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Spin-orbit mediated single heavy hole spin resonance with tunable g-factor in a lateral GaAs/AlGaAs quantum dot device

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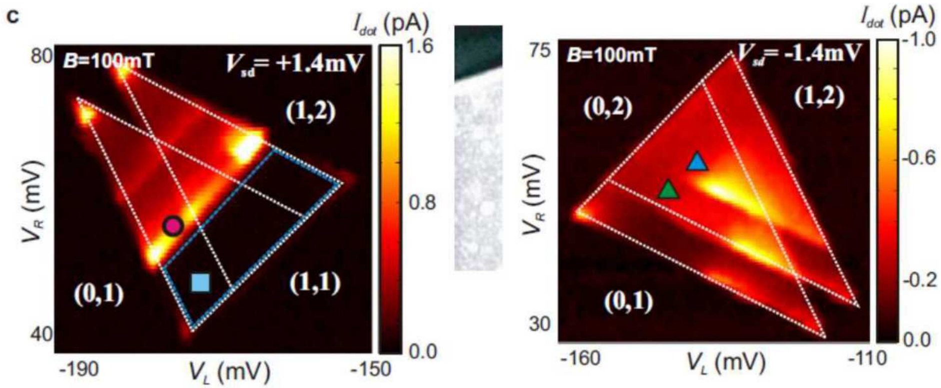
Single hole $g^*(\varepsilon)$-controlled EDSR

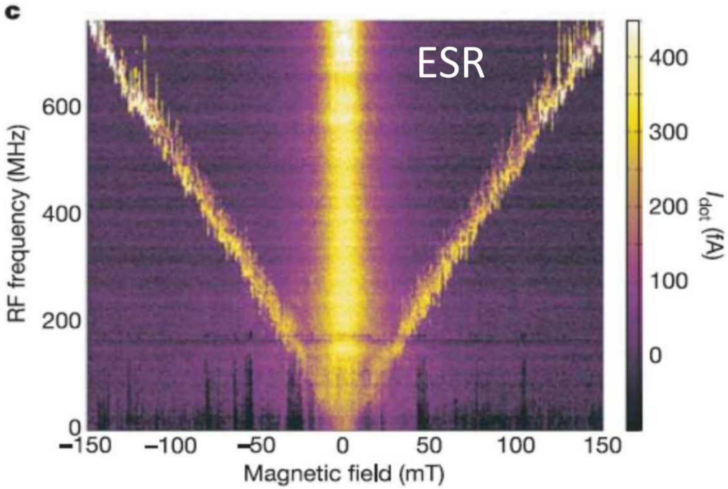
Mechanisms of electrically tunable g-factor:

1. Wave function penetration into QW barrier with different g-factors.
2. Composition gradient + soft z-confining potential, e.g. PQW (kV/cm).
3. Light-heavy hole coupling vs Vg (e.g. Voisin et al. Nano Lett . 2016)
4. Voltage-dependent g-factor, Stark shift (e.g. Veldhorst et al. Nature Nano. (2014)
5. **Spin-orbit coupling with an auxiliary QD => $g^*(\varepsilon)$**

Electron EDSR experiments in Double Quantum Dots (DQDs)

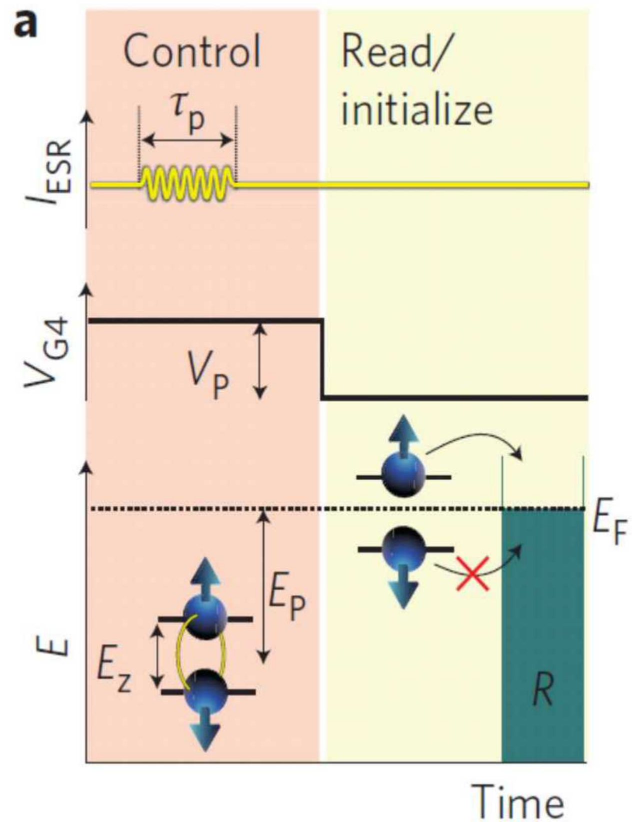
Spin-blockade readout mechanism:
Koppens et al. Nature (2006)





Electron transport

Energy-blockade readout mechanism:
Veldhorst et al. Nature Nano (2014)

