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Three Dimensional Thermal Analysis for Laser Annealing and Its Applicaiton to the Design of the SOI Structures

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Laser annealing(LA) has recently been used to obtain recrystallized silicon films, where 3D devices could be realized. The precise process control required in their applications encourages the construction of a computer model for the temperature rise caused by LA. We simulated the stationary temperature profiles induced by a moving cw laser beam in multi-layered SOI structures. In order to improve the crystal quality, we proposed the SOI structures capped with polysilicon and applied this simulation to the design of these structures. They forced single nucleation and the grain boundaries would be located beneath the outside of the polysilicon encapsulation.

§1.Introduction

Many thermal models of cw laser annealing have been already given[1)-3)]. But these models have not dealt with the structures patterned into stripes. In this paper, we outlined a three dimensional model taking scan speed into account.

The laser beam scanning and the patterned structure can affect the laser melting process, so we simulated the stationary temperature profiles induced in multi-layered SOI structures by a moving cw laser with several different intensity distributions. Then, the temperature profiles inside the sample are governed by the following nonlinear thermal conduction equation,

$$\nabla\cdot(K\nabla T) + Q - Cv\frac{\partial T}{\partial x} = 0 \qquad (1)$$

where v is the velocity of the beam scanned along the x axis, T is temperature, C is heat capacity, K is thermal conductivity, Q is the rate of the internal heat generation due to absorption of the laser power and ∇ is $(\partial/\partial x, \partial/\partial y, \partial/\partial z)$.

The finite element method and Newton's method were applied to solve this equation.

The normal boundary conditions for T are

$$dT/dz = 0 \quad \text{at } z = 0 \qquad (2)$$

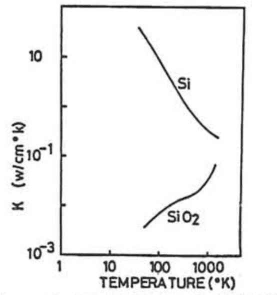
$$T(z=L) = T_S \ \text{(constant)} \qquad (3)$$

where z is the depth coordinate and L is the sample thickness. Condition (2) means that heat does not escape from the front surface of a sample by radiation or convection. Condition (3) means that the back surface of a sample is assumed to be in perfect thermal contact with a heat sink at temperature T_S.

Table 1 Physical constants.

	crystal Si	poly Si	SiO_2	Si N	liquid Si
C ($J/cm^3\cdot k$)	2.21	2.21	1.65	2.25	2.21
K ($w/cm\cdot k$)	see fig.	see fig.	see fig.	0.12	0.64
Tm (°C)	1410	1410	—	—	—
LH (J)	1809	1809	—	—	—
N	4.4	4.4	1.5	2.0	2.27
α (cm^{-1})	7.8×10^3	2×10^4	0	0	1×10^6

Tm: melting point, LH: latent heat, N: refractive index



Thermophysical Properties of Matter, Volume 1, TPRC Data Series, IF, Plenum, New York (1970)

Fig.1 Temperature dependence of the thermal conductivities.

The physical constants as shown in Table 1 were used. The thermal conductivities of crystal silicon and silicon dioxide depend on the temperature as shown in Fig.1. But the temperature dependence of absorption coefficient was not considered in this paper.

§2.Results of this simulation

The temperature profiles are shown in Fig.2 for the three cases currently used to achieve single-crystallization (CASE1: the island structure[4)], CASE2: "selective annealing" technique$^{5)}$, CASE3: "dual beam" technique$^{6)}$). In CASE1, the trailing edge for two scan speeds, v=1,10 cm/sec formed a succession of concave interfaces. But for v=10 cm/sec, the peaks of the temperature lagged behind the laser beam.

The results for CASE1 and CASE2 resembled one another and the trailing edges were very steep. For CASE3, the trailing edge was concave over the large regions, but it was loose.

