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Crystal Orientations for Unseeded SOI Films Recrystallized by a mm Long CW Line-Source Electron Beam

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This paper describes SOI crystal orientations normal to the substrate surface when unseeded SOI films were recrystallized by a cw line-source electron beam (3-5 mm) at relatively high scan speeds (35-180 cm/sec). It has been found that the main orientation of grains was <111> at higher scan speeds. Nearly 100 % <111> orientation within 2 degrees standard deviation was obtained for samples annealed at 180 cm/sec.

I. Introduction

A mm long line source electron beam[1] has several advantages for recrystallizing a large SOI area, short processing time, overlapping region reduction, thick silicon film formation capability and so on. When SOI films are melted and solidified by using a mm long line-source electron beam, a high scan speed, above 50 cm/sec, is necessary in order to reduce wafer warpage.

On the other hand, SOI recrystallization and its mechanism were mainly examined at slow scan speed ($\leq$ 20 cm/sec) by using a strip-heater or a laser beam, in which case, main grains orientation, normal to the substrate surface, was <100>by a slow scan[2] or partial molten state formation[3] in unseeded SOI films. Few investigations on crystal orientations in unseeded SOI films have been reported at high scan speeds. Therefore, examining the crystal orientations at a high scan speed is necessary for use of a line-source electron beam in the SOI formation.

This paper describes SOI crystal orientations normal to the substrate surface when unseeded SOI films were recrystallized by a cw line-source electron beam (3-5 mm)[1] at relatively high scan speeds(35-180 cm/sec).

II. Experimental

The 0.5 µm thick LPCVD polysilicon films were deposited at 630 °C on 1.0 µm thick SiO_2 layers grown on Si substrates. These films were capped with a 0.5 µm thick CVD SiO_2 layer or a double layer consisting of a 50 nm thick CVD Si_3N_4 layer and a 0.5 µm thick CVD SiO_2 layer. These samples were annealed at 1000 °C for 20 minutes in N_2 atmosphere. No seeding area and no patterns were formed in SOI samples.

SOI films recrystallization by the electron beam annealing technique was performed under the following conditions; 15 kV acceleration voltage, 45-115 mA beam current, 35-180 cm/sec scan speed, 600 °C substrate temperature and 3-5 mm x 0.3 mm beam size.

After recrystallization, the SOI films were chemically etched with Secco etchant (HF: $K_2Cr_2O_7$(0.15 mol)=2:1) to reveal grain boundaries. Grain boundaries were observed by optical microscopy and scanning electron microscopy. Crystal orientations for grains were measured by Electron Channeling Pattern (ECP) method.

III. Results and Discussion

Figure 1(a) shows an SEM photograph of an SOI film recrystallized at 180 cm/sec. Electron Channeling Patterns (ECPs) for regions A, B and C are shown in Fig. 1(b). These ECPs indicate that their crystal orientations, normal to the substrate surface, were <111>. However, the crystal axis for region B, normal to the substrate surface, was tilted about 2.1 degrees from that of region A. Also in-plane orientation was different by 5-6 degrees between regions A and B. So boundary I between regions A and B was a grain boundary. On the contrary, the tilt angle for the crystal axis between regions B and C was below 0.1 degree. In