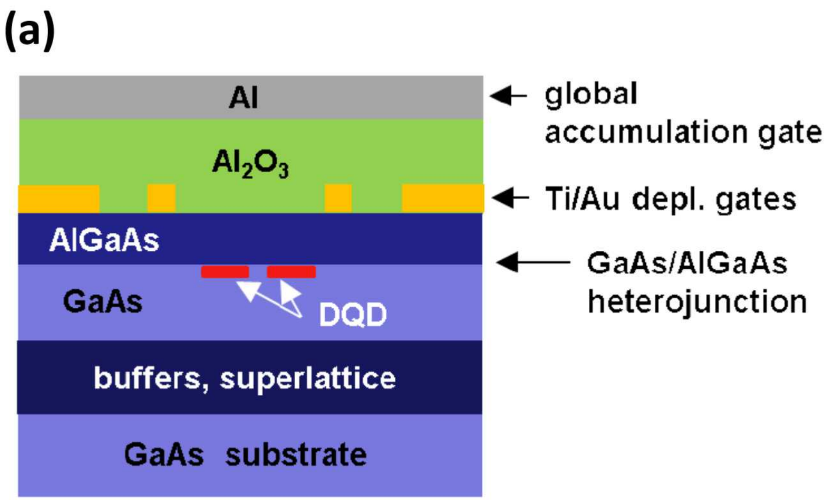


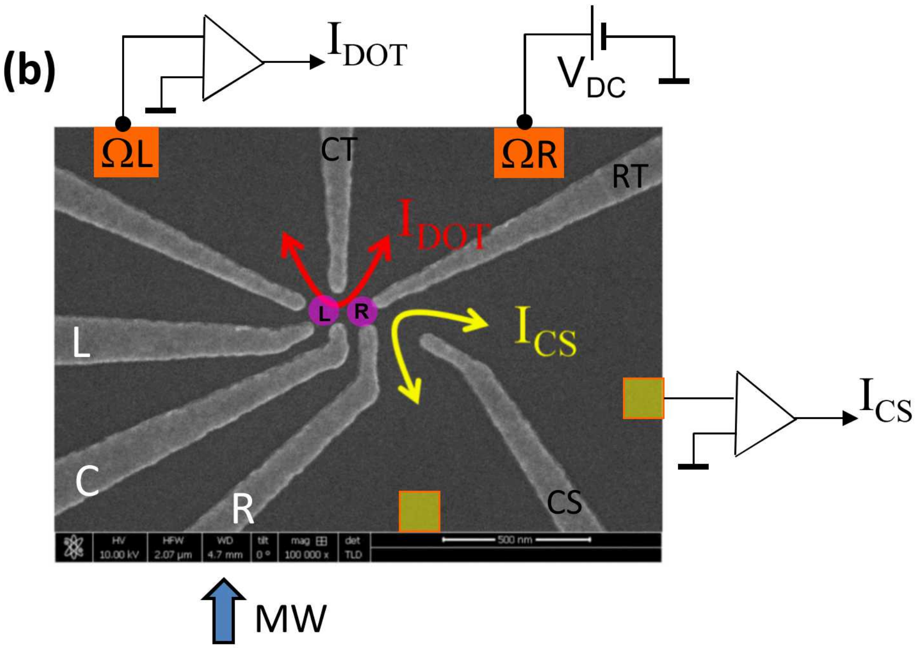
Single-shot charge sensing

This work: single hole EDSR in a DQD using transport in energy blockade regime +
g* factor control via auxiliary QD

Details of the hole Double Quantum Dot (DQD)

L. A. Tracy, et al. *"Few-hole double quantum dot in an undoped GaAs/AlGaAs heterostructure," APL, v. 104, 123101 (2014).*

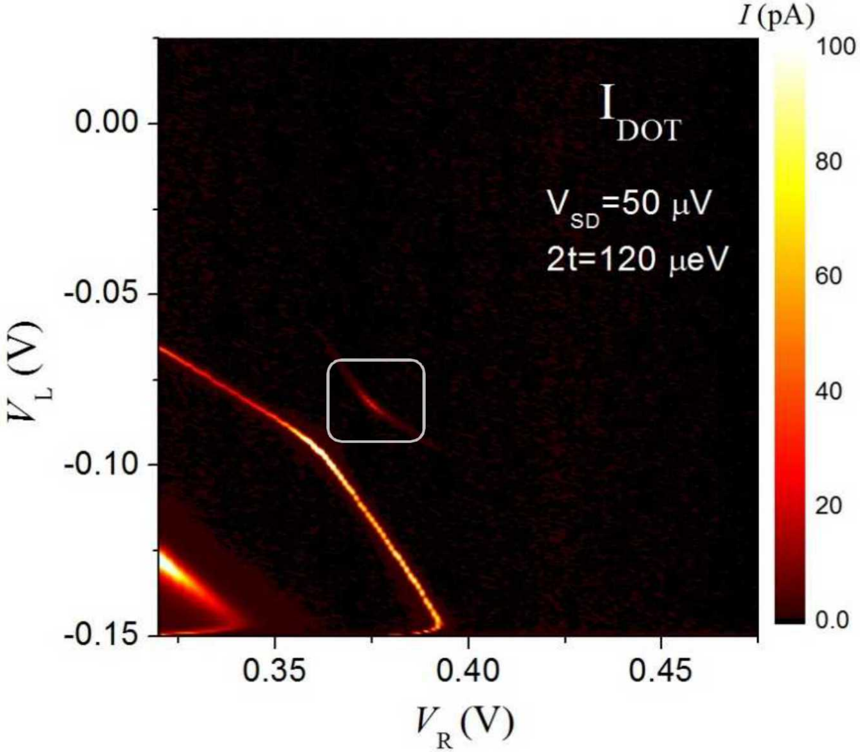




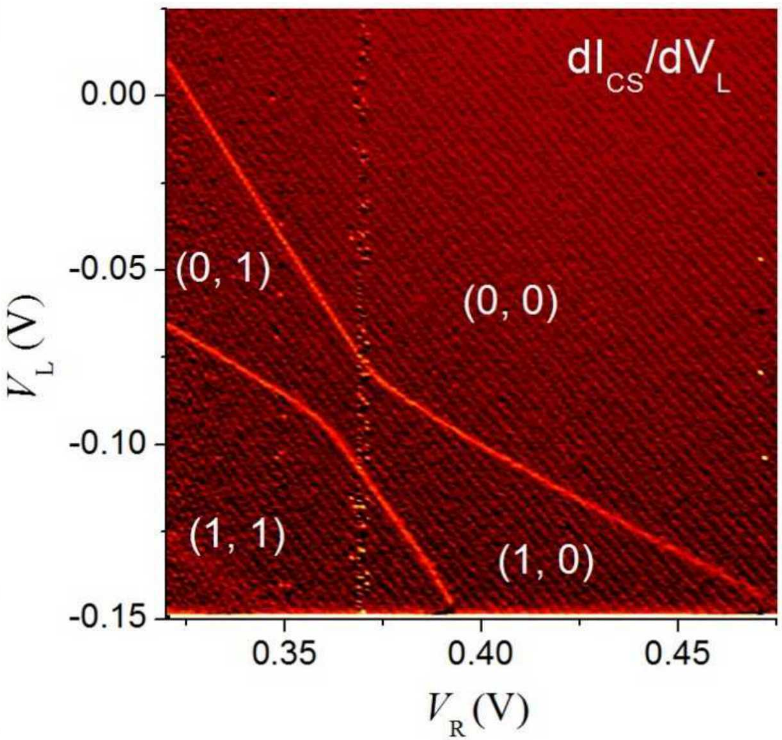
(a) Cross section, and (b) SEM image of the DQD device

