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High Hole Mobilities in Single-Crystalline Ge Thin-Films on Insulating Substrate Formed by SiGe Mixing-Triggered Directional Melting-Growth

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1. Introduction

Recently, we demonstrated the SiGe mixing-triggered liquid-phase epitaxy (LPE) of Ge using Si substrates as seeds and realized single Ge crystals on SiO_2 films [1]. Since this process is triggered by decrease in solidification temperature due to SiGe mixing, it is expected that poly-Si grown on glass substrates can be used as the seeds for crystallization. If the poly-Si seeds can control the growth direction of Ge layers during the liquid-phase crystallization (LPC), large Ge crystals can be obtained on glass substrates, which are useful for fabrication of high-speed TFTs for high-performance displays with multi-functions. In the present study, we have investigated the poly-Si seeding LPC of Ge and investigated the crystal quality and electrical properties of the Ge crystals.

2. Experimental Procedures

In the experiment, a-Si layers (100 nm thickness) were deposited on quartz substrates using an MBE system and annealed (650 ^{o}C, 15h) in N_2 to obtain poly-Si layers. The poly-Si layers were patterned into island shapes by wet etching to form seeding areas. Subsequently, a-Ge layers (100 nm thickness) were deposited using the MBE system and patterned into narrow stripes (3 μm width). For comparison, Ge stripes with poly-Ge seeds were fabricated. Then capping SiO_2 layers were deposited by RF magnetron sputtering. The sample structure is schematically shown in Fig. 1(a). The samples were heat-treated by RTA (1000 ^{o}C, 3 sec), to induce directional growth from the poly-Si seeds.

3. Results and discussion

The Nomarski optical micrograph of the Ge stripe with the poly-Si seed after RTA is shown in Fig.1(b). In order to reveal the crystal structures, electron backscattering diffraction (EBSD) observations were performed. The EBSD images obtained from Ge stripes with the poly-Si and poly-Ge seeds are shown in Figs.2(a) and 2(b), respectively. Interestingly, it is found that a very long single crystalline Ge (~400 μm length) is obtained for the sample with the poly-Si seed. This surprisingly large single Ge crystal is speculated to originate from the necking at the edge of the poly-Si seed. On the other hand, for the sample with the poly-Ge seed, the growth region becomes polycrystalline, which clearly indicates that Si-Ge mixing at seeding areas is the important force to cause the directional lateral growth.

Fig.3 shows the Si concentration profiles and full width at half maximum (FWHM) of the single Ge crystal evaluated by micro-probe (~1μmϕ) Raman scattering spectroscopy. It is found that Si-Ge mixing (Si concentration: 5-10%) occurs on the seeding area; however, Si atoms scarcely diffuse into the laterally grown Ge region, namely, the whole growth region is pure Ge. The FWHM (~3.8 cm^{-1}) of the growth region was slightly larger than that (~3.2 cm^{-1}) of single crystalline Ge wafers; however, it was much smaller than that (~5 cm^{-1}) of the poly-Ge obtained with poly-Ge seeds, which indicates high quality of the Ge crystals obtained by the poly-Si seeding method.

Furthermore, detailed crystal structures were characterized by X-TEM, as shown in Figs.4(a) and 4(b). EDX profile is also shown in Fig.4(a). The results indicate Si-Ge mixing and high defect density at the Si/Ge interface regions in the seeding area. On the other hand, no defects are observed in the laterally grown regions. This is a splendid result considering that the single-crystalline Ge films obtained by the oxidation-induced Ge condensation process include many defects [2].

Fig.5(a) shows the temperature dependence of the electrical conductivity of the single-crystalline Ge. For comparison, the data of poly-Ge obtained by LPC with poly-Ge seed and solid-phase crystallization (SPC) (500^{o}C, 40min) are also shown. The hot-probe measurements revealed all samples as p-type. The conductivity of poly-Ge increases with increasing temperature, which is because thermal activation is necessary to cause carrier transport crossing grain-boundaries. On the other hand, the conductivity of LPC-Ge decreases with increasing temperature, which indicates that the phonon scattering is dominant compared with the impurity scattering. From fitting the conductivity data to theoretical curves of c-Ge, calculated by considering the phonon scattering and the impurity scattering, the hole concentration was obtained as 6×10^{16} cm^{-3}, where the mobility was 1040 cm^2/Vs.