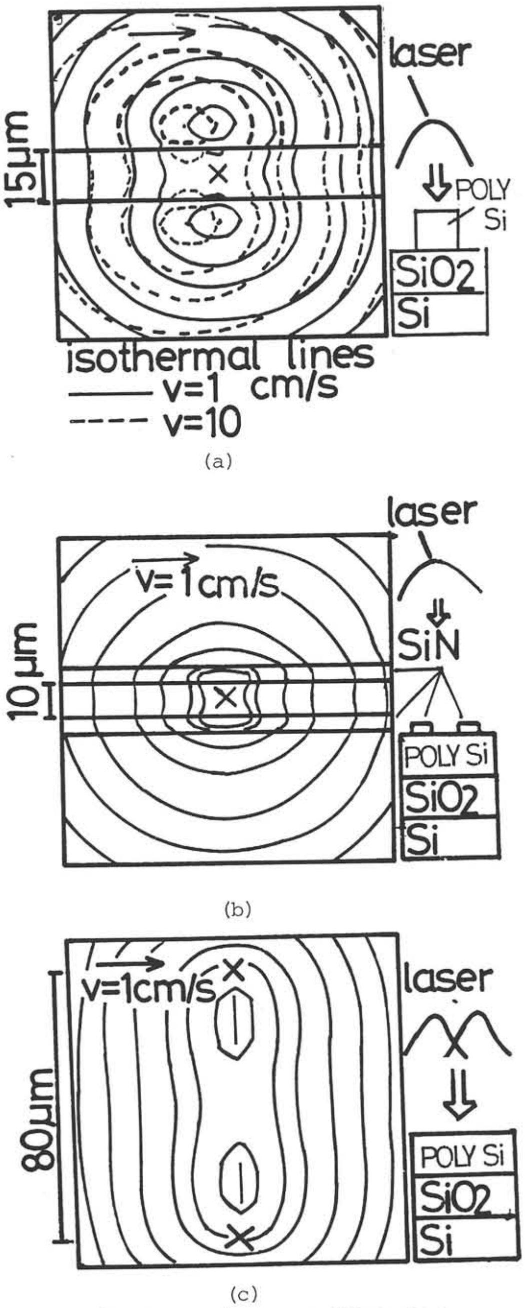


Fig.2 Temperature profiles for
(a) CASE1: the island structure,
(b) CASE2: "selective annealing" technique and
(c) CASE3: "dual beam"technique.
X represents the beam center.

§3.Measurement of temperature profiles

In order to confirm the validity of this simulation, we devised the method of measuring temperature profile in the simplified SOI structures. The structue shown in Fig.3 was formed. We measured the resistance change of the metal stripe under the surface polysilicon film induced by an argon ion laser beam with the gaussian intensity distribution and estimated the temperature.

We assumed that the temperature distribution was gaussian, then the temperature at beam center T_0 is proportional to the resistance change of the metal at beam center $\Delta R(d=0)$.

$$T_0 = \frac{t\ W}{\sqrt{\pi}\ \rho_T \sigma_T} \Delta R(d=0) \qquad (4)$$

where ρ_T is the unit specific resistance per unit temperature and σ_T is the radius of the temperature. d is the distance of the metal stripe from the beam center.

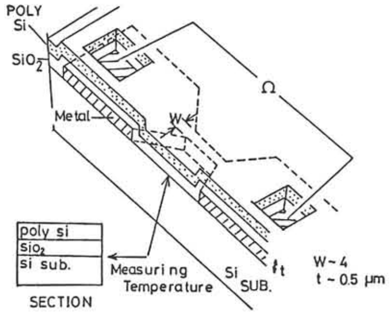


Fig.3 Simplified SOI structures used to measure the temperature profiles.

This assumption was confirmed by the experimental results that ln(ΔR) was proportional to d^2 as shown in Fig4. σ_T was calculated from the slopes of these lines.

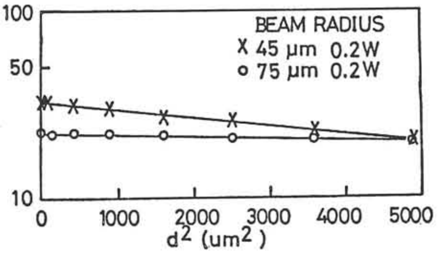


Fig.4 Logarithm ΔR vs. d^2.

We compared these experimental results with the simulation. They fitted well with each other, but the temperature distributions were about 30μm larger than the simulated temperature profiles. We thought it's reason was that the thermal conductivity of the insulator film was smaller than the that of the bulk insulator used in this simulation.

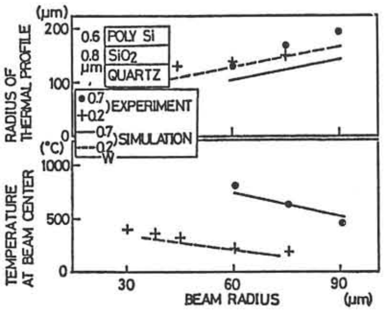


Fig.5 Comparison between experimental results and the simulation.

§4.Application to the design of the SOI structures

In order to improve the crystal quality, we proposed the SOI structures capped with polysilicon. Polysilicon encapsulation controlled both the optical absorption and the heat flow and caused single nucleation.

