

Stress-Induced Anomalous Growth in Lateral Solid Phase Epitaxy of Ge-Incorporated Si Films

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Lateral solid phase epitaxy (LSPE) characteristics of Ge incorporated amorphous Si films deposited on SiO_2/Si (100) structures with [010] seed openings are studied. It has been found in P-doped amorphous Si films that the LSPE growth rate at 600°C is about 6 times enhanced by incorporation of 0.5 at.% Ge atoms, and that the maximum growth length is about $21\mu\text{m}$. It has also been found that the growth in the film with 1 at.% Ge atoms stops for about 1 hour at a length of about $2\mu\text{m}$ from the seed edge and it proceeds again for the longer annealing. To clarify the origin of the anomalous growth rate, the residual stress in the films has been measured using microprobe Raman spectrometry, and it is concluded that the origin of the enhanced growth is the residual stress in the films.

1. Introduction

Lateral solid phase epitaxy (LSPE) is one of the promising methods to form SOI (silicon-on-insulator) structures at low temperatures. So far, two factors are known to be effective for enhancing the LSPE growth rate and enlarging the SOI area. The first one is electrically active impurities such as P atoms [1], and the second one is intrinsic or extrinsic stresses which are generated in the films either by increasing the film thickness [2] or by applying hydrostatic pressure [3]. In order to fabricate three-dimensional IC's, introduction of intrinsic stresses seems to be suitable. However, in the previous report [2], the stress has been introduced by increasing amorphous Si (a-Si) film thickness, and thus this method can not be applied to thin film SOI structures. In this paper, we demonstrate that the LSPE growth rate is effectively enhanced even in thin a-Si films by the stress effect due to incorporation of Ge atoms.

2. Experimental

$\text{Si}(100)$ substrates were covered with SiO_2 films about 40nm thick and seed stripes about $10\mu\text{m}$ wide were opened in the films along a [010] direction. Polycrystalline Si films 220nm thick were deposited by electron-gun evaporation on the thermally cleaned substrates at a temperature of about 600°C . The Si films were then amorphized by implantation of 300keV Si^+ ions to a dose of $2 \times 10^{15}\text{cm}^{-2}$. P ions were also implanted to doses on the order of 10^{14}cm^{-2} , in order to enhance the LSPE growth rate and the growth length [1]. Concerning implantation of Ge ions, the energies of 200keV and 300keV were used and doses were so adjusted that the maximum Ge concentration ranged from 0 to

$5 \times 10^{20}\text{cm}^{-3}$ (1 at.%) [4]. The samples were finally furnace-annealed at 600°C in dry N_2 ambient for inducing LSPE. The growth characteristics were observed with Nomarski optical microscopy. Crystalline quality of the grown films was analyzed by cross-sectional TEM (transmission electron microscopy) and residual stress in the films was measured using a microprobe Raman spectrograph (Jobin Yvon U-1000).

3. Results and Discussion

Figure 1 shows optical micrographs of the Si LSPE samples with Ge concentration of 0.5 and 1 at.%,

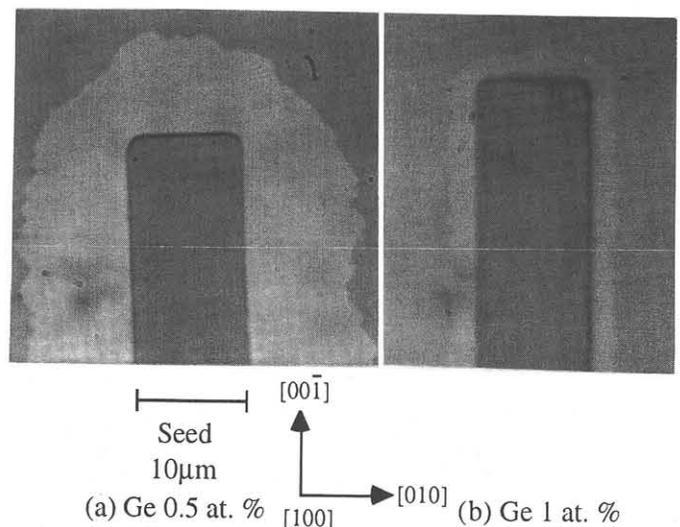


Fig.1 Nomarski optical micrographs for the grown regions of the Ge-incorporated Si LSPE samples annealed at 600°C .

which were annealed at 600°C for 40 minutes. The white area around the rectangular seed region corresponds to the LSPE region, while the black area farther from the seed region remains as an amorphous film. We can see from these photographs that the average LSPE lengths for the samples with 0.5 and 1 at.% Ge atoms are about 10 μm and 2 μm , respectively. We can also see from comparison with a reference sample with no Ge atoms in the film that the growth rate is much enhanced only in the 0.5 at.% Ge sample.

