

## RBS TOMOGRAPHY OF SOI STRUCTURES USING A MeV ION MICROPROBE

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Germanium patterns having a semiconductor-on-insulator (SOI) structure were inspected by Rutherford backscattering (RBS) analysis using a 1.8 MeV  $H_2^+$  microprobe. Tomographic images of the Ge layer embedded in  $SiO_2$  layers for capping and isolation were obtained by scanning the microprobe over the sample without removing the upper layer. The tomographic images revealed an abrupt transition from a normal to an overheating condition during a zone-melting recrystallization (ZMR) process. An agglomeration of the Ge pattern, whose thickness was 3.1 times greater than the normal thickness, was observed.

### 1. Introduction

RBS analysis has been widely used for studies of semiconductor fabrication processes [1]. Recent progress in a microprobe technique for high-energy ion beams realized an RBS analysis of microareas such as semiconductor integrated circuits [2,3]. Although lateral distributions of elements could not be analyzed by the conventional RBS using a flood probe beam, scanning of the microprobe over a sample made it possible to analyze the lateral distributions of elements [4,5].

A combination of the depth profile, taken from the RBS spectra, and of the lateral profile, obtained by scanning the microprobe in one direction, provides a tomographic image of the sample [6]. Such a tomographic technique, based on the capability of detecting the depth profile with RBS, differs from the computerized tomography (CT) using energy loss of a transmitted beam [7]. Since the sensitivity to heavy elements is large for RBS, tomography by micro-RBS is suitable for an inspection of semiconductor layers embedded in insulating layers, which consist of lighter elements than the semiconductor layers in many cases.

In this study, a ZMR process of an SOI structure, consisting of Ge island patterns embedded in  $SiO_2$  insulating and capping layers, was characterized by the RBS tomography technique using a 1.8 MeV hydrogen ion microprobe. The tomographic images, obtained without cleaving substrates, revealed an abrupt transition of the ZMR condition and an agglomeration of Ge.

### 2. Experimental procedures

A beam line for a 1.8 MeV hydrogen ion microprobe consisted of piezo-driven objective slits and a magnetic

quadrupole doublet [3]. Ion beams were supplied from a Van de Graaff accelerator with a PIG-type ion source. Although  $H^+$  and  $H_2^+$  beams were available when hydrogen gas was used for the ion source,  $H_2^+$  was chosen to obtain increased beam current. The accessible depth of the 1.8 MeV  $H_2^+$  beam was 3.5  $\mu m$  in the SOI substrate used in this study. A microprobe with a spot size of 4  $\mu m \times 4 \mu m$  (50 pA) was used [3].

Data of the tomographic images consist of a series of micro-RBS spectra having 256 channels. During scanning of the microprobe, full RBS spectra were collected at each microprobe position [6]. The scanned area had a width of 140  $\mu m$  and was separated into 128 points. Dwell time of the microprobe at each position was constant. Since the current fluctuation of the beam was less than 5% in our system, the fluence for each micro-RBS spectrum was considered to be constant. The tomographic images were indicated on a computer display with 256  $\times$  128 pixels and eight kinds of dot densities, indicating backscattering yields.

Fig. 1 shows the schematic view of the SOI structure analyzed in this study. The Ge layer has island patterns connected to each other by bridging stripe patterns. This island pattern was prepared by the ZMR process to form a crystalline Ge layer on the insulating  $SiO_2$  layer [8]. The capping  $SiO_2$  layer was used to suppress agglomeration of the Ge.

In the ZMR, a strip heater with a diameter of 0.3 mm was scanned along the bridging patterns. The gap between the strip heater and the substrate was 1.2 mm. The scanning velocity of the strip heater was 0.2 mm/s. The temperature of Ge just below the strip heater was regulated to be the melting point of Ge by controlling the temperature of the strip heater and the lower heater on which the substrate was mounted. Although the Ge

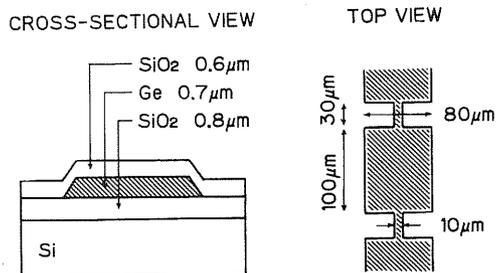


Fig. 1. Schematic view of the SOI structure analyzed in this study. Ge island patterns were connected to each other with bridging stripe patterns.

layer deposited by an evaporating process has an amorphous phase in the initial stage, the well controlled ZMR process realizes a single-crystalline island [8].

