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SOI Structures Prepared by Lateral Annealing of a-Si Films in Steep Temperature Gradient

Yasuhiro KIZU, Keiichi KONDA, Masaki TAKEUCHI, Akio KITAGAWA and Masakuni SUZUKI

Dept. of Electrical & Computer Engineering
Faculty of Technology, Kanazawa University
2-40-20, Kodatsuno, Kanazawa 920, Japan

The a-Si films on quartz substrares were crystallized by lateral annealing in steep temperature gradient. The steep temperature gradient was found to be effective for the suppression of random nucleation in amorphous region, so that lateral solid phase epitaxial growth more than 100 μm was attained. Although crystallographic orientation of L-SPE films varied from sample to sample to sample, (100) plane appears to spread over broader area.

1. Introduction

Lateral solid phase epitaxy (L-SPE) of amorphous Si (a-Si) films on amorphous substrates such as SiO_2 is one of preferable techniques for silicon-on-insulator (SOI) structures. The L-SPE growth by thermal annealing, however, is limited to several 10 μm in length so far,[1] since random nucleation in amorphous region prevents large area L-SPE growth.

When a-Si films are heated at a certain temperature, nucleation does not start at once even at high temperature. There exists an induction time for nucleation, which decreases with increasing heating temperature.[2] Induction time for nucleation in amorphous films is, thus, a key factor and it should be taken into account in L-SPE growth experiments.

In order to attain large area L-SPE growth, higher temperature annealing is desirable, since L-SPE growth rate increases with increasing temperature.[3] On the other hand, the a-Si films should be maintained at low temperature to suppress random nucleation. In this situation, the conflict between L-SPE growth and random nucleation would be minimized.

We developed a new annealing method reducing the contrary factors in L-SPE growth. The sample films are annealed passing through a steep temperature gradient at a constant speed. In our experiments random nucleation was effectively suppressed by lateral annealing of the sample films in steep temperature gradient, so that large area L-SPE growth was attained.

2. Experimental and its background

When the sample films pass through an ascending temperature gradient from To to Tep (To<Tep) at a constant speed V, as shown in Fig.1, continuous L-SPE growth is expected to be possible if two conditions are satisfied. That is, random nucleation does not occur before the arrival at the position at Tep and the growth front of L-SPE at Tep goes ahead into amorphous region at a speed V. The latter condition is, thus, given by

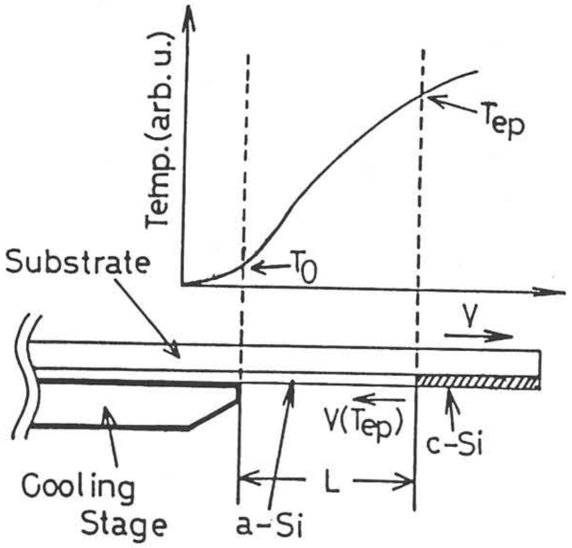


Fig.1. Lateral annealing of a-Si in the steep temperature Gradient.

$$Vep]_{Tep} > V \qquad (1)$$

where the left hand side of eq.(1) is L-SPE growth rate at Tep.

The induction time for nucleation in amorphous solids decrease with temperature as

$$t_{ind} = \tau_0 \exp[Ea/kT] \qquad (2)$$

where τ_0 pre-exponential factor, Ea the activation energy for nucleation, k Boltzmann factor and T temperature in degree Kelvin.

The effective induction time during passing through temperature gradient from To to Tep can be calculated using eq.(2), and it should not be negative. This condition is given by[4)]

$$\int_0^L \exp[-Ea/kT]dx \leq \tau_0 V \qquad (3)$$

where L is the distance between the positions To and Tep. Equation (3) can be calculated assuming linear temperature gradient.

Applying experimental data to these equations, the conditions of continuous L-SPE growth can be estimated as follows: Once Tep is determined, the pushing speed of sample films is automatically determined from eq.(2), and the temperature gradient is calculated from eq.(3). An example of continuous L-SPE growth is given as Tep = 800°C, V = 1 mm/h and temperature gradient = ~10°C/um respectively. Thus, very steep temperature gradient is found to be necessary.

The lateral annealing system for L-SPE consists of heating and cooling system providing steep temperature gradient and a fine-feeding system for forward motion of the sample film. Local heating for the steep temperature gradient in the sample film was produced by the reverberator furnace or line or ribbon heater. The sample films placed on the cooling stage were pushed out at a constant speed into steep ascending temperature gradient.

