High Room Temperature Hole Mobility In $Ge_{0.7}Si_{0.3}/Ge/Ge_{0.7}Si_{0.3}$ Modulation Doped Heterostructures In The Absence Of Parallel Conduction

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Recently there has been a lot of interest in two dimensional hole gas systems in pure germanium channels, since Ge has the highest intrinsic bulk hole mobility of all the commonly employed semiconductors, being comparable to the electron mobilites in bulk Si. König et. al. [1] have reported a maximum extrinsic transconductance of 125mS/mm(290mS/mm) at 300K(77K) in these Ge channel FETs. However, the hole mobility achieved in these systems are limited by roughness scattering at the alloy-Ge interface at low temperatures and by parallel conduction at high temperatures. Engelhardt et. al. [2] have reported a maximum hole mobility of $1300cm^2/Vs$ at room temperature with the channel density changing by about 50% from 4.2K to 300K, indicating the presence of parallel conduction.

In order to measure the true hole mobility and identify the mobility limiting mechanism in the strained Ge channels it is very essential to overcome the contribution from the parallel channels due to the substrate and the doped supply layers. In this abstract we report results on the mobility and the carrier density of a two dimensional hole gas (2DHG) in strained Ge quantum wells with very low parallel conduction. We report a measured room temperature hole mobility in germanium channel of $1700cm^2/Vs$ which is the largest measured to date in these systems.

Fig. 1 gives the schematic of the sample structure showing the active layers. The fabrication procedure for making ohmic contacts were optimized to avoid contact with the substrate in order to prevent parallel conduction. To further reduce the contribution of parallel channels, the substrate was etched down by chemical etching and polishing techniques. Fig. 2 and Fig. 3 show the mobility and carrier concentration from Hall measurements as a function of temperature, respectively. In comparison to sample #B which has parallel channels, samples #A and #C show very little parallel conduction as can be seen from the temperature dependence of the carrier concentration. For these samples we measured a very small carrier concentration decrease of about 26% as the temperature was lowered from 300K to 13K. Sample #A showed a hole mobility of $1500cm^2/Vs$ at 295K. The maximum mobility at 295 K measured in sample #C was $1700cm^2/Vs$. To the best of our knowledge this is the largest hole mobility reported at room temperature in any kind of silicon based heterostructures. This is close to hole mobility in pure intrinsic bulk Ge ($1900cm^2/Vs$) and substantially higher than that of doped Ge with an equivalent carrier density of $\sim 10^{18}cm^{-3}$ ($400cm^2/Vs$). In order to determine the mobility of the channel without any contribution from the substrate, though small, we use the two carrier model [figure 4] and obtain a maximum mobility of $1900cm^2/Vs$ at room temperature. However, Fischetti and Laux [3] based on theoretical calculations suggest that the maximum hole mobility in strained Ge should be substantially higher than the hole mobility in bulk Ge being about $4000cm^2/Vs$ near room temperature for 1% strain and about $8000cm^2/Vs$ for 4% strain in the layer. The discrepancy between the experimental and theoretical predictions indicates that the coupling between the carriers and the phonons is stronger in these Ge strained layers sandwiched between $Si_{0.3}Ge_{0.7}$ layers. Such a situation can arise if the phonons are confined to the two dimensional channel layer due to mass density mismatch with the cladding layers. Phonon confinement effects have been reported previously in similar systems by Song et.al. [4] in 1997. It should be noted that the theoretical calculations reported for strained Ge do not take into account such phonon confinement effects. In order to determine the scattering mechanism that limits the high temperature mobility in these systems, we fit an empirical relation to the high temperature data of the form $\mu \sim T^{-\alpha}$ and obtain $\alpha \simeq 2$ (Figure 5). The higher value for the exponent compared to $\alpha = 1$ expected for acoustic phonon scattering in two dimensions indicates that substantial contribution due to optical phonon scattering exists near room temperature. Similar power law behavior with α=2 has been observed for bulk Si and Ge systems where the role of optical phonon scattering has been well established.

In conclusion, we report for the first time the largest room temperature hole mobility of 1700 cm^2/Vs at 295K in $Ge_{0.7}Si_{0.3}/Ge/Ge_{0.7}Si_{0.3}$ modulation doped heterostructures grown on Si substrate, by reducing the effect of parallel conducting channels. This mobility is 30% higher than the best value for the hole mobility reported previously and is of great significance for high hole mobility p-MODFETs.

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3. M.V. Fischetti and S.E.Laux, Jl. Appl. Phys. **80**, 2234(1996)
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Sample number	wafer numbe	channel width($\AA$)	spacer ($\AA$)	carrier conc. (cm^{-2})	mobility (cm^2/Vs)
#A	411	200	100	1.01×10^{12}	1500
#B	410	200	150	3.84×10^{13}	340
#C	410	200	100	7.9×10^{11}	1700

Mobility and carrier concentration of the samples reported

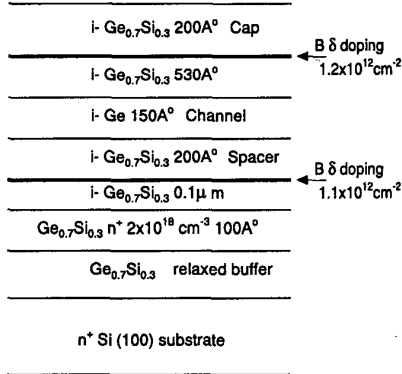

Fig.1:Schematic diagram of 2DHG sample

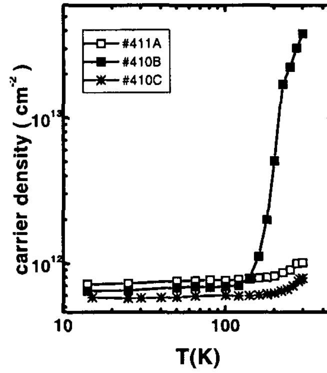

Fig.2:Temperature dependence of mobility

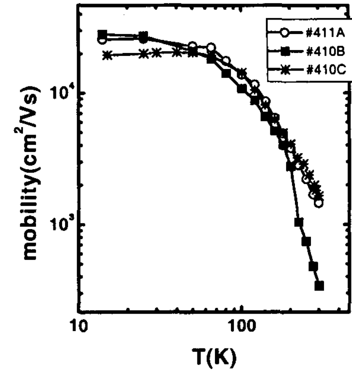

Fig.3: Carrier density as a function of temperature

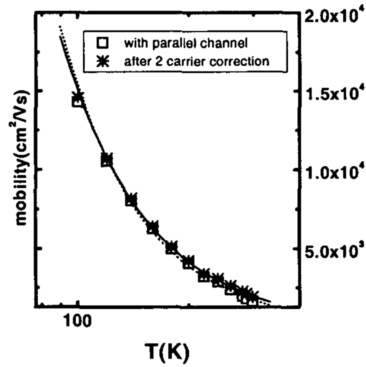

Fig.4:Temperature dependence of the channel mobility

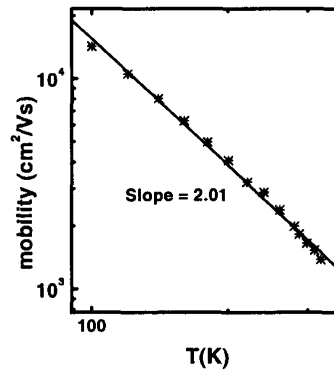

Fig.5:Empirical fit for the high temperature data for samples #D and #F