### 3. Results and discussion

An overheating condition of the ZMR process gave rise to the agglomeration of the Ge island [8]. Fig. 2 shows the optical micrograph of the substrate after the ZMR under such condition. The mark with an arrow on the right-hand side indicates the border of the normal and the overheating condition.

Fig. 3 shows the micro-RBS spectrum of the center of the Ge island processed under normal conditions. The horizontal axis on the upper side shows the Ge thickness calculated by an energy loss process of backscattered ions [1]. The microprobe dose to obtain this

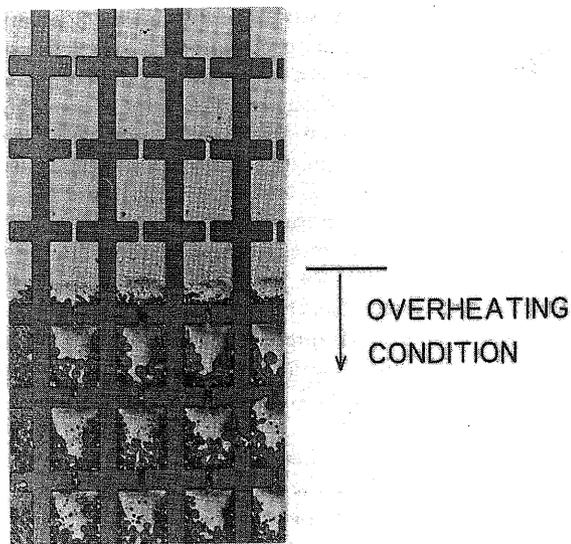


Fig. 2. Optical micrograph showing a transient area from the normal condition to the overheating condition in the ZMR process. The agglomeration of Ge can be observed on the lower side.

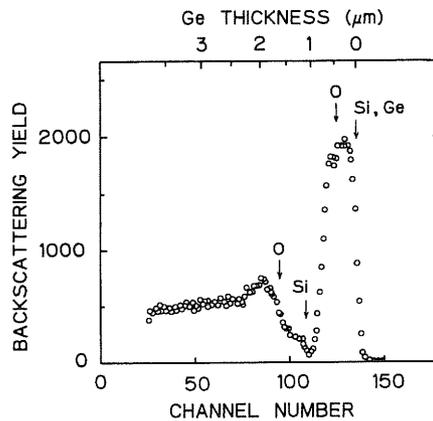


Fig. 3. Micro-RBS spectrum of the center of a normal Ge island. The two pairs of arrows indicating O and Si edges correspond to the signals arising from the capping layer and the insulating layer, respectively.

spectrum was  $2 \times 10^{17} \text{ H}_2^+/\text{cm}^2$ . The Si and O signals from the capping layer overlap the Ge signals. The ratios of spectrum heights for Ge to the surface Si and O were calculated to be 8.0 and 9.5, respectively, so that the influence on the shape of the Ge spectrum was small. The Si and O signals for the insulating layer appear in a lower energy region than the Ge signal. Therefore, the Ge spectrum was not seriously affected by the Si and O signals.

Fig. 4 shows the tomographic image of the Ge island processed under normal conditions. The horizontal and vertical axes stand for the microprobe position and channel numbers (i.e. energies of backscattered particles). The vertical axis on the right-hand side shows the calculated Ge thickness. The dot density of each pixel corresponds to the backscattering yields for the microprobe position. The microprobe dose to obtain this image was  $4.7 \times 10^{16} \text{ H}_2^+/\text{cm}^2$ . Data taking time for this image was 10 min.

The black dense patterns indicated by arrows correspond to the Ge island. The Ge signal on the left-hand side shows the edge of the neighboring Ge island. Although higher-energy edges of the surface Si and Ge appear at the same channel, the Ge signal was dominant due to the difference of scattering cross sections for Ge and Si. The Ge signal appearing in fig. 4 is considered to show a tomographic image of the substrate. The band pattern of medium density below the Ge signals corresponds to the O signal arising from the inner insulating layer. The gap between the Ge signal and the inner-layer O signal arises due to the energy loss relation of Ge and O, so that this gap does not indicate the geometric arrangement of the substrate. Although further computer analysis can give fully accurate tomography, for simplicity only the direct Ge signals are used.

