Electron Spin Relaxation in Quantum Dots: Effect of 3D Shape

J. Planelles, J. I. Climente, C. Segarra

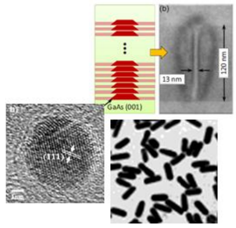
[1] Department of Physical and Analytical Chemistry, Universitat Jaume I, Castelló, Spain

E-mail: climente@uji.es

Motivation

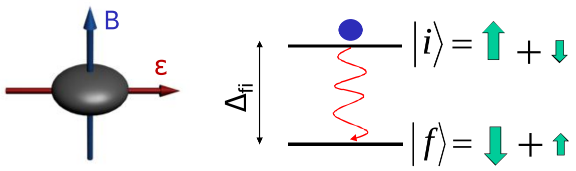
- Quantum confinement has a profound influence on the spin degrees of freedom through the spin-orbit interaction (SOI).
- This has been widely exploited for the development of spintronic and quantum information devices in 2D nanostructures [1]
- Recent synthetic and spectroscopic developments open venues for spin study in **fully 3D** quantum dot nanostructures[2-4]

• What is different from the well-known spin dynamics of 2D systems?



System and Model

We calculate the spin relaxation of electrons in spheroidal QDs



Transition mediated by acoustic phonons + SOI [5]

$$\frac{1}{T_1} = \frac{2\pi}{\hbar} \sum_{\lambda \vec{q}} \left| M_\lambda(\vec{q}) \langle f | e^{-i\vec{q}\vec{r}} | i \rangle \right|^2 \delta(\Delta_{fi} + E_q)$$

Strength of phonon electric field (either piezoelectric or deformation potential) [5]

Electron-phonon coupling

Electron Hamiltonian:

$$\hat{H} = \sum_{j=x,y,z} \left(\frac{p_j^2}{2m^*} + \frac{1}{2} m^* \omega_j^2 \, j^2 \right) + e\,\vec{\varepsilon}\,\vec{r} + \frac{1}{2}\mu g B \sigma_z + H^{SOI}$$

$$H^{SOI} = H^R + H^D$$

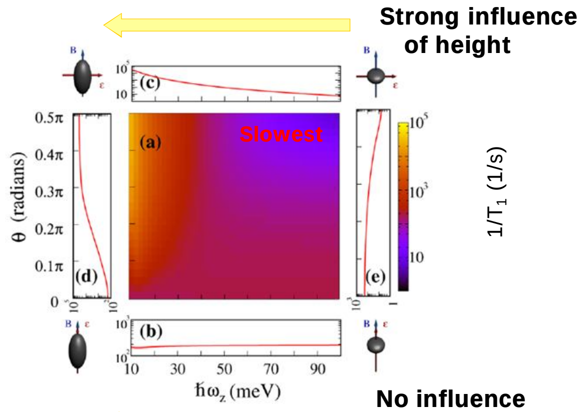
$$H^D = d\left[p_x (p_y^2 - p_z^2)\sigma_x + p_y (p_z^2 - p_x^2)\sigma_y + p_z (p_x^2 - p_y^2)\sigma_z \right]$$

$$H^R = r\,\vec{\sigma}(\vec{p} \times \vec{\varepsilon})$$

Harmonic oscillator eigenstates (analytical matrix elements)

Rashba Spin-Orbit Interaction

Strong influence of height

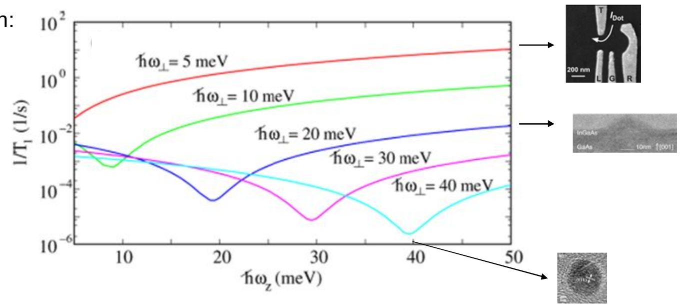


No influence of height

$$H_{mix}^R = r\left[\varepsilon_z (p_y \sigma_x - p_x \sigma_y) + \varepsilon_x p_z \sigma_y - \varepsilon_y p_z \sigma_x \right]$$

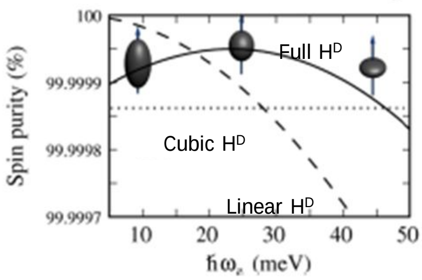
Dresselhaus Spin-Orbit Interaction

Variable heigth: (InAs, B=1 T)



Strong suppression for spherical quantum dots

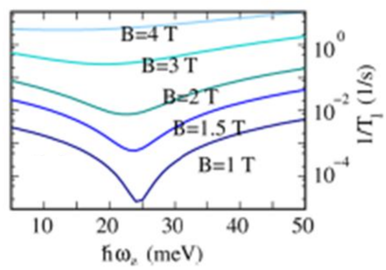
Why?



$$H_{mix}^D = d\left[p_x (p_y^2 - p_z^2)\sigma_x + p_y (p_z^2 - p_x^2)\sigma_y \right]$$

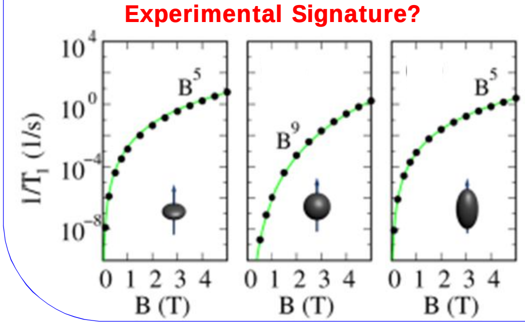
Note that: $\langle p_x^2 \rangle = \langle p_y^2 \rangle \approx \langle p_z^2 \rangle \longrightarrow \langle H_{mix}^D \rangle \approx 0$

When?



For strong fields, electron-phonon coupling rules the geometry dependence

Experimental Signature?



B^9 power law

instead of B^5, owing to suppression of linear-in-p terms in H^D

Conclusion

In a 3D nanostructure, the shape can be used to tailor the spin lifetimes by several orders of magnitude. Absolute minima are obtained for isotropic confinement [5]

References

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