{0.8}$ growth on Ge MQW layer, smeared interface is observed due to segregation of Ge atom. On Ge VS, slightly higher Ge segregation into $Si_{0.2}Ge_{0.8}$ is observed compared to that on SiGe VS with 85% Ge content. No misfit dislocations are detected in the $Si_{0.2}Ge_{0.8}$/Ge MQW layers by Transmission Electron Microscopy (TEM). Si concentration in the $Si_{0.2}Ge_{0.8}$/Ge MQW is slightly increasing by increasing of Ge content of the VS. By depositing 10 cycles of $Si_{0.2}Ge_{0.8}$/Ge MQW on SiGe VS with 85% Ge content, almost no improvement of threading dislocation density (TDD) is observed. However with increasing Ge content in VS, TDD is reduced by depositing $Si_{0.2}G_{0.8}$/Ge MQW.

1. Introduction

High quality Ge/SiGe superlattice (SL) structure enables high efficient Ge multi quantum well (MQW) laser [1]. In order to fabricate the Ge MQW laser, high quality Ge/SiGe SL fabrication is required. To realize high crystal quality MQW, strain and heteroepitaxial growth of Ge and SiGe have to be investigated. In this study we fabricated $Si_{0.2}Ge_{0.8}$/Ge MQW structures on Ge and SiGe virtual substrate (VS) with different Ge content and discuss influence of strain on Ge and SiGe growth.

2. Experimental

Epitaxial SiGe/Ge MQW fabrication is carried out by using a reduced pressure chemical vapor deposition (RPCVD) system. Si (100) substrates are used. SiH_4 and GeH_4 are used for precursors. For Ge VS, ~2 µm thick Ge is deposited by two step epitaxy with cyclic annealing at 800°C [2]. To fabricate SiGe VS with 95%, 90% and 85% Ge content, ~500 to ~600 nm thick SiGe layer deposition followed by postannealing at 850°C is performed on a ~1.5 µm thick Ge layer. By this reverse graded buffer approach, high crystal quality SiGe VS is possible [3]. After the VS fabrication, the wafers are cleaned by HF dip and loaded into the RPCVD reactor again. Then the wafer is baked at 850°C to remove native oxide. Afterwards 10 cycles of Ge and $Si_{0.2}Ge_{0.8}$ layers are deposited using H_2-GeH_4 and H_2-SiH_4-GeH_4 system at 500°C, respectively. Target thickness of the Ge and the SiGe layers are 15 nm. Ge concentration of the SiGe layer is targeted to 80%.

X-ray diffraction (XRD) is used for periodicity and degree of relaxation measurement. Cross section transmission electron microscope (TEM) is used for crystallinity and profile analysis. Energy dispersive X-ray spectrometry (EDX) and X-ray photoelectron spectroscopy (XPS) with monochromated Al Kα (1486.7 eV) are used for Si composition analysis of the deposited Ge / SiGe superlattice. Threading dislocation density (TDD) is measured by combination of Secco defect etching and angle view scanning electron microscope (SEM) measurement.

3. Results and Discussion

In Fig. 1, cross section STEM and EDX of 10 cycles of $Si_{0.2}Ge_{0.8}$/Ge MQW grown on Ge VS and SiGe VS with 85% Ge content are shown. No stacking faults and misfit dislocations are observed by TEM for both cases. In both EDX images (Fig. 1c and 1d), steep profiles are observed at the interface of Ge on $Si_{0.2}Ge_{0.8}$ layer, however the interface of SiGe on Ge is smeared out indicating Ge segregation into SiGe during the growth due to surface energy reduction. In the case of $Si_{0.2}Ge_{0.8}$/Ge MQW deposition on Ge VS, segregation length seems to be higher compared to that on $Si_{0.15}Ge_{0.85}$ VS as shown in Table 1. A possible reason could be that higher tensile strain energy is contained in the $Si_{0.2}Ge_{0.8}$ layer on Ge VS resulting in higher Ge segregation.

In Fig. 2, XRD RSM of the 10 cycles of 0 $Si_{0.2}Ge_{0.8}$/Ge MQW deposited on Ge VS and $Si_{0.15}Ge_{0.85}$ VS are shown. For both cases, periodic orders of SL peaks are observed toward Q_z direction indicating periodicity of the SL is well aligned.

Next the influence of strain of the 10 times $Si_{0.2}Ge_{0.8}$/Ge MQW on Si incorporation is discussed. By EDX analysis, ~18% of Si is incorporated in the SiGe layer of MQW for the sample SiGe VS with 85% Ge content (Fig. 3). With increasing Ge concentration of the VS, Si concentration in the SiGe of MQW increases. This increase is also supported by XPS analysis of the top SiGe layer of the 10 cycles of SiGe/Ge MQW. Si incorporation of SiGe growth seems to be influenced by strain in the SiGe layer.

In Fig. 4, we summarized the improvement of the TDD by the SiGe/Ge MQW deposition on Ge or SiGe VS with various Ge content. In the case of SiGe/Ge MQW deposition on SiGe VS with 85% Ge content, the TDD is the same level as that of the SiGe VS. With increasing Ge concentration of the VS, improvement of the TDD is observed by the 10 cycles of $Si_{0.2}Ge_{0.8}$/Ge MQW deposition. A 50% reduction of the TDD is realized for the Ge VS sample. The 50% reduction of the TDD is not possible by adding the same thickness (300 nm) of simple Ge layer on the ~2 µm thick Ge VS [2]. The TD network seems to go downwards by tensile strained SiGe growth on Ge. Further investigation is required to clarify the mechanism behind.