Single hole regime: charge stability and current diagrams

Transport



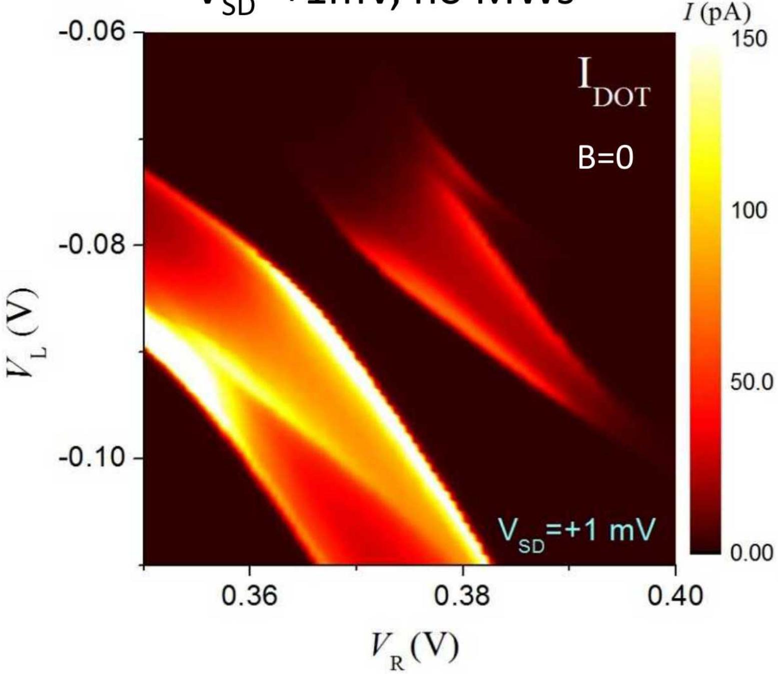
Charge sensing



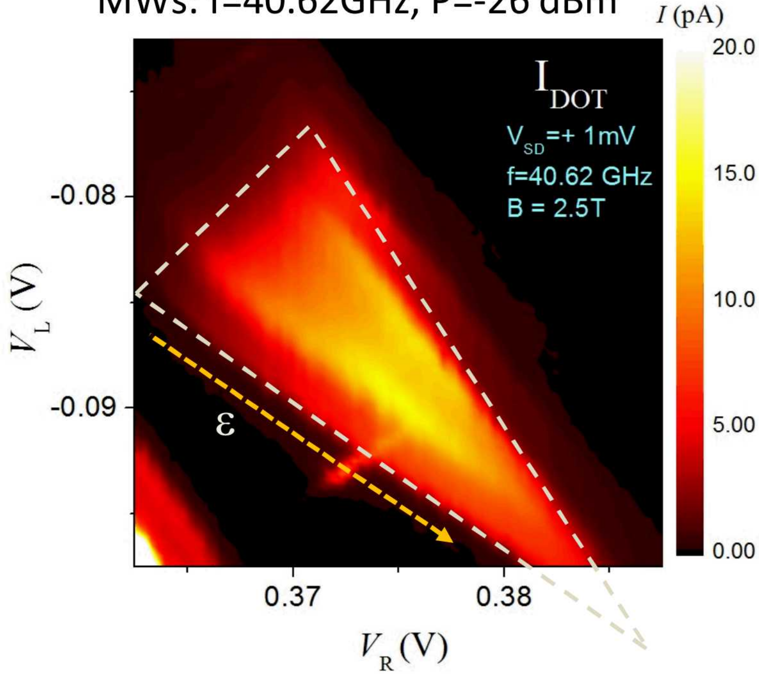
High-bias current diagrams in strong coupling regime

NRC·CNRC

V_{SD}=+1mV, no MWs



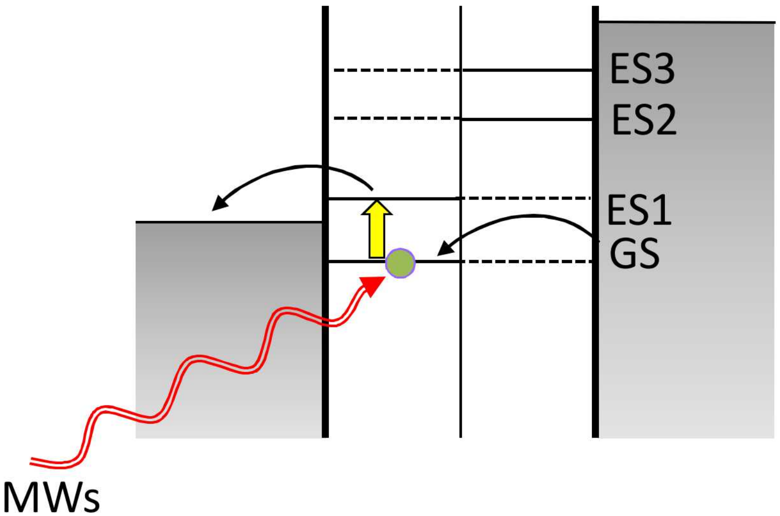
MWs: f=40.62GHz, P=-26 dBm



$\hat{H}|\Psi\rangle = \varepsilon|\Psi\rangle$

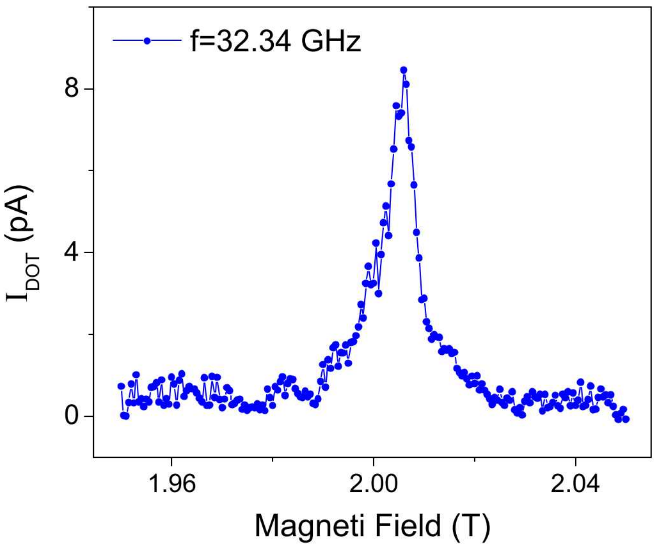
With basis: $\{|L\uparrow\rangle, |L\downarrow\rangle, |R\uparrow\rangle, |R\downarrow\rangle\}$

