# TEM STUDY ON LOCALIZED RECRYSTALLIZATION SOI ①

Liu Ansheng, Shao Beiling, Li Yonghong, Liu Zheng
*General Research Institute for Non-ferrous Metals, Beijing 100088*
Zhang Pengfei, Tsien Peixin
*Institute of Microelectronics, Tsinghua University, Beijing 100084*

**ABSTRACT** Crystallographic orientations and characters of various defects (subgrain boundaries, dislocations etc.) in Si film of heat-sink structure SOI (silicon on insulator) prepared by unseeded rapid zone-melting-recrystallization (ZMR) process with a RF-induced graphite strip heater system have been studied with a TEM. The study shows that the process used in this experiment can effectively confine the defects in the predetermined regions of Si film strips on the thicker parts of the $SiO_2$ layer, and makes the other Si strips with a width of more than 50 μm defect-free.

**Key words** SOI(silicon on insulator) localized recrystallization crystallographic orientations characters defects TEM

## 1 INTRODUCTION

SOI (silicon on insulator) offers many advantages for integration circuits, including faster switching speed, high packing density and radiation resistance. However, the SOI materials used for preparing VLSI are required to be defect-free, infinitely small internal stress, uniform thickness of Si film, insulating layer without electrical leakage. But it is very difficult to make the whole Si film defect-free. So several ZMR techniques and defect localization methods are developed in order to reduce defects in the Si film or to confine defects in a predetermined region, leaving the other areas of the recrystallized Si film defect free. The defect-free areas can be used as the active regions, and the regions containing defects may be used for resistances and connection wires.

Microstructures of some SOI materials and defects in the Si film treated by various ZMR processes had been studied. Tsaur[1] observed the dislocation distributions and densities, and subgrain boundary (SGB) positions with an etch-pit method. Theunissen *et al*[2] investigated the defects in laser ZMR specimens with X-ray topography and the Wright etching analysis of angle-beveled samples. Geis *et al*[3] studied the morphology, orientation and defect trails in ZMR Si film using the plane-view specimen TEM. Trimble *et al*[4] observed the dislocations and dislocation loops in a thick (10~100 μm) single crystal Si film on an oxidized Si substrate using the TEM weak beam imaging technique. They also used the plane-view specimen technique of TEM. Li *et al*[5] studied the twins in laser ZMR SOI specimen using a plane-view specimen TEM. Liu *et al*[6] have determined the crystallographic characters of various defects in valley localized structure SOI specimens using the cross-section specimen technique of transmission electron microscopy.

## 2 EXPERIMENTAL

Schematic cross-section of the heat-sink structure SOI material is shown in Fig. 1. The SOI specimens were heated in a RF-induced graphite strip heater system for zone-melting recrystallization. The temperatures of the plate-heater and the strip-heater were about 1 200 ℃ and 2 000 ℃ respectively. The moving speed of

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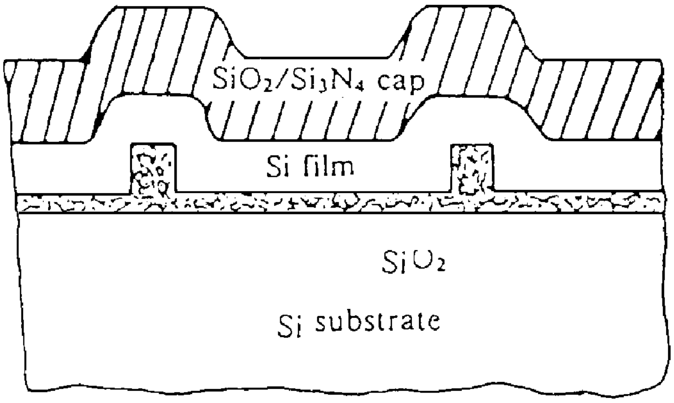


**Fig. 1 Scheme of cross-section of a heat-sink structure SOI material**

the specimens was 11 mm/s. After ZMR treatment, the TEM cross-section specimens were prepared by the technique described in Ref. [6].

The observations of the experiments were performed on a JEM-2000FX analytical electron microscope equipped with a Link-10000 EDS system. The operation voltage was 200 kV.

