

Lateral Solid Phase Epitaxy of Amorphous Si Films under Ultrahigh Pressure

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The effect of hydrostatic pressure on the lateral solid phase epitaxy (L-SPE) of amorphous Si (a-Si) films has been investigated. It has been found from the annealing experiment under ultrahigh pressure up to 2GPa (20kbar) that the L-SPE growth rate is increased with increase of pressure but that the nucleation probability of polycrystallites is also enhanced. It has also been found that the nucleation probability is decreased when a-Si films are spin-coated with SiO₂ films prior to L-SPE. It is concluded from the growth characteristics that the pressure effect is more pronounced in the growth on {110} facets than the growth on {111} facets.

§ 1. Introduction

L-SPE of a-Si films deposited on SiO₂/Si structures with seeding area is a promising method to form silicon-on-insulator (SOI) structures at low temperatures around 600°C¹⁾. In this method, it has been reported that the L-SPE growth length strongly depends on the residual strain in the film²⁾. It has also been reported in vertical SPE that the growth rate is about 5 times enhanced by applying a hydrostatic pressure of 3.2GPa to the sample^{3) 4) 5)}. In this paper, we attempt to grow a-Si films laterally under ultrahigh pressure (UHP).

§ 2. Experimental procedure

Ultrahigh pressure up to 2.1GPa was generated using a pressure apparatus of piston-cylinder type, as shown in Fig.1. An electric furnace with a maximum temperature of 800°C and insulating pipes were placed in the cylinder and the space in the cylinder was filled with Ar gas which was used as a pressure transmission medium. The ceramic parts for heating were initially made of pyrophyllite (Al₂Si₄O₁₀(OH)₂), then they were changed to BN (boron nitride). In order to decrease the residual oxygen in the cylinder, the filling and releasing processes of Ar gas at 15MPa (150bar) were repeated five times. Then, the ceramic parts were baked at 400°C for 30min in 15MPa Ar gas so that absorbed air was ejected from pores of ceramics. Finally, Ar gas was again changed before the L-SPE

annealing was started. During L-SPE annealing, the temperature of samples was controlled within ±1°C. A typical sample size was 2 × 2mm².

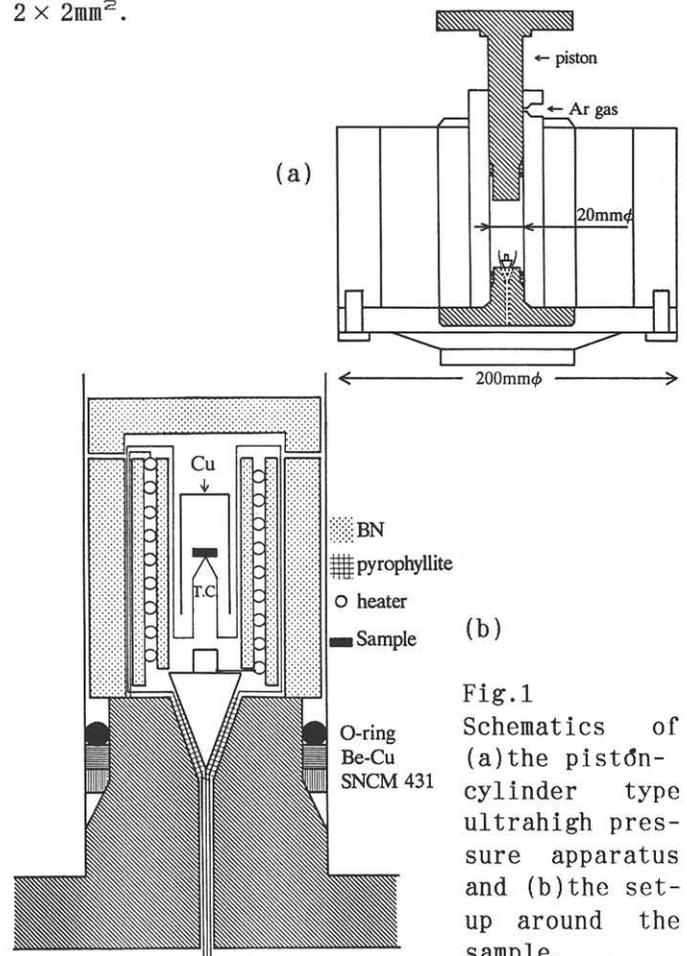


Fig.1 Schematics of (a) the piston-cylinder type ultrahigh pressure apparatus and (b) the setup around the sample.

