High-Mobility Strained Si for Spintronics Applications

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We have grown modulation-doped $Si_{1-x}Ge_x$ quantum wells ($0 \leq x \leq 0.1$) on relaxed $Si_{1-xs}Ge_{xs}$ buffer layers, and have investigated this system using conduction electron spin resonance (CESR) and conventional Hall measurements. For a pure Si channel, mobilities of up to 341 000 cm²/Vs at carrier densities of $2.8 \cdot 10^{11}$ cm^{-2} were found in Hall measurements under illumination at 1.6 K. In CESR, extremely narrow line widths of down to 40 mG can be observed. In pulsed-ESR experiments, spin lifetimes T_1 and T_2 in the order of microseconds have been found. This is two orders of magnitude longer than the length of the microwave pulses used to flip the spins. The g-factor for the electrons in Si (g = 1.998) and Ge (g = 1.563) is significantly different. We grew samples with $Si_{1-x}Ge_x$ quantum wells with x = 0.05 and x = 0.1. In these samples, a clear shift of the g-factor could be observed although in this first attempt the line width of the CESR signal was significantly increased.

Introduction

Electrons in silicon are very promising for spintronics and quantum information processing. The main reasons are the extremely long spin lifetimes, which are due to silicon's weak spin-orbit coupling, and the suitability of this material system for very large scale integration (VLSI). Especially the spin properties of two-dimensional electron gases (2DEGs) in the Si/SiGe heterosystem have attracted considerable interest recently. [1]

For a quantum computer [2] it would be useful to change the g-factor and therefore the position of the resonance in an electron spin resonance (ESR) experiment. This can be accomplished by using the fact that the g-factor for the electrons in Si (g = 1.998) and Ge (g = 1.563) is significantly different.

Experiments

We have grown modulation-doped $Si_{1-x}Ge_x$ quantum wells ($0 \leq x \leq 0.1$) on relaxed $Si_{1-xs}Ge_{xs}$ buffer layers with $0.20 < x_s < 0.3$. The properties of the two-dimensional electron gases (2DEGs) have been investigated using conduction electron spin resonance (CESR) and conventional Hall measurements.

Growth was performed by solid source molecular beam epitaxy (MBE), and doping with Sb was done at the low growth temperature of 300 °C to suppress the strong segregation. On top of a relaxed buffer layer (3.4 µm linear grading + 0.6 µm constant composition part) the strained $Si_{1-x}Ge_x$ channel was deposited, followed by an undoped spacer layer, the doping layer, and $Si_{1-x}Ge_x$ and Si cap layers.

Results

For a pure Si channel, mobilities of up to 341 000 cm²/Vs at carrier densities of $2.8 \cdot 10^{11}$ cm^{-2} were found in Hall measurements under illumination at 1.6 K (see Fig. 1). In CESR, extremely narrow apparent line widths of down to 40 mG can be observed (see Fig 2).

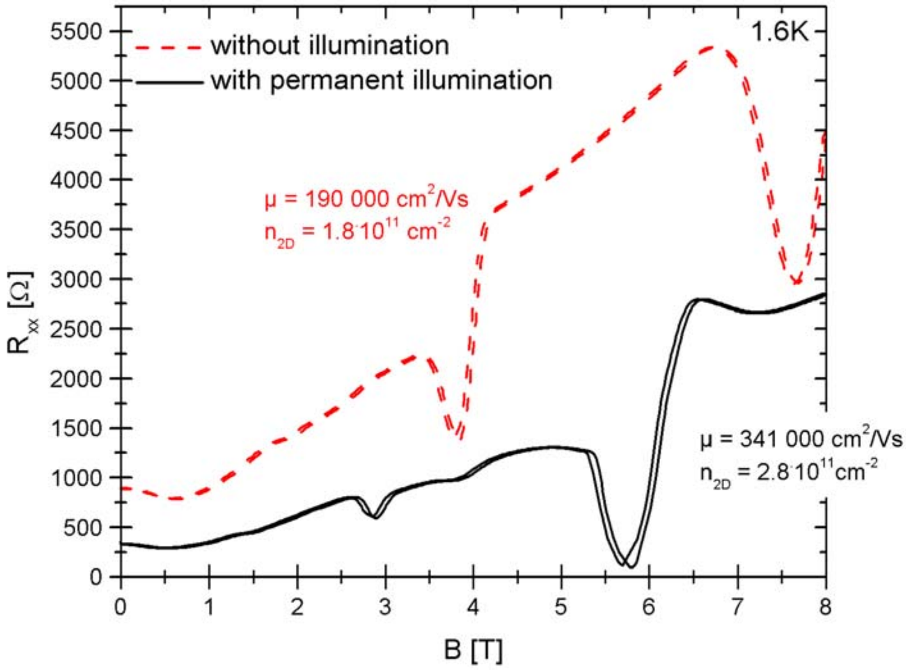

Fig. 1: SdH measured at 1.6 K with (solid line) and without permanent illumination.

