Extended Abstracts of the 18th (1986 International) Conference on Solid State Devices and Materials, Tokyo, 1986, pp. 569-572

Multi-Level SOI Recrystallization Using a Novel Seed Structure

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A new seed structure, Partially Thickened SOI (PTS), has been proposed for multi-level seeded-laterally-epitaxial SOIs. Through computer simulation of the recrystallization process, lateral heat conduction within the SOI proved to be important in smoothly melting the seed and field SOI regions. Two-level seeded-laterally-epitaxial silicon films on thick SiO_2 (2.5 μm) were successfully fabricated using the PTS structure.

1. Introduction

Two- or three-level stacked integrated circuits, such as a ring oscillator, image processor and static random access memory, have been fabricated by using laser or electron beam recrystallization of thin poly- or amorphous silicon film on insulating materials (SOI).[1,2] To control the crystallographic orientation of SOI, various sample structures have been proposed. Among them, seeded lateral epitaxy,[3] where crystallographic orientation of the silicon film layer is controlled by the single crystalline silicon substrate through the seed opening of the insulating layer, has been studied as a prospective technique.

To smoothly melt the seed region, an improved seed structure was proposed, in which the seed opening was narrowed and the insulator edge in the seed region was tapered.[2] From the view-point of 3-dimensional device application, a thick insulating layer (> 2.0 μm) is required to protect underlying devices during beam irradiation. It becomes more difficult to smoothly melt both the seed and SOI field regions, as insulating layer thickness increases, owing to the difference in heat dissipation towards the substrate between the two regions. So, the insulating layer thickness was limited up to about 1.5 μm in this seed structure. To overcome these problems, a new seed structure has been required.

This paper reports results of analysis on the limitation factor in seed melting, using dynamic computer simulation of an electron-beam-irradiated SOI structure, where the role of lateral heat conduction within the thin silicon film towards the seed opening is proved to be essential. The authors demonstrate the first multi-level seeded-laterally-epitaxial silicon films on thick insulators(>2.0 μm), using a newly developed seed structure, Partially Thickened SOI (PTS), in conjunction with Amplitude Modulated Pseudo-Line Electron Beam technique(AMPL-EB).[4]

2. Dynamic Simulation of Recrystallization Process

2.1 Simulation Procedure

The two-dimensional finite element method was used to accurately simulate the time-dependent seeded-lateral-epitaxy process. The simulated system is shown in Fig.1. The top figure shows the detailed structure near the seed region, where divided elements have smallest size of 0.2 μm x 1.0 μm. Thicknesses of the insulating SiO_2 layer, poly-silicon layer, and capping SiO_2 layer are 1.7 μm, 0.6 μm, and 0.5 μm, respectively. The seed position (700 μm from

the beam starting position) was decided from several trial simulations. Namely, the system size and the seed position were designed so as to arrive at a steady state, when the beam center approached the seed. This condition was proved to agree with the experimental results.

Unlike a spot beam laser, AMPL-EB provides a nearly-ideal two dimensional system for simulation. The beam intensity profile in a direction parallel to beam scanning (from left to right) is Gaussian with a 200 μm beam width, which is defined as full width at half maximum.

The heat equation to be solved is written as

$$\kappa \Delta T + Q = \rho c \frac{\partial T}{\partial t} \qquad (1)$$

All the energy for an electron beam, Q, were assumed to be supplied to the top capping SiO_2 surface. Temperature-dependent thermal conductivity for Si, κ, is shown in Fig.2(a). The change in specific heat, ρc, due to latent heat absorption and release at melting temperature, was approximated by four value steps, as shown in Fig.2(b).[5] Initial system temperature was set at 600°C and the bottom surface temperture was kept constant at 600°C throughout the calculation.

2.2 SOI Recrystallization Process

Figure 3 shows the SOI recrystallization process as a function of time. As the electron beam, whose scanning velocity is 100 mm/s, approaches and passes by the seed region, the silicon film, 10 μm from the seed opening, begins to melt faster than the film on the seed opening, because of its lower heat conduction. Then, the molten region extends widely over the seed region and recrystallization starts from the seed opening, when the seed opening melts (see Fig.3(b)). From this simulation, more improvement is required to melt the seed region smoothly, such that the lateral heat conduction within the SOI towards the seed opening would be increased. On the contrary, vertical heat dissipation through the seed opening should be decreased.