The hole mobility of Ge films obtained by various methods are compared in Fig. 5(b). The mobility of single-crystal Ge obtained by poly-Si seeding LPC is significantly higher than that of poly-Ge, and even higher than single-crystal Ge obtained by the oxidation-induced Ge condensation process (410 cm^2/Vs) [3]. This is because defect originated high hole concentration (1.3×10^{17} cm^{-3}) reported in Ge condensation process can be decreased to 6×10^{16} cm^{-3} by melt-grown process combined with poly-Si seed. In addition, this melt-grown process does not need Si substrates, which is also a great advantage over the oxidation-induced Ge condensation process.

4. Conclusions

In summary, surprisingly large single crystalline Ge (~400 μm length) was obtained on quartz substrates by the SiGe mixing-triggered LPC process, which enabled very high carrier mobility (~1040 cm^2/Vs).

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References

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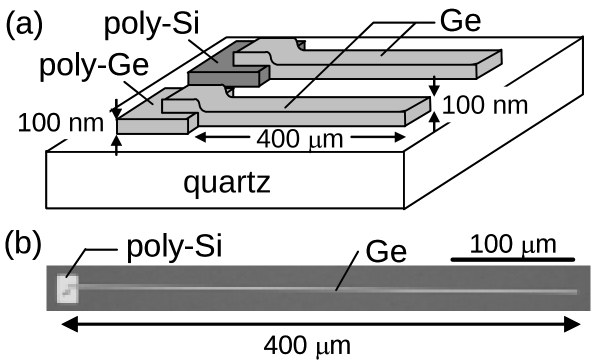

Fig.1 Schematic structure of sample (a), and Nomarski optical micrograph of Ge stripe with poly-Si seed (b) after RTA (1000°C, 3 sec).

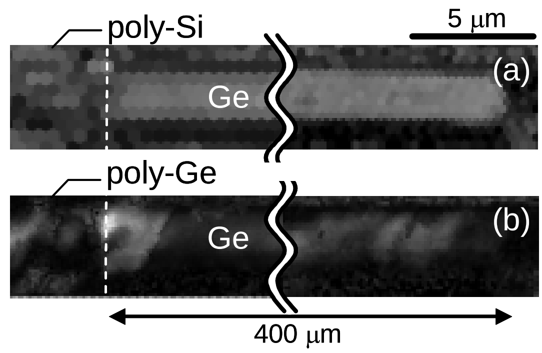

Fig.2 EBSD images of Ge stripes with poly-Si seed (a) and poly-Ge seed (b) after RTA (1000°C, 3 sec).

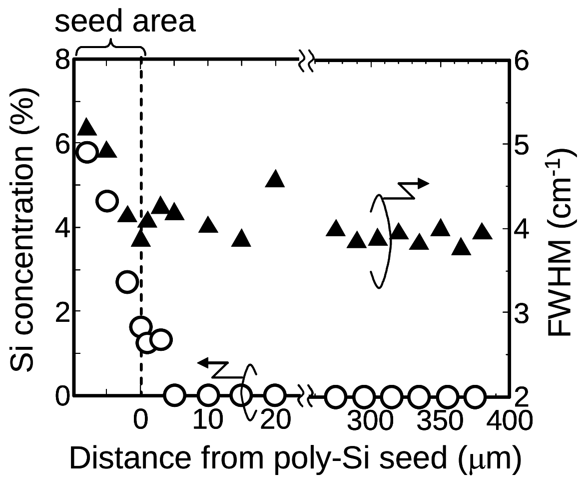

Fig.3 Si concentration profile (open circles) and full width at half maximum (FWHM) (closed triangles) in grown Ge evaluated from micro-probe (~1 μmϕ) Raman spectroscopy.

