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Amplitude Modulated Pseudo-Line Electron Beam Recrystallization for Large Area SOI Growth

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A new electron beam annealing technique, amplitude modulated pseudo-line electron beam (AMPL-EB) has been proposed for large area chip size SOI. Through computer simulation of the temperature distribution of the sample surface, precise control of the position probability density profile of the line beam proved to be essential in obtaining wide and uniform recrystallization, and an optimum oscillation wave form was obtained. SOI recrystallization of 4mm in width was successfully carried out.

1. Introduction

Silicon on insulator (SOI) technology has been extensively investigated using beam annealing technologies. From the viewpoint of 3-dimensional device application, a large area SOI comparable with device chips is strongly required, where the electron beam annealing technique has many advantages over laser annealing due to having higher electrical beam controllability, higher wafer through-put and wider line beam application.

Line electron beam annealing with lateral seeded epitaxy is one of the most promising ways and has been studied in two ways; line source electron beam [1] and pseudo-line shaped electron beam [2,3]. The latter is superior in controlling the line beam length and intensity profile along the line beam, which are neccessary in growing large area, high quality SOI. The molten zone width, however, is limited to less than 1 mm in the conventional pseudo-line beam by using simple sinusoidal wave oscillation, as shown in Fig. 1(a).

In this paper, we propose a new sophisticated pseudo-line electron beam technique, amplitude modulated pseudo-line electron beam (AMPL-EB). We analyzed the limitation factor in the enlargement of the molten zone width, especially concerning the uniformity of the surface temperature profile, where precise control of the position probability density of the beam (PPDB) was proved to be essential. Several amplitude modulation wave forms were studied by using computer simulation of the sample surface temperature profile, and examined them experimentally, wherein first successful large area SOI recrystallization was finally attained.

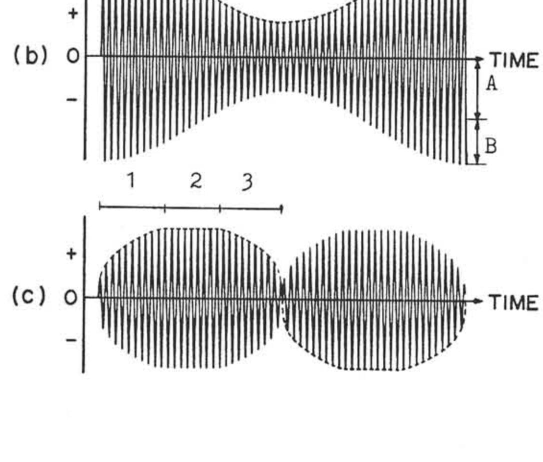

Fig.1 Typical wave forms for electron beam oscillation.

2. Concept of AMPL-EB

As mentioned above, conventional sinusoidal beam oscillation has a limitation in molten zone width. This is because the position probability density of the beam (PPDB) as well as the cooling response time of SOI dramatically increases toward both edges as shown by the dash and dot line in Fig. 2. So, the molten zone splits into two zones as the oscillation amplitude increases. In order to obtain a uniformly recrystallized SOI at a large oscillation amplitude, it is required to moderate the profile of the PPDB. In case of a triangular wave oscillation, PPDB is constant and the temperature profile is identical to a line-shaped beam with uniform intensity for any beam width. In a practical equipment, however, it is impossible to supply a perfect triangular waveform at high oscillation frequency over 10 MHz and we can hardly avoid a high PPDB value at both edges of the beam. Amplitude modulation of a high frequency oscillation wave is considered to be useful for the formation of a moderate profile of the PPDB. Figure 1 (b) shows an example of a sinusoidally modulated wave shape for beam oscillation. It is obvious that the frequency of the amplitude modulation wave should be larger than the inverse of the thermal response time. In order to estimate the effect of sinusoidal modulation, the PPDB was calculated with the degree of modulation as a parameter, which is defined as m=A/B (Figs. 1 and 2). By increasing the degree of modulation, the height of the summit located at the neck of the modulation decreases and the PPDB becomes broader and moderate. It is well known, however, that the annealing margin is very sensitive to the PPDB and so the oscillation width may be limited owing to this summit. From the above consideration, we can make an image of an ideal amplitude modulation wave form, in which the neck is formed to be as deep and sharp as possible to moderate the PPDB and to eliminate the summit, respectively, as shown in Fig. 1 (c). Practically speaking, the rise and drop curves of the modulation wave (regions 1 and 3) are approximately proportional to the 0.4 power of time.

3. Simulation of AMPL-EB

Thermal analysis using computer simulation was performed in order to understand the relation between the PPDB profile of the pseudo-line electron beam and the surface temperature profile. This simulation method[4] utilized Green's function analysis, assuming the target material to be isotropic and semi-infinite.

