

Thickness dependent crystal and electrical properties of polycrystalline Ge on a plastic substrate formed by solid-phase crystallization

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Abstract

Polycrystalline Ge thin films are fabricated on a plastic substrate using low-temperature (375 °C) solid-phase crystallization of densified amorphous precursor. The 400-nm-thick Ge layer exhibited the Hall hole mobility of 500 cm²/Vs, exceeding that of single-crystal Si wafers.

1. Introduction

Ge on insulator (GOI) technology has been widely studied for lowering the fabrication cost and improving the device performance of Ge metal-oxide-semiconductor field-effect-transistors. Solid-phase crystallization (SPC) is a simple method to directly form polycrystalline Ge (poly-Ge) thin films on glass substrates at low temperatures [1]. Recently, we improved the hole mobility of SPC-Ge from 450 cm²/Vs to 620 cm²/Vs by combining preparing an amorphous Ge (a-Ge) precursor with heating the substrate, GeO₂ underlayer insertion and post annealing (PA) [2]. This hole mobility was the highest ever recorded for a thin film formed on insulators at temperatures below the melting point of Ge (937 °C). In this study, we develop this SPC-method onto plastic substrate, and realize high hole mobility 500 cm²/Vs.

2. Experimental Procedures

In the experiment, 50-nm-thick GeO₂ underlayer was formed on both SiO₂ glass and plastic (Polyimide) substrate using RF magnetron sputtering. After that, amorphous Ge (a-Ge) precursors were prepared using a Knudsen cell of a molecular beam deposition system (base pressure: 5 × 10⁻⁷ Pa) while heating the samples at 150 °C. The thickness of the a-Ge layer was ranged from 100 to 500 nm. The samples were then loaded into a conventional tube furnace in a N₂ atmosphere and annealed at 375 °C for 150 h to induce SPC. After annealing for SPC, the grown Ge layers were evaluated by using electron backscattering diffraction (EBSD) analysis. The electrical properties of the SPC-Ge layers were evaluated using Hall effect measurements.

3. Results and Discussion

The Raman Spectrum of Ge layer on plastic in Fig. 1(a) shows that the samples exhibit sharp peak near 300 cm⁻¹, corresponding to Ge-Ge bonding [1,3]. These peaks are almost symmetrical, suggesting that the Ge layers are completely crystallized for whole film thickness. Figure 1 (b) shows the shift of the Ge-Ge peak of the sample on plastic and on glass substrates relative to that of the Ge substrate. The shift direction is opposite in glass and plastic. This is

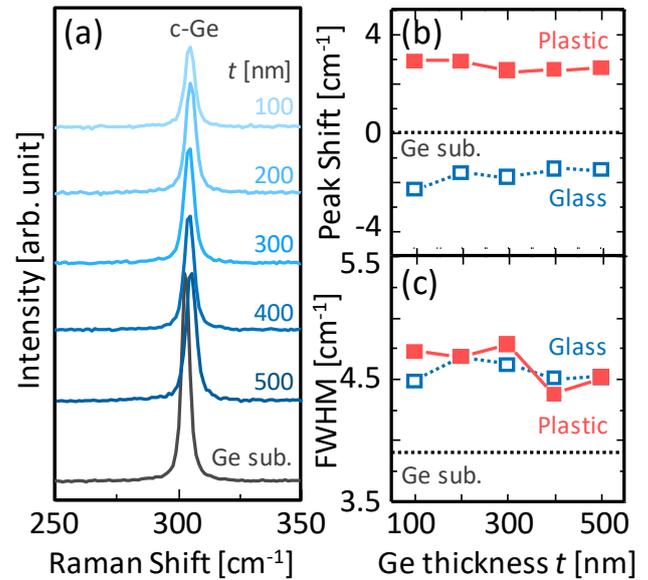


Fig. 1 Raman spectroscopy study of the Ge layers formed on plastic substrate. (a) Raman spectra of the samples. (b) Peak shifts from Ge substrate and (c) FWHMs of the Ge-Ge peaks as a function of t .

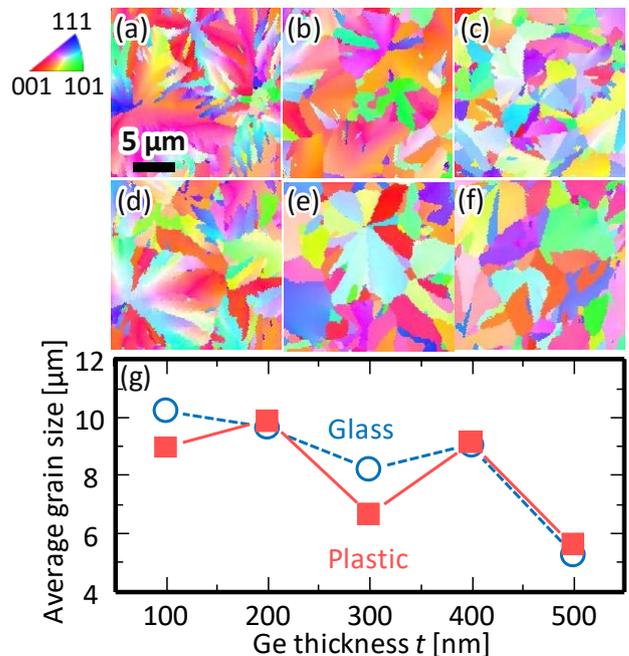


Fig. 2 Grain size of the SPC-Ge layers. EBSD images of the samples formed on (a-c) glass and (d-f) plastic substrate with Ge thickness = (a,d) 100 nm, (b,e) 300 nm, and (c,f) 500 nm. (g) Ge thickness and substrate dependence of average grain size.

considered to be caused by the difference of thermal expansion coefficient between the substrate and Ge, which is lower for the glass and higher for the plastic. Figure 1 (c) shows the full width at half maximum (FWHM) of the sample. The FWHM is almost the same between Glass and Plastic. Therefore, it is considered that Ge layer has the same crystal quality between on glass and plastic.