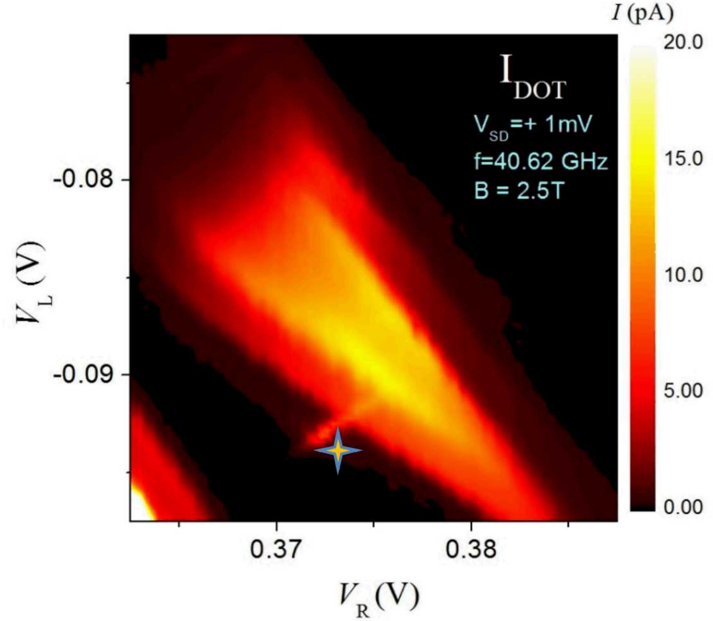
$$\hat{H} = \begin{bmatrix} \varepsilon_{L\Uparrow} & 0 & -t_N & -it_F \\ 0 & \varepsilon_{L\Downarrow} & -it_F & -t_N \\ -t_N & it_F & \varepsilon_{R\Uparrow} & 0 \\ it_F & -t_N & 0 & \varepsilon_{R\Downarrow} \end{bmatrix}$$

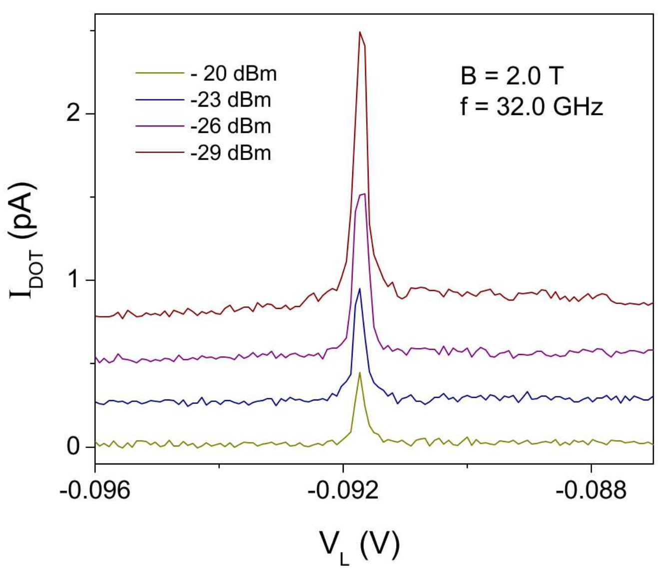


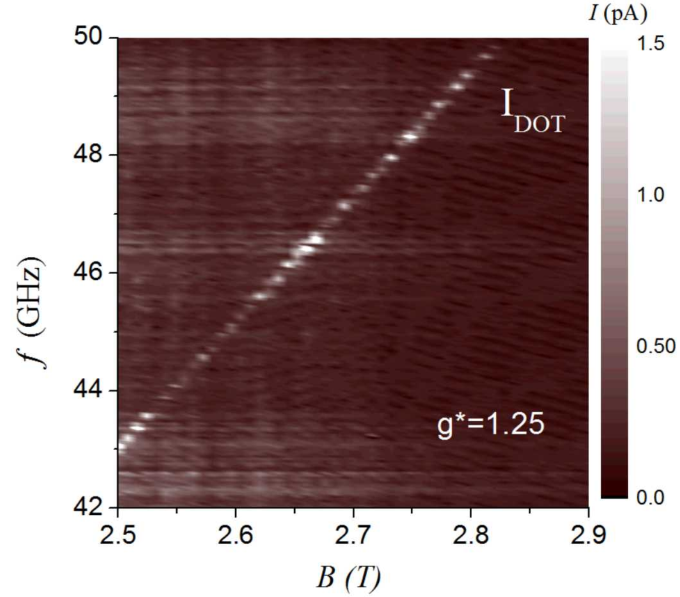
Single heavy hole EDSR by sweeping B or V_L

