Atom-by-atom tomography of isotopes in semiconductor spin qubits

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Semiconductor quantum-wells are a promising material basis for the large-scale fabrication of spin qubits and their monolithic integration with CMOS-electronics [1]. Fabricating spin-qubits that have long decoherence times and can be efficiently controlled in large numbers necessitates that the quantum-well is free of a background spin baths and that its interfaces are close to atomically sharp and well [1,2].

Measuring the atomic scale roughness of buried interfaces and mapping the distribution of isotopes on the nanometer- or near-atomic scale is challenging but needed to support the development of these qubit devices. Interactions utilized in common techniques like electron-, X-ray- or scanning probe microscopy are not sensitive to isotopes and hence cannot image isotopes in standard operation [3,4]. Furthermore, tomographic techniques are needed to resolve the atomic structure in three dimensions and allow for the mapping of buried interfaces [5,6].

Here we will show that Atom Probe Tomography can provide the necessary metrology support to develop spin qubit materials. Working with quantum-wells used in qubit devices [7], we will showcase the mapping of interfaces at the near atomic scale [8] and the probing of the isotopic purity of these heterostructures with close to parts per million sensitivity and hence down to a level where the majority to of electrically defined silicon or germanium quantum dots are expected to contain one or less spin-full nuclei.

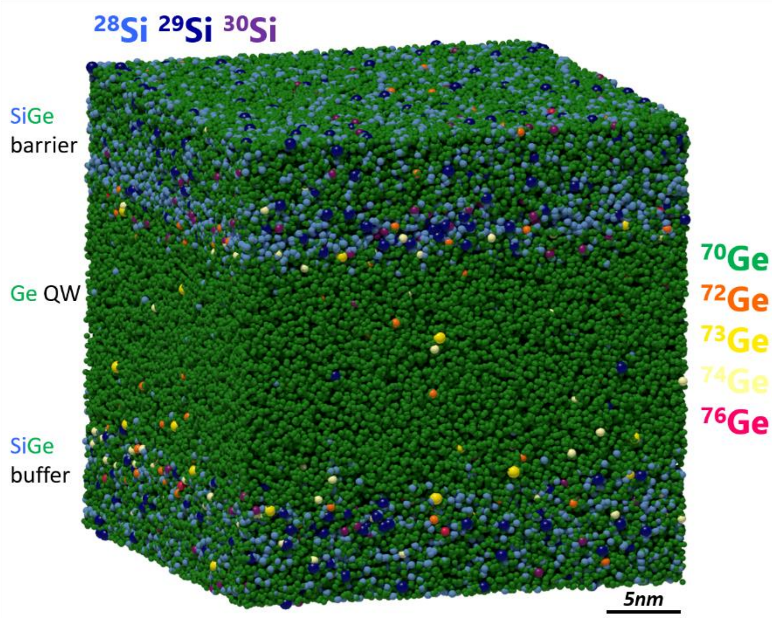

Fig.1. APT data from a Ge quantum well with SiGe barriers epitaxially grown with precursors purified in ^{28}Si and ^{70}Ge. Note the scarcity of the spin-full ^{73}Ge nuclei in the quantum well [9].

References

[1] Scappucci et al., Nat. Rev. Mat., **6** (2021) 926
[2] Philips et al., Nature, **609** (2022) 919
[3] Susi et al., Nat. Commun., **7** (2016) 13040
[4] Cannara et al., Science, **318** (2007), 780
[5] J. Miao et al., Science **348**, (2015) 530
[6] J. Miao et al., Science **353**, (2016) 1380
[7] Paquelet Wuetz et al., Nat. Commun., **13** (2022) 7730
[8] Koelling et al., Adv. Mater. Interfaces, **10** (2023) 2201189
[9] Moutanabbir. et al., Adv. Mater., **36** (2024) 2305703