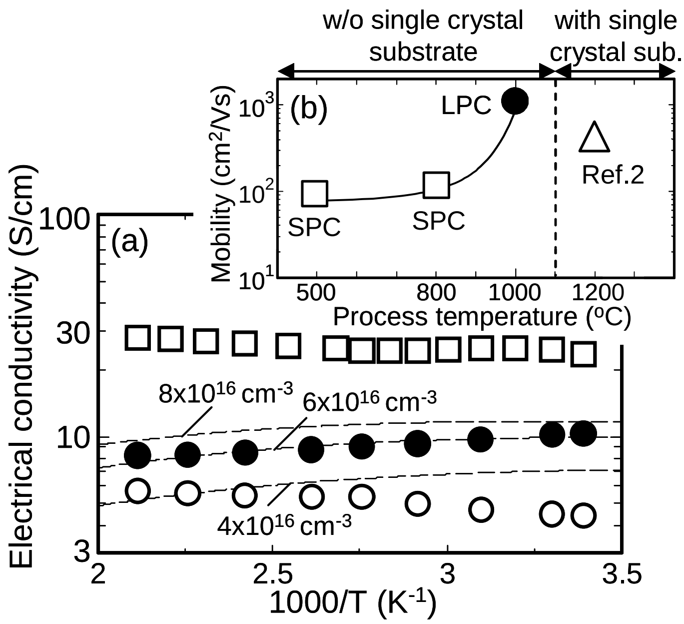

Fig.5 (a) Temperature dependence of electrical conductivity of LPC-Ge with poly-Si seed (closed circles) and poly-Ge seed (open circles), and SPC-Ge (500°C, 40 min) (open squares). Theoretical value of c-Ge are also shown (dashed lines). (b) Comparison for carrier mobility of Ge films obtained by LPC with poly-Si seed, SPC, and oxidation-induced Ge condensation process [ref.2].

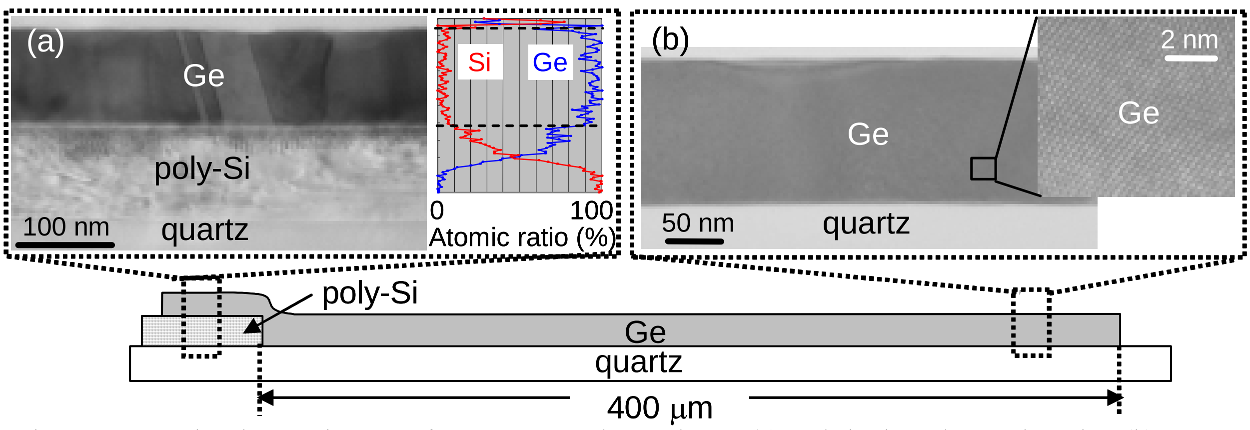

Fig.4 Cross-sectional TEM images of grown Ge at the seed area (a) and the lateral growth region (b). EDX profile at the seed area is inserted in (a).