Modelling of Thermally-Activated Dipoles in Silicon Spin Qubits

G. Boschetto[1]
V. Champain[2], S. De Franceschi[2], Y.-M. Niquet[3], B. Brun[2], B. Martinez[1]

[1]Univ. Grenoble Alpes, CEA, Leti, F-38000, Grenoble, France
[2]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France
[3]Univ. Grenoble Alpes, CEA, IRIG-MEM-L_Sim, 38054, Grenoble, France

gabriele.boschetto@cea.fr

Quantum-dot-based spin qubits have attracted considerable attention recently due to their advantages over other qubit types, such as superconducting qubits [1]. Among their key strengths are the ability for large-scale integration and co-integration with classical microelectronics. Moreover, these qubits are small, which allows for a higher density of qubits on a single chip.

A major challenge of spin qubits is their sensitivity to charge noise, which causes decoherence. The manipulation of spin often relies on precise electrical control through spin-orbit coupling (SOC) mechanisms [2,3], which also makes them vulnerable to electrical noise in their environment [2]. Additionally, if electric fields vary with temperature, the qubit properties also become sensitive to it.

Here, we focus on investigating heating effects in silicon spin qubits, which have been shown to cause systematic drifts in the Larmor frequency [4]. While the physical origin of such drifts is yet to be fully understood, empirical models involving the activation and deactivation of dipoles at cryogenic temperatures have been proposed [5]. In this context, dipoles are considered as two-level fluctuators (TLFs) to which a fluctuating electric dipole moment is associated. Such local, small, electric field fluctuations may interfere with spin qubits via spin-orbit coupling (SOC) mechanisms, thus leading to frequency shifts on the order of ~1 MHz.

In our work, we carry out device simulations using Poisson and k·p solvers on realistic device geometries. We introduce dipoles in the device and compute the dipole-induced variation of the Larmor frequency as a function of temperature. Our results suggest that for dipoles to produce experimental frequency shifts, these have to be either extremely small (on the order of picometers) or to involve the displacement of only a small fraction of a charge. Our work provides physical insights to the empirical dipole models previously proposed.

References

[1] S.G.J. Philips et al., Nature 609, 919-924 (2022)
[2] A. Crippa et al., Phys. Rev. Lett. 120, 137702 (2018)
[3] J. C. Abadillo-uriel et al., Phys. Rev. Lett. 131, 097002 (2023)
[4] B. Undseth et al. Phys. Rev. X 13, 041015 (2023)
[5] Y. Choi et al., Phys. Rev. Res 6, 013168 (2024)