Figure 4 shows the SOI recrystallization process for a newly developed seed structure, PTS, where SOI layers around the seed region are thickened to 1.2 μm. This figure resembles Fig.3, except that the seed opening (position A) temperature and slope edge (position B) temperature slightly increase and decrease, respectively, as shown in Fig.5. From this, it is confirmed that not only direct beam irradiation but lateral heat conduction within SOI plays an important role in seed melting.

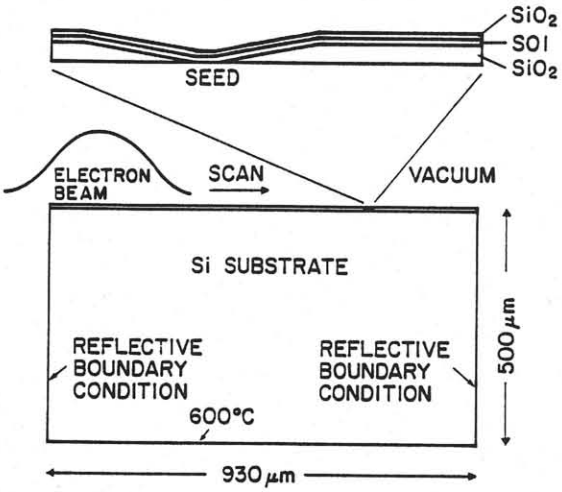

Fig.1 Simulated region illustration. Electron beam scan, which has a Gaussian intensity profile, starts at a point 100 μm to the left from the sample edge.

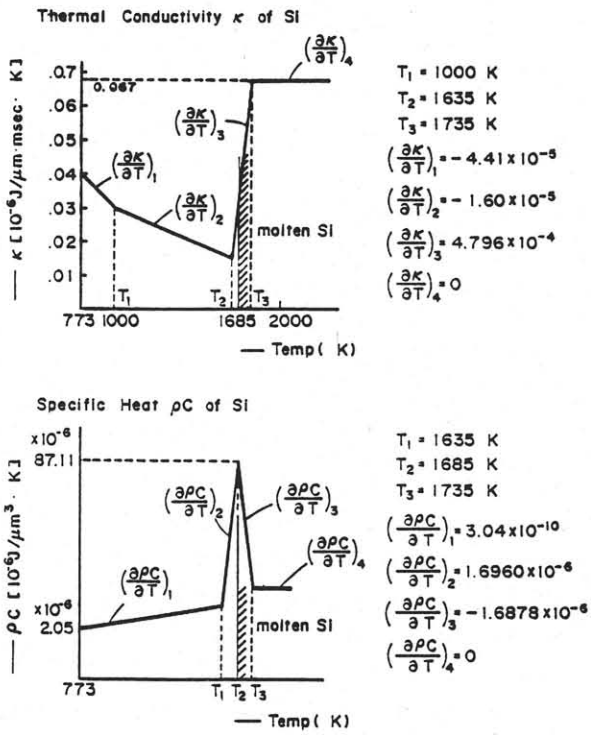

Fig.2 (a)Thermal conductivity, (b)approximated specific heat for Si used in the calculations.

