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Subband structure and effective mass of two dimensional hole gas in strained Ge channels

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1. Introduction

The compressively strained Ge channel is considered to be one of the promising candidates for next-generation complementary metal oxide semiconductor (CMOS) devices since significantly high hole mobility can be attained owing to the suppressed interband phonon scattering and reduced effective mass. Although theoretical studies comprehensively presented subband structures and associated transport properties for strained Ge channels [1], there are few experimental reports especially on the subband structure. We reported the strain dependence of transport properties, such as hole mobility and effective mass, of strained Ge channels, where only the first subband of heavy hole was relevant at low temperatures. In this study, we study effects of enlarging the channel thickness on the subband structure and mobility by means of analyzing low-temperature magnetotransport properties.

2. Experimental procedure

A schematic of sample structures is illustrated in Fig. 1. P-type compressively strained Ge channel modulation-doped structures were formed on SiGe virtual substrates with a Ge content of 0.65 or 0.80. A 20-nm-thick strained Ge channel layer and 20-nm-thick $Si_{0.35}Ge_{0.65}$ spacer layer were successively grown by means of gas-source (GS) MBE at 550 ºC on the SiGe virtual substrates, followed by B delta doping and growth of 30-nm-thick $Si_{0.2}Ge_{0.8}$ and 3-nm-thick Si capping layer with solid-source (SS) MBE at 300 ºC. It was confirmed from X-ray diffraction that the Ge channel layers were fully-strained on the SiGe virtual substrates.

3. Results and discussion

Hole Hall mobility and hole density obtained from standard Hall measurements at 3 K and room temperature (RT) for samples on SiGe virtual substrates with Ge content of 0.65 and 0.80 are summarized in Table 1. The hole Hall mobility largely increases with decreasing the Ge content in the SiGe virtual substrate both at 3 K and RT, indicating that the strain in the Ge channel enhances hole mobility effectively.

Figure 2 shows longitudinal resistance (R_{xx}) as a function of inverse of magnetic field ($1/B$) at 1.7 K for the samples. Shubnikov-de Hass (SdH) oscillations with multi periodicities are obviously observed. Fast Fourier transformation (FFT) for the SdH oscillations is performed to extract components of periodicities as is shown in the insets. It is found that SdH oscillations are composed of mainly two periodicities irrespective of the amount of strain in the Ge layers. This indicates that holes occupy two subbands in the two dimensional hole gas (2DHG). Hole densities in ground and excited states estimated from the periodicities are 6×10^{11} cm^{-2} and 7.3×10^{11} cm^{-2} for the sample with strain of -1.5 % (Ge content of 0.65) while they are 6×10^{11} cm^{-2} and 4.7×10^{11} cm^{-2} for the sample with the strain of -0.88 % (Ge content of 0.80). Sums of the hole densities in the ground and excited states are in good agreements with hole densities obtained from standard Hall measurements. In contrast, as is reported in Ref. [2,3], for the 7.5-nm-thick strained Ge with hole density of 1.5×10^{12} cm^{-2} a single periodicity of SdH oscillation is seen, indicating one subband occupation in the 2DHG. These facts imply that the subband splitting is sufficiently reduced by increasing the channel thickness, leading to the second subband occupation.

From the temperature dependence of SdH oscillations, hole effective mass was deduced for the first subband and plotted as a function of hole density in Fig. 3, where reported values obtained from 7.5-nm-thick strained Ge channels are also plotted. The deduced effective mass for

*Present address: Institute for Materials Research, Tohoku University, Miyagi 980-8577, Japan the samples with thicker channels is found to be much lower than those with thinner channels, which is attributable to the lower hole densities of the first subband since the effective mass is strongly dependent on the hole density due to the nonparabolicity of the heavy hole band as is explicitly shown by the calculated curves. Additionally, it is found that the lowest effective mass around 0.08 is realized with the larger strain. It is important to note that the lower effective mass can be obtained for thicker channels in spite of the almost equivalent total hole density with the thinner channels.

4. Summary

We investigated hole transport properties for 20-nm-thick strained Ge channel modulation doped heterstructures with various compressive stress. For the Ge channels with the strain of -1.5 % and -0.88 %, SdH oscillations with double periodicities were clearly seen, implying hole occupation in two subbands in 2DHG. We found that the two subbands occupation leads to the lower density in each subband and resultantly the lower effective mass. Moreover, the effective mass can be reduced by increasing the strain even in such a low density region. These results indicate that strained Ge channels with larger compressive stress and thickness have high possibility to offer higher mobility.

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Reference

[1] Y. Zhang et al., J. Appl. Phys. **106**, 083704 (2009)
[2] K. Sawano et al., Appl. Phys. Lett. **89**, 162103 (2006)
[3] K. Sawano et al., Appl. Phys. Lett. **95**, 122109 (2009)
[4] J.F. Nützel et al., J. Cryst. Growth **150**, 1011 (1995)

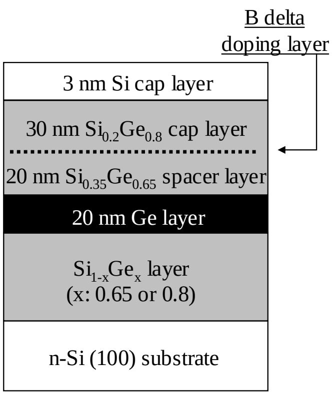

Figure 1. A schematic of the fabricated sample structures

Table 1. Ge content of SiGe virtual substrates, strain in the Ge channel layers, hole Hall mobility and hole density of samples fabricated in this work.

Ge content (%)	Strain (%)	Hole mobility (cm^2/Vs) 3 K	Hole mobility (cm^2/Vs) RT	Hole density ($\times 10^{12}$ cm^{-2}) 3 K	Hole density ($\times 10^{12}$ cm^{-2}) RT
65	-1.50	29,500	2,400	1.2	2.8
80	-0.88	11,000	1,000	1.0	9.3

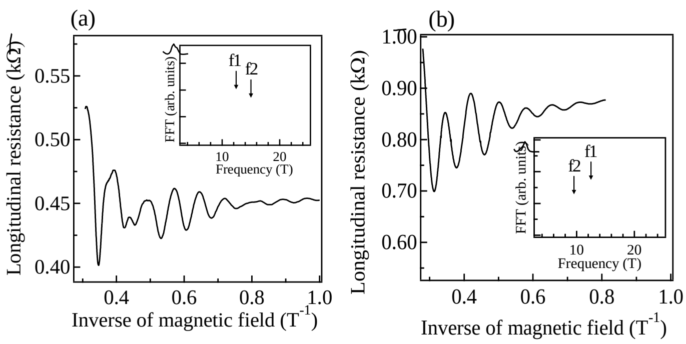

Figure 3. Shubnikov-de Hass oscillations at 1.7 K of the samples with Ge content of (a) 0.65 and (b) 0.8.

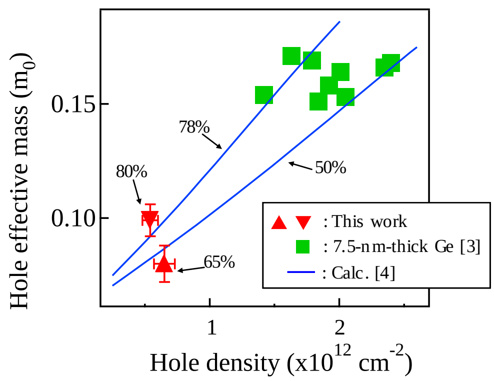

Figure 4. Hole density dependence of hole effective mass in the strained Ge on SiGe virtual substrate with Ge content of 0.65 and 0.8 shown at each plot.