NRC·CNRC

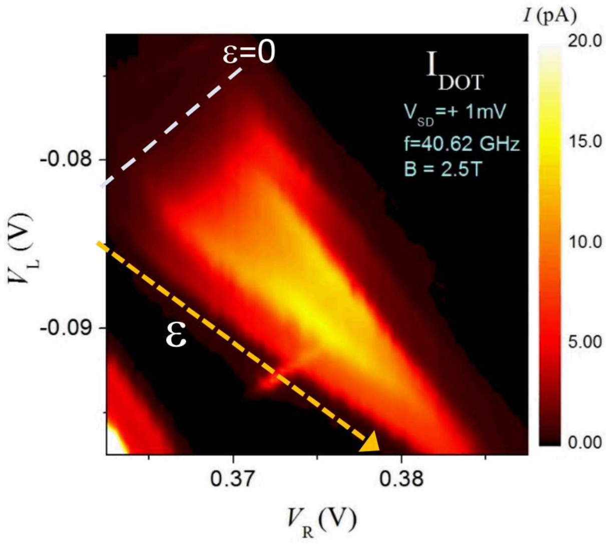


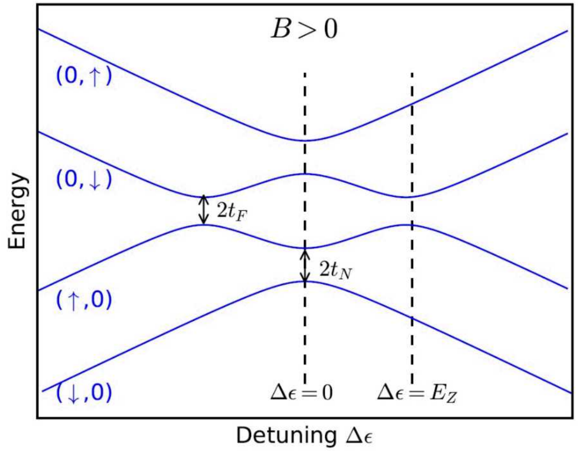


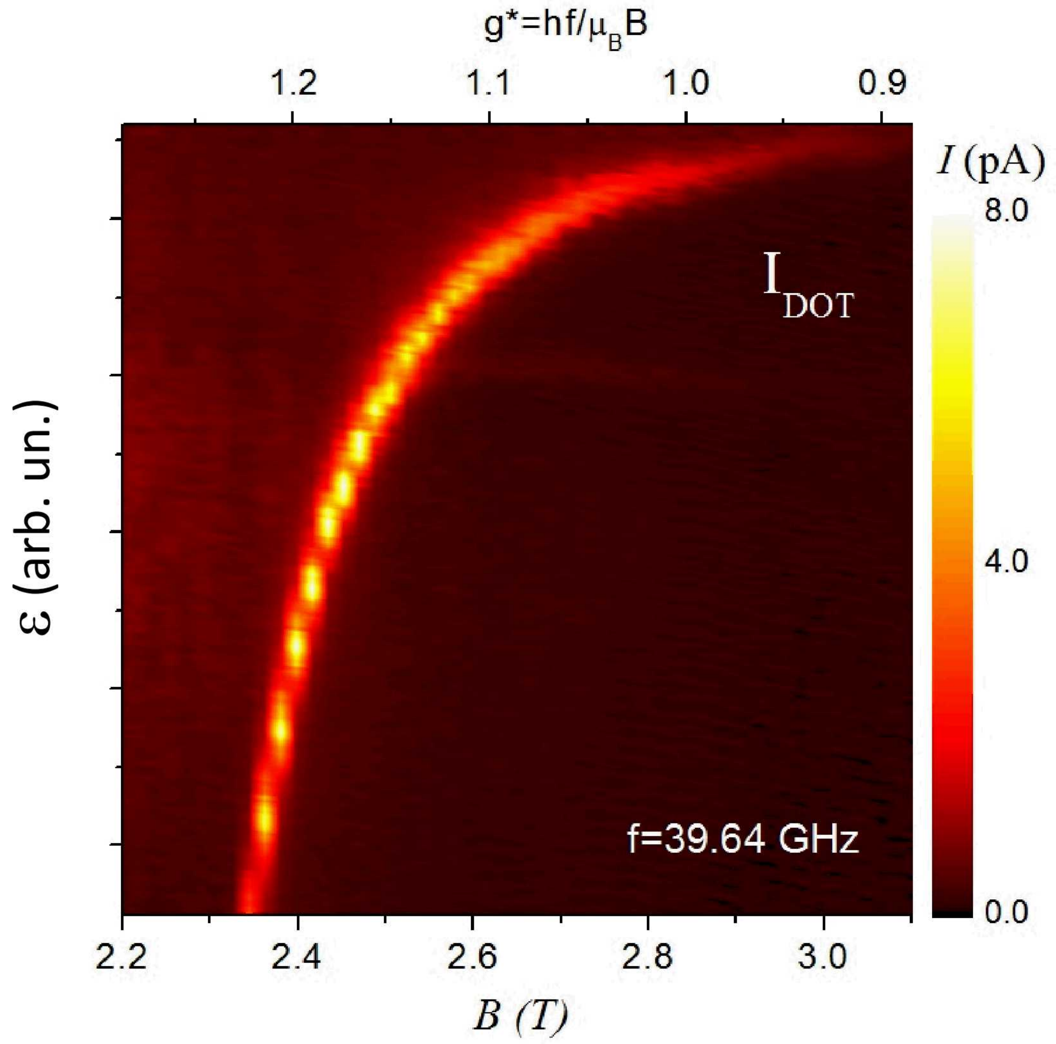




The hole EDSR position vs detuning ε and B



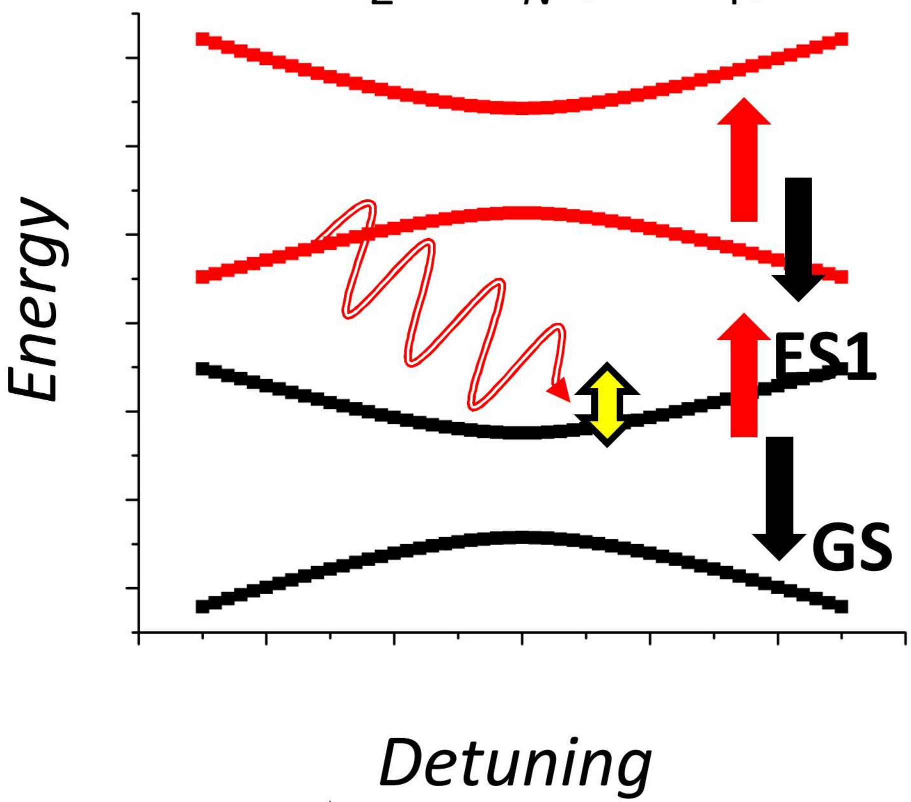




Bogan et al. PRL (2018)