4. Summary and Conclusion

10 cycles of 15 nm thick $Si_{0.2}Ge_{0.8}$/15 nm thick Ge MQW is fabricated on SiGe virtual substrate with 85% - 100% Ge content to discuss the influence of strain on SiGe and Ge growth. In the case of $Si_{0.2}Ge_{0.8}$ growth on Ge MQW layer, smeared interface is observed due to segregation of Ge atom. On Ge VS, slightly higher Ge segregation into SiGe is observed compared to that on SiGe VS with 85% Ge content. Small increase of Si concentration in the $Si_{0.2}Ge_{0.8}$/Ge MQW is observed by incasing by increasing of Ge content of the VS from 85% to 100%. By depositing 10 cycles of $Si_{0.2}Ge_{0.8}$/Ge MQW on SiGe VS with 85% Ge content, almost no improvement of the TDD is observed. However with increasing Ge content in VS, higher reduction of the TDD is observed by depositing the 10 times $Si_{0.2}G_{0.8}$/Ge MQW.

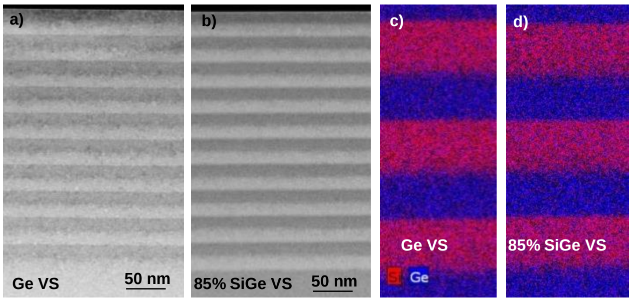

Fig. 1. a) Cross section bright field STEM images of 10 cycles of SiGe/ Ge MQW deposited on a) Ge VS and b) $Si_{0.15}Ge_{0.85}$. c) and d) show Si and Ge distribution EDX mapping of the SiGe/Ge MQW on Ge VS and $Si_{0.15}Ge_{0.85}$ VS, respectively

Table 1. Summary of steepness of interface between SiGe and Ge of MQW measured by TEM.

Virtual substrate	Interface thickness: Ge on SiGe (nm)	Interface thickness: SiGe on Ge (nm)
Ge	1.8	7.4
$Si_{0.15}Ge_{0.85}$	1.5	6.4

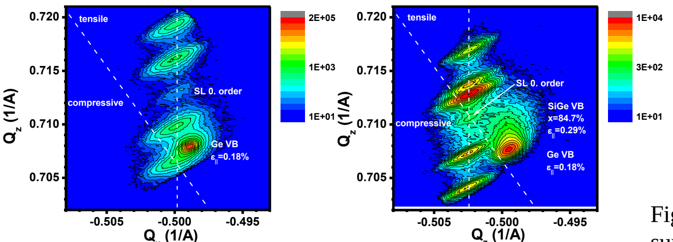

Fig. 2. XRD RSM images of 10 cycles of SiGe/Ge MQW deposited on a) Ge VS and b) $Si_{0.15}Ge_{0.85}$.

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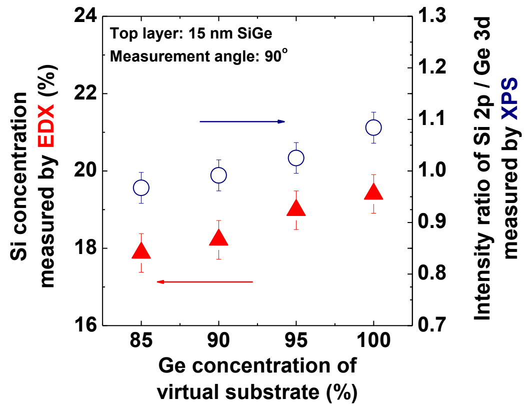

Fig. 3. Si concentration measured by EDX and intensity ratio of Si2p and Ge3d in SiGe / Ge superlattice grown on Ge or SiGe virtual substrate with different Ge content. Thickness of SiGe and Ge layers are 15 nm and top layer of the SiGe MQW is SiGe.

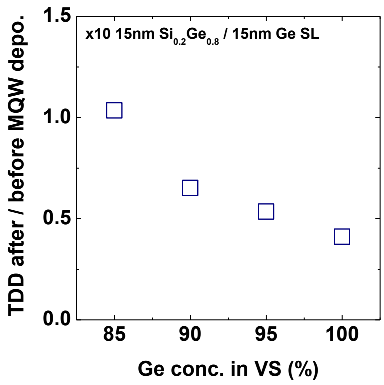

Fig. 4. Ratio between TDD before and after 10 cycles of $Si_{0.2}Ge_{0.8}$/Ge superlattice deposited on Ge or SiGe VS of various Ge concentrations. Thicknesses of SiGe layers and Ge layers of SL are 15 nm.