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Critical Thickness of Heteroepitaxial $Si_{1-x}Ge_x/Si$ Layers as Studied by Atomic Force Microscopy

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A detailed study has been made on the evaluation of the surface of heteroepitaxial $Si_{1-x}Ge_x/Si$ layers by atomic force microscopy (AFM). It has been found that misfit dislocations in the heteroepitaxial layers can be observed by AFM. On the basis of these results, a new non-destructive method of evaluating the critical thickness of strained heteroepitaxial layer will be proposed in this paper.

1. Introduction

The heteroepitaxial structure of strained $Si_{1-x}Ge_x$ layers on Si substrates attracts attention in recent years since they allow the fabrication of heterobipolar transistors (HBT) compatible with silicon processing technologies. To form HBT, the pseudomorphic growth films which are free from dislocation are required. In the above application, the determination of critical thickness is indispensable and transmission electron microscopy (TEM)[1] or electron beam induced current (EBIC) technique[2] is usually used for this purpose. Although TEM has an ability to observe a single misfit dislocation in high resolution, its measurement area is very small. On the contrary, the measurement area of EBIC is large, but the resolution is much lower than that of TEM. In addition, in both methods, specimen must be prepared in a destructive manner for measurements. We have, in detail, investigated the surface of heteroepitaxial $Si_{1-x}Ge_x$ layers by AFM. On the basis of this study, we will propose a new non-destructive and preparation-free method of evaluating the critical thickness of strained heteroepitaxial layers.

2. Experimental

Heteroepitaxial $Si_{1-x}Ge_x/Si$ films were prepared on Si wafers with (100) orientation by rapid thermal chemical vapor deposition (RTCVD) as shown in Fig.1. Si wafers were treated with $H_2SO_4 + H_2O_2$. After that, they were cleaned with diluted HF acid, and then put into the vacuum chamber. $Si_{1-x}Ge_x$ films were grown on them from a mixture of SiH_4 (10 %) and GeH_4 (1 %) diluted in H_2 at 850 ℃. Just before $Si_{1-x}Ge_x$ layer deposition, the substrate surface was pretreated, in the reactor, with SiH_4 (10 %) in H_2 at 900 ℃ for a few seconds[3].

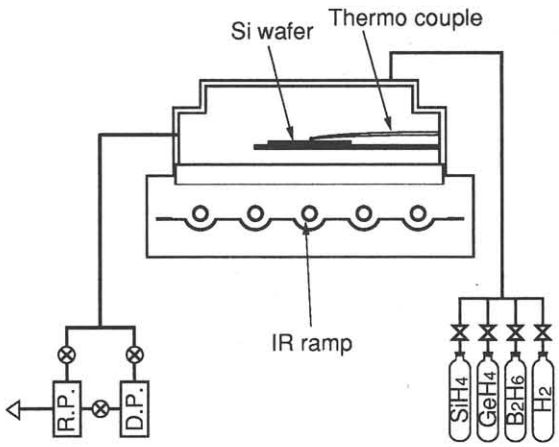

Fig.1 Schematic drawing of the RTCVD system.

The film thickness was evaluated from step height measurements. Film compositions were determined by high resolution X-ray diffraction (HXRD) by use of non-relaxed $Si_{1-x}Ge_x$ films. The composition x was calculated on the Vegard rule under the condition that the lattice constant was converted into bulk's one using Poisson's ratio $\nu = 0.28$. The networks of misfit dislocations at the interface of $Si_{1-x}Ge_x/Si$ were investigated by TEM. The surface of $Si_{1-x}Ge_x$ film was evaluated on a low tension cantilever type (Nanoscope II (Digital Inst.)) atomic force microscope.

3. Results and Discussion

Figure 2 shows a cross sectional TEM micrograph of heteroepitaxial $Si_{0.89}Ge_{0.11}/Si$ film. In Fig.2, epitaxial Si layer formed during SiH_4 pretreatment and $Si_{0.89}Ge_{0.11}$ layer are clearly seen. The thicknesses of $Si_{0.89}Ge_{0.11}$ and epitaxial Si layers were 250 nm and 50 nm, respectively. No defects were observed in both layers. The crystallinity of films was evaluated by Rutherford backscattering spectroscopy (RBS). The minimum RBS yield of the $Si_{0.89}Ge_{0.11}$ layer was found to be 3.7 %, which is comparable with that of the Si wafer.

