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Lateral Graphoepitaxy of Germanium Controlled by Microholes on SiO_2 Surface

Takahiro Numai, Takeshi Koide, Takashi Minemoto, Hideyuki Takakura and Yoshihiro Hamakawa

Ritsumeikan University, College of Science and Engineering
1-1-1, Noji-Higashi, Kusatsu, Shiga 525-8577, Japan
Phone: +81-77-561-5161 E-mail: numai@se.ritsumei.ac.jp

1. Introduction

In graphoepitaxy, many approaches [1]-[7] have been reported to control the orientation of semiconductor crystals on a SiO_2 surface. If more flat semiconductor surfaces are obtained, the applications of graphoepitaxy are expected to expand.

In this paper, we report the successful control of the germanium (Ge) orientation on a 10-nm-thick SiO_2 layer, which was formed on a flat Si (100) surface, by lateral graphoepitaxy. As a seed crystal, a Ge crystal with a (400) orientation was grown on microholes with four 10-nm-thick SiO_2 sidewalls, which were formed by the thermal oxidization of Si {111} planes. From this seed Ge crystal, a (400) orientation was laterally transferred to a Ge crystal grown on a flat SiO_2 layer, which was a thermally oxidized Si (100) surface, by zone melting. Because the thicknesses of both Ge and an evaporated cap SiO_2 layer on Ge were less than 100 nm, cracks were not observed in the grown Ge crystal.

2. Fabrication

First, a two-dimensional hole array with a base of 1 μm square and a depth of 320 nm was selectively fabricated on a 320-nm-thick SiO_2 layer on a Si (100) substrate by nano-imprint lithography using a novolak photoresist.[8] The specific surface energy has a minimum value on {111} planes when only nearest neighbor interactions are taken into account.[9] Therefore, microholes with four Si {111} sidewalls were prepared by chemically etching the Si (100) substrate with tetramethyl ammonium hydroxide (TMAH) for 5 min at 90°C using the patterned SiO_2 layer as an etching mask. These four Si {111} sidewalls were thermally oxidized, and a 10 nm SiO_2 layer was formed on Si {111} planes. On the thermally oxidized 10-nm-thick SiO_2 layer, 75-nm-thick Ge and 95-nm-thick cap SiO_2 layers were successively formed by electron beam evaporation. These layers were sufficiently thin to relax strains induced by a difference in thermal expansion constant. Also the cap SiO_2 layer was sufficiently thick to overcome the surface tension of liquid Ge during the following heating process.

Secondly, the layered wafer, which was prepared in the preceding process, was gradually heated up to 800°C with a lower heater. The layered wafer was irradiated by infrared light, which was condensed using a quartz rod, and was laterally scanned at 1 mm/s, as illustrated in Figure 1.

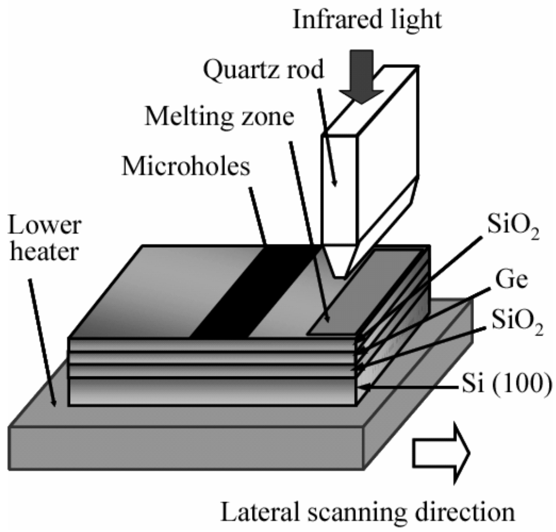


Fig. 1 Schematic of the experimental apparatus for the heating process.

3. Experimental Results and Discussions

Figure 2 shows the scanning electron micrograph (SEM) of the top- view of the layered wafer after the heating process.