The LSPE growth characteristics of the Ge-incorporated Si LSPE films at 600°C are summarized in Fig.2. In this measurement, the LSPE growth direction is a [001] direction. We can see that the growth rate of the sample with 0.5 at.% Ge is largest and its growth length is longest. We can also see that the growth in the 1 at.% Ge sample is stops at 2 μm from the seed edge for about 1 hour and it proceeds again for the longer annealing time. The growth characteristics were further investigated by changing the Ge atom concentrations in the films. Figure 3 shows the LSPE growth rate as a function of Ge concentration, in which the average rate for the initial one hour is plotted. As can be seen from this figure, the growth rate is anomalously enhanced in the range of Ge concentration between 0.25 at.% and 0.75 at.%.

Figure 4 shows a cross-sectional TEM micrograph for a sample with 0.5 at.% Ge atoms in the film, in which periodic defect regions are observed along the LSPE growth region. It was also found from diffraction patterns that the crystal orientation of the film is the same with that of Si substrate at least in the region within 10 μm from the seed edge, and it is rotated by 45° near the growth front region. These results suggest that the crystalline quality of the LSPE film degrades as the growth proceeds farther from the seed edge. From these TEM analyses, however, we could not find clear difference of the crystalline quality between the 0.5 at.% and 1 at.% Ge samples. In other words, we could not judge whether the LSPE characteristics peculiar to Ge-incorporated a-Si films are based on accumulation of stress in the films or on the pile-up (snow-plow) effect of Ge atoms along the growth direction.

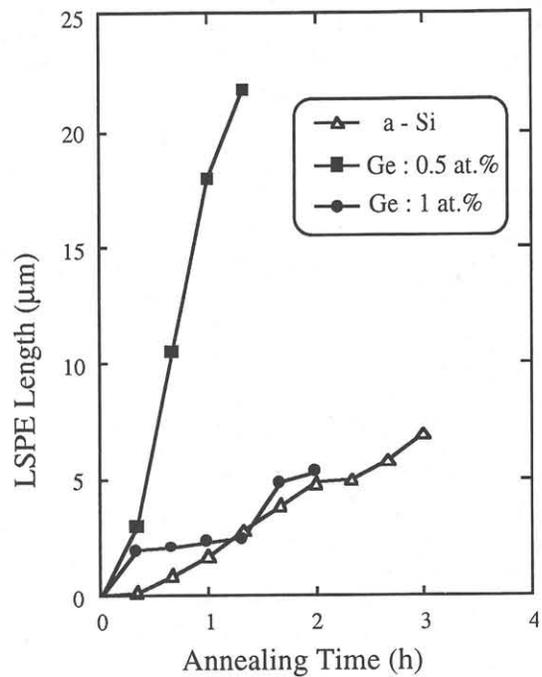


Fig.2 Annealing time dependence of the growth length for Ge-incorporated Si LSPE samples at 600°C.

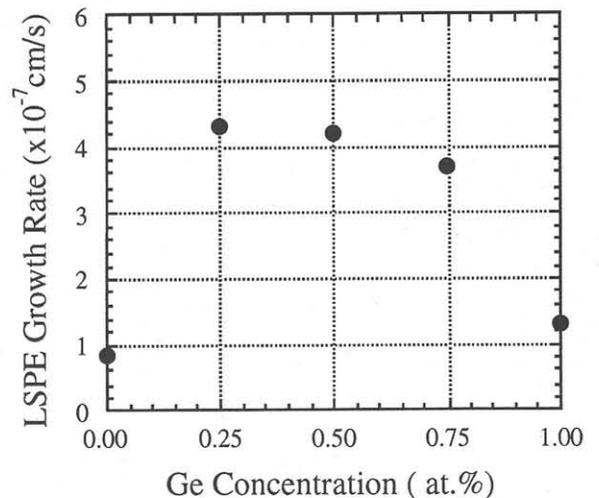


Fig.3 Ge concentration dependence of the growth rate for Ge-incorporated Si LSPE samples.

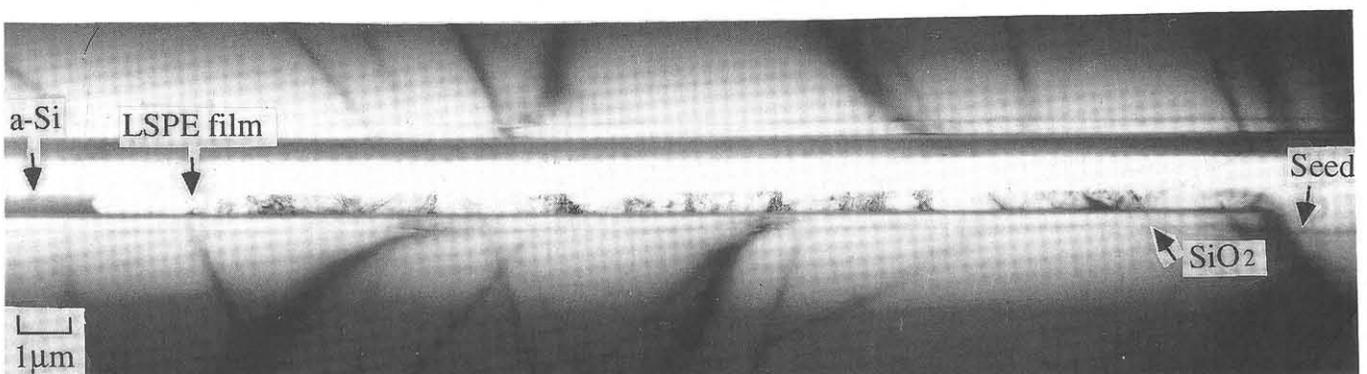


Fig.4 TEM micrograph of 0.5 at.% Ge LSPE samples.