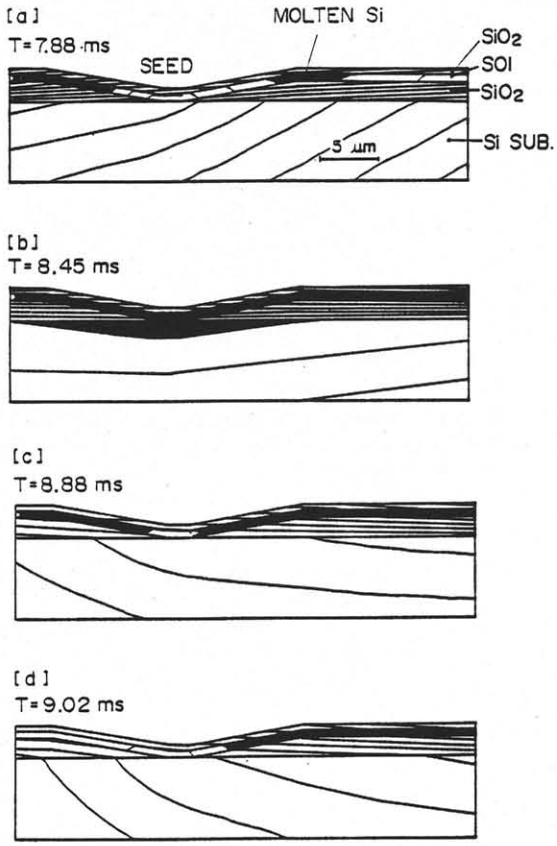

Fig.3 Time dependence of temperature profile near the seed region for conventional structure. Shaded area corresponds to molten silicon. Equi-temperature line increment is 25 degrees centigrade. Beam center positions for (a),(b),(c),and (d) are -17 μm, +40 μm, +83 μm, and +97 μm, respectively, along the scan direction from the seed.

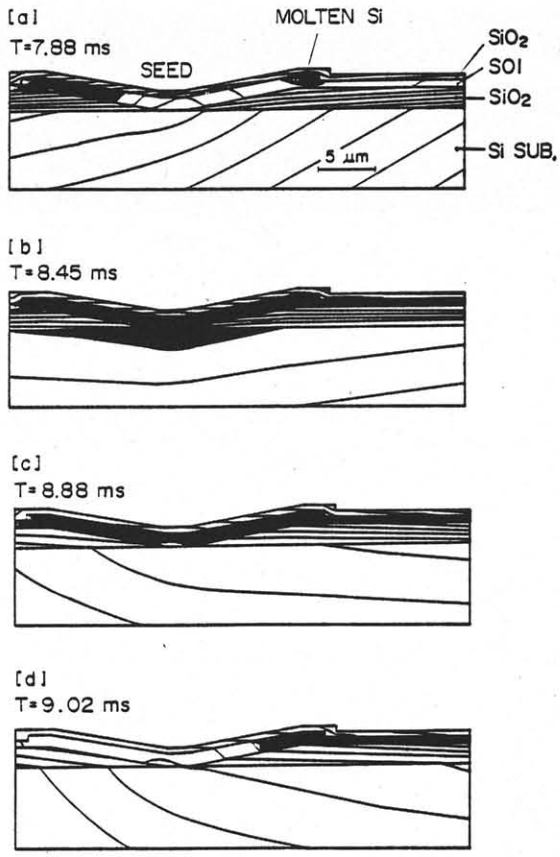

Fig.4 Time dependence of temperature profile near the seed region for PTS structure. Beam center positions are the same as in Fig.3.

3. Multi-Level SOI Recrystallization

Figure 6 shows an SEM photograph of a cross-sectional view of a 2-level SOI structure. The thickness and deposition method for each layer used in this study are summarized in Table I. Taking into account application for a 3-dimensional device, the 2nd insulating layer thickness is 1.25 times the 1st insulating layer thickness. A PTS structure was used in both the 1st and 2nd SOI layers to increase the lateral heat conductance. A shift in the seed opening position for the 2nd SOI layer, along the scan direction by about 5 μm from that for the 1st SOI layer, reduces the heat dissipation towards the substrate through the 2nd and 1st seeds. Seeded-laterally-epitaxial growth for the 1st SOI layer was performed before the 2nd level SOI process. So, the 1st SOI region on the