## 3 RESULTS AND DISCUSSION

The polycrystal Si film deposited by LPCVD at 620 ℃ has a thickness of 0.55 μm. The specimens of heat-sink structure with an interval (thin $SiO_2$ layers) of 10 ~ 50 μm were practically prepared in our experiment. Fig. 2 shows the structure of an unannealed SOI specimen with an interval of 10 μm. Polycrystal Si film consists of columnar grains. The diffraction analyses indicate that the Si film has evident texture and its [110] direction is along the width of the heat-sink structure. The obvious reciprocal spikes in the diffraction pattern imply that the columnar grains consist of stacking crystal plates with [110] direction. The columnar grains grow along approximately

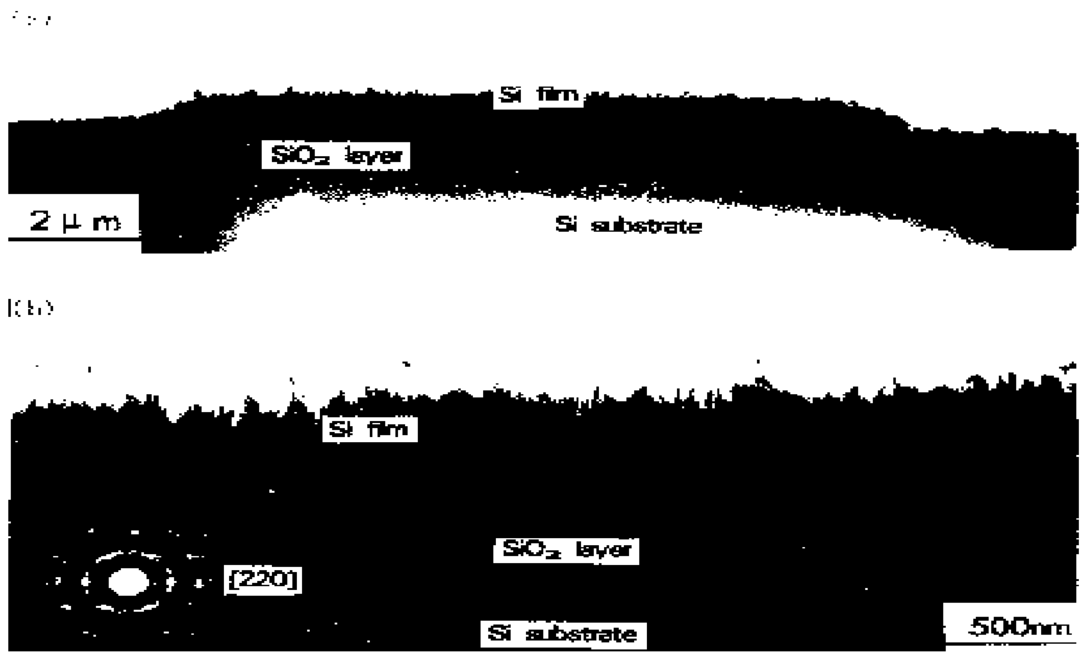


**Fig. 2 Image of unannealed SOI material (a) and enlarged image of a part of (a) and electron diffraction pattern of deposited Si layer (b)**

[111] or [112] directions, as shown in Fig. 2 (b). Fig. 3 shows the cross-section image of a ZMR SOI specimen with an interval of 10 μm. It can be seen from Fig. 3 that the thickness of ZMR Si film is about 0.55 μm and that the thick and thin $SiO_2$ layers have the thicknesses of about 0.93 μm and 0.11 μm, respectively. The image shows that defect-free Si film can be obtained from Si layer on the thin $SiO_2$ layer and the defects are confined in the Si film on the thicker $SiO_2$ layer. In fact, the defect-free Si film with width of more than 50 μm was observed on the sample. The normal direction of the ZMR Si film is [100] and happens to be consistent with the orientation of Si substrate, althought it is unseeded growth. In our experiment, the [010] orientation of the Si film is about 5° deviating from the [010] direction of the Si substrate.

Several micro-defects were observed in defect localized regions. The most commonly observed defects are SGBs, whose orientation differences are usually to an extent less than 3°. The Kikuchi pattern analyses have demonstrated that the orientation differences of SGBs $AA'$ and $BB'$ in Fig. 4 are 0.3° and 0.7°, respectively. Some boundaries with orientation differences of more than 3° were sometimes observed, such as