In the sample preparation, in order to obtain dense a-Si films, polycrystalline Si films were first deposited on SiO₂/Si structures with seeding area and they were subsequently amorphized by Si ion implantation. P ions were also implanted to enhance the growth rate and the growth length⁽⁵⁾. In some samples, the surfaces were covered with spin-coated SiO₂ films. Finally, the samples were annealed at 600°C under atmospheric pressure (AP) or under ultrahigh pressure (UHP:1GPa and 2GPa).

The L-SPE characteristics were investigated using Nomarski optical microscopy. The impurity profiles in the L-SPE grown films were analyzed by secondary ion mass spectrometry (SIMS).

§ 3. Results

Fig.2 shows Nomarski optical micrographs for the grown regions of the P-doped samples annealed at 600°C for 30min at AP and 2GPa. We can clearly see that L-SPE growth rate is much enhanced by applying UHP.

The results described above seem to be promising. However, it was found that the growth length at 2GPa was stopped at 10 μm and the film became polycrystals. At the same time, the surface of the sample was found to be covered with a film, which was very difficult to etch with any acid solution. From

SIMS measurement, it was found that the film contained SiO₂ composition in it. So, all ceramic parts in the cylinder were changed to BN, and the treatments for decreasing residual oxygen were carried out. As a result, the film formation problem was solved and no thick oxide layer was found by SIMS measurement. Even in this case, however, polycrystallization of the films occurred by annealing for about 1 hour.

Then, the surface of an a-Si film was covered with a spin-coated SiO₂ film, since we speculated that the nucleation for polycrystallization originated from unintentional damage of the Si surface during annealing at UHP. Nomarski optical micrographs of the coated and uncoated samples are shown in Fig.3, in which the samples were annealed at 600°C for 30min at 2GPa. As can be seen from the figure, the polycrystallization time is much longer in the coated sample and the growth length of 24.3 μm was obtained by annealing for 2 hours.

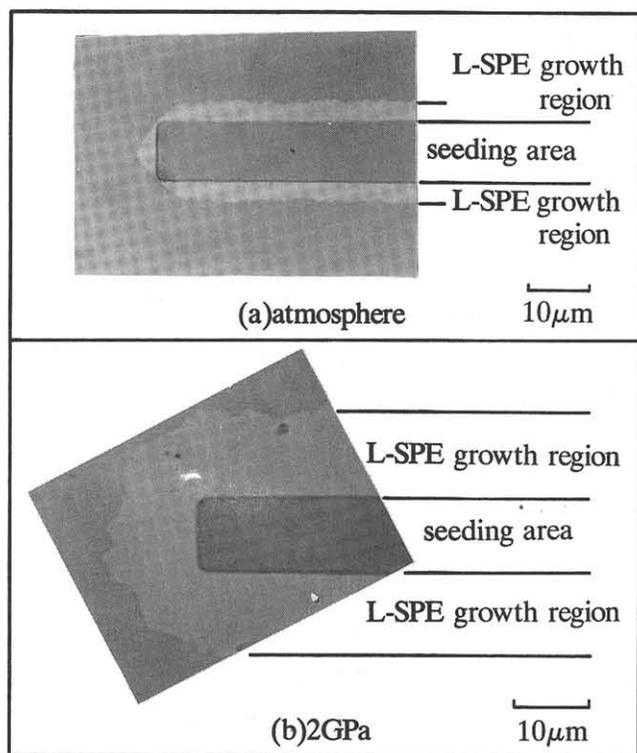


Fig.2 Nomarski optical micrographs for the L-SPE growth regions of the P-doped samples annealed at (a)AP and (b)2GPa.