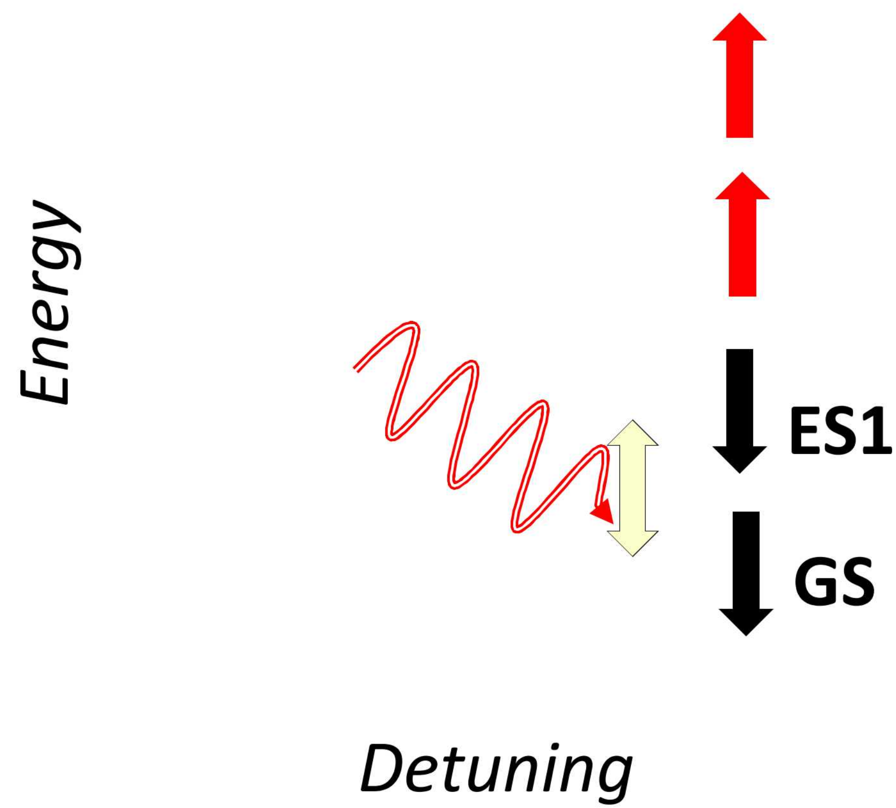
$E_Z = g^* \mu_B B$ is Zeeman energy
t_N *is* spin-conserving tunneling; t_F is spin-flip tunneling

$E_Z < 2t_N$ ($= 4t_F$)

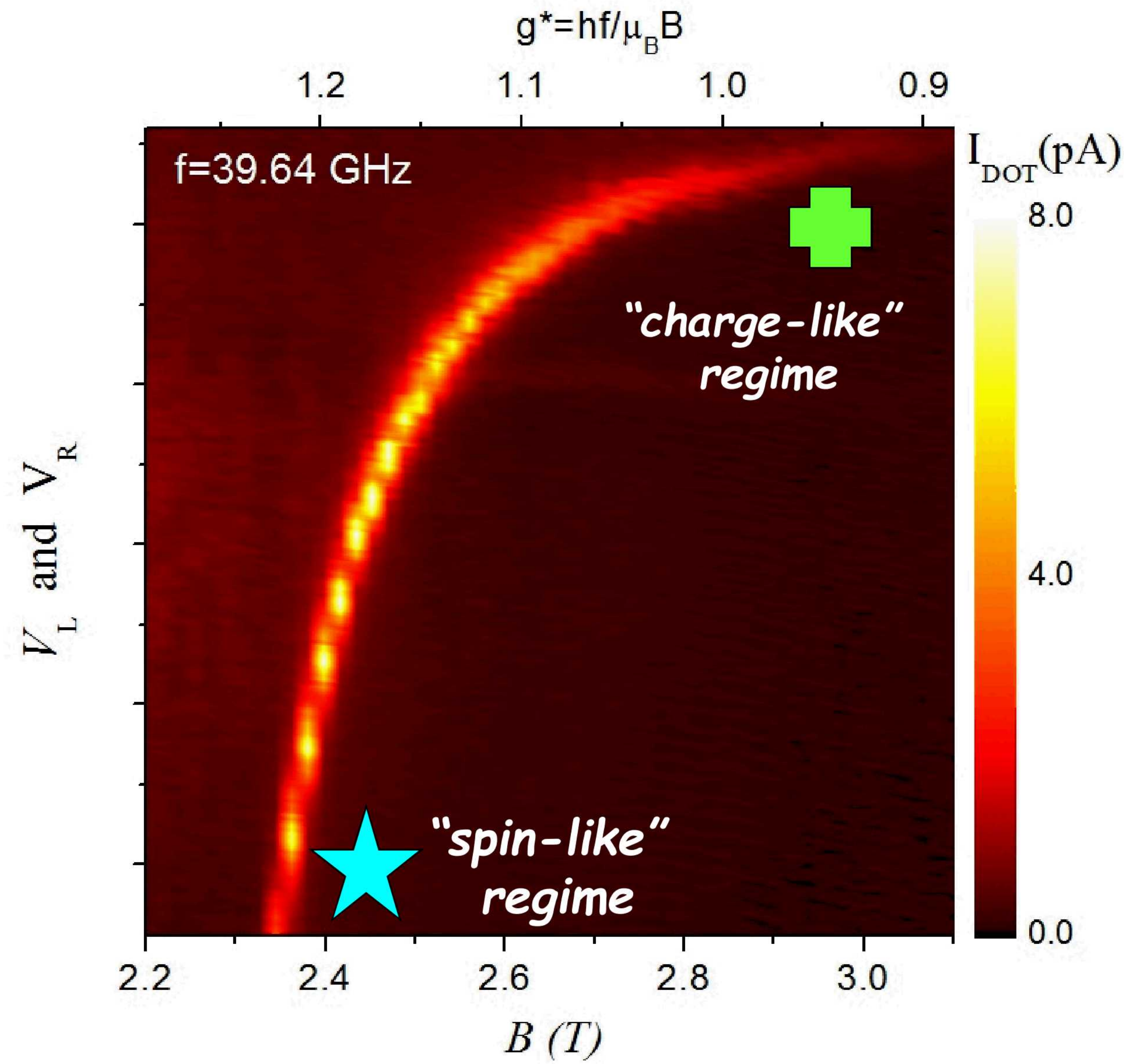


"spin-like" regime

$E_Z > 2t_N$ ($= 4t_F$)