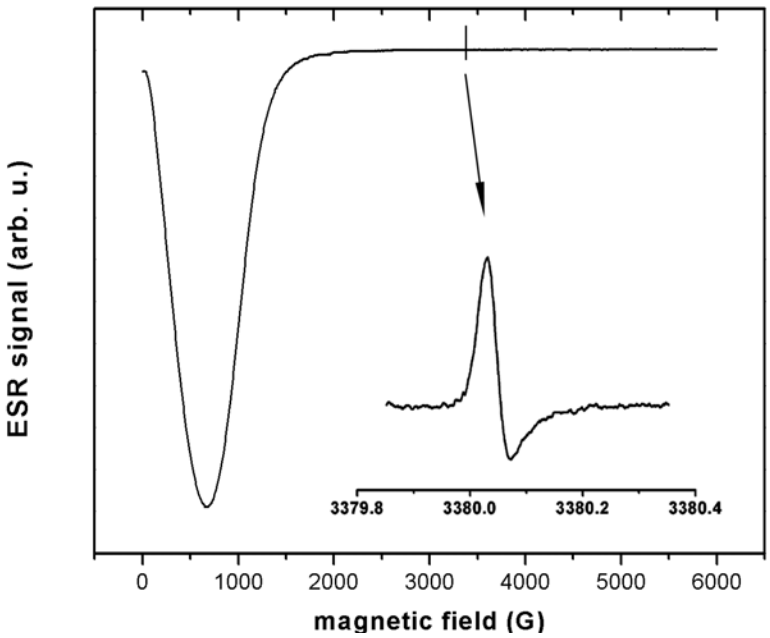

Fig. 2: Cyclotron resonance and CESR signal (inset) measured at 2.5 K. The line width of the CESR signal is only 40 mG.

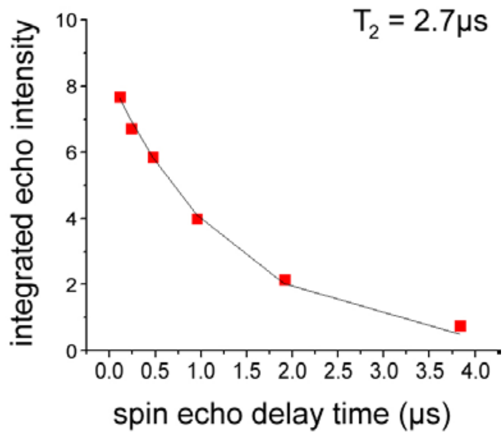

Fig. 3: Determination of T_2 from spin echo experiments [4].

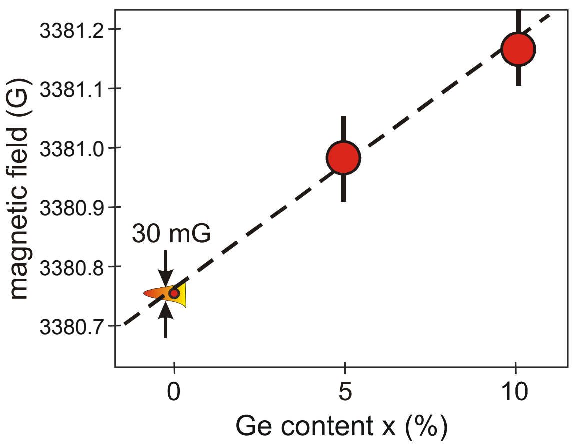

Fig. 4: Change of g-factor of the two-dimensional conduction electrons as a function of Ge-content in the quantum well.

In pulsed-ESR (spin echo) experiments in a comparable sample [3], it was found that the spin-lifetime T_1 (longitudinal relaxation time) and the phase memory time T_2 (transverse time) are both in the order of microseconds (see Fig. 3) [4]. This is two orders of magnitude longer than the length of the microwave pulses used to flip the spins. A typical π-pulse, which flips a spin by 180°, is 10 ns long. Consequently, many coherent spin operations are possible.

The g-factor for the electrons in Si (g = 1.998) and Ge (g = 1.563) is significantly different. Since for a quantum computer [2] it would be useful to change the g-factor and therefore the position of the resonance in a CESR experiment, we grew samples with $Si_{1-x}Ge_x$ quantum wells for the electrons with x = 0.05 and x = 0.1. In these samples, a clear shift of the g-factor could be observed (see Fig. 4), although in this first attempt the line width of the CESR signal was significantly increased.

Conclusion

We have demonstrated the growth of high mobility modulation-doped Si quantum wells with spin lifetimes in the range of microseconds. Furthermore, first steps towards the manipulation of these spins have been made with promising results.

References

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