Figure 3 shows plane-view TEM micrographs of heteroepitaxial $Si_{0.89}Ge_{0.11}/Si$ films whose thicknesses are (a)250, (b)140 and (c)100 nm, respectively. In Figs.3(a) and 3(b), the networks of misfit dislocations at interfaces are observed in the <110> direction, but not in Fig.3(c). These findings indicate that the thicknesses of both films in Figs.3(a) and 3(b) are above the critical value of pseudomorphic growth and that of the film in Fig.3(c) is below the critical value, that is, indicate that the critical thickness of this film is between 100 and 140 nm.

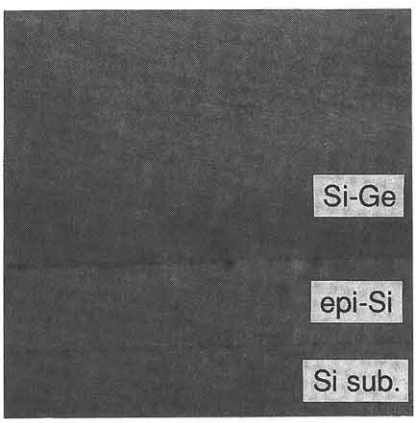

Fig.2 Cross-sectional TEM micrograph of $Si_{0.89}Ge_{0.11}/Si$ film.

Figure 4 shows AFM images of heteroepitaxial $Si_{0.89}Ge_{0.11}/Si$ films. Crosshatched patterns parallel to the <110> direction are observed in Figs.4(a) and 4(b), but not in Fig.4(c). In spite of observations on the

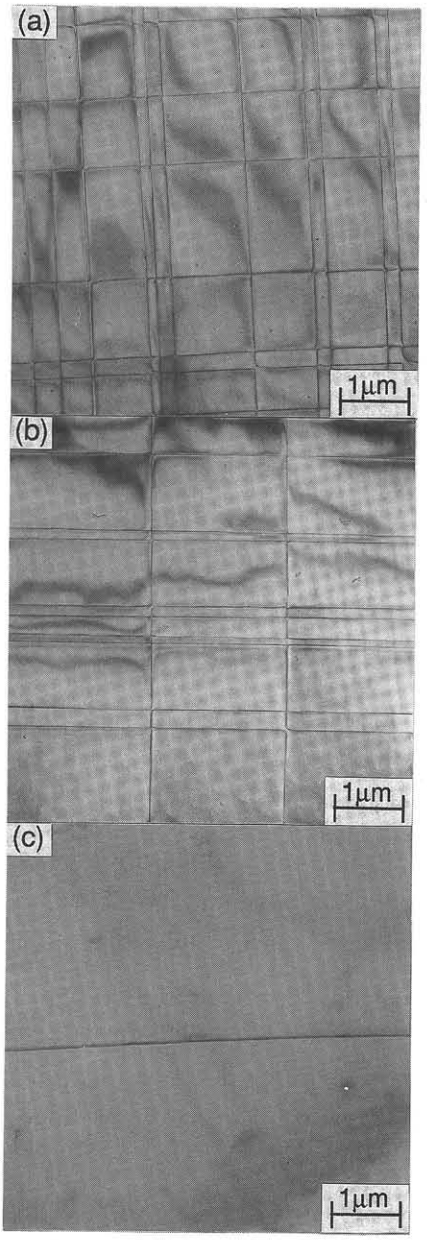

Fig.3 Plane-view TEM micrographs of $Si_{0.89}Ge_{0.11}/Si$ films.
(a) 250nm, (b) 140nm, (c) 100nm

surface, these crosshatched pattern images obtained by AFM are close resemblance to the network of misfit dislocations observed by TEM (Fig.3). The periods of the crosshatched AFM patterns in Fig.4 are coincident with those of the networks of misfit dislocations shown in Fig.3. These results indicate that AFM observation makes it possible to evaluate misfit dislocations in $Si_{0.89}Ge_{0.11}$ films in a non-destructive manner.

We tried to determine the critical thickness of strained $Si_{1-x}Ge_x/Si$ heteroepitaxial films by applying this phenomenon. Figure 5 shows the critical thickness determined by the present method as a function of lattice mismatch.

