Device Processing for Spintronics Applications

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The SiGe material system is a promising candidate for solid-state spintronics application due to its very long relaxation lifetimes and compatibility to standard Si device processing technology. We investigate the possibilities of g-factor tuning of conduction electrons in SiGe heterostructures as proposed for spin transistors. The g-factor dependence on the Ge content in SiGe quantum wells was investigated, showing promising results. Devices for demonstrating a high enough shift of the electron g-factor to bring electrons in and out of resonance with an external microwave field - thus allowing spin manipulation - are being developed.

Introduction

Recently, the new area of spintronics has attracted great attention in connection with quantum computing. Vrijen et al. [4] proposed the use of Si/SiGe heterostructures as spin transistors for a quantum computer, in which the spins of electrons in a quantum well act as qubits. Our experimental results revealed long spin coherence times of several µs [1], [2] in this material system. One of the key requirements for qubit operation is the ability of tuning the electron g-factor, hence bringing electrons into and out of resonance with an applied microwave frequency magnetic field.

Experimental

g-factor Dependence on the Ge Content in SiGe Quantum Wells

An important issue for the realization of spintronics in the SiGe material system is a sufficiently strong dependence of the electronic g-factor on the Ge content in the SiGe quantum wells. To investigate this, we have grown SiGe quantum wells with 3 different Ge contents (0%, 4%, and 9.5%) on relaxed SiGe buffers with SiGe barriers (Ge content between 19 and 25%). The samples were modulation-doped with Sb after growth of a spacer layer on top of the quantum well. Low-energy Rutherford backscattering experiments [3] were performed to measure the exact Ge contents of the barriers and wells as well the thicknesses thereof.

Electron spin resonance (ESR) [3] experiments reveal sharp resonances and g-factor shifts that clearly separate the ESR resonances. The g-factor dependence (see Fig. 1) is found to be linear in the investigated Ge content range.

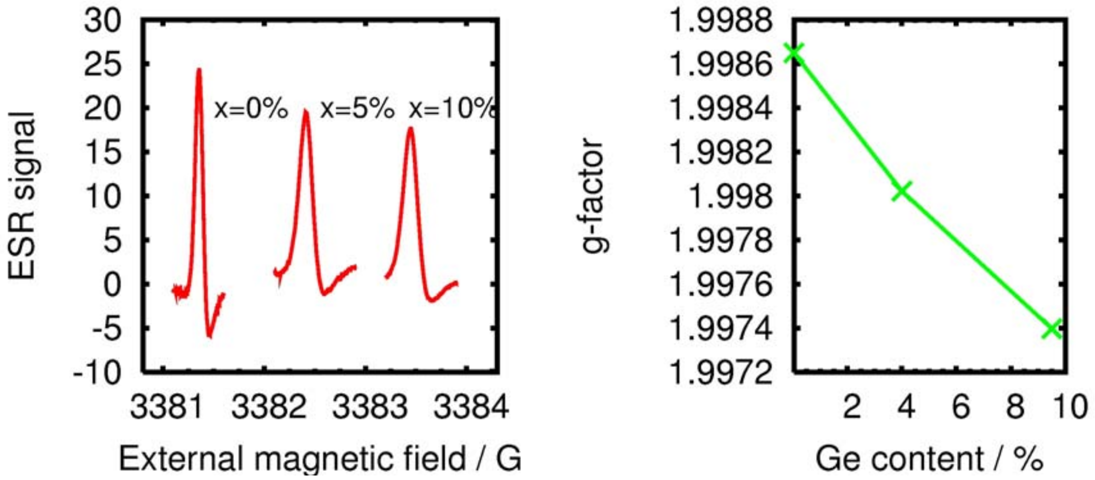

Fig. 1: Electron spin resonance lines for the three samples investigated for in-plane magnetic field (left). The corresponding g-factors are shown on the right.

Self Consistent Simulations

Using data from [3], our simulations [5] show that it should be possible to reach a large enough electron g-factor shift in a suitable Si/SiGe quantum well structure. This is achieved by applying electrical fields on both top and bottom gates of the structure, shifting the wave function to areas with different Ge content while keeping the carrier density constant. Figure 2 shows the simulated electron wave function in the ground state for two different gate voltage sets in the proposed structure. The estimated change of the electron g-factor is sufficiently large to clearly separate the resonance frequencies in an ESR experiment, thus allowing spin manipulation in a pulsed ESR experiment.

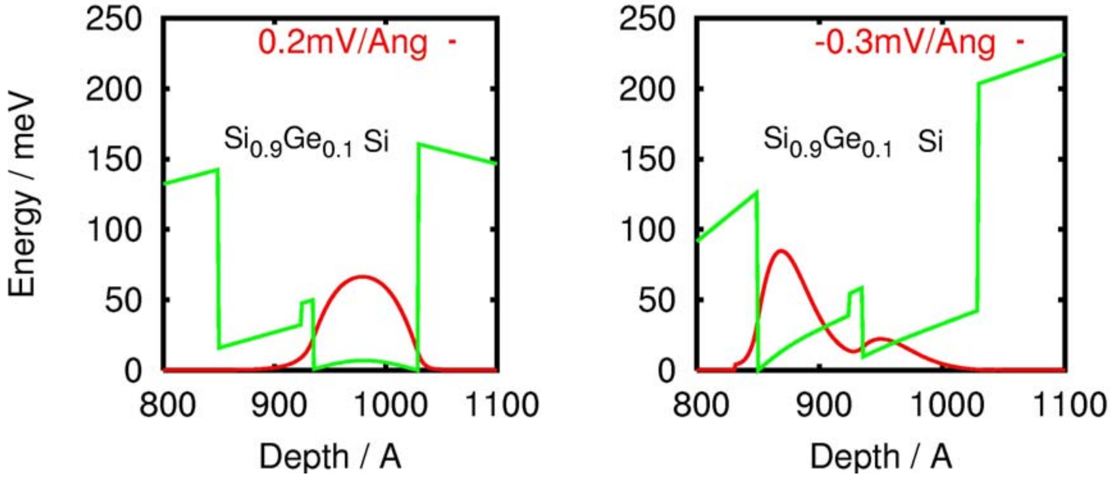

Fig. 2: Simulated electron wave function of the ground state in the region of the proposed SiGe double quantum well structure for different top and bottom gate voltages. The wave function can be shifted from the Si part to the SiGe part, hence changing the g-factor of the electrons. The carrier density is constant and only the ground levels of the quantum wells are populated.