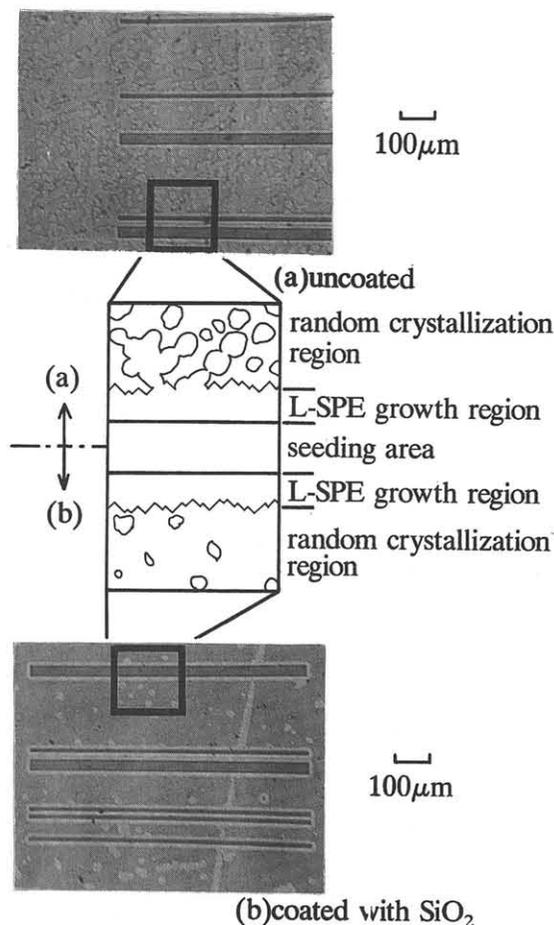


Fig.3 Nomarski optical micrographs for the random crystallization regions of the P-doped samples. (a)an uncoated sample and (b)a sample covered with a spin-coated SiO₂.

In Fig.4, the L-SPE growth lengths in the samples annealed at AP, 1GPa and 2GPa are plotted against the annealing time with open circles, triangles and squares or closed circles, respectively. In these samples, L-SPE growth proceeds along a <001> direction of a (100) substrate. We can see that the growth rate is increased with increase of pressure. We can also see from this figure that the enhancement of the rate is particularly pronounced in the first stage of the growth, where the L-SPE growth is considered to proceed on {110} facets at the growth front and the crystalline quality of the grown region is as good as that of bulk single crystal Si. The growth rates in the first and second stages are summarized in Fig.5, where in the second stage the growth on {111} facet is dominant.

Finally, we can derive the activation volume V_a using Eq.(1)⁴⁾.

$$v = v_0 \exp\{-(E_a + pV_a)/kT\} \quad (1)$$

where, v is the growth rate, v_0 is the pre-exponential factor, E_a is the activation energy, and p is pressure. The V_a value calculated from the first stage in Fig.5 is $-9.0\text{cm}^3/\text{mol}$ (-0.75Ω , where Ω is the atomic volume of Si), while the V_a of the second stage is $-3.8\text{cm}^3/\text{mol}$ (-0.32Ω). The latter value agrees well with the reported value ($-3.3\text{cm}^3/\text{mol}$ or -0.28Ω) for the vertical SPE⁴⁾.

