

Germanium Planar Quantum Structures: Isotopic Purification and Optical Activity

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Hole-based qubits hosted in Ge-based quantum dots have emerged as a promising system for scalable quantum processors. However, recent experimental results demonstrated that nuclear spin bath contributes significantly to dephasing, setting an approximate T_2^* bound of $\sim 1 \mu\text{s}$ under their natural isotopic composition. Eliminating this hyperfine-limited decoherence requires the development of nuclear spin-free heterostructures. Here, we report the realization of isotopically purified quantum-grade $^{70}\text{Ge}/^{28}\text{Si}^{70}\text{Ge}$ planar heterostructures and describe their structural and transport characteristics based on through atom probe tomography (APT) and low-temperature magneto-transport analyses [1].

In addition to the ability to remove nuclear spin-full isotopes, group IV materials also offer additional degrees of freedom to engineer a variety of heterostructures leveraging the tunability of lattice strain and composition [2,3]. Herein, by incorporating tin (Sn) in Ge lattice, we demonstrate the formation of strain-engineered heavy-hole heterostructures with a direct bandgap [2]. We present a comprehensive structural characterization of these GeSn-based systems using APT, transmission electron microscopy (TEM), and X-ray diffraction (XRD). Temperature-dependent photoluminescence (PL) measurements, combined with k.p modeling, are employed to assess the bandgap directness. The ability to control hole spin confinement in this optically active quantum structure enables a unique platform to implement spin-qubit-optical photon interfaces for quantum processor networking and communication.

References

- [1] P. Daoust et al., *Advanced Science*, In press (2026); arXiv:2511.01916.

- [2] N. Rotaru et al., *Phys. Rev. B* 112 (2025) 125428.

- [3] S. Assali et al., *Adv. Mater.* 34 (2022) 2201192.

Figures

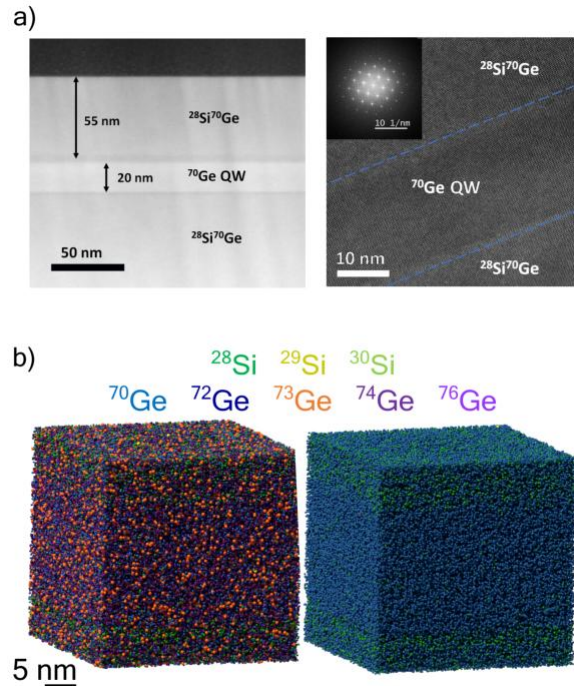


Figure 1: a) TEM of isotopically purified quantum wells. b) Three-dimensional Atom Probe Tomography reconstruction of a $\text{Ge}^{\text{Nat}}/\text{Si}^{28}\text{Ge}^{\text{Nat}}$ quantum well (left) and a fully isotopically purified $\text{Ge}^{70}/\text{Si}^{28}\text{Ge}^{70}$ QW (right).

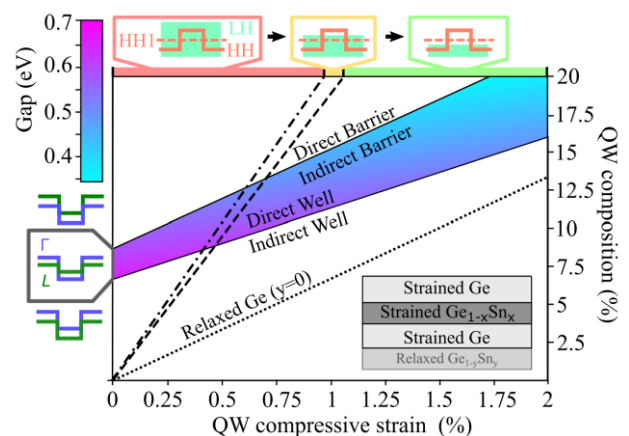


Figure 2: Valence and conduction band alignment in the $\text{Ge}_{1-x}\text{Sn}_x/\text{Ge}$ heterostructure. The absence of a direct bandgap for growth on relaxed Ge highlights the necessity of strain engineering.