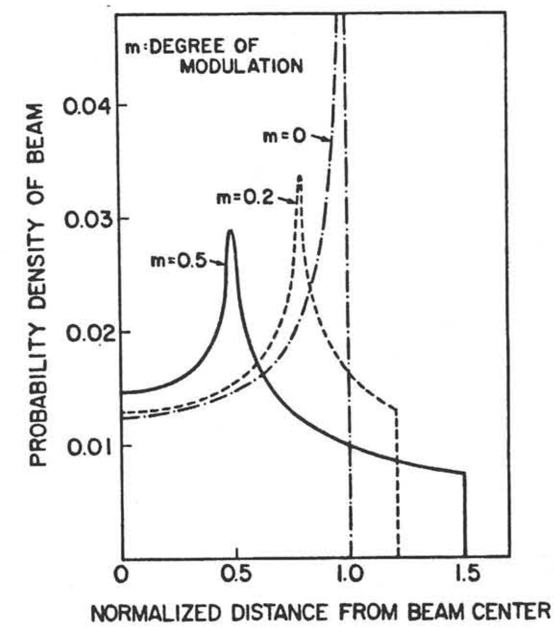

Fig.2 Position probability density profiles of the beam for sinusoidally amplitude modulated waves with the degree of modulation as a parameter.

Typical examples of dynamic stereographic temperature profiles are shown in Fig. 3 for silicon surfaces irradiated with the pseudo-line electron beams formed by (a), (b) and (c) oscillation waves of Fig. 1. The scanning velocity is 100 mm/s and W is the normalized beam oscillation length(oscillation amplitude / beam radius). For wave form (a), the temperature profile becomes concave with increasing W. This feature leads to a split molten zone.

Sinusoidal wave amplitude modulation improves the above mentioned non-uniformity. By increasing the degree of modulation (m), the temperature profile becomes more uniform, but the molten zone width (distance between the summits in Fig. 2 (b)) becomes smaller. Best results are obtained when m = 0.4 $\sim$ 0.5. The characteristic feature in the use of sinusoidal modulation is the shoulders in the temperature profile near both edges of the beam. This may be effective in moderating the temperature gradient in the vicinity of annealing

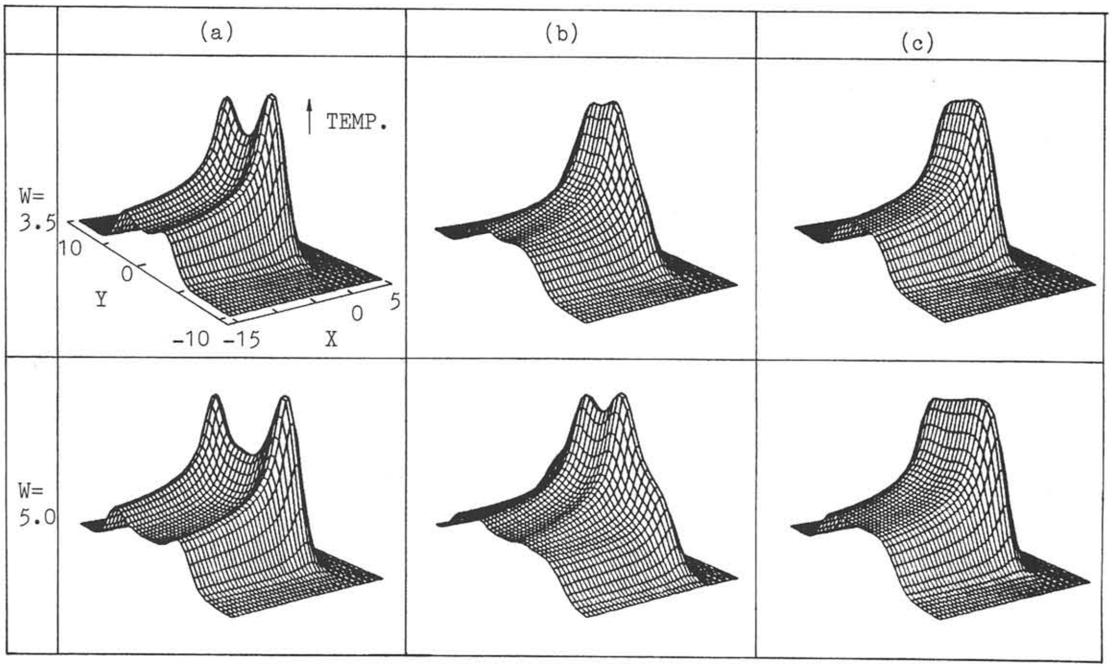

Fig.3 Stereographic illustrations of temperature profiles of silicon surface irradiated by conventional pseudo-line beam (a) and AMPL-EB(b,c). Scan velocity is 100 mm/s. X and Y coordinates, and oscillation amplitude (W) are normalized by beam radius.

area boundaries. A nearly flat profile appears when W=3.5, whereas the profile becomes concave when W=5.0.

The amplitude modulation wave of type (c) gives a nearly flat temperature profile, independent of W. This result indicates that modulation wave (c) will be most useful in large area SOI recystallization.

