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E-Beam Recrystallized SOI

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Recrystallization of Si films on SiO_2/Si structures by an electron beam is reviewed. In order to produce the concave trailing edge of the molten zone, a spot beam is scanned faster than the thermal response time of the substrates either along a straight line sinusoidally or along a "V" shape. It was found from Nomarski optical microscopy that both scanning methods were effective to obtain large single-crystal grains. The maximum grain size with flat surface was about 20x450 μm^2.

1. Introduction

Growth of crystalline Si films on insulator substrates (SOI structures) has attracted attention for fabrication of 3-dimensional LSI's as well as 2-dimensional high-speed LSI's. One of most promising techniques to realize the SOI structures is liquid phase recrystallization of amorphous or fine-grained polycrystalline Si films deposited on amorphous insulator substrates. A considerable amount of works using laser[1)], electron beam[2-4)], carbon strip heater[5)], RF-heated carbon susceptor[6)], focused infrared light[7)] and so on have been devoted to increasing grain sizes in the Si films.

Among these methods, the electron beam annealing has the following merits and demerits.

1) Temperature profile in the substrate can be electrically controlled over large areas by use of line-shaped beams or fast-scanned spot beams.
2) The beam power introduced in the substrate is virtually independent of its crystalline quality, surface condition, electrical resistivity, optical reflectivity, and so on. This future also means that annealing of specific layers or areas in the substrate utilizing the selective absorption of light or RF power is impossible.
3) The throughput rate is expected to be higher than the laser annealing because of the higher output power of electron beams.
4) The annealing can not be performed in the atmospheric pressure.

The electron beam annealing techniques so far reported are classified in four groups; (1) spot heating by a spot beam[2)], (2) linear heating by a line-shaped beam[3)], (3) linear heating by a pseudo-line-shaped beam which is formed by fast scanning of a spot beam[4)], and (4) planar heating by a 2-dimensionally multi-scanned spot beam[8)]. Though, the first three methods are useful for formation of the SOI structure, we are particularly interested in the third method, since the pseudo-line-shaped beam method seems to be easiest to control the temperature profile in the substrate over a large area.

In this paper, we review two experimental approaches in the pseudo-line-shaped beam method, which are expected to produce the concave trailing edge of the molten zone and to form large grains in the film. In both experiments, a spot beam is scanned faster than the thermal response time of the substrate so that the substrate is steadily heated along the scan line. In the first experiment, the beam is sinusoidally scanned in one direction (X-direction) to increase the position probability density of the beam at both edges and it is also scanned slowly in the perpendicular Y-direction. In the second experiment, the beam is scanned in the shape of V and slowly moved downward in this letter to produce the concave trailing edge of the molten zone.

2. Theoretical Consideration on Temperature Profiles in a Substrate

Steady-state temperature profiles in a substrate are calculated for pseudo-line-shaped electron beams. In the calculation, a spot beam with a Gaussian intensity profile is assumed to be scanned along one direction faster than the thermal response time of the substrate. The calculation is performed for both triangular and sinusoidal scanning waveforms. In case of the triangular waveform, the position probability density of the beam is constant and the temperature profile is identical to the line-shaped beam with uniform intensity, while in case of the sinusoidal waveform, the position probability density is higher toward both edges.

When the surface of a substrate with infinite thickness is heated by a Gaussian beam, the linearized temperature Θ of the substrate surface at a distance r from the beam center is given by the next equation[9].

$$\Theta(r) = \exp(-2r^2/d^2)\, I_0(2r^2/d^2) \qquad (1)$$

where d is the beam diameter and I_0 is the 0th order modified Bessel function. Then, the linearized surface temperature $\Theta(x,y)$ at a point (x,y) is given by Eq.(2), where the beam is assumed to be scanned along the x-axis within ± a.

$$\Theta(x,y) = \int_{-a}^{a} f(\xi)\exp(-2\{(x-\xi)^2+y^2\}/d^2)\cdot I_0(2\{(x-\xi)^2+y^2\}/d^2)d\xi \qquad (2)$$

$f(\xi)$ is the position probability density for the beam to be found at a position ξ. For triangular and sinusoidal scanning waveforms, $f(\xi)$ is given by $1/(2a)$ and $1/(\pi\sqrt{a^2-\xi^2})$, respectively. The real temperature in Si is related to Θ by Eq.(3)[10].

$$T = T_k + (T_0-T_k)\exp(p\Theta/\sqrt{\pi}Ad) \qquad (3)$$

where T_k=-174°C, A=299 W/cm, T_0 is the temperature at infinity, and p is the beam power.