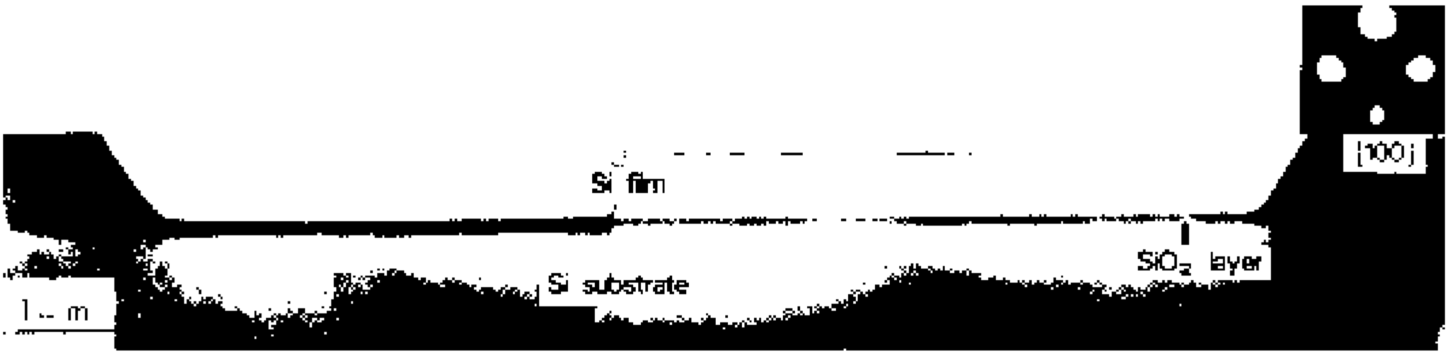


**Fig. 3 Cross-section image of ZMR heat-sink structure SOI material**

(The defect-free area is 10 μm wide.)

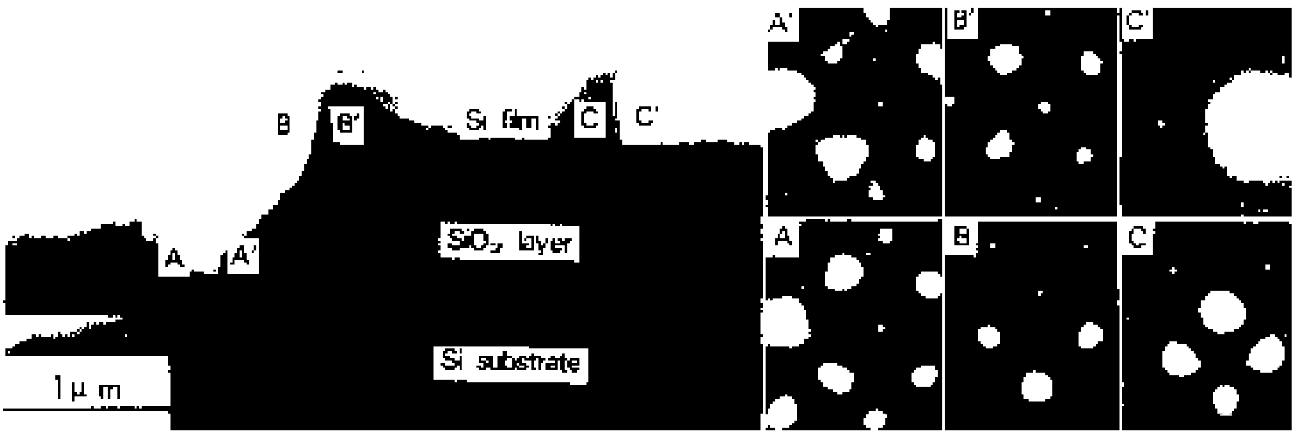


**Fig. 4 Subgrain boundaries in ZMR Si film and electron diffraction patterns of both sides of subgrain boundaries**

(The orientation difference of the grain boundary $CC'$ in the defect localized region is 5°.)

SGB $CC'$ in Fig. 4. Both pure tilt and twist SGBs may exist in the ZMR Si film, but most of the SGBs observed are of the mixed type. The diffraction pattern analysis indicates that the normal direction of many grain boudaries is nearly parallel to the surface of the ZMR Si film. The dislocations in various directions and the dislocation networks composing SGB were also observed in the defect localized regions, as shown in Fig. 5. The two-beam diffraction contrast analysis has indicated that the Burgers vectors of these dislocations are of the same type, namely, $\boldsymbol{b}= \boldsymbol{a}/2\langle 110\rangle$, and the dislocations are located in $\{111\}$ planes. The crystallographic characters of the dislocations are the same as those in bulk single crystal Si. A few interface dislocations exist in the single crystal Si substrate, as shown in Fig. 6. But due to the existence of the amor-phous $SiO_2$ seperating layer, no influence of those dislocations on ZMR