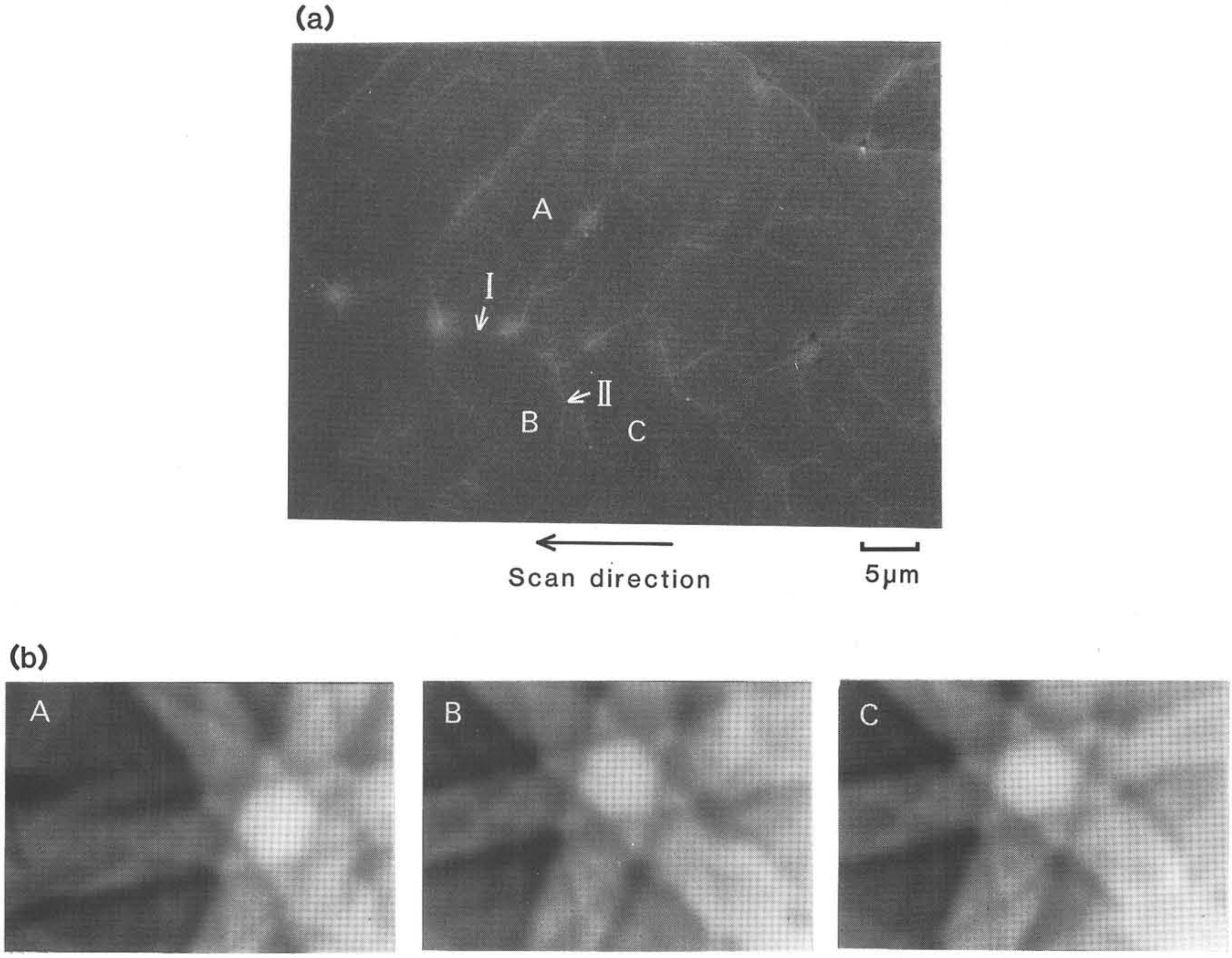

Fig.1 (a) SEM photograph of an SOI film recrystallized at 180 cm/sec. (b) ECPs corresponding to regions A, B and C.

this case, in-plane orientation rotation was not observed within the ECP measurement error limits (1-2 °). Boundary II, between regions B and C, may be a subgrain boundary.

Figure 2(a) shows grain width dependence on scan speed. This figure indicates that grain width was almost constant at 15-20 μm, regardless of scan speed. Figure 2(b) shows surface photographs after Secco etching for samples annealed at 50 and 180 cm/sec, respectively. Boundaries denoted by the arrows were grain boundaries, such as boundary I. Others were boundary II (possibly a subgrain boundary). In this figure, crystal orientation, normal to the substrate surface, was <111> and many boundaries, identified as boundary II, were observed in <111> oriented grains. Therefore, in the following, grain boundaries, identified as boundary I, were considered.

Figure 3 shows crystal orientations dependence on scan speed. The number of grains oriented in <111>, <110> and <100> was counted by using the ECP method. In this figure, grains within 10 degrees deviation from the substrate normal direction were grouped in the same orientation. Other orientations, shown in Fig. 3, were mostly <211> and <311>. The degree of <110> and <100> orientations decreased as scan speed increased. On the contrary, the <111> orientation degree increased at higher scan speeds. However, about 10 % grains with orientations other than <111> remained in an annealed area even at 180 cm/sec scan speed. Figure 4 shows angle θ, between the orientations of grains and a substrate normal direction, along the molten width (~3 mm) in the SOI film annealed at 180 cm/sec. Crystal orientation for grains near the central molten