Laser beam was completely absorbed by the polysilicon encapsulation and heated up the underlain polysilicon layer through the SiO_2 layer. At the outside of the polysilicon encapsulation, laser beam directly heated up the underlain polysilicon. If we selected reflection coefficient Ri larger than Ro, the temperature profiles was controlled as shown in Fig 6.

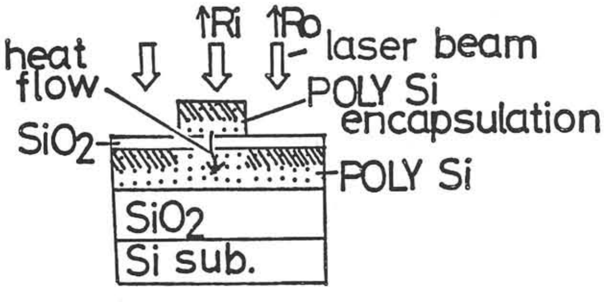
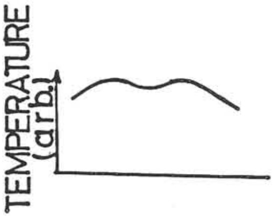


Fig 6 (a)



(b)

Fig.6 Schematic illustrations of the structure capped with polysilicon and the temperater at the underlain polysilicon. The hatched areas were irradiated by the laser beam.

The temperature profiles in these structure were calculated as shown in Fig.7. For the transparence coefficient ratio A=1.4 (A is defined as 1-Ro/1-Ri), the trailing edge became concave interfaces beneath the central two polysilicon encapsulation. Fig.8 shows the optical micrographs of the crystallization pattern resulting from a cw laser scan after delineating the grain boundaries by etching the sample with a Dash's etchant. The area under the polysilicon encapsulation was single-crystalline in the sense that there were no grain boundaries. Also, the grain boundaries were located exactly within the uncapped area between adjacent polysilicon encapsulations.

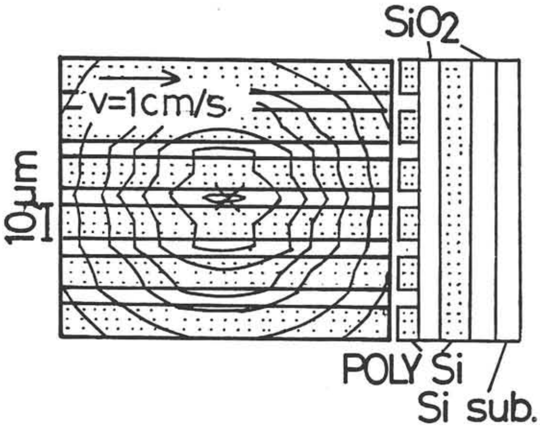


Fig.7 The temperature profiles in the structure capped with polysilicon.

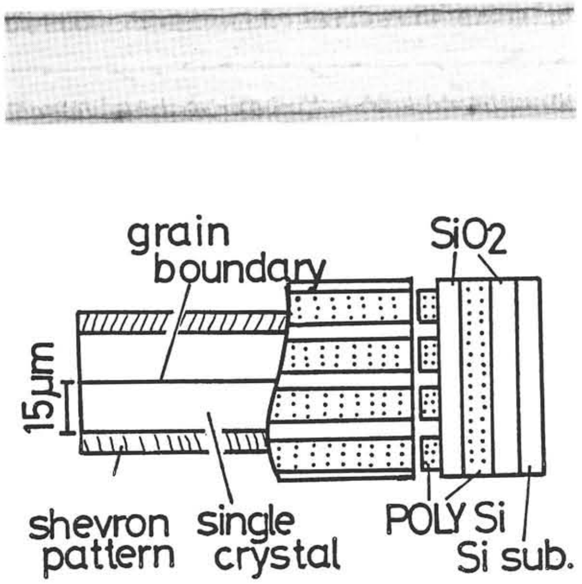


Fig.8 Optical micrographs of the crystallization pattern resulting from a cw laser scan and schematic illustration of the structure.

§5.Conclusions

We could simulate the stationary temperature profiles induced in multi-layered SOI structures by a moving cw laser beam.

It was confirmed that the temperature profiles simulated here neary coincided with the temperature profiles estimated by the experiment.

Finally, we proposed the SOI structures capped with polysilicon. This simulation was applied to the design of these SOI structrures. They controlled the temperature profile and caused single nucleation.

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