Atomic-scale tomography of isotopically purified group-IV materials for qubit integration

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Electrostatically defined quantum dots in isotopically purified group IV quantum wells are one of the most promising qubit technologies [1, 2]. Their small size of a few 10nm and straightforward integration with CMOS-technology makes them the most promising candidates for the monolithic integration of qubits and classical bits and hence scalable hybrid classical-quantum computing systems [3, 4].
Mapping the distribution of the isotopes in the nano-structured materials used to fabricate these qubits is unfortunately challenging as the typical 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 [5-7].
Here we show that Atom Probe Tomography can be used to probe isotopic purity in nanostructures down to the parts-per-million level and hence down to a level were the majority to of electrically defined silicon or germanium quantum dots are expected to contain one or less spin-full nuclei [8, 9].
Furthermore, the three-dimensional maps generated from detecting single atoms during Atom Probe Tomography, as exemplary shown in Figure 1, make it possible to evaluate the quality and topography of interfaces between layers of different material and different isotopic compositions at the sub-nm scale.
Finally, we will show that we can use the information gained from the atomic-scale tomography to seed models for quantum-simulations of the respective qubits [10].

References

[1] Scappucci et al., Nat. Rev. Mat., 6 (2021) 926
[2] Philips et al., Nature, 609 (2022) 919
[3] Veldhorst et al., Nat. Commun., 8 (2017) 1766
[4] Charbon et al., IEEE IEDM San Francisco, USA (2016) 13.5.1
[5] Susi et al., Nat. Commun., 7 (2016) 13040
[6] Neilson et al., Philos. Trans. Royal Soc. A 359 (2001) 1575
[7] Cannara et al., Science, 318 (2007), 780
[8] Gault et al., Nat Rev Methods Primers, 1 (2021) 51
[9] Koelling et al., Nano Lett. 17 (2017) 599
[10] Paquelet Wuetz et al., Nat. Commun., 13 (2022) 7730

Figures

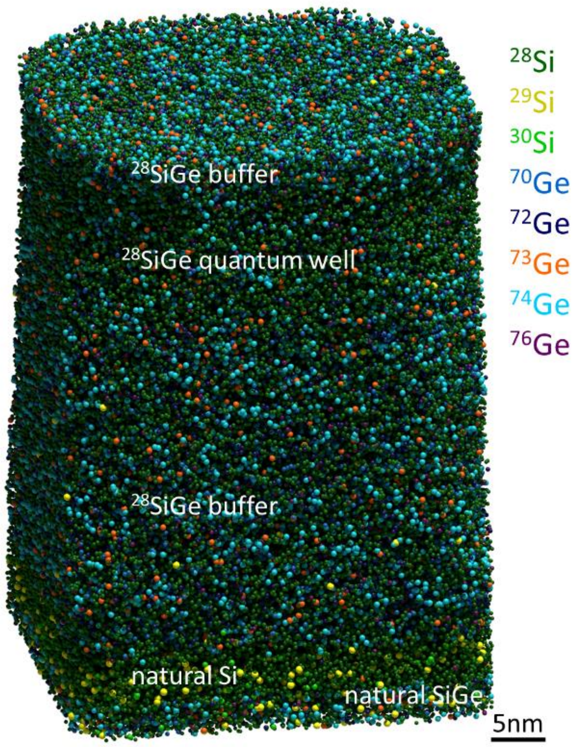

Figure 1: Atom Probe Tomography analysis of a quantum well grown sandwiched between silicon germanium buffers grown with ^{28}Si enriched Silicon.