Here, we introduce the uniformity parameter, T1/T2, where T1 and T2 are temperatures at the center of the oscillated beam and peak temperature, respectively. Figure 4 shows the relations between T1/T2 and the oscillation length W. Using oscillation wave (a), T1/T2 decreases drastically down to 0.5 at W=8, and then decreases rather slowly. Oscillation wave (b) greatly improves this T1/T2 reduction. Oscillation wave (c) gives more improvement so that T1/T2 remains above 0.8, even if W reaches 30. There exists a threshold value for T1/T2 to obtain continuous and uniform molten zone. Assuming the threshold value to be 0.8, the maximum molten zone width when using (a), (b) and (c) waves are estimated to be 5, 6 and 30 in the normalized unit, respectively.

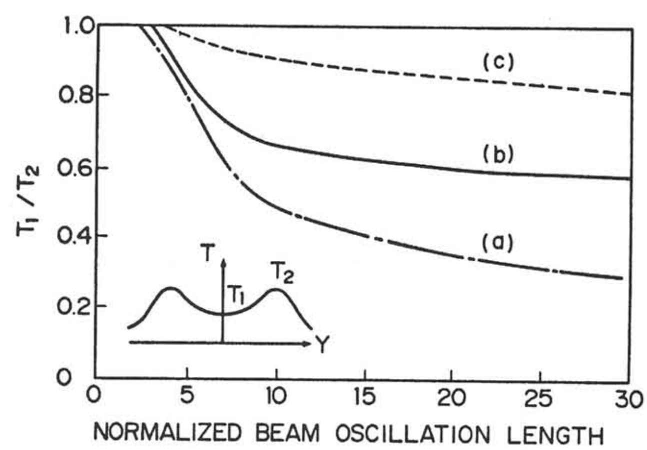

Fig.4 Temperature uniformity factor(T1/T2) as a function of W.

4. Experiments

The apparatus employed for AMPL-EB is schematically shown in Fig. 5. A 100 µm diameter electron beam was electrostatically oscillated by two plates, on which amplitude modulated rf voltage was supplied from a synthesizer with a dummy resistor.

SiO_2 layers (1.3 µm) were deposited by the conventional LPCVD method on (100) silicon wafers. After photo-engraving for seed opening, 0.6 μm thick polycrystalline silicon layers and 0.5 μm thick capping SiO_2 layers were deposited. The oxide edge in the seed region was tapered, to suppress the silicon film disconnection at the seed edge during beam scanning from the seed to the SOI[5]. AMPL-EB annealing was carried out,

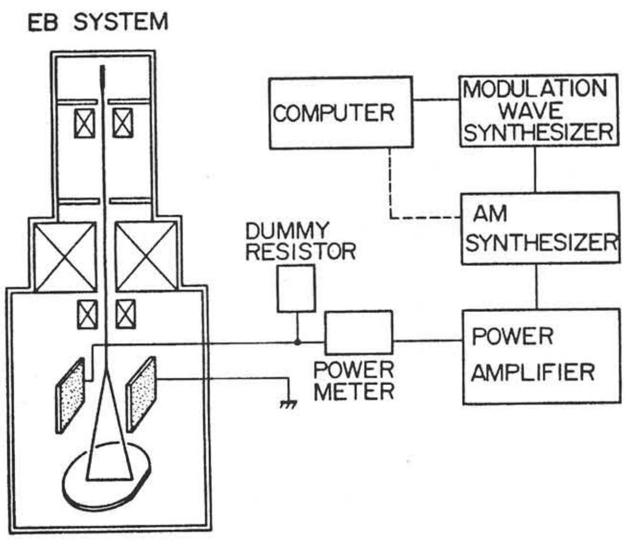

Fig.5 Experimental setup for AMPL-EB.

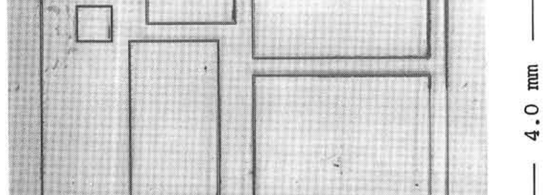

Fig.6 Typical optical microscopic ovservation of seeded-epitaxially grown SOI of 4 mm width, after preferential etching.

where the acceleration voltage, beam current, substrate temperature and beam scan velocity were 12 kV, 6 ~ 8 mA, 600°C and 20 mm/s, respectively.

Figure 6 shows an optical microphotograph of a typical sample annealed by using an ideal oscillation wave as shown in Fig. 1 (c). The uniformly recrystallized area has a dimension of 4 mm in width, where grain boundaries are scarcely seen.

5. Summary

A pseudo-line electron beam formed by amplitude modulated high frequency oscillation (AMPL-EB) was proposed for the first time and verified to be useful in growing a large area SOI.

1) Computer simulation clarified the relation between the PPDB profile and uniformity in the surface temperature profile.

2) The AMPL-EB technique was very effective for precise control of the temperature profile along the line beam.

3) A large area SOI of 4 mm in width was successfully recrystallized.

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