Piezoresitivity of Epitaxial SiGe and Its Temperature Dependency

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Abstract

Strain sensors are highly demanded in industrial fields, such as for manipulators of industrial robots to handle soft materials and recognize the state of grabbed objects(1). Si-based membrane strain sensors have great potential for downscaling and monolithic integration into CMOS technologies because it is possible to fabricate the epitaxial membrane, which enables reduced noise and fluctuations in device parameters. To utilize the membrane strain sensors, the influence of temperature dependence should be considered. In the last decades, polycrystalline Si has been used as an effective material for highly sensitive strain sensors. Here we review our recent results of the piezoresistivity of the epitaxial SiGe(2) and extend the discussion on temperature dependence of the piezoresistivity.

The piezoresistivity of epitaxial SiGe layers is investigated based on gauge factor(GF). A 100 nm-thick, B-doped SiGe with 10-30% Ge content is pseudomorphically grown using reduced pressure CVD on n-type Si(001). B concentrations are targeted from ~1×1017 to ~1×1019 cm-3 as measured by SIMS. The deposited SiGe is patterned by photolithography and dry etching to form a 16 µm wide and 300 µm long stripe, as schematically shown in Fig. 1 (a). Afterwards, the SiGe is passivated with 200 nm thick SiO2 and windows for metal contact pads are opened. For the metal contact pads, Al/Ni silicide/~1×1019 cm-3 B-doped Si layer stack is deposited on the SiGe layer. Then, the substrate is thinned to 200 µm thickness and diced into 2×2 cm2 squares. The test structure is located at the center of the diced wafer. To prevent unintended plastic relaxation of the deposited SiGe layer, the temperatures of post-epitaxy processes are limited to below 550°C.

To measure the piezo resistivity, the resistance is measured using a four-terminal setup by bending the sample with the four-point bending method, as shown in Fig. 2(3). By the wafer bending, uniaxial compressive strain is externally applied along the 300 µm direction. The GF is estimated by the slope of the relative resistivity as a function of induced strain.

Figure 3 shows I-V characteristics of the B-doped SiGe with 10%, 20%, and 30% Ge content with dopant concentrations of 1×1019 cm-3. For all Ge concentrations, the current increases with the supplied voltage in both directions, indicating that ohmic contacts are successfully fabricated by introducing the Ni silicide layer. A possible reason for the variation in the slope of the I-V characteristics could be the slight differences in dopant concentrations in the SiGe layers. Because of the ohmic contact, the fabricated sample structures are suitable for the following piezoresistivity analysis.

Figure 4 shows the relative resistivity change of the 100 nm-thick B-doped SiGe with 10%, 20%, and 30% Ge content and a dopant concentration of 1×1019 cm-3 as a function of externally induced strain. In the range of our experiment, a linear resistivity reduction with induced strain is observed. For samples with higher Ge concentrations, the slope of the resistivity change is slightly higher. A possible reason for the reduction in resistivity may be related to increased hole mobility(4).

In Fig. 5, the temperature dependences of the GF of Si0.9Ge0.1 are shown. At room temperature, the GF of the SiGe with the dopant concentrations of 1×1019, 1×1018, and 1×1017 cm-3 are approximately -60, -75, and -95, respectively. This drastic enhancement could also be related to increased hole mobility by lower dopant concentration. With increasing measurement temperature, the GF decreases for all B concentrations. The sample with a high B concentration shows a lower temperature dependency because the influence of ion scattering is more dominant compared to phonon scattering even at room temperature.

Figure 6 shows the temperature dependence of the resistance of Si0.9Ge0.1. For the sample with B concentration of 1×1019 and 1×1018 cm-3, the resistance monotonically increases with increasing temperature because of increased phonon scattering at the higher temperature. On the other hand, for the sample with 1×1017 cm-3, a decrease in resistance due to increased excited carrier concentration is observed. These results may be related to the balance between increased carrier density and ion and phonon scattering.

These results offer valuable information for the fabrication of membrane pressure sensors integrated into CMOS platforms.

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References

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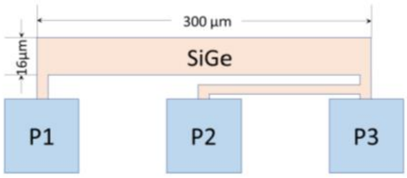

Fig. 1. (a) Schematic top-view image of piezo resistivity measurement structure. The SiGe structure is covered by CVD SiO_2. Al with Ni silicide is used for contact pads at P1, P2, and P3. The length and width of the SiGe layer are 300 µm and 16 µm, respectively (2).

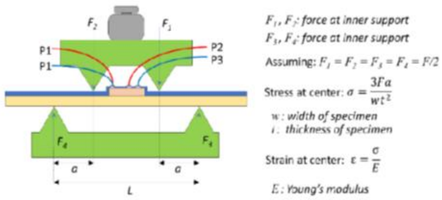

Fig. 2. Schematic diagram of tool to apply compressive strain into SiGe layer on Si substrate for piezo resistivity measurement. Current is supplied between P1 and P2 (also shown in Fig. 1) and voltage between P1 and P3 is measured for resistance measurement (2, 3).

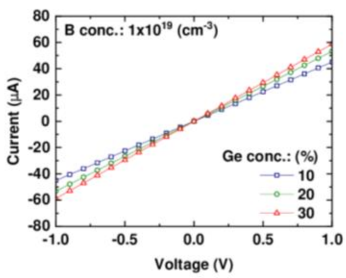

Fig. 3. I-V characteristics of B-doped SiGe with 10%, 20%, and 30% Ge content. The current between pads P1 and P3 in Fig. 1 is measured. The growth temperature of SiGe is 600°C for all cases (2).

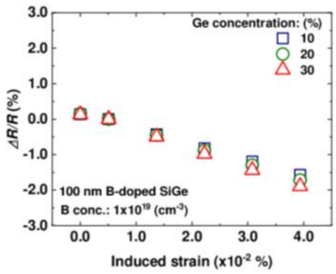

Fig. 4. Relative resistance of 100 nm-thick B-doped SiGe with 10%, 20%, and 30% Ge content. The current between pads P1 and P3 in Fig. 1 is measured. The length and width of the SiGe layer are 300 µm and 16 µm, respectively. Measurement is performed at room temperature (2).

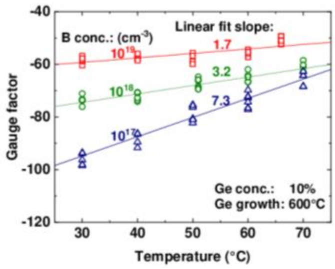

Fig. 5. GF of SiGe as a function of temperature. Ge concentration in the SiGe is 10% and the thickness is 100 nm. B concentration is varied from 1×10^{17} to 1×10^{19} cm^{-3}.

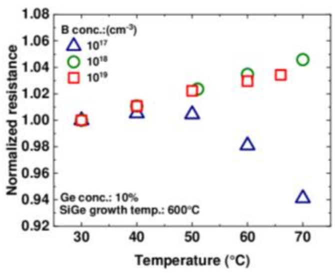

Fig. 6. Normalized resistance as a function of temperature. Ge concentration in the SiGe is 10%. B concentration is varied from 1×10^{17} to 1×10^{19} cm^{-3}.