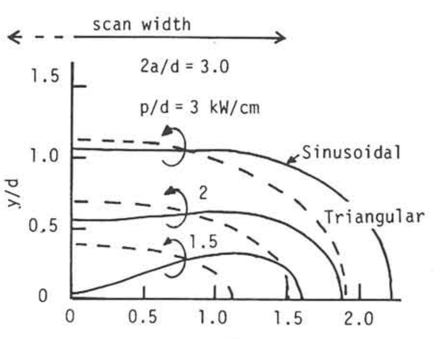

Fig.1 Contours of molten zones in Si. p : beam power, d : beam diameter, 2a : scan width

Figure 1 shows typical temperature profiles in Si by the scanned beams. The solid and broken lines show contours of the molten zones produced by scans with the sinusoidal and triangular waveforms, respectively. We can see from this figure that the concave edge is obtained when a beam with moderate power density is scanned sinusoidally. In practical sample structures, the heat flow toward the inside of the substrate may be disturbed by the underlying insulator film, however, the above conclusion is considered at least qualitatively correct.

3. Experimental Procedure

Sample preparation in this experiment is schematically shown in Fig.2. Si films about 720 nm thick were deposited by the vacuum evaporation technique onto thermally grown SiO_2 films on Si substrates at temperature of 500°C. The Si films were then coated by sputtered SiO_2 films about 1.1 μm thick, and mounted on a copper holder kept at 300°C using Pb-Bi alloy. The films were recrystallized by an electron beam with an acceleration voltage of 30 kV, beam diameters of 40 to 60 μm, and beam currents of 0.15 to 0.4 mA.

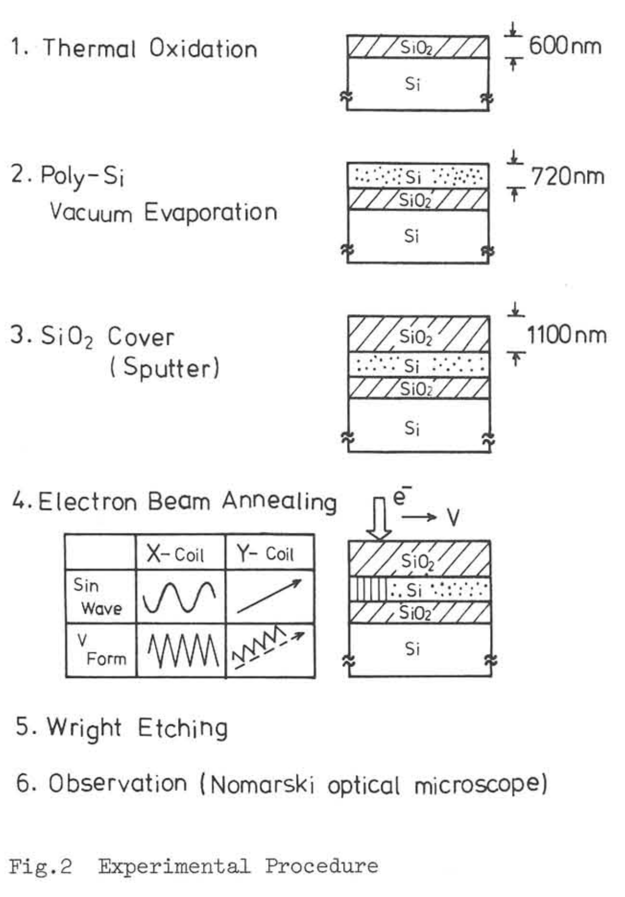

Fig.2 Experimental Procedure

In the first experiment, the beam was scanned in one direction (X-direction) with frequencies of 1 to 10 kHz and amplitudes of 100 to 500 μm, and also scanned in the perpendicular Y-direction with speeds of 1 to 10 cm/s. Sinusoidal, triangular, and rectangular waveforms were used in the X-scan. In the second experiment, in order to form the V-shaped beam and to move it slowly, a spot beam was scanned in the X-direction by the triangular waveform with frequencies of 1 to 10 kHz and it was also scanned in the Y-direction by superposition of a slow ramp waveform and a triangular waveform which is synchronized to the second harmonic of the X-scan wave.