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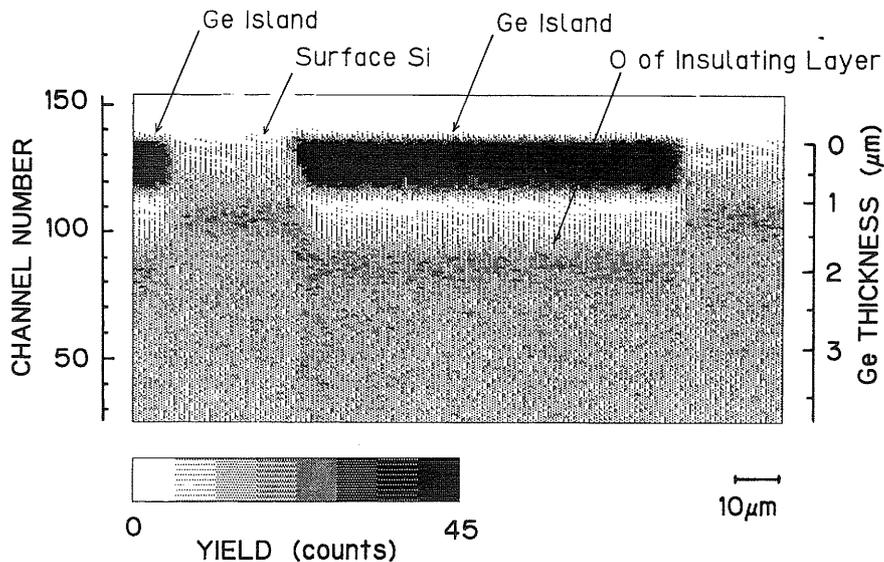


Fig. 4. Tomographic image of a normal Ge island. The RBS spectrum in fig. 3 corresponds to the central position of this image.

The morphology of the Ge island and bridging patterns could be inspected by micro-RBS tomography to study the transition from the normal to the overheating

state. Although a stylus profile meter could provide a surface profile, the information obtained by the profile meter contains not only the germanium thickness but

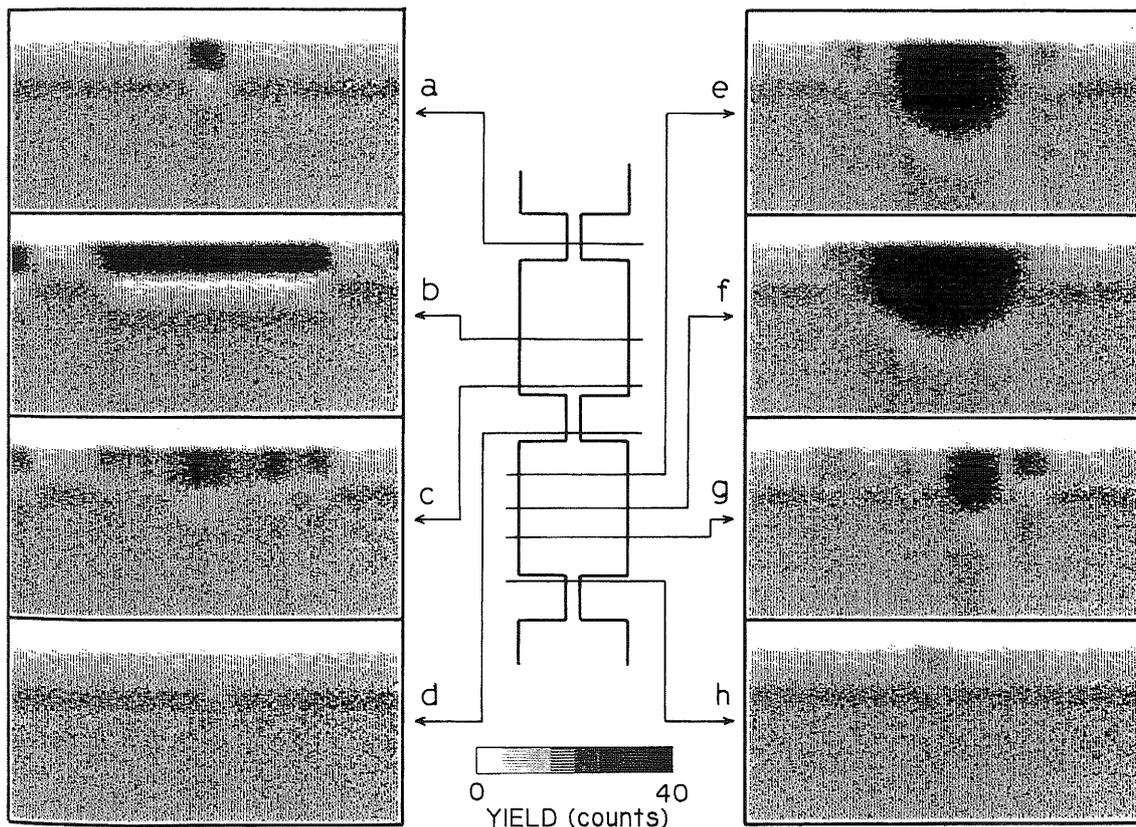


Fig. 5. Tomographic images of Ge islands and bridges in the transient area.

