Effect of growth temperature on lattice relaxation during SiGe growth on Si substrates

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Relaxed and high Ge composite SiGe layers having flat surfaces are strongly needed as substrates for the strained silicon channels in MOSFETs. Here, the growth temperature is one of the most important factors not only to control the relaxation behavior but also to obtain the smooth surfaces. In high temperature SiGe growth on Si substrates, it has been reported that the SiGe films have rough surfaces, although they are easily relaxed[1,2]. It is known, on the other hand, that the SiGe films with flat surfaces can be obtained in low growth temperatures. Thus, if we can effectively control the lattice relaxation of SiGe films at low temperatures, SiGe substrates satisfied with both the surface flatness and the relaxation ratio can be realized. Thus, in this report, the lattice relaxation, the structural defect and the surface morphology of SiGe films at high and low temperatures were studied as a function of the grown SiGe thickness, in order to clarify the behavior of relaxation in the low temperature SiGe growth.

$Si_{1-x}Ge_x$ films (x=0.40) were grown at 400C on Si(100) substrates by UHV-CVD method. As references, x=0.15 films were also grown at 600C. The type of dislocations or defects and the density were evaluated by the plan view TEM. The relaxation ratio, the film thickness and the surface roughness were measured by Raman spectroscopy, GIXR/SEM and AFM, respectively.

AFM images of the x=0.40 SiGe film surfaces grown at different temperatures were shown in Fig.1. A 15nm film grown at 600C had a very rough surface (Rrms=3.9nm @10μm×10μm) and high relaxation ratio (R=0.42). On the other hand, a 65nm film grown at 400C had a much more flat surface (Rrms=0.59nm @10μm×10μm) although it started to relax (R=0.32).

In the high temperature growth (600C, x=0.15), a large density of long misfit dislocations along (110) direction were observed. In the low temperature grown films (400C, x=0.40), however, a lot of short stacking faults were observed as shown in Fig.2. These facts mean that the types of generated structural defects are strongly dependent on the growth temperature. The misfit dislocation density and the relaxation ratio of the 600C grown samples were plotted in Fig.3 (a) as the function of the SiGe film thickness. It is found that the increase in the lattice relaxation is in good agreement with the increase in the misfit dislocation density, confirming that films are relaxed by misfit dislocations, according to the relaxation model reported before[3,4]. On the other hand, it is found in the SiGe films grown at 400C that, as plotted in Fig.2 (b), the lattice relaxation suddenly occurred at the film thickness of almost 60nm, while the number of stacking faults increased gradually from the initial stage of the film growth. Here, the increase in the surface roughness at the film thickness of 60nm was small, suggesting that the contribution of roughening the surface to the relaxation is negligible.

As a result, we think that the mechanism of the lattice relaxation of the low temperature grown SiGe films is different from that of the high temperature ones, which is attributed to the generation of the misfit dislocations[3,4]. This difference might be caused by the slow dislocation velocities[4] because of the low temperature and by the existence of stacking faults.

In summary, the variation of the relaxation ratio and the dislocation/defect density were measured systematically as the function of the SiGe film thickness. In the low temperature, a large number of small stacking faults were observed instead of long misfit dislocations, which were easily moved at high temperature and contributed to the relaxation. Also different behavior of the relationship between the relaxation ratio and the defect density was observed between high and low growth temperature.

This work was supported by NEDO.

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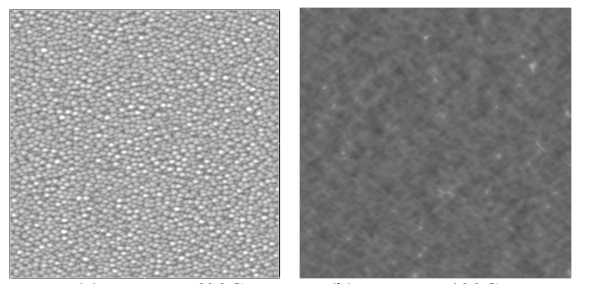


(a)grown at 600C (b)grown at 400C

Fig.1: AFM images of SiGe (x=0.40) surfaces (a)grown at 600C, 15nm (b)grown at 400C, 65nm (5μm×5μm).

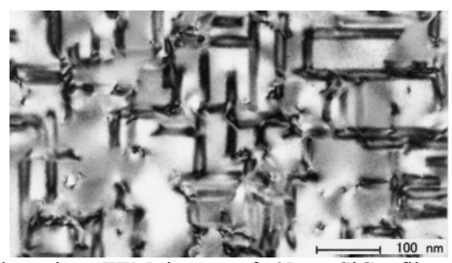
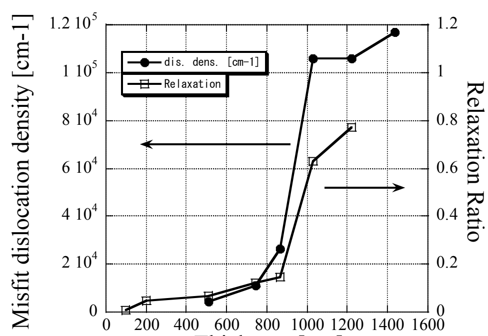
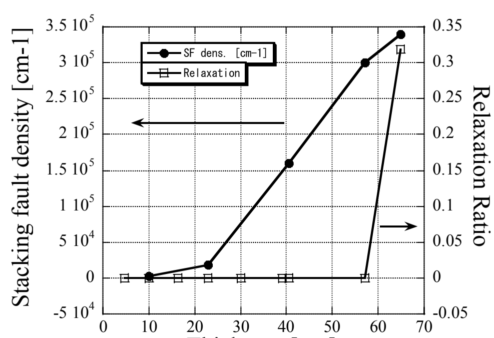


Fig.2: Plan view TEM image of 65nm SiGe film (x=0.40). Stacking faults were observed mainly.



(a) x=0.15, grown@600C



(b) x=0.40, grown@400C

Fig.3: Changes of stacking fault / misfit dislocation density and relaxation ratio as SiGe film thickness changed. (a) x=0.15, grown@600C, (b) x=0.40, grown@400C