After single scans with various conditions, the SiO_2 cover was etched and the Si film was dipped in the Wright etchant to make grain boundaries clear. The surface morphology was observed by Nomarski optical microscope.

4. Experimental Results

Figure 3 shows a Nomarski optical micrograph of the recrystallized region in the Si film after a single Y-scan of an electron beam with Gaussian intensity profile. Since the beam is not scanned in the X-direction in this case, it is speculated that the temperature at the beam center is highest and the molten zone is recrystallized from both edges. As can be seen from the figure, the grains generated at the both edges cover the whole recrystallized region and the above speculation is experimentally shown to be correct.

Figure 4 shows typical Wright-etched samples after annealing by the pseudo-line-shaped electron beams. In Fig.4(a), the beam was scanned by the triangular waveform in which the trailing edge of the molten zone was expected to be flat or somewhat convex. We can see from this figure that the recrystallized area has still many grain boundaries, though the maximum grain size is as large as about 5x50 μm^2. In Fig.4(b), the beam was scanned by the sinusoidal waveform in which the trailing edge was expected to be concave. We can see from this figure that there is no grain boundary in the center region of about 20 μm wide [4]. The length of this grain was about 450 μm. Recrystallization of the Si film was also tried using an electron beam scanned by a rectangular

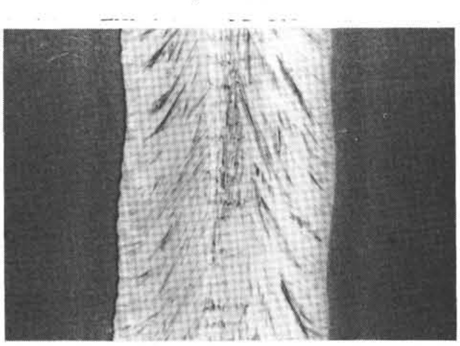

Fig.3 Nomarski optical micrograph of a Si film recrystallized by a Gaussian beam. The molten zone width is about 60 μm.

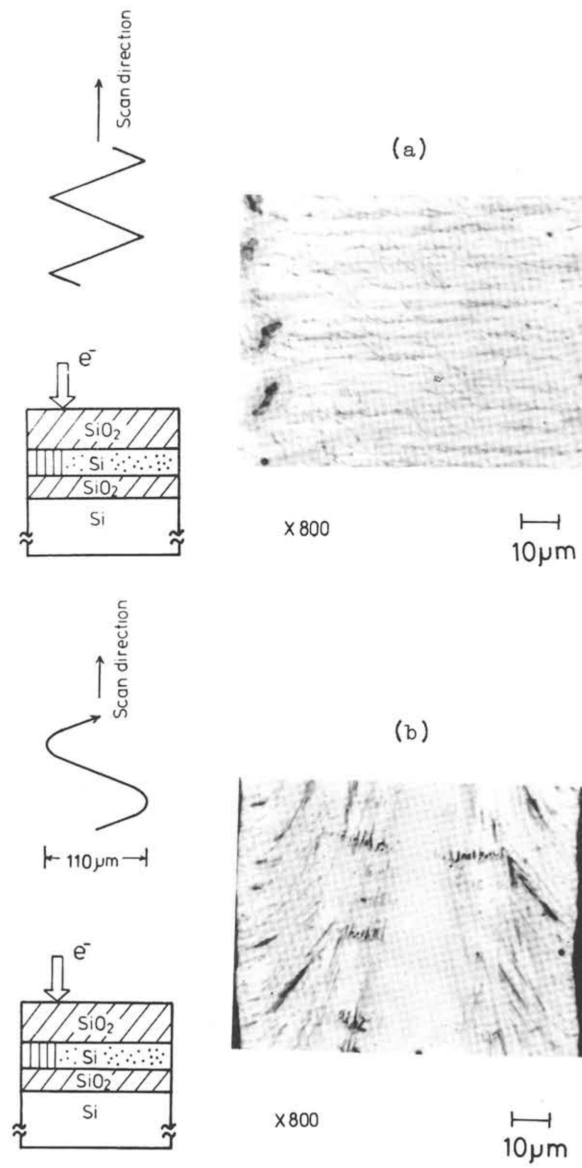

Fig.4 (a) Recrystallized region by a pseudo-line-shaped beam with triangular scanning waveform. V_a=30kV, I_B=168μA, d=40μm, f_x=1kHz, v_y=0.1cm/s and T_{sub}=300°C.
(b) In case of sinusoidal scanning waveform. V_a=30kV, I_B=185μA, d=40μm, f_x=10kHz, v_y= 1cm/s, and T_{sub}=300°C.

waveform. In this waveform, however, two parallel molten zones were observed under the same amplitude. From these results, we conclude that fast sinusoidal scan is essential to produce the concave trailing edge of the molten zone and to form large single-crystal grains.