The a-Si films (0.3 ~ 0.4 μm thick) were deposited on quartz substrates (0.1 ~ 0.2 mm thick) by electron beam at 150°C in a vacuum (< 5×10^{-8} torr). After deposition, sample films were annealed at 400°C for 60 min in a vacuum (< 5×10^{-8} torr) to densify amorphous structures. Sample films were then processed in the lateral annealing system with steep temperature gradient under various conditions.

3. Results and Discussion

The sample films turned transparent after annealing in steep temperature gradient, as seen in Fig.2. Transmission electron diffraction patterns of those films are shown in Fig.3. L-SPE grown films showed mesh pattern. Although an identical mesh pattern was observed in broader area, the diffraction pattern varied from area to area and of course from sample to sample, for example, (100), (110) or (123).

An etch pit technique was applied to estimate L-SPE growth area. Figure 4 shows optical micrograph of a grid array of etch

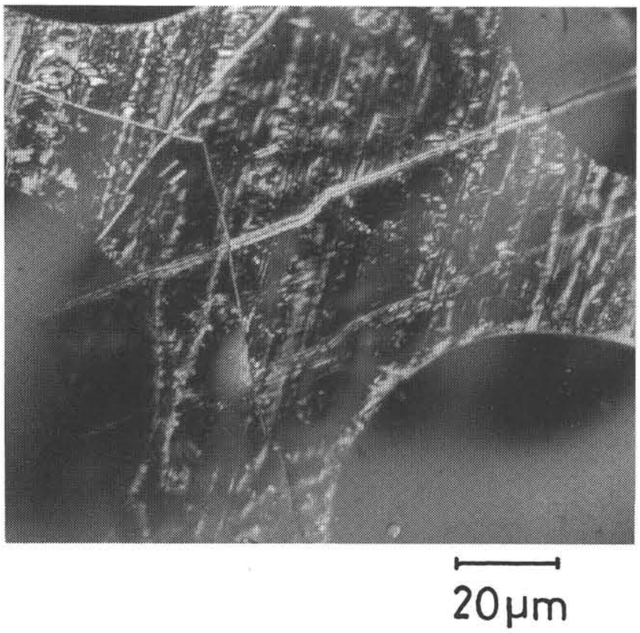
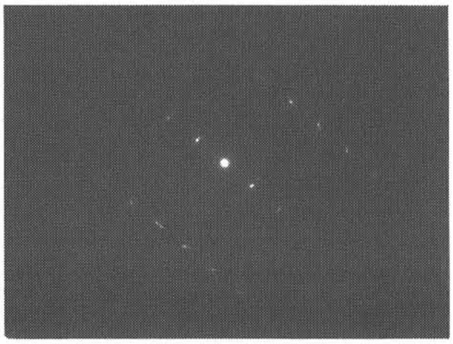


Fig.2. Optical micrograph of the Si film crystllized by lateral annealing in the steep temperature gradient.

(a)



(b)

Fig.3. TED pattern of the Si film crystallized by lateral annealing in the steep temperature gradient.
(a): (100)plane, (b): (123)plane.

pit of annealed sample films. The distance between grids is 50 µm. The L-SPE growth area estimated from optical micrograph is more than 100 µm.

In many cases, broader L-SPE area showed square etch pit, and the diagonal of squares coincides well with the direction of lateral annealing. Crystallographic orientation of L-SPE growth was not controlled at the present stage, that is, the seeds for L-SPE growth are crystallites with random orientation, which are generated at the beginning of the annealing. The fact that the Si films crystallized by L-SPE exhibited mainly the etch pit of (100) plane and the diagonal of etch pit coincided with the direction of the lateral annealing suggests that (110) facet growth are dominant.

Broader L-SPE growth is still prevented even in the lateral annealing with steep

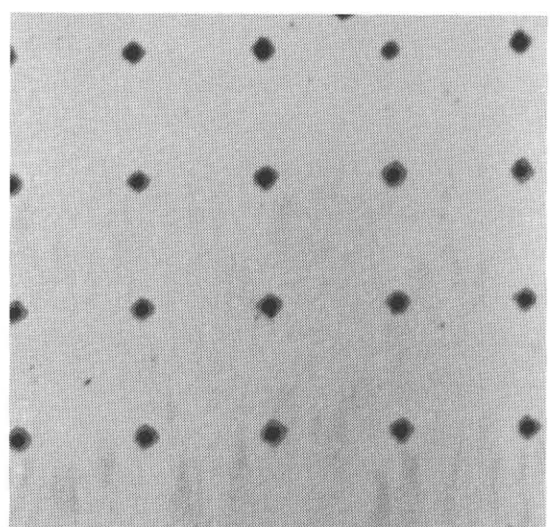


Fig.4. Optical micrograph of a grid-array of etch pits. The spacing between pits is 50 µm.

temperature gradient, because of insufficient and fluctuated temperature gradient, fluctuated feeding speed, surface roughness of quartz substrates etc. Especially scars on quartz substrates would provide nucleation sites. Defect-free substrates and careful processing would make large area L-SPE growth possible.

4. Summary

Taking into account the temperature dependence of the induction time for nucleation and SPE growth rate in amorphous films, lateral annealing of a Si films in a steep temperature gradient was tried for growing single crystal Si films on quartz substrates. L-SPE growth more than 100 µm was attained. More precise control of lateral annealing processes is expected to make large area L-SPE growth possible.

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