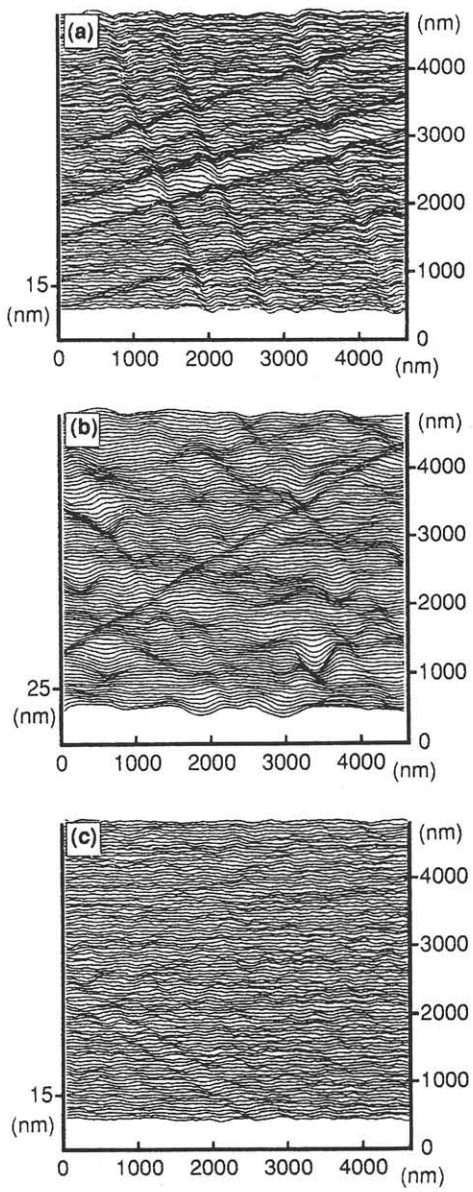

Fig.4 AFM images of $Si_{0.89}Ge_{0.11}/Si$ films (a) 250nm, (b) 140nm, (c) 100nm

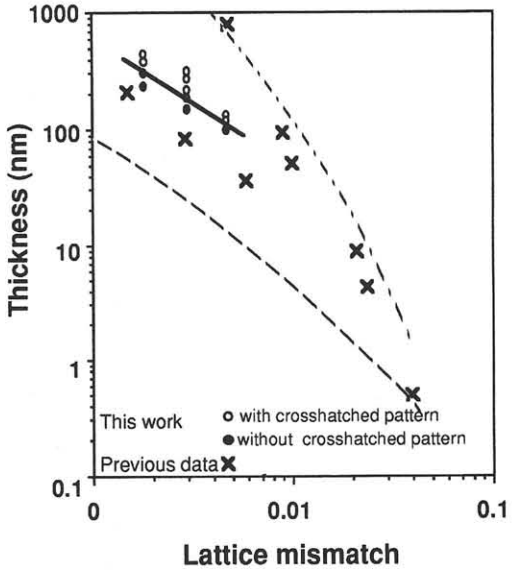

Fig.5 Plots of the critical thickness of $Si_{1-x}Ge_x/Si$ films vs. lattice mismatch.

As Fig.5 shows, our data (● and ○) are in reasonable agreement with those reported previously, where cross symbols show previous experimental data[1),4)] and dotted and dot-dash lines are theoretical ones[4)].

4. Conclusion

We have found that crosshatched patterns are observed, under particular conditions, in the AFM measurement images of $Si_{1-x}Ge_x/Si$ heteroepitaxial layers and that these crosshatched patterns correspond to the networks of misfit dislocations in $Si_{1-x}Ge_x/Si$ layers. We tried successfully to develop a new method of evaluating the critical thickness of strained $Si_{1-x}Ge_x/Si$ heteroepitaxial layers by applying the above results. This method makes it possible to evaluate the density of misfit dislocation and the critical thickness of strained $Si_{1-x}Ge_x/Si$ heteroepitaxial films in a non-destructive manner.

References

1) E. Kasper et al., Appl. Phys. **8** (1975) 199.
2) Y. Fukuda et al., Jpn. J. Appl. Phys. **26** (1987) L944.
3) K. Ashikaga et al., Extended Abstracts of Int. Conf. SSDM (1991) 255.
4) P. M. Maree et al., J. Appl. Phys. **62** (1987) 4413.