Device Processing

For the experimental demonstration, Si quantum wells and the simulated SiGe double quantum well structure with SiGe barriers with Ge contents between 25 and 30% were grown on graded SiGe buffers. The layers are low temperature modulation-doped with Sb and have a thick, highly p-doped layer beneath the graded buffer, which acts as a bottom gate. For the samples a special mask with a small Hall-bar structure for transport measurements and larger areas for ESR measurements together with the contacts for both top and bottom gate was designed. The ohmic contacts are implanted with As and annealed. For the top gate a Pd Schottky gate and for the bottom contact annealed Al contacts are used. So far, the samples have been characterized and the process has been established. I-V curves of top and bottom gates on the processed samples work as expected (see Fig. 3 (a)). Figure 3 (b) shows the variation of the carrier density as a function of the top gate voltage.

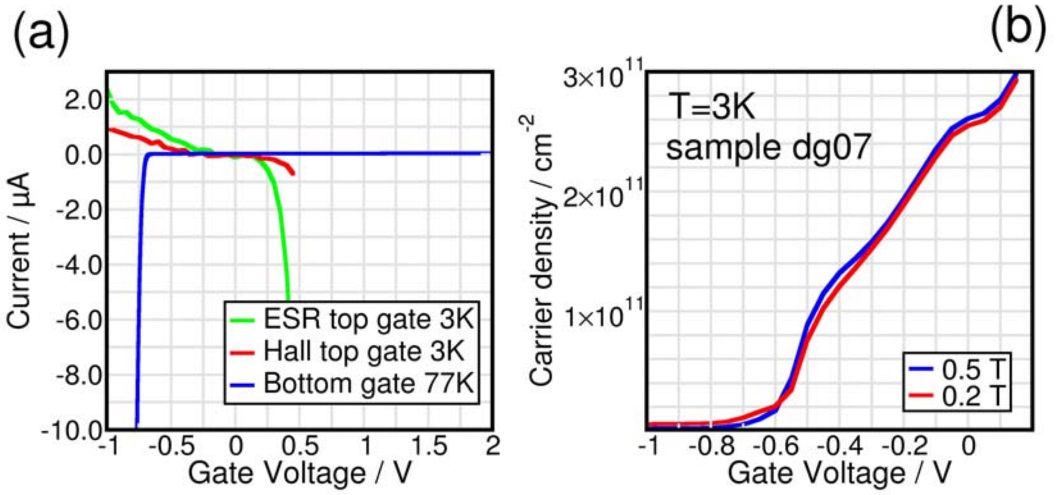

Fig. 3: I-V curves for the processed gates (left). Influence of top gate voltage on the carrier concentration in a Si quantum well structure without bottom gate measured *in-situ* (right). The channel can be fully depleted.

Additionally, a Bruker X-band ESR machine was adapted to allow in-situ electrical measurements. For this a special sample holder (see Fig. 4) and a computer-controlled goniometer were designed and built.

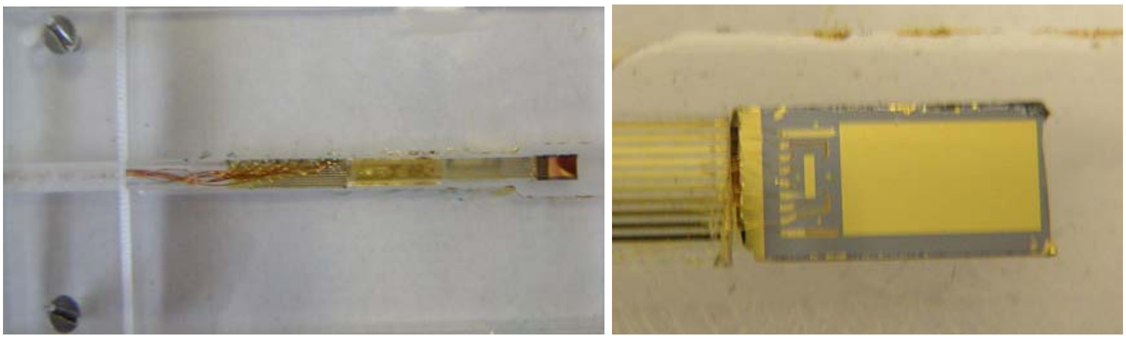

Fig. 4: ESR sample holder with mounted sample (left). The part reaching into the cavity is made of quartz with Au leads out of the cavity. On the sample (right) the large top gate for the ESR structure can be seen.

Conclusion

We investigated the dependence of the electron g-factor of conduction electrons on the Ge content in SiGe quantum wells. The resonances found are very sharp and well separated with respect to the Ge content. The promising results are used to develop devices that will give us the possibility to change the g-factor of the electrons in the quantum wells, thus allowing selective spin manipulation by pulsed Electron Spin Resonance techniques.

Acknowledgements

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