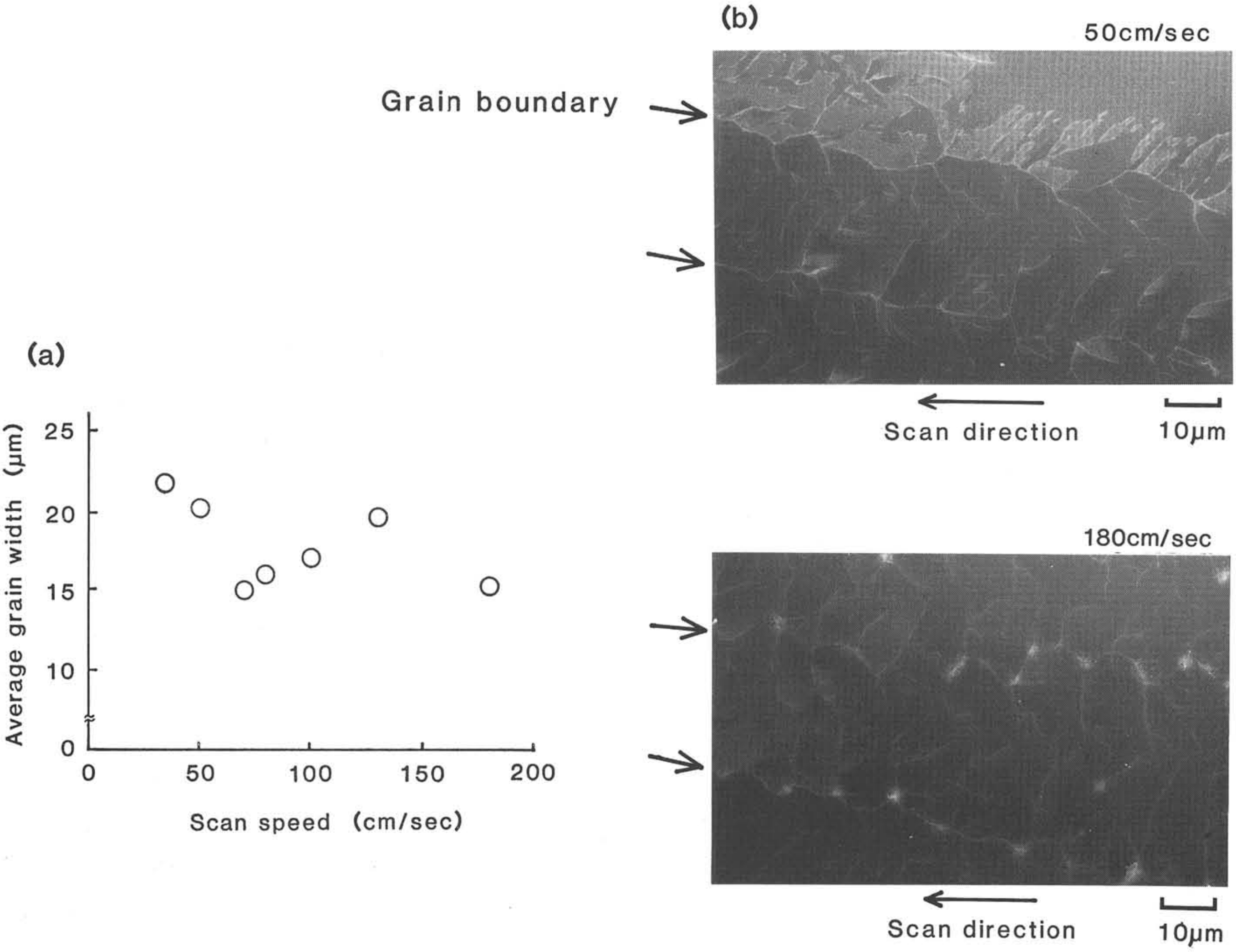

Fig.2 (a) Grain width dependence on scan speed. (b) Surface photographs after Secco etching.