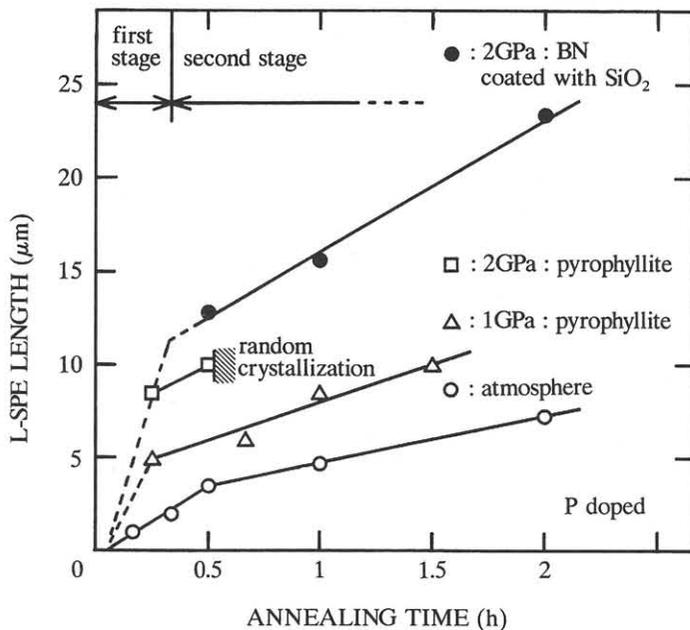


Fig.4 Annealing time dependence of L-SPE length for the P-doped SOI samples. At the time shown by crosshatched marks, the films changed to polycrystals.

§ 4. Conclusion

We investigated lateral solid phase epitaxy (L-SPE) of amorphous Si films under ultrahigh pressure. The main results are summarized as follows.

(1) L-SPE growth rate was enhanced by applying UHP. The pressure effect was more effective to expand the first stage of the growth, whose crystalline quality is as good as that of bulk crystal, rather than the second stage.

(2) Unexpected oxide layers were formed on the samples annealed at 600°C for 1 hour at 2GPa, when oxide ceramics were used and the residual air in the cylinder was not decreased carefully.

(3) The nucleation probability for polycrystallization was decreased by spin-coating a-Si films with SiO₂ films. The L-SPE length of 24.3 μm was obtained in the P-doped sample.

References

- 1) H. Ishiwara, H. Yamamoto, S. Furukawa, M. Tamura and T. Tokuyama; Appl. Phys. Lett., **43** (1983) 1028
- 2) M. Moniwa, K. Kusukawa, E. Murakami, T. Warabisako and M. Miyao; Appl. Phys. Lett., **52** (1988) 1788
- 3) E. Nygren, M. J. Aziz, D. Turnbull, J. M. Poate, D. C. Jacobson and R. Hull; Appl. Phys. Lett., **47** (1985) 232
- 4) G. Q. Lu, E. Nygen, M. J. Aziz and D. Turnbull; Appl. Phys. Lett., **54** (1989) 2583
- 5) G. Q. Lu, E. Nygen and M. J. Aziz; J. Appl. Phys., **70** (1991) 5323
- 6) H. Yamamoto, H. Ishiwara and S. Furukawa; Appl. Phys. Lett., **46** (1985) 268

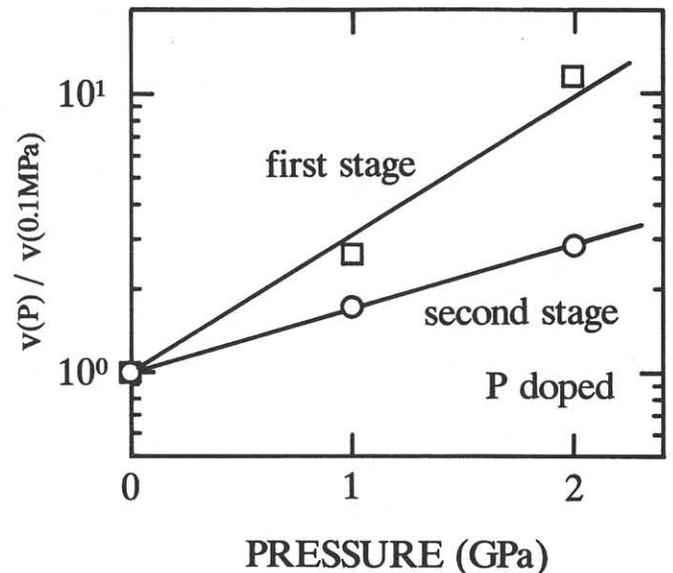


Fig.5 Pressure dependence of the growth rates for the P-doped SOI samples.