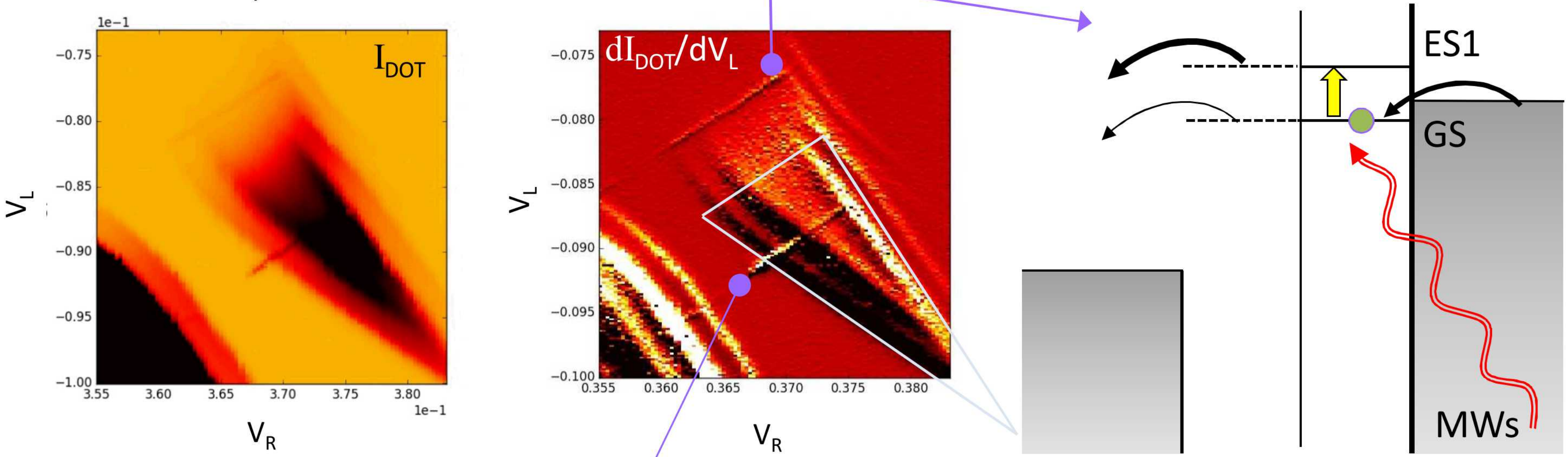
"charge-like" regime

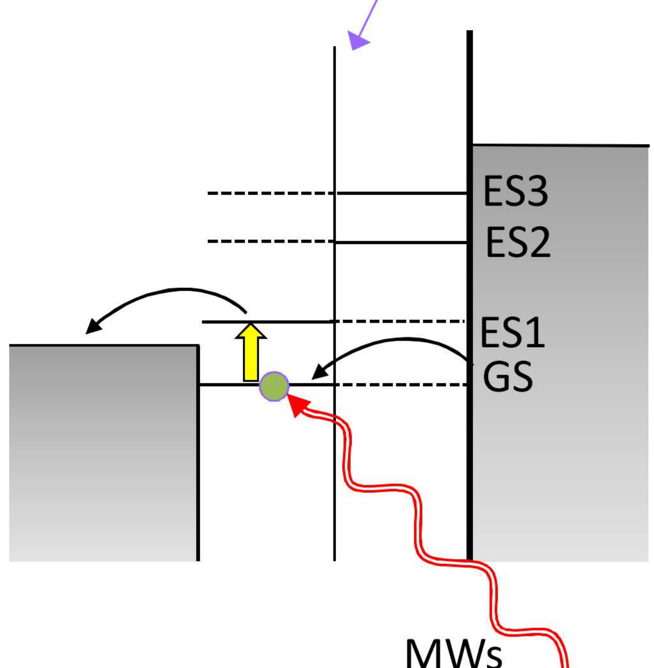


Magnetic field dependence of EDSR peak at f = 39.64 GHz.

Positive and negative detuning EDSR resonance lines

B=2.5 T, f=37.12 GHz

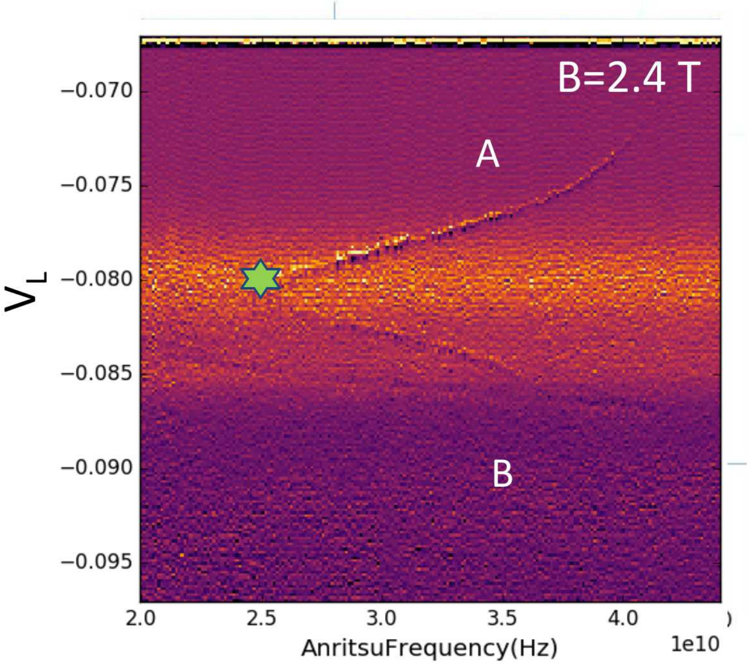


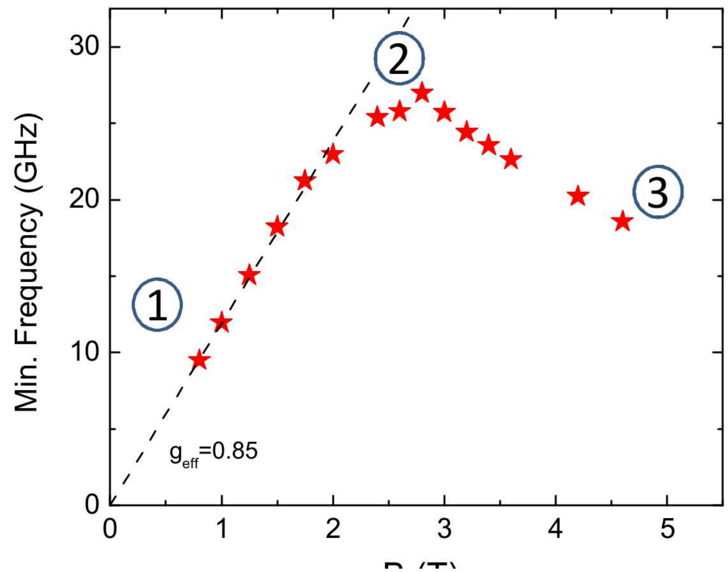


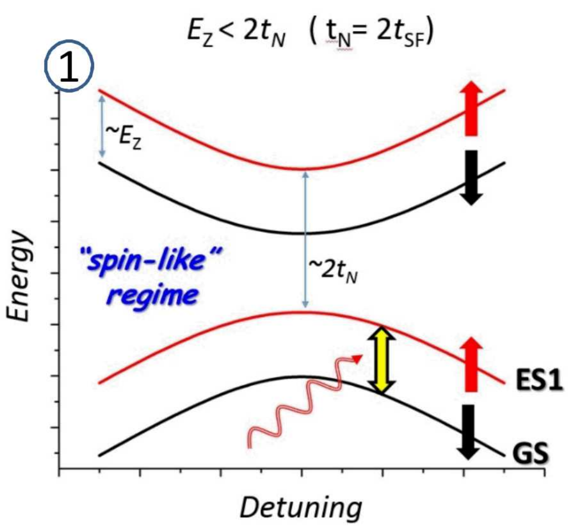
Spin-dependent tunneling:
Bogan et al. Nat.Comms.Phys. (2019)