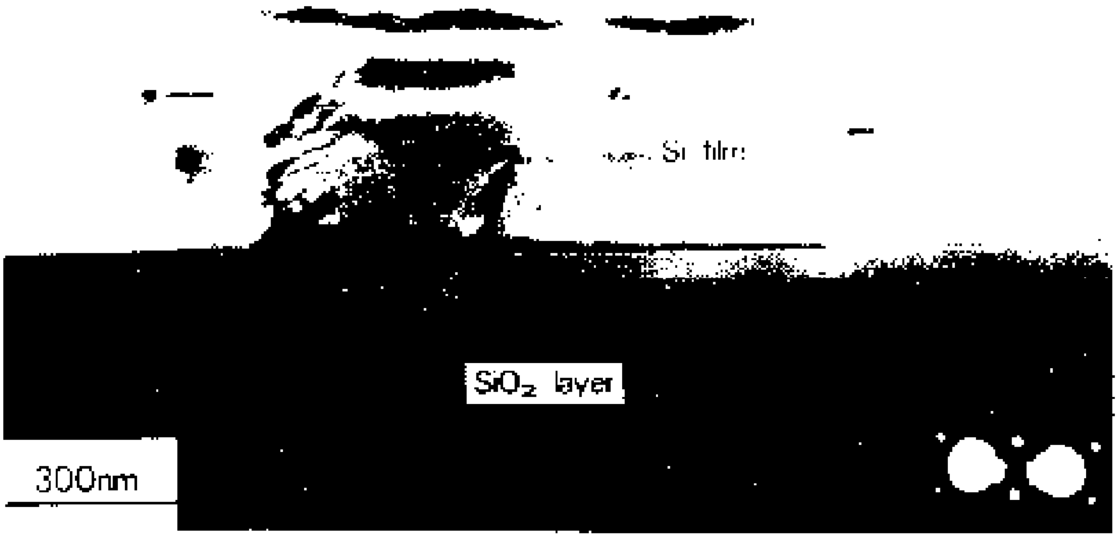


**Fig. 5 Dislocations and grain boundary in ZMR Si film**

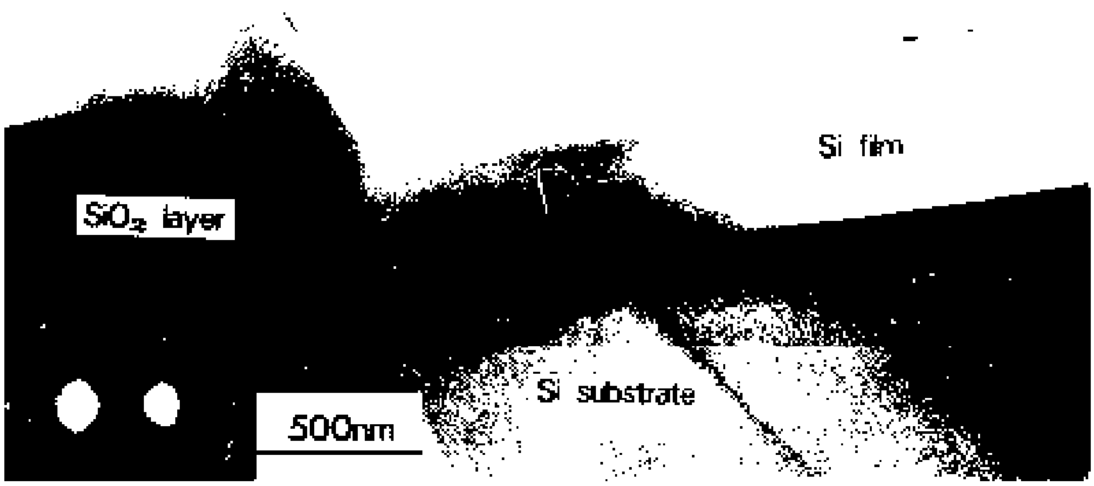


**Fig. 6 Dislocations in single crystal Si substrate near interface**

Si film has been observed. When the surface of the amorphous $SiO_2$ layer is not smooth, the small protruding points will cause stress fields around them in the ZMR Si film.

## 4 CONCLUSIONS

(1) Using a RF-induced graphite strip heater system, defects in the heat-sink structure SOI specimen can be confined in the Si film on the thicker $SiO_2$ layer. Silicon film on thin $SiO_2$ strips is defect-free. In our experiments, defect-free Si single crystal region with about 50 μm wide can be obtained by the process. The Si film has [100] orientation and a thickness of about 0.55 μm.

(2) Commonly observed defects in the defect localized regions are SGBs. Most of SGBs observed are of the mixed type, and have an orientation difference of less than 3°.

(3) The dislocations and dislocation networks have been also observed in the defect localized regions of the SOI material. The Burgers vectors of the dislocations are $\boldsymbol{a}/2\langle 110\rangle$. A few interface dislocations in the Si substrate have no influence on the ZMR Si film, due to the existence of the amorphous $SiO_2$ seperating layer.

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5 Li Yonghong *et al*. In: Proceedings on ICSICT' 92.
6 Liu Ansheng *et al*. Rare Metals, 1992, 11: 2.


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graph. It is beyond the argument that the values of diffusion and chemicaly activation energies ($E_D$ and $E_C$) calculated from Arrhenius formula are coincident with the common values of diffusion and chemically controlled process.

Let the conversion function $f = 1 - (1-\alpha)^{2/3}$, then

$$E = \frac{R\ln(f_1/f_2)}{1/T_1 - 1/T_2} \tag{27}$$

According to figure 6, substituting respectively the data of two straight lines into formula (27), we get $E_D = 39.935$ kJ/mol and $E_C = 78.854$ kJ/mol.

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