Light-Hole Spin-Orbit Qubit in Germanium

Patrick Del Vecchio
Nicolas Rotaru
Anis Attiaoui
Simone Assali
Samik Mukherjee
Oussama Moutanabbir

Polytechnique Montreal, 2500 Chem. De Polytechnique, Montreal, Canada

oussama.moutanabbir@polymtl.ca

Holes in Germanium (Ge) attract a great deal of attention due to their numerous attractive properties for the realization of quantum processors. Notably, they have proven to be extremely effective for encoding and manipulating quantum information. [1] In contrast to electrons, hyperfine interactions are weaker for holes, which enables longer relaxation and dephasing times. Moreover, spin-orbit coupling effects are larger for holes, which leads to fast all-electrical spin-manipulation schemes such as electric-dipole spin resonance (EDSR).
EDSR has been demonstrated in Ge quantum wells, nanowires, and hut wires, and is especially convenient in gate-defined quantum dots because the driving field can be applied through the same gates that define the dots. Heavy-holes have been the center of attention regarding studies of EDSR in gated quantum dots due to material limitations and their large out-of-plane effective mass which favors them to the ground state. However, a novel type of two-dimensional hole gas consisting of light-holes can be achieved by applying a significant amount of tensile train (>1%) to the quantum well. [2] A light-hole based quantum device benefits of an effective transfer of quantum information from a photon to a spin.
This work proposes a new qubit design leveraging the properties of light-hole spins in highly tensile strained Ge quantum wells grown epitaxially on silicon wafers using GeSn as barriers [2]. A perturbative framework describing Rabi-flopping and relaxation time of a light-hole spin in a parabolic isotropic gate-defined quantum dot is derived from 8-band k·p theory. An analysis of the Rabi frequency shows that light-holes can be manipulated 2 to 3 orders of magnitude faster than heavy-holes, thanks to a constructive interference between two kinds of Rashba spin-orbit effects exclusive to light-hole systems. The relaxation time is also found to scale as B^7 in most cases. The framework is suitable for any out-of-plane confining potential. Ongoing work focuses on describing rabi-flopping in different magnetic field configurations as well as different LH qubit-optical photon coupling mechanisms.

References

[1] N.W. Hendrickx *et al.*, Nature, **591** (2021) 580
[2] S. Assali *et al.*, Adv. Mater., **34** (2022) 2201192
[3] P. Del Vecchio *et al.*, arXiv:2211.10514 (2023)

Figures

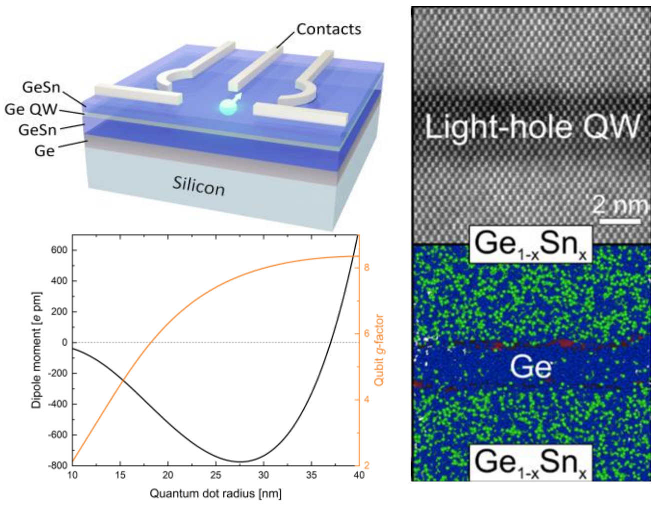

Figure 1: Top: schematic of a gated LH quantum dot in Ge. Bottom: dipole moment and g-factor of a light hole qubit. Right: TEM+APT