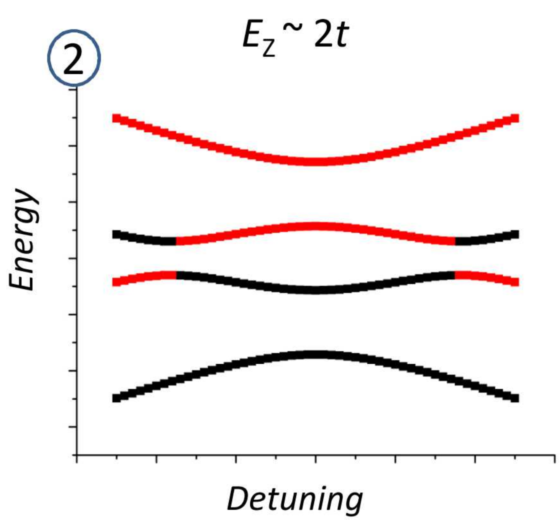
The EDSR dispersion minimum frequency vs B

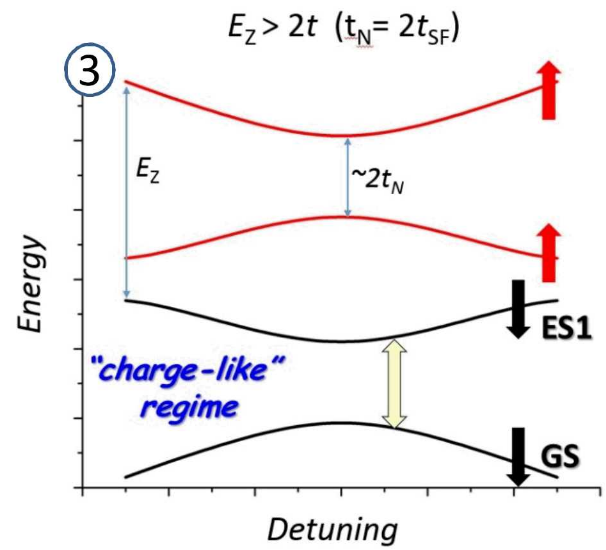
NRC·CNRC





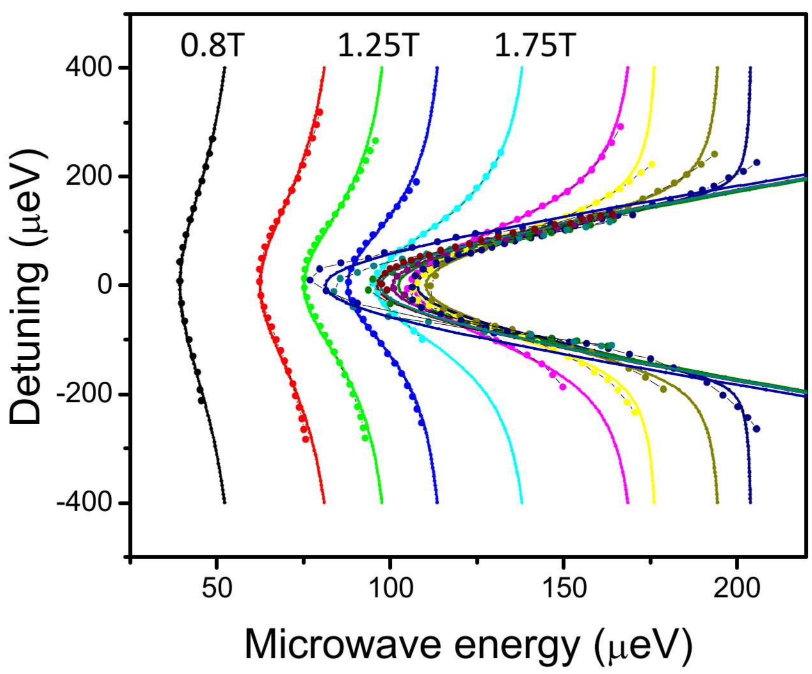


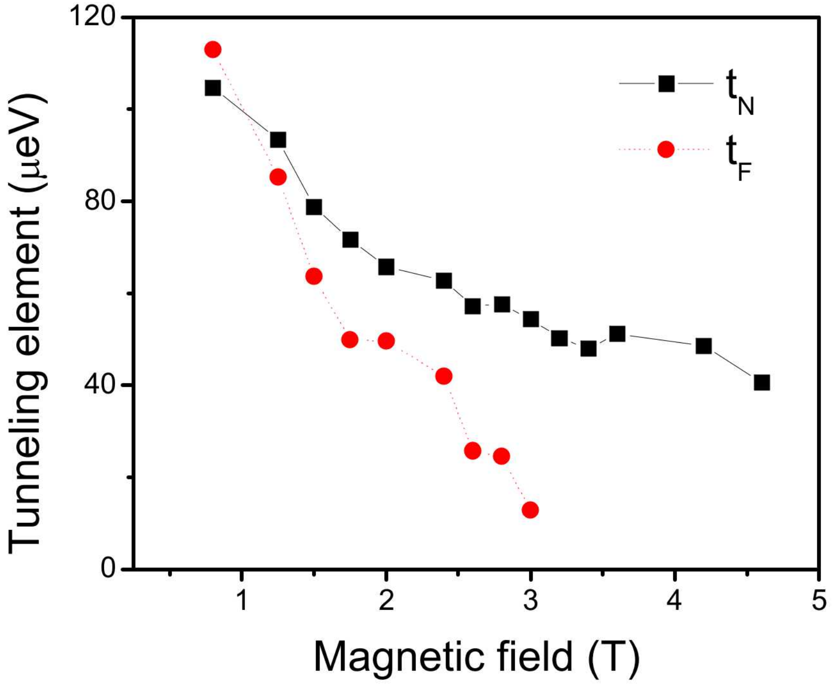




Hybrid spin-charge dispersion spectra fit with theory: t_N and t_F vs B

Spectra for B-field range 0.8T – 4.6T





Summary

- ***A single heavy hole spin system has been realized in the strong tunnel coupling regime and EDSR has been observed. The characteristics are strongly influenced by the spin-orbit interaction which induces spin-flip tunneling.***

In particular, here we have:

- ***Extracted an effective g-factor for heavy-holes that is gate voltage tunable***
- ***Realized a hybrid spin-charge system where the EDSR signal can be continuously changed from "spin-like" to "charge-like"***
- t_N ***and*** t_F ***tunneling elements extracted from the EDSR spectra***