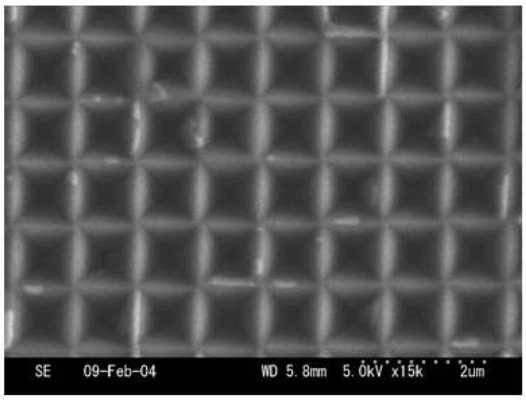
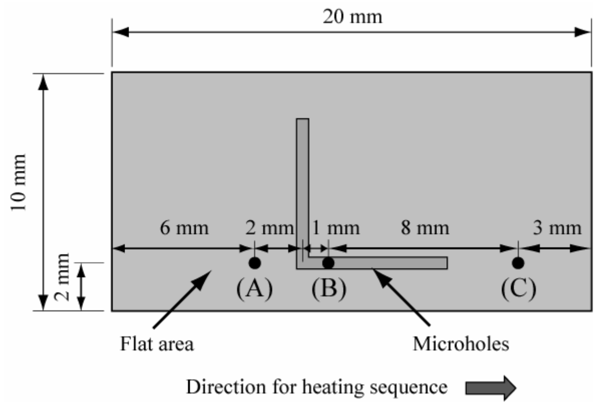
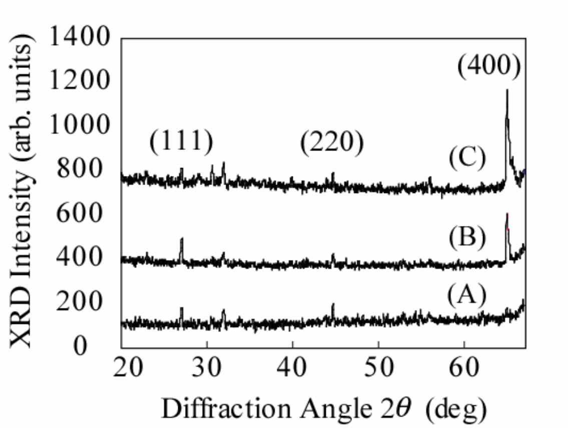


Fig. 2 Scanning electron micrograph (SEM) of the top-view of the layered wafer after the heating process.

After the heating process, the 75-nm-thick Ge and 95-nm-thick cap SiO_2 layers had no cracks, and the cap SiO_2 layer did not peel off Ge as shown in Fig. 2. Also, there were no cracks and peeled regions on the entire wafer with a size of 10 mm × 20 mm. These results indicate that the layer was sufficiently thin to relax strains induced by a difference in thermal expansion constant. Also, the Ge crystal did not bead during the heating process. Therefore, it is concluded that the cap SiO_2 layer was sufficiently thick to overcome the surface tension of liquid Ge during the heating process. In contrast, when the Ge layer was 1.65 μm thick and the cap SiO_2 layer was 1.45 μm thick, the Ge layer and the cap SiO_2 layer had cracks upward from the substrate and peeled off each other on the thermally oxidized Si (100) surface. Also, in the microhole region, dislocations were accumulated in 1.65-μm-thick Ge on the bases of the microholes. When the cap SiO_2 layer was as thin as 10 nm, the 85-nm-thick Ge layer was transformed to beads after the heating process.



(a)



(b)

Fig. 3 (a) Schematic top view of the XRD-measured points of Ge and (b) XRD intensities versus 2θ for three measured points.

The crystal orientation of the grown Ge after the heating process was measured by the X-ray diffraction (XRD) θ-2θ method with an X-ray beam size of less than 3.8 mm × 3.8 mm.

Figure 3(a) illustrates the schematic top view of XRD-measured points indicated by closed circles, and Fig. 3(b) shows XRD intensities versus 2θ for three measured points where the maximum value of the horizontal axis is 68.0 deg. The wafer was heated from left to right, and point (A) was heated at first, and point (C) was heated finally among points (A), (B), and (C). An L-shaped microhole region has two sides with a length of 6 mm and a width of 0.06 mm. In all areas, the SiO_2 thickness was uniform, and there were neither cracks nor peeled regions.

In point (A) with no microholes, the Ge (400) XRD intensity peak was not observed. However, the Ge (400) peak was observed in point (B) with microholes. In addition, the intensity of the Ge (400) peak increased in point (C) despite the absence of microholes. These results tell us that the Ge (400) orientation appeared in point (B) at first, and then it was transferred to point (C) through lateral scanning during the heating process. It is interesting that the Ge (400) XRD intensity increased with lateral scanning.

The mechanisms by which the (400) orientations were obtained in the Ge crystal grown on the thermally oxidized Si {111} planes are probably due to the minimum specific surface energy of the {111} planes.[9] The experimental results in Fig. 3(b) suggest that the Ge crystal with a (400) orientation on the thermally oxidized Si {111} planes acted as a seed crystal, and the (400) orientation was transferred to the Ge crystal on the thermally oxidized Si (100) surface by lateral scanning with heating, which is also known as the zone melting method.

It should be noted that Si (400) peaks were observed at 2θ =69.2 deg, which existed outside the plotted regions in Fig. 3(b) with a maximum horizontal value of 68.0 deg.

4. Conclusions

The lateral graphoepitaxy of Ge on a SiO_2 surface was successfully demonstrated using microholes with thermally oxidized Si {111} planes and a layered structure with a moderate thickness.

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