The EBSD images, in which Fig. 2 (a)-(c) are on the glass, and Fig. 2 (d)-(f) on the plastic show that the grains are randomly oriented and that the grain sizes vary with thickness t . Figure 2 (g) shows that SPC-Ge formed on a plastic has almost the same crystal grain size as that on a glass. In addition, it shows that the Ge grain size, as determined by the EBSD analyses, decreases with increasing t for all the sample conditions. This result likely reflects the increase in bulk nucleation with increasing t [4].

Hall-effect measurements showed that all samples showed p-type conduction, similar to conventional undoped poly-Ge [1.5]. This is because dangling bonds in Ge provides shallow acceptor levels that generate holes at room temperature [6]. Figure 3 shows the Ge t and substrate dependence of electrical properties of Ge layer. It can be seen that there is no difference between the samples on plastic and glass substrates. Figure 3 (a) shows that the hole density is almost constant for whole film thickness. Figure 3 (b) shows that the hole mobility is lower for thin films and higher for thick films. This is considered to be caused by interface scattering [4]. The above results suggest that the quality of SPC-Ge strongly depends on the interface underlayer species. The sample formed on plastic substrate, 400-nm-thick Ge layer exhibited the highest hole mobility, 500 cm^2/Vs in any semiconductor thin films directly synthesized on plastic substrate.

The results obtained in this research are summarized in Fig. 4. We effectively reduced the defects in the Ge film by the insertion of the GeO_2 underlayer and the superposition of PA. As a result, SPC-Ge on glass shows the highest hole mobility among the semiconductor layers formed on insulators at temperatures below the melting point of Ge (937 °C) [2]. We developed this method on a plastic substrate this time. The photograph in the Fig. 4 shows that Ge formed on the plastic substrate keeps its flexibility even after heat treatment. The hole mobility is higher than that of single crystal Ge formed by the condensation process [7]. Moreover, the hole motility of the present poly-Ge exceeds that of bulk Si [8]. These results mean that single-crystal wafers are no longer necessary for fabricating a high-hole mobility semiconductor thin film.

4. Conclusion

We realize to develop high quality SPC-Ge layer onto plastic by controlling t (100–500 nm) and inserting GeO_2 underlayer (50 nm). The resulting hole mobility 500 cm^2/Vs is the highest value to date among that of semiconductor layers directly formed on plastic. This achievement will give a way to realize advanced electronic and optical devices simultaneously allowing for high performance, in-expensiveness, and flexibility.

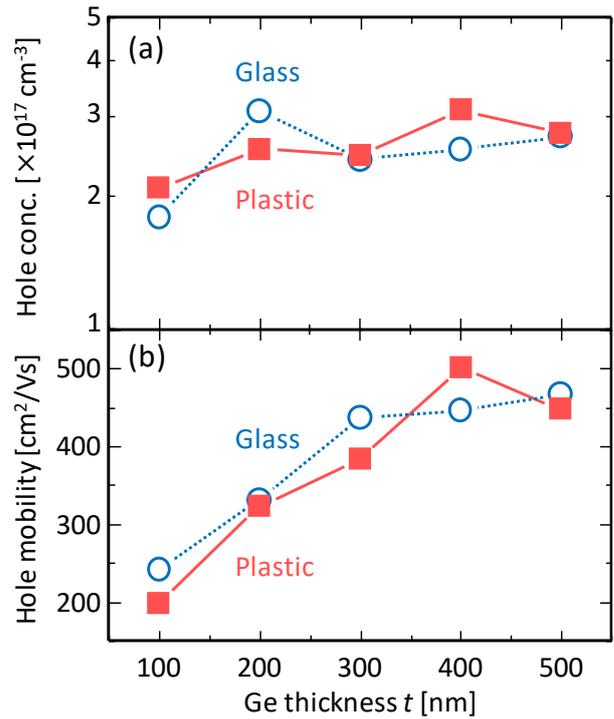


Fig. 3 Ge thickness and substrate dependence of electrical properties of the poly-Ge layers, (a) hole concentration and (b) hole mobility.

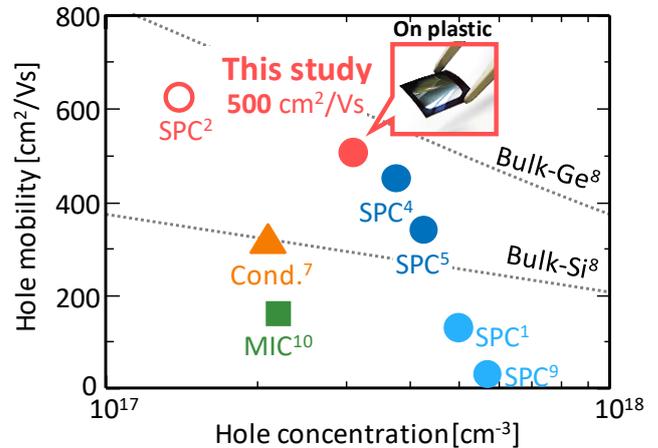


Fig. 4 Comparison of the hole mobility and hole concentration of Ge on insulators.

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