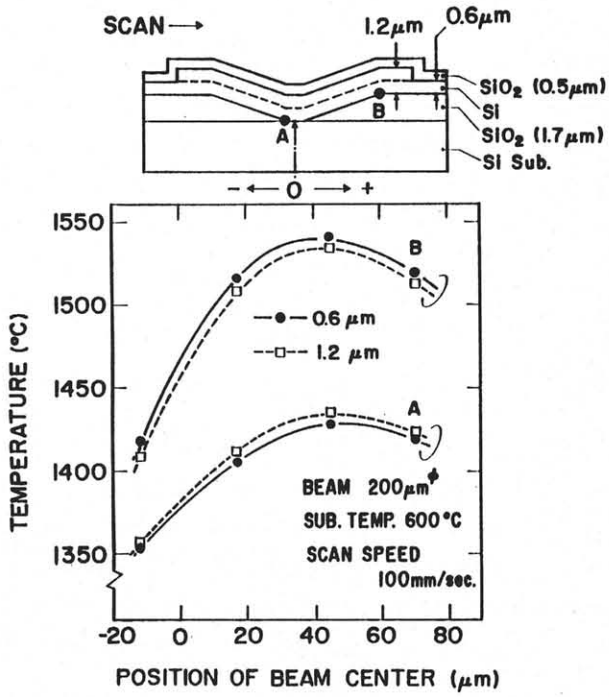

Fig.5 Difference in temperature change between conventional seed and PTS structures. Points A and B are indicated in the top figure.

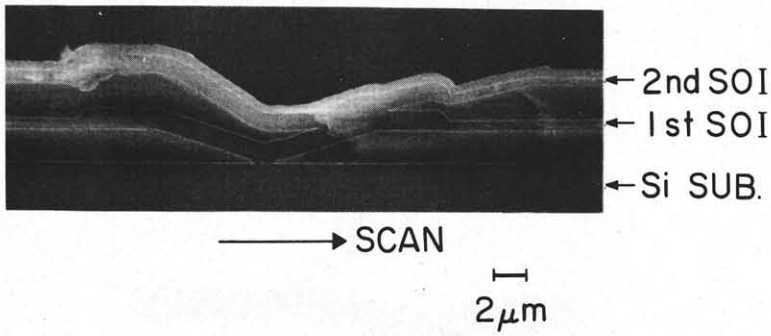

Fig.6 SEM photograph showing cross-sectional view of 2-level SOI. PTS structure is employed for both 1st and 2nd SOI.

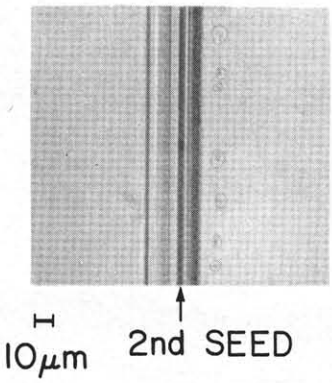

Fig.7 Typical optical microscopic observation of seeded-laterally-epitaxial 2nd SOI layer, after preferential etching.

Table I 2-level SOI structure composition.

Layer	Deposition Method	Thickness(μm)
Cap	APCVD SiO_2	0.5
2nd SOI	LPCVD poly-Si	0.6
2nd Insulator	Bias sputtered SiO_2	2.5
1st SOI	LPCVD poly-Si	0.6
1st Insulator	LPCVD SiO_2	2.0

right-hand seed edge can act as a seed for the 2nd SOI layer.

AMPL-EB annealing was employed, where the acceleration voltage, beam width, beam scan velocity and substrate temperature were, 12kV, 1 mm, 100 mm/s and 600 °C, respectively. Figure 7 shows a Nomarski optical microscopic photograph of a recrystallized 2nd SOI layer after the SiO_2 capping layer removal and preferential etching, which shows that crystallographic orientation of the SOI film is well controlled by the (100) seed. This indicates that the new PTS technique has superiority in realizing 3-dimensional integrated circuits.

4. Summary

The recrystallization process for laterally-seeded-epitaxy was analyzed using dynamic computer simulation. A partially thickened SOI structure was proposed and verified to be useful for laterally-seeded-epitaxy of SOIs. Main results are as follows:

(1) Computer simulation clarified that the lateral heat conduction within the SOI is important to smoothly melt the seed.

(2) The PTS structure was very effective to increase the lateral heat conduction towards the seed.

(3) Two-level seeded-laterally-epitaxial silicon on thick SiO_2 (2.5 μm) was successfully fabricated.

Acknowledgment

This work was performed under the management of the Research and Development Association for Future Electron Devices, as a part of the Research and Development Project of Basic Technology for Future Industries sponsored by Agency of Industrial Science and Technology, MITI.

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