Strained Silicon Two-dimensional Electron Gases On Commercially Available $Si_{1-x}Ge_x$ Relaxed Graded Buffers

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In this work, we describe the growth of two-dimensional electron gas (2DEG) structures in strained Si on commercially available SiGe relaxed graded buffers with 20% Ge fraction. Most work to date on 2DEG's focuses on x=0.3 and above for larger conduction band offsets. In this work we demonstrate the suitability of commercially available relaxed buffers for these structures, for eventual quantum computing applications based on the spin of electrons in Si (1). The use of commercially available buffers is desirable because of their very high quality and because it is often difficult for a single system to grow both the thick buffer and the thin precise layers for 2DEG's. 20% Ge buffers are used because higher Ge fractions are not easily commercially available. The modulation of the electron gases we grow using atomic layer deposited (ALD) Al_2O_3 is also demonstrated.

Growth of 2DEG's On SiGe Relaxed Graded Buffers

The relaxed buffers were grown at 1100 ^oC. They had very low threading dislocation density ($<10^5$ cm^{-2}) and dislocation pileup density (<1 cm^{-1}) (2). Following an 800 ^oC bake in hydrogen for cleaning, a thin SiGe buffer was grown by rapid thermal chemical vapor deposition followed by the modulation doped Si/SiGe heterostructure. The 2DEG resides in a 10-nm strained Si channel. A 10-nm phosphorus doped $Si_{0.8}Ge_{0.2}$ layer is separated from the channel by an undoped 10-nm $Si_{0.8}Ge_{0.2}$ spacer layer. A 4-nm Si cap was grown on top of the structure. The Si and SiGe layers were grown at 700 ^oC and 625 ^oC, respectively.

Hall bars are etch defined and Ohmic contacts are made to the 2DEG by Au/Sb evaporation and subsequent annealing at 380 ^oC. At 0.3K, clear Shubnikov-de Haas oscillations were observed (Fig.1) indicating a 2-D gas. The mobility and electron density of a typical 2DEG are 10,000 cm^2/Vs and 1.7×10^{12}cm^{-2}. At present, the mobility in these samples is limited by the high background phosphorus doping ($>10^{17}$cm^{-2}), which also contributes to the 2D density. Work is in progress to reduce the background impurity by switching the Si precursor as this is not related to the substrates.

Modulation of 2DEG's With Al_2O_3 Gate Dielectric By ALD

We also show the successful gating of these Si/SiGe 2DEG by growing high-κ gate dielectric material (Al_2O_3) with atomic layer deposition (ALD) (3). The modulation of electron density in the Si/SiGe 2DEG is of great interest because modulation with a nano-patterned gate could form quantum dots from the remaining electrons in undepleted regions. However, it is difficult to reduce the leakage current from surface Schottky gates

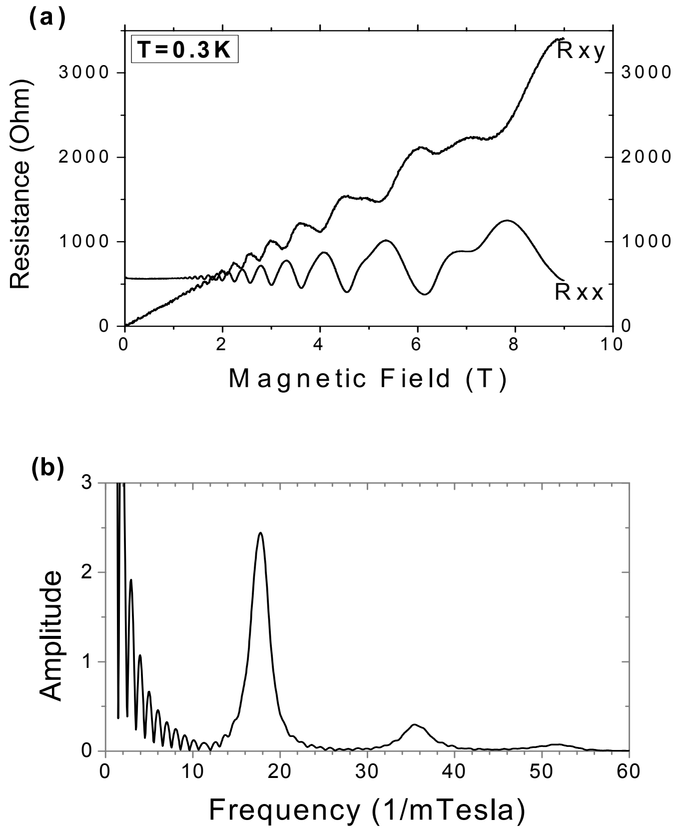

Figure 1. (a) Longitudinal and transverse resistance of the 2DEG at 0.3K. (b) The Fourier spectrum of the SdH oscillations in Rxx. The main peak shows only a single subband is filled, and Zeeman splitting at high magnetic field creates the second peak.

on top of 2DEG (4). Our gate shows very low leakage as well as the ability to manipulate electron density. A 40-90 nm Al_2O_3 was deposited on a predefined Hall bar at 300 ^oC. An Al gate is defined by lift-off on the gate dielectric (Fig.2). At 4.2K, the resistance of the Hall bar and the gate leakage were measured as a function of the gate voltage. The longitudinal resistance increased by an order of magnitude when a negative bias was applied. This indicates a great reduction in the electron density in the channel. Most critically, the leakage current is very low (<25 pA) within the entire scan range (Fig. 3).

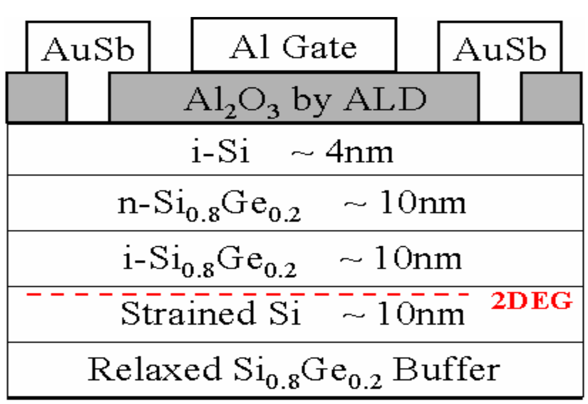

Figure 2. Cross-sectional schematic of the device structure.

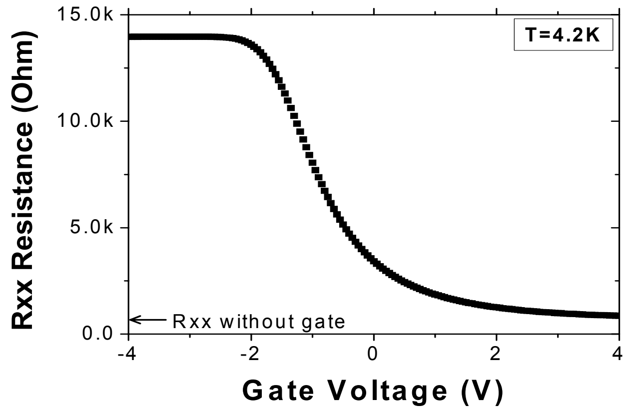

Figure 3. Hall bar Resistance measurement as a function of the gate voltage.

Conclusion

In conclusion, we have demonstrated the growth of Si/SiGe 2DEG on commercially available SiGe relaxed graded buffers. We anticipate that reducing the background concentration will further improve the mobility. Combining these structures with top-gates should enable Si-base quantum dots for quantum computing applications.

Acknowledgments

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