

Growth Conditions of Evaporated Amorphous Si Films onto SiO₂ Patterns by Lateral Solid Phase Epitaxy

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Lateral solid phase epitaxy of amorphous Si films vacuum-evaporated on Si substrates with SiO₂ patterns has been investigated, in which the films first grow vertically in the regions directly contacted to the Si substrates and then grow laterally onto SiO₂ patterns. It was found from transmission electron microscopy and Nomarski optical microscopy that the lateral growth occurred in dense amorphous Si films formed by evaporation on heated substrates and subsequent amorphization by Si⁺ ion implantation, but it hardly occurred in porous films deposited at room temperature. The maximum length of the epitaxial film on SiO₂ was 5-6μm after 10hour-annealing at 600°C.

1. Introduction

Single or large-grained recrystallization of silicon films on insulating substrates (SOI) has successfully been realized by liquid phase techniques such as laser¹⁾, electron-beam²⁾ or carbon-heater annealing³⁾. These methods, however, may not be applied to fabrication of 3-dimensional LSI's, since the surface of the recrystallized layer is usually not smooth and since the impurity profile in the underlying Si layer is probably deformed by thermal diffusion during the heating process to melt the top Si film. An alternative approach to realize the SOI structure at low temperature is lateral solid phase epitaxy (L-SPE) of a deposited amorphous Si (a-Si) film, in which the film first grows vertically in the regions directly contacted to the Si substrate and then grows laterally onto SiO₂ patterns, until the growth is stopped by random nucleation as schematically shown in Fig.1.

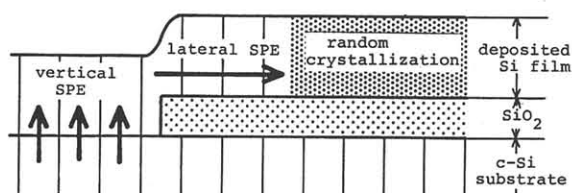


Fig.1. Schematic diagram showing formation of an SOI structure by lateral solid phase epitaxy.

So far, two experimental results on L-SPE of vacuum-evaporated⁴⁾ and chemical-vapor-deposited a-Si films⁵⁾ onto SiO₂ patterns have been reported. However, no detailed conditions necessary for the L-SPE were reported. In this paper, the growth conditions and the growth rate in L-SPE of vacuum-evaporated a-Si films onto SiO₂ patterns are investigated.

2. Experiment(1); L-SPE of a-Si Films Evaporated at Room Temperature

Si(100) wafers were thermally oxidized and etched in such patterns as stripes, square-islands, square-windows and so on. Thicknesses of the SiO₂ films were first 100-300nm, but later they were reduced to less than 100nm. The pattern sizes ranged from 2μm to 20μm and their edges were directed parallel to the <001> or <011> axes of the Si substrates. The wafers were chemically cleaned by HNO₃ acid and RCA solutions and etched slightly by diluted HF (HF:H₂O=1:19) acid. Reduction of the thickness of the SiO₂ patterns is estimated to be less than 20nm after the chemical cleaning process. They were then loaded in a vacuum chamber equipped with ion pumps and heated at 800°C for 30min to flash-clean the bare Si regions. In the early stage of the experiment, a-Si films of 300-500nm thick were deposited onto the patterned wafers at room temperature by

evaporation of polycrystalline Si source with 0.1ppm purity. The vacuum pressure during evaporation was less than 5×10^{-6} Pa. The deposited samples were then heated in the same vacuum at about 400°C for 60min to decrease the void densities in the films. Without this heat-treatment, a-Si films are known not to grow vertically after being exposed to air⁶⁾. The samples were finally annealed using an electric furnace in N_2 atmosphere at temperatures ranging from 550 to 650°C for 0.5 to 20hours to induce vertical (V-) and L-SPE.

The grown samples were investigated by transmission electron microscopy (TEM), scanning electron microscopy (SEM), and Nomarski optical microscopy. It was found from TEM that the a-Si films grew almost perfectly by V-SPE on the bare Si regions but the growth was completely stopped at the edge of the underlying SiO_2 patterns. That is, no lateral growth was observed in these samples, although the V-SPE was almost perfect. After several trials, we found that the transition time from the amorphous state to the polycrystalline one is about 5 times faster in an Si film on the patterned SiO_2 (100nm)/Si structure than that in the film on a flat SiO_2 /Si structure,

which was specially fabricated for measuring the transition time. We also found from cross-section SEM observation of the annealed sample that the Si film was anomalously etched at the pattern edge regions by Wright etchant as shown in Fig.2, which was probably due to the internal stress produced by non-uniform volume shrinkage of the porous evaporated film during the annealing processes in the vacuum chamber ($\sim 400^{\circ}\text{C}$) and/or in the electric furnace ($\sim 600^{\circ}\text{C}$). From these results we presumed that the internal stress which was produced by non-uniform volume shrinkage of porous films on patterned substrates enhanced the random nucleation rate and that the stress near the pattern edge was as large as to stop the L-SPE of the films.

