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Channel Width Dependence of Mobility in Ge Channel Modulation Doped Structures

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We previously reported [1.2] that Ge channel modulation doped structures having very high hole mobility were successfully fabricated by utilizing low-temperature growth technique [3] which made it possible to obtain high quality relaxed SiGe buffer layers on Si substrates, i.e. low threading dislocation density, smooth surface, high relaxation ratio and thin layer thickness. In this report, we present the channel width dependence of the mobility in these structures with the purpose of structural optimization.

All samples were grown by solid source molecular beam epitaxy (SSMBE). Relaxed $Si_{0.33}Ge_{0.67}$ buffer layers were grown at 500℃ by using 2-step low-temperature buffer technique. Doping layer, Ge channel and capping layers were successively grown on the buffer. Growth temperature above the doping layer was kept at 350℃ Ge channel width (W_{ch}) was systematically varied in a range of 3.5- 20nm.

It was found that the mobility had a maximum around W_{ch}=7.5nm and that it reached 13000cm^2/Vs at 20K, 1200cm^2/Vs at RT, which is much higher than that in SiGe channel modulation doped structures and Si p-MOS devices. This clearly indicates that this structure is promising as p-type devices in C-MOS type circuits. The decrease of mobility with decreasing channel width (W_{ch}<7.5nm) is attributed to the interface roughness scattering, since its influence increases as W_{ch} becomes thin. On the other hand, the decrease of mobility for the wider channels (W_{ch}>7.5nm) is considered to come from strain relaxation of Ge channel layers. In fact, high-resolution x-ray diffraction measurements revealed that strain relaxation of Ge channel layers occurred in the sample with W_{ch}=20nm. It is well known that critical thickness of $Si_{0.65}Ge_{0.35}$ on Si grown by MBE (at 550℃) which has almost the same strain as that of Ge on $Si_{0.35}Ge_{0.65}$, is thicker than 30nm. Moreover, mobility in $Si_{0.65}Ge_{0.35}$ channel modulation doped structures is found not to decrease with increasing W_{ch} up to 40nm [4]. These results suggest that the strain relaxation is significantly enhanced in Ge growth on SiGe layers compared with SiGe growth on Si, even though they have the same strain. Therefore, optimization of not only channel width but also growth conditions of Ge channel layer is important to realize farther high mobility.

[1] T. Ueno, T. Irisawa, and Y. Shiraki, Physca E (to be published)
[2] T. Ueno, T. Irisawa, and Y. Shiraki, Thin. Solid. Films (to be published)
[3] J. H. Li, C. S. Peng, Y. Wu, D. Y. Dai, J. M. Zhou, and Z. H. Mai, Appl. Phys. Lett. **71**, 3132 (1997)
[4] A. Yutani, and Y. Shiraki (unpublished)

Supporting materials for
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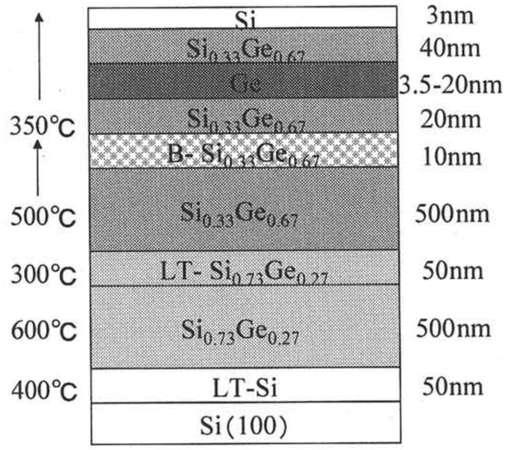

Fig.1 Sample structure and growth temperature.

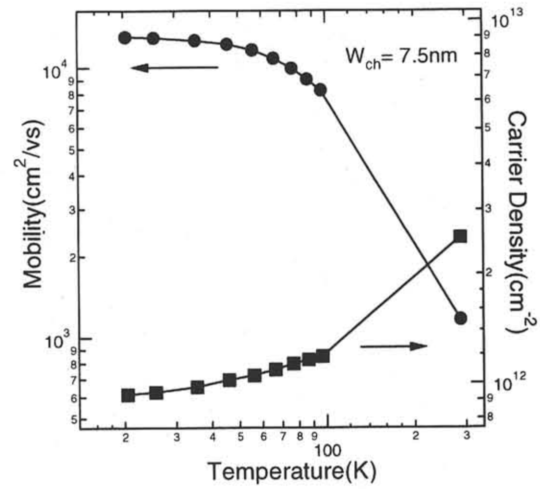

Fig.2 Temperature dependent Hall mobility and sheet carrier density of 2D hole gas in Ge channel modulation doped structure with channel width of 7.5nm.

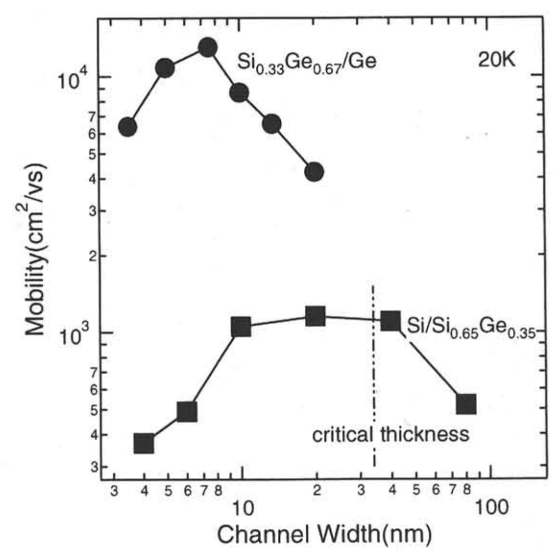

Fig.3 Mobility in (●)Ge channel, (■)$Si_{0.65}Ge_{0.35}$ channel modulation doped structures as a function of channel width. Dashed line shows the critical thickness of $Si_{0.65}Ge_{0.35}$ on Si.

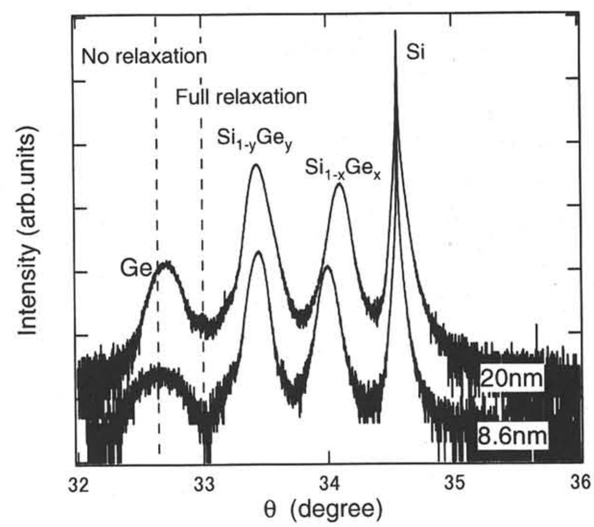

Fig.4 X-ray (004) rocking curves of Ge channel modulation doped structures with channel width of 20 and 8.5nm. Dashed lines show peak positions of Ge layer in case of fully strained and fully relaxed.