Turning low and anisotropic electron *g*-factors in GaAs QDs into coherent and controlled coupling to nuclear magnons

N. Shofer[1], L. Zaporski[1], M. H. Appel[1], S. Manna[2], S. Covre da Silva[2], A. Ghorbal[1], U. Haeusler[1], A. Rastelli[2], C. Le Gall[1], M. Gawełczyk[3], M. Atatüre[1], and D. A. Gangloff[1]

[1] *Cavendish Laboratory, University of Cambridge, Cambridge, UK*
[2] *Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria*
[3] *Institute of Theoretical Physics, Wrocław University of Science and Technology, Wrocław, Poland*

GaAs quantum dots (QDs) grown by filling Al-droplet-etched nanoholes in AlGaAs have become the leading solid-state emitters of quantum light [1], with the possible shift of the emission of such QDs to the telecom bands by replacing As with Sb [2]. Entangling a QD-confined spin with a flying photonic qubit is essential for quantum communication and can be achieved in QDs. The nuclear spin environment has long been the primary decoherence source for QD-confined spins. This effect has recently been tamed by cooling spin fluctuations to an effective temperature well below the nuclear Zeeman energy [3]. Thanks to this and GaAs QD material homogeneity, the once hostile reservoir of nuclear spins can now be used as a quantum register to store entanglement with a photonic qubit [4]. All that remains is to achieve controlled coupling between the electron spin and the nuclear ensemble to effectively couple and decouple the qubit from the register on demand.

Here, we show that the apparent disadvantage of GaAs dots of low electron *g*-factor can be exploited to achieve such controlled coupling [5]. While electron *g*-factors are in-plane anisotropic in all QDs without the structural inversion symmetry, the effect becomes significant only thanks to the overall low *g*-factor values in GaAs QDs. This anisotropy, in turn, can be utilized to enable the noncollinear interaction between nuclear and electron spins in an in-plane magnetic field tilted from the main anisotropy axes. The strength of this coupling can then be tuned in situ by shifting the mean-field polarization of the nuclear spin ensemble, providing a first practical demonstration of direct control over the qubit-register interaction parameters [5].

This contribution will mainly focus on details of QD theory and modeling within the multiband $\boldsymbol{k}\cdot\boldsymbol{p}$ method, including tuning the electron *g*-factor and its anisotropy with QD morphology. Thanks to the combination of precise determination of QD structural data with the state-of-the-art implementation of the computational methods, we obtain a *g*-factor prediction that proves effective over a wide range of dot geometries and emission energies.

[1] S. F. C. da Silva, G. Undeutsch, B. Lehner, S. Manna, T. M. Krieger, M. Reindl, C. Schimpf, R. Trotta, and A. Rastelli, Appl. Phys. Lett. **119**, 120502 (2021).
[2] T. Hakkarainen, J. Hilska, A. Hietalahti, S. Ranta, M. Peil, E. Kantola, A. Chellu, E. Sen, J.-P. Penttinen, M. Guina, arXiv:2404.06083.
[3] D. A. Gangloff, G. Éthier-Majcher, C. Lang, E. V. Denning, J. H. Bodey, D. M. Jackson, E. Clarke, M. Hugues, C. Le Gall, M. Atatüre, Science **364**, 62 (2019).
[4] M. H. Appel, A. Ghorbal, N. Shofer, L. Zaporski, S. Manna, S. F. C. da Silva, U. Haeusler, C. Le Gall, A. Rastelli, D. A. Gangloff, M. Atatüre, arXiv:2404.19680.
[5] N. Shofer, L. Zaporski, M. H. Appel, S. Manna, S. F. C. da Silva, A. Ghorbal, U. Haeusler, A. Rastelli, C. Le Gall, M. Gawełczyk, M. Atatüre, D. A. Gangloff, arXiv:2404.19679.