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Extremely High Hole Mobility in SiGe/Ge/SiGe/ Heterostructures Characterized by Mobility Spectrum Analysis

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1. Introduction

There is much attention to realize high-speed p-type field-effect transistors (FETs) using Si-based materials, because the performance of CMOS type circuits is limited by p-type devices due to their lower hole mobility. Since Ge has very high mobility (1900cm^2/Vs at RT), the enhancement of the hole mobility is expected by utilizing Si/Ge heterostructures and we have already reported that strained pure-Ge channel modulation-doped structures provide very high hole mobility (1300cm^2/Vs at RT) on Si substrates [1]. However, the intrinsic mobility of the Ge channel layers is higher than this value, and it was found that our samples had parallel conduction in the doping layers and/or SiGe strain relaxed buffer layers. To characterize such multi-layer structures with several current paths, we employed here the mobility spectrum analysis which was proposed by Beck et al [2] and improved by several authors [3,4], and found that the mobility of carriers in Ge channel layers was extremely high and beyond the bulk Ge value.

2. Experiments

Samples were grown by solid source molecular beam epitaxy and two-step low-temperature (LT) buffer technique, which made it possible to obtain high quality SiGe strain relaxed buffer layers with low threading dislocation density and smooth surfaces [5]. The sample structures and growth conditions are shown in Fig. 1 and Tab. 1. The mobility and carrier density at RT deduced from standard Hall measurements are also shown in Tab. 1.

In the mobility spectrum analysis, we measured magnetic field dependence of conductive tensor $\sigma_{xx}(B)$ and $\sigma_{xy}(B)$ which can be expressed by

$$\sigma_{xx}(B)+i\sigma_{xy}(B)=\int_{-\infty}^{\infty}\frac{s(\mu)(1+i\mu B)}{1+(\mu B)^2}d\mu \qquad (1)$$

where μ is mobility and $S(\mu)$ is conductive density function (mobility spectrum) [2]. By fitting this equation to measured data of $\sigma_{xx}(B)$ and $\sigma_{xy}(B)$ using maximum-entropy mobility spectrum method [4], we obtained mobility spectrum in which the conductivity of different carrier groups appeared in distinct peaks.

3. Results and discussion

Figure 2 shows the measured magnetic field dependence of conductive tensor, $\sigma_{xx}(B)$ and $\sigma_{xy}(B)$, at RT and the fitting results of (a) sample A and (b) sample B. It is seen that the almost perfect fitting can be obtained in both samples by using Eq. (1).

Figure 3 shows the obtained mobility spectra of both samples. The mobility deduced from the standard Hall measurements and the mobility of bulk Ge are also shown for comparison. Three peaks can be seen in both spectra, suggesting that at least 3 types of carriers exist in our samples. The peaks with the highest mobility are considered to correspond to two-dimensional hole gases (2DHG) in the strained Ge channel layer. It is remarkable that the mobility reaches to 2400 and 2900cm^2/Vs in samples A and B, respectively, which are much higher than the bulk Ge mobility. This indicates that the strain increases hole mobility of Ge layers probably by reducing the effective hole mass and increasing the band splitting between heavy-hole and light-hole bands to reduce inter-valley scattering. From the best of our knowledge, this is the first report to show that the mobility of strained Ge exceeds the bulk one. The slightly higher mobility of sample B is consistent with the results of Hall measurements, which may come from the difference in the interface roughness scattering. The peaks with much lower mobility are considered to correspond to carriers in B-doping layers and/or SiGe buffer layers. The small peaks with negative mobility in the spectrum show the existence of electrons, which may come from Si n-type substrates or Si thin capping layers. These parallel conductions significantly reduce not only the Hall mobility but also the device performances. Optimizations of doping concentration and spacer thickness to reduce the parallel conductions are now under way.

4. Conclusion

We characterized the pure-Ge channel modulation-doped structures by using the mobility spectrum analysis and found that the mobility of carriers in Ge channel layers reached to 2900cm^2/Vs at RT which exceeded the bulk Ge value for the first time. This result clearly indicates that the strain really increases the carrier mobility.

Acknowledgements

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References

[1] T. irisawa, H. Miura, T. Ueno and Y. Shiraki, Jpn. J. Appl. Phys. **40**, 2694 (2001).

[2] W. A. Beck and J. R. Anderson, J. Appl. Phys. **62**, 541 (1987).

[3] I. Vurgaftman, J. R. Meyer, C. A. Hoffman, D. Redfern, J. Antoszewski, L. Faraone, J. R. Lindemuth, J. Appl. Phys. **84**, 4966 (1998).

[4] S. Kiatgamolchai et al, Phys. Rev B (to be published)

[5] T. Ueno, T. Irisawa and Y. Shiraki, Thin Solid Films **369**, 320 (2000).