Next, in order to increase the width of the molten zone, the scanning amplitude of the sinusoidal waveform was increased. However, it was difficult to melt a wider region without evaporation of the Si film at both edges. So, in order to solve this problem, the second experiment was performed. Figure 5 shows an optical micrograph of the Si film annealed by the V-shaped electron beam. We can see from this figure that no grain boundary exist in the center region of about 50 μm wide. We can also see, however, that the center region do not stay flatly on the substrate. We can speculate from this result that the surface region of the Si substrate as well as the Si film is melted as the beam width and power are increased. In order to avoid this phenomenon, it is considered effective to decrease the beam energy to such a low value that the electrons do not reach the substrate.

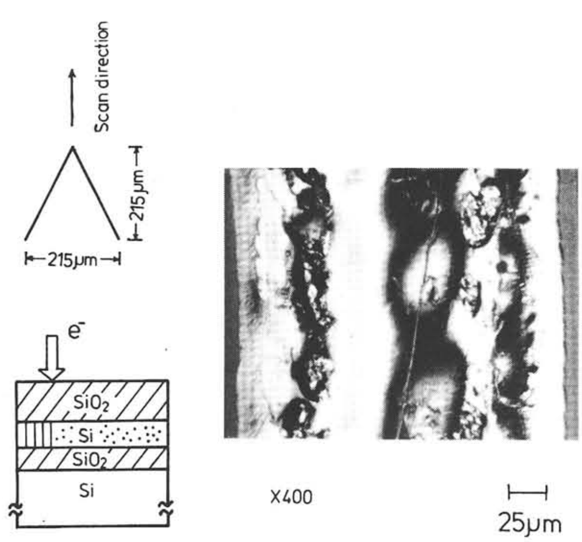

Fig.5 Recrystallized region by the V-shaped beam. V_a=30kV, I_B=296μA, d=40μm, f_x=10kHz, v_y= 1cm/s, and T_{sub}=300°C.

5. Summary

Recrystallization of Si films deposited on SiO_2/Si structures by pseudo-line-shaped electron beams was reviewed. It was found that the fast-sinusoidal or V-shaped scans were effective to produce concave trailing edge of the molten zone and to form large single-crystal grains. The observed maximum grain size with flat surface was about 20x450 μm^2. The wider grain is expected to be obtained by the V-shaped scan method with a lower beam energy.

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References

1) S.Kawamura, J.Sakurai, M.Nakano and M.Takagi; Appl. Phys. Lett. 40 (1982) 394
2) K.Shibata, T.Inoue, T.Takigawa and S.Yoshii; Appl. Phys. Lett. 39 (1981) 645
3) J.A.Knapp, S.T.Picraux, K.Lee, J.F.Gibbons, T.O.Sedwick and S.W.Deep; "Laser and Electron-Beam Interactions with Solids", B.R.Appleton and C.K.Celler eds. (North-Holland, N.Y. 1982) p.511
4) H.Ishiwara, M.Nakano, H.Yamamoto and S. Furukawa; Japan. J. Appl. Phys. Suppl. 22-1 (1983) 607
5) M.W.Geis, H.I.Smith, B-Y.Tsaur, J.C.C.Fan, E.W.Maby and D.A.Antoniadis; Appl. Phys. Lett. 40 (1982) 158
6) Y.Kobayashi, A.Fukami and T.Suzuki; Abstract of 1983 Spring Meeting of Japan Soc. Appl. Phys. 6p-E-6 (in Japanese)
7) J.Sakurai and M.Nakano; ibid, 7p-N-2
8) R.A.McMahon and H.Ahmed; Electron Lett. 15 (1979) 45
9) M.Lax; Appl. Phys. Lett. 33 (1978) 786
10) R.B.Gold and J.F.Gibbons; J. Appl. Phys. 51 (1980) 1256