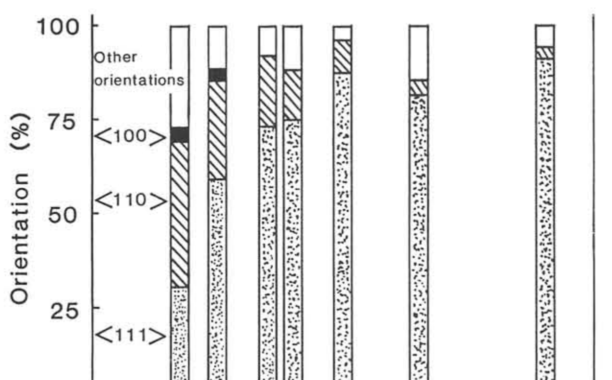

Fig.3 Crystal orientations dependence on scan speed.

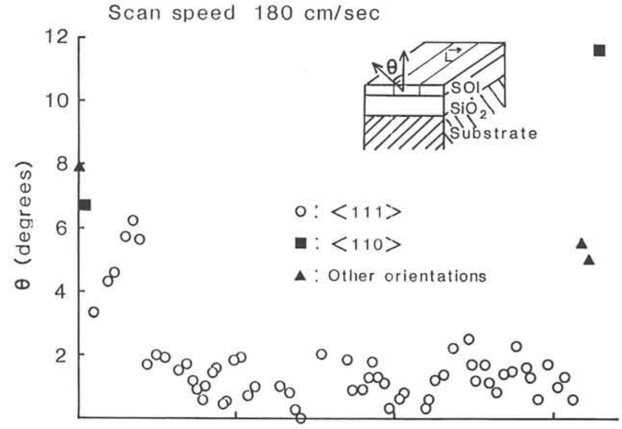

Fig.4 <111> axis deviation θ from the surface normal direction measured along the molten width.

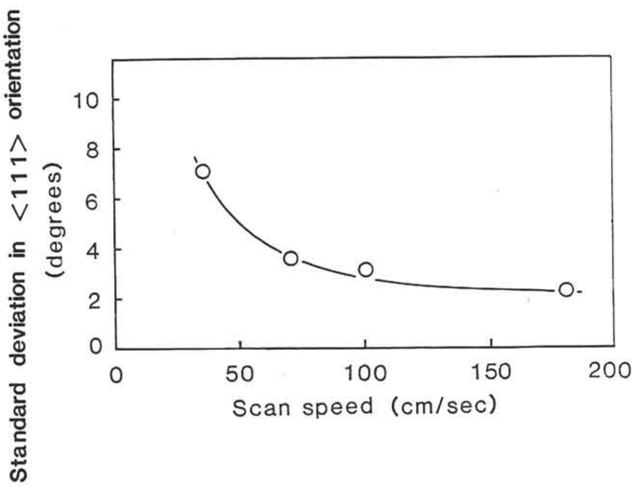

Fig.5 Standard deviation in <111> orientation dependence on scan speed.

region was <111> and grains with orientations other than <111> were observed only at the edges of the molten region. However, at scan speeds below 130 cm/sec, orientations other than <111> were observed near the central molten region. X-ray diffraction measurement indicated that <110> texture was dominant in the poly-Si films used in the experiments. These results indicate that <111> orientation was not affected by the deposited poly-Si grains. Therefore, the <111> orientation was caused by a grain growth speed, but not by the deposited poly-Si grains. These results are quite different from results obtained by a strip-heater or a laser beam. In a strip-heater case, <100> orientation was obtained by a slow scan[2]. In a laser case, the <100> orientation was obtained by partial molten state formation[3] in unseeded SOI films. However, random orientations were caused by the deposited poly-Si grains in a usual laser annealing case. These results indicate that growth mechanism at high scan speed by line-source electron beam is different from that at slow scan speed by a strip-heater or a laser beam.

Figure 5 shows the standard deviation in <111> orientation from substrate normal direction. The standard deviation in <111> orientation decreased as scan speed increased. The standard deviation value was about 2 degrees at 180 cm/sec, scan speed.

Therefore, orientation control, normal to the substrate surface, may be possible in the sample annealed at high scan speed by using a line-source electron beam.

IV Conclusion

Crystal orientations, normal to the substrate surface, were investigated for unseeded SOI films, which were recrystallized by a cw line-source electron beam (3-5 mm) at relatively high scan speeds(35-180 cm/sec).

The following conclusions were obtained.

(1) Main orientation for grains annealed at higher scan speeds was <111>. Nearly 100 % <111> orientation within 2 degrees standard deviation was obtained for samples annealed at 180 cm/sec.

(2) <111> orientation was caused by a grain growth speed, but not by the influence of deposited poly-Si grains.

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