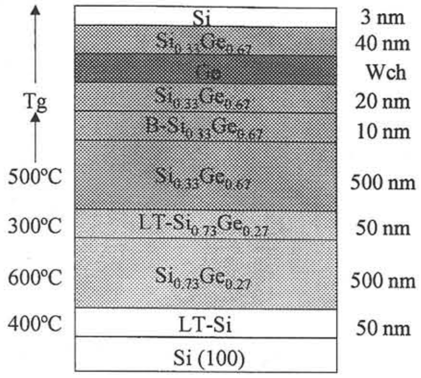

Fig. 1 Sample structure and growth temperature.

Tab .1 Growth conditions, and mobility and carrier concentration at RT deduced from Hall measurement.

	W_{ch} (nm)	T_g (°C)	μ_{Hall} (cm^2/Vs)	n_{Hall} (cm^{-2})
Sample A	7.5	350	1175	$3x10^{12}$
Sample B	20	300	1320	$2.5x10^{12}$

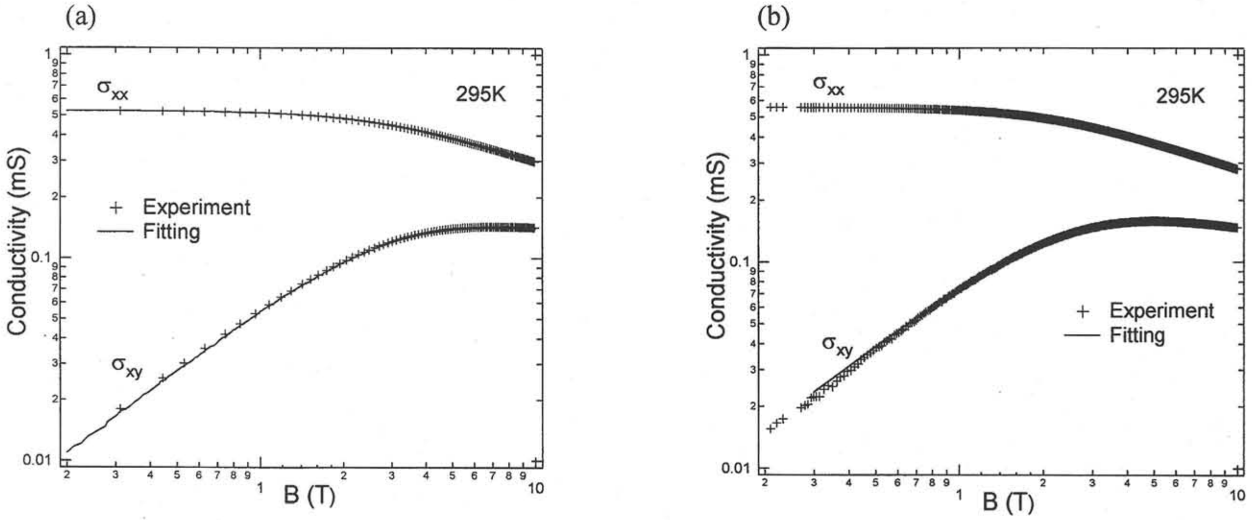

Fig. 2 Measured magnetic field dependence of conductive tensor at RT of (a) sample A and (b) B and fitting results by using Eq. (1).

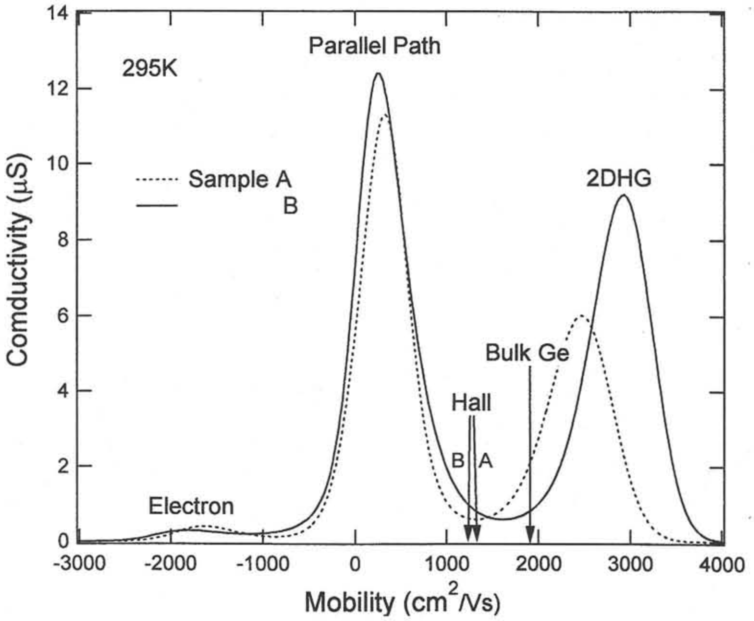

Fig. 3 Mobility spectra of sample A (dotted line) and B (normal line). Bulk Ge mobility and measured Hall mobility of the sample are shown by arrows.