3. Experiment(2); L-SPE of Dense a-Si Films

In order to minimize the internal stress, we improved the sample structure and the fabrication process, that is, the SiO_2 thickness was reduced to 50nm and dense a-Si films 200-300nm thick were prepared in the following process. At first, polycrystalline Si films with nearly the same density as single crystal Si were deposited on the patterned substrates which were kept at about 500°C . Then, the films were amorphized by Si^+ ion implantation. The ion energies were varied with the thicknesses of the deposited films, i.e. they were 70 and 180keV for the 250-300nm thick films and 60 and 160keV for the 200-250nm thick films. The dose at each energy was $2 \times 10^{15} \text{ cm}^{-2}$. Under these conditions, the Si films on SiO_2 are thought to be completely amorphized. These samples are classified as samples A. We also prepared the samples B for comparison, in which a-Si films were deposited on the 50nm thick SiO_2 patterns at room temperature by conventional e-gun evaporation and heated in the same vacuum at about 400°C . Other structures and processes were almost the same between the samples A and B.

A TEM image for a sample A annealed at 600°C for 7hours is shown in Fig.3. In this sample, the pattern edges were parallel to the $\langle 01\bar{1} \rangle$ direction of the Si substrate. We can see from this figure that the Si film on SiO_2 grows laterally from the pattern edge and the orientation of the grown region is identical to that of the Si substrate.

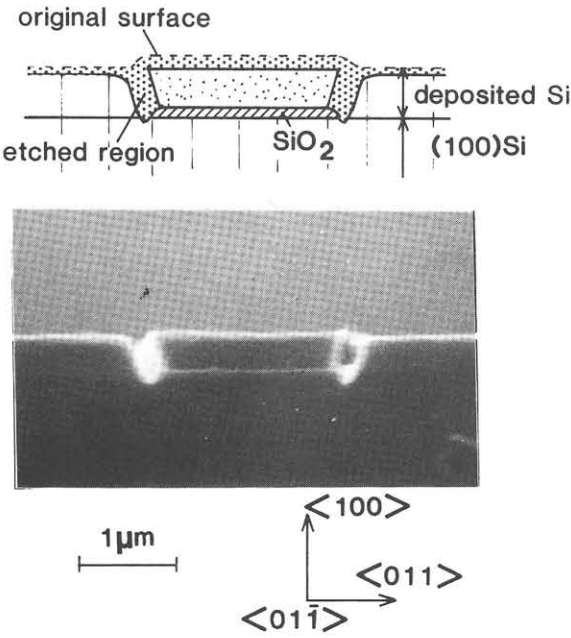


Fig.2. Cross-section SEM micrograph for a sample annealed at 600°C for 2hours, cleaved, and etched in Wright etchant. The thicknesses of SiO_2 and deposited Si films are 100nm and 500nm, respectively. The Si film was evaporated at room temperature.

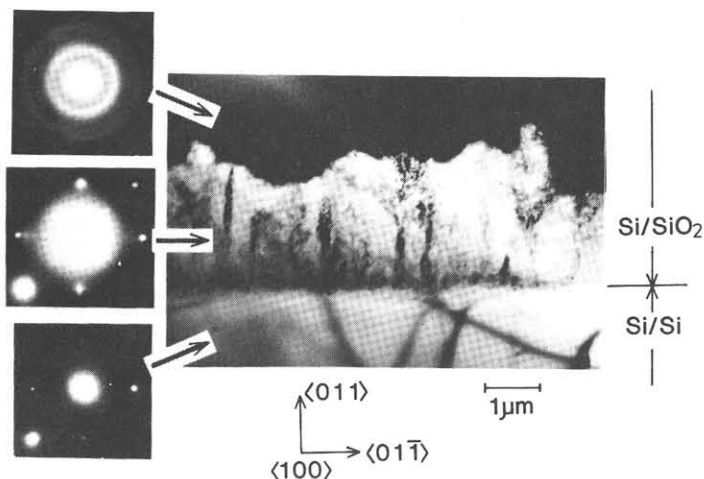


Fig.3. TEM image (top view) and TED patterns for the sample A annealed at 600°C for 7hours.

It was also found from Nomarski optical microscopy that, when the samples were etched in Wright etchant, the laterally grown regions were easily distinguished from the ungrown a-Si regions due to the difference of the etching rates. Figure 4 shows Nomarski optical micrographs of the samples A and B annealed at 600°C and etched in Wright etchant. In these samples, the patterns were formed in parallel to the $\langle 001 \rangle$ direction of the substrates. As can be seen in the figure, the growth fronts of L-SPE and defects in the grown layers are evident by the difference of the etching rates. In the samples A, the film grows laterally from the both sides of the bare Si regions onto the SiO_2 patterns. The grown layers near the SiO_2 edges are relatively defect-free but the farther regions contain many defects. After 8hour annealing, formation of polycrystalline islands was observed in the remaining a-Si film and the L-SPE was stopped by these polycrystalline grains. The maximum growth length in this sample was 5-6 μm . On the other hand, it can be seen from the roughly etched surface that the a-Si film in the sample B changed to polycrystals at least after 4hour-annealing. In this sample, however, some L-SPE was also observed at the left hand sides of the Si/Si structures. This fact suggests that the internal stress is somewhat reduced even in a room-temperature-deposited film by reducing the step height of the SiO_2 patterns. We conclude from these results that the use of dense a-Si films is essentially important for L-SPE, though partial L-SPE may occur even in porous a-Si films

when the thickness of the underlying SiO_2 film is thin enough.