also the thickness of the capping SiO<sub>2</sub> layer. Observation of a cleaved surface by an electron beam microscope could show the Ge distribution in a cross-sectional plane. However, it is difficult to precisely cleave the substrate at the required position. Therefore, micro-RBS tomography, which can provide the elemental distribution in a cross-sectional plane without cleaving the substrate, is suitable for inspection of microstructures.

Fig. 5 shows the tomographic images of the Ge islands in the transient area from the normal to the overheating condition as shown in fig. 2. The border of the two conditions exists around position (b) in fig. 5. The vertical and horizontal scales of the tomographic images in fig. 5 are identical with those of fig. 4.

The thickness of the island at the position (b) is equal to the thickness of the normal island shown in fig. 4. The Ge widths of the island and bridge at the positions (a) and (b) correspond to the designed values. Therefore, the region around (a) and (b) was processed under normal conditions.

The initial stage of the Ge agglomeration was observed in the position (c). The Ge thickness at the center of this position was 1.0 μm. Although the agglomeration of Ge is not remarkable, small droplets of Ge were observed. The diameter of the strip heater was 0.3 mm. The length of the Ge island was 100 μm. Note that the transition from the normal to the overheating condition occurred in one Ge island whose length is smaller than the diameter of the strip heater. The abrupt transition revealed that a melting area of Ge was localized (i.e. zone-melted), at most, within a range of 40 μm corresponding to the distance between the position (b) and (c).

Ge was not observed at the position (d). Most of the Ge consisting of the bridging stripe pattern is considered to have moved to the neighboring island pattern during the ZMR process. Figs. 5e–g indicate a prominent agglomeration. The thickness of the center of the position (f) was measured to be 2.2 μm, which is 3.1 times larger than the thickness of a normal Ge island. Besides the large Ge droplet shown in fig. 5f, subsidiary small droplets were observed in fig. 5g. The Ge in the bridging stripe pattern at the position (h) is also consid-

ered to have moved to the neighboring island. However, a very small amount of Ge can be observed in this case.

The energy shifts of the Ge signals due to the vanishment of the capping SiO<sub>2</sub> were not observed through figs. 5a–h. It turned out that the capping layer was not broken in spite of the prominent agglomeration of Ge.

#### 4. Conclusion

Ge island patterns having an SOI structure were inspected by micro-RBS tomography. An abrupt transition from a normal to an overheating condition in a ZMR process was observed. The transient area was within a length of one Ge island, which was smaller than the diameter of a strip heater used to heat up the substrate in the ZMR. The agglomeration of Ge was clearly observed in the tomographic images. The maximum thickness of the agglomerating Ge was 3.1 times larger than the thickness of a normal Ge island.

The authors wish to thank N. Ueyama (Glory Ltd.) and T. Yamamoto for their invaluable discussion on SOI structures.

#### References

- [1] See for example: W.K. Chu, J.W. Mayer and M.A. Nicolet (eds.), Backscattering Spectrometry (Academic Press, New York, 1978).
- [2] J.A. Cookson, Nucl. Instr. and Meth. 165 (1979) 477.
- [3] M. Takai, K. Matsunaga, K. Inoue, M. Izumi, K. Gamo, M. Sato and S. Namba, Jpn. J. Appl. Phys. 26 (1987) L550.
- [4] A. Kinomura, M. Takai, T. Matsuo, S. Ujiié, S. Namba, M. Satou, M. Kiuchi, K. Fujii and T. Shiokawa, Nucl. Instr. and Meth. B39 (1989) 40.
- [5] B.L. Doyle, Nucl. Instr. and Meth. B15 (1986) 654.
- [6] A. Kinomura, M. Takai, T. Matsuo, M. Satou, A. Chayahara and S. Namba, Jpn. J. Appl. Phys. 28 (1989) L1286.
- [7] C. Muhlbauer and B.E. Ficher, in: GSI Scientific Report 1988 (GSI, Darmstadt, FRG, 1988).
- [8] M. Takai, T. Tanigawa, K. Gamo and S. Namba: Jpn. J. Appl. Phys. 22 (1983) L624.

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#### 1. Introduction

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