Low Disorder and High Mobility 2DEG in Si/SiGe Fabricated in 200 mm BiCMOS Pilot line

Alberto Mistroni, Felix Reichmann, Yuji Yamamoto, Marvin Hartwig Zöllner, Giovanni Capellini, Laura Diebel, Dominique Bougeard and Marco Lisker

ECS Meeting Abstracts, Volume MA2024-02, G03: SiGe, Ge, and Related Compounds: Materials, Processing, and Devices 11: In Memory of Qizhi Liu

Citation Alberto Mistroni *et al* 2024 *Meet. Abstr.* **MA2024-02** 2320

DOI 10.1149/MA2024-02322320mtgabs

Abstract

In 1997, Loss and DiVincenzo proposed that the fundamental unit of a quantum computer, the quantum bit, could be physically encoded as the spin of a single electron confined within a semiconductor quantum dot. Since then, silicon-based spin qubits have emerged as a leading platform for the advancement of large-scale quantum computation systems [1]. Silicon-based spin qubits present notable advantages, including extended coherence times and high fidelities, due to weak spin-orbit coupling and hyperfine interactions. Additionally, their compatibility with complementary metal-oxide-semiconductor (CMOS) technologies enables the efficient fabrication of numerous physical qubits on a single quantum chip. However, the production of complex quantum circuits, such as multi-qubit quantum processors, requires all quantum dot devices to be as uniform and consistent as possible. This is a crucial condition for practical control and manipulation of the qubits. Hence, comprehensive characterization of quantum devices and heterostructures quality becomes imperative for the scalability of spin qubit technology.

Hall bar shaped FETs fabricated on the heterostructures provide a practical platform for extensive material stack characterization, their relatively large area facilitates efficient assessment of material uniformity. Most importantly, magneto-transport measurements of Hall bars allow for the extrapolation the figures of merit that indicate the quality of 2D electron gas (2DEG), that is directly related to quantum dot quality eventually fabricated on such heterostructure. [2,3]. High density mobility, constrained by scattering from within and around the quantum well [4,5], measures disorder in high-density regimes, while percolation density probes disorder in low-density regimes, which is where quantum dots operate. These are two of the main relevant metrics assessing device quality.

This study investigates the properties of the 2DEG within a Si/SiGe heterostructure through magneto-transport measurements conducted at cryogenic temperatures. Our hall bar-shaped FET were fabricated entirely using the IHP 200 mm BiCMOS pilot line, demonstrating complete compatibility with industry standards.

The heterostructure under examination comprises a 7 nm Si quantum well and a 35 nm $Si_{0.66}Ge_{0.34}$ barrier, grown via reduced pressure chemical vapor deposition (RP-CVD) on 200 mm Si wafers with an optimized buffer structure. A notable advancement compared to prior studies is the complete consumption of the epitaxial Si-cap of the heterostructure and the utilization of a low-temperature, high-density plasma SiO_2.

Our findings reveal that the heterostructure exhibits a remarkable low percolation threshold density of 6.3×10^{10} cm^{-2}, and a high maximum mobility μ of over 320000 cm^2/Vs (figure 1), suggesting a low disorder and good scattering properties of the 2DEG. These measurement outcomes underscore the

high quality achieved by IHP's optimized heterostructure compared to similar state-of-the-art studies [3]. In figure 1a, the fitting of the mobility power-law density dependence confirms that scattering from impurities inside or close the quantum well to be the main limiting mechanism of mobility in high density regimes ($\mu \propto n^{0.3}$), while remote impurities scattering hinders mobility in the low density ($\mu \propto n^{2.1}$) [4,5]. This, combined with low percolation threshold density indicates the high quality of the interface formed between the SiGe top barrier and the HDP Si oxide in our heterostructure. To assess additional metrics relevant to spin qubit operation, we also investigate our device at 300 mK and discuss the results.

Finally, density measurements on our uncapped heterostructure confirm the absence of secondary channel formation at higher gate voltages, consistent with observations in the literature on standard heterostructures with a Si cap layer [6].

These results motivate further in-depth investigation of the properties of these heterostructures to characterize other important parameters relevant for spin qubit applications.

This work is part of the joint project QUASAR "Halbleiter-Quantenprozessor mit shuttlingbasierter skalierbarer Architektur" and is supported by the German Federal Ministry of Education and Research.

[1] Philips, S.G.J., *et al.* Universal control of a six-qubit quantum processor in silicon. *Nature* 609, 919–924 (2022).

[2] Davide Degli Esposti, *et al* Wafer-scale low-disorder 2DEG in 28Si/SiGe without an epitaxial Si cap. Appl. Phys. Lett. 2 May (2022).

[3] Degli Esposti, et al. Low disorder and high valley splitting in silicon. npj Quantum Inf 10, 32 (2024).

[4] Mi, X. *et al*, Magnetotransport studies of mobility limiting mechanisms in undoped Si/SiGe heterostructures, Phys. Rev. B 92, 035304 (2015).

[5] D. Laroche, *et al*; Scattering mechanisms in shallow undoped Si/SiGe quantum wells. AIP Advances 1 October 2015; 5 (10): 107106.

[6] Di Zhang *et al* 2023 *J. Phys. D: Appl. Phys.* **56** 085302.

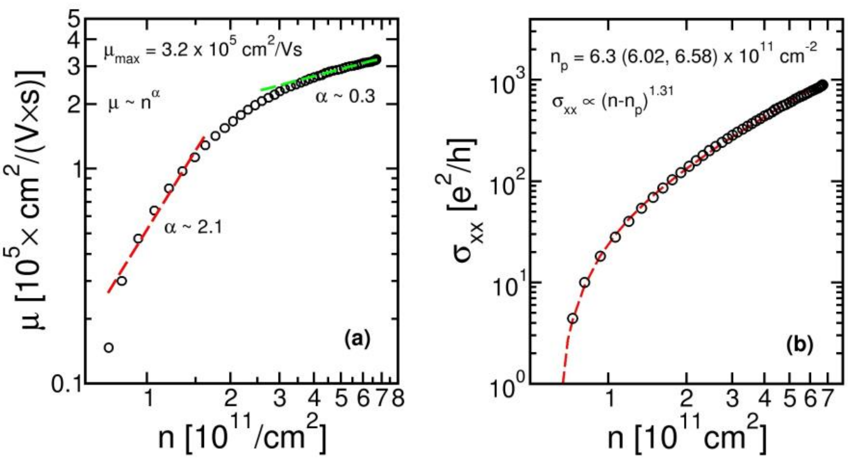

Figure 1 Electrical transport measurements performed at 1.5 K. **a)** log-log plot of mobility μ as a function of density n. Red and green lines are the fitting of the mobility power-law density dependence ($\mu \propto n^{\alpha}$) where we calculated α~2.1 in the low density regime and α~0.3 in the high density regime. **b)** Longitudinal conductivity σ_{xx} plotted as function of density n. Red line represent the percolation density fit in the low density region $\sigma_{xx} \propto (n-n_p)^{1.31}$ with $n_p = 6.3\ (6.02, 6.58) \times 10^{11}\ cm^{-2}$.

Figure 1