In order to clarify the origin of the enhanced growth rate, the residual stress in the films was measured using microprobe Raman scattering spectrometry with spatial resolution of about $1\mu\text{m}$. In this measurement, an Ar laser with 496.5nm of wavelength was used as an exciting source, and the frequency shift of the transverse optical phonon mode ($\text{TO}(\Gamma)$ line) of Si-Si bonding was observed. Under these conditions, the relative shift of -1cm^{-1} corresponds to a tensile stress of $2.5 \times 10^8 \text{ Pa}$ ($2.5 \times 10^9 \text{ dyne/cm}^2$). The measured Raman shifts are plotted as a function of distance from the seed edge, as shown in Fig.5. In the seed area, Raman shift of 520cm^{-1} was obtained in all samples, which indicates that no stress remains in the vertical SPE region.

The figure also shows that tensile stresses are generated in the LSPE regions and the difference among the samples is small near the seed region. We can see, however, that the residual stresses in the farther regions are different between the 1 at.% Ge sample and the 0.5 at.% Ge sample. The stress in the 0.5 at.% Ge sample continues to increase with LSPE length, while it tends to saturate at a distance around $2\mu\text{m}$ in the 1 at.% Ge sample. This length corresponds to the length at which the LSPE growth stops for about 1 hour in Fig.2. The maximum stress value in the 0.5 at.% Ge sample is estimated about 1GPa at a distance of $10\mu\text{m}$. Similar increase of the stress was also observed in the 0.75 at.% Ge sample. We conclude from these results that the origin of the anomalous growth rate is the residual stress in the film due to incorporation of Ge atoms.

4. Conclusion

We derived a model of stress-induced anomalous growth due to incorporation of Ge atoms. The Ge

concentration used in this experiment seems to be relatively low. However, since the critical thicknesses of pseudomorphic growth of 0.5 at.% and 1 at.% Ge incorporated Si layers on Si are estimated to be from $0.6\mu\text{m}$ (by Matthew's formula [5]) to $26\mu\text{m}$ (by Merwe's formula [6]) and from $0.3\mu\text{m}$ to $13\mu\text{m}$, respectively, we speculate that the strain effect is extended to a distance of $10\mu\text{m}$ in the 0.5 at.% Ge sample. This speculation is also supported from the FWHM measurement of Raman peaks, in which the peak width in the 0.5 at.% Ge sample was narrowest.

References

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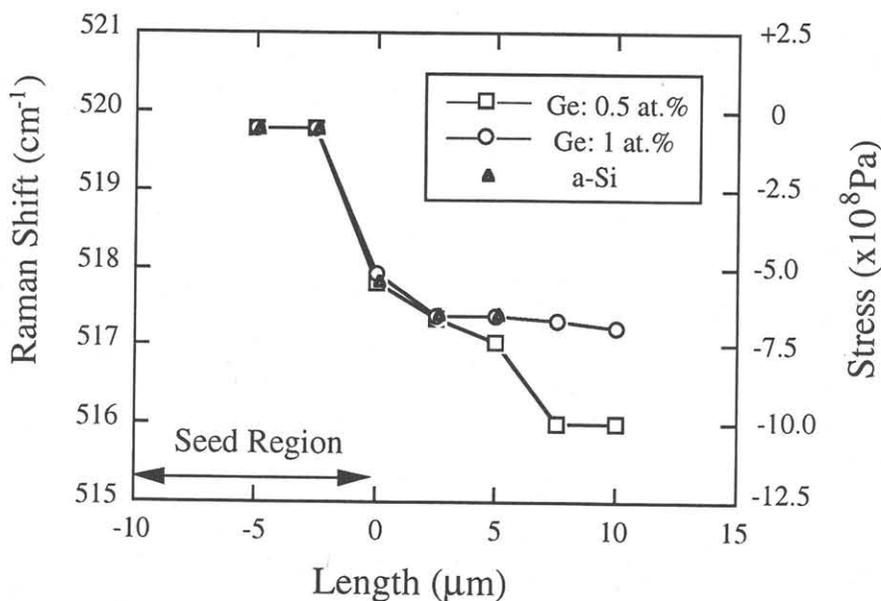


Fig.5 Stress distribution in Ge-incorporated Si LSPE samples.