Finally, the L-SPE growth rate along the $\langle 010 \rangle$ direction in the sample A was derived from the micrographs in Fig.4 and the related ones. The result shown in Fig.5 has revealed that the L-SPE at 600°C is composed of two stages; the first one with a higher growth rate ($\sim 2.4 \times 10^{-8} \text{ cm/s}$) and the second one with a lower growth rate ($\sim 1.2 \times 10^{-8} \text{ cm/s}$). As can be seen from this figure, the growth rate of L-SPE is $1/2$ - $1/4$ of that of vertical SPE on the (100) plane⁷⁾. In such samples, the (110) facet should be formed during the vertical growth stage⁸⁾ and the L-SPE growth rate for the first stage can be understood by the consideration of this facet formation and the rate of the vertical SPE on the (110) plane⁹⁾. While, we presume that the lower growth rate for the second stage should be related to the (111) facet formation. The total SPE length through the both stages was 5-6 μm after 10hour-annealing.

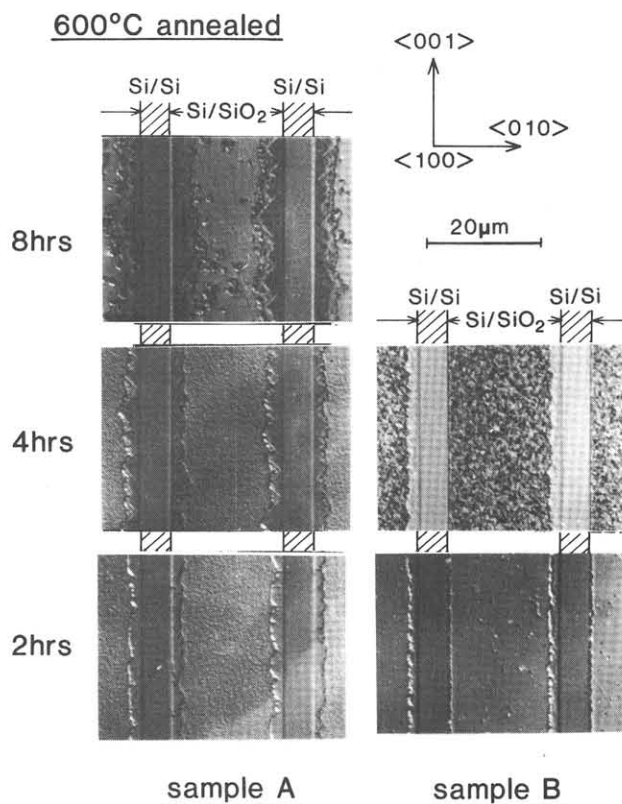


Fig.4. Nomarski optical micrographs for the samples A and B annealed at 600°C for various periods and etched in Wright etchant.

3. Summary

We showed that dense a-Si films formed by evaporation on heated substrates and subsequent amorphization by Si^+ ion implantation grew laterally onto SiO_2 patterns by SPE. The lateral SPE along the $\langle 010 \rangle$ direction was composed of two stages with different growth rates and the rate in the faster stage was 1/2-1/4 of that of vertical SPE. The maximum SPE length along this direction was 5-6 μm after 10-hour-annealing at 600°C.

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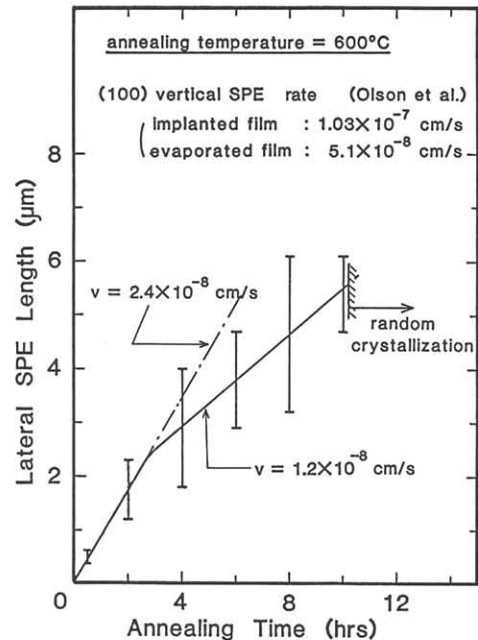


Fig.5. Plot of L-SPE length along the $\langle 010 \rangle$ direction versus annealing time for the sample A annealed at 600°C. The L-SPE lengths were determined from optical micrographs for the Wright-etched samples.

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