Field Tuning the $g$ Factor in InAs Nanowire Double Quantum Dots

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We study the effects of magnetic and electric fields on the $g$ factors of spins confined in a two-electron InAs nanowire double quantum dot. Spin sensitive measurements are performed by monitoring the leakage current in the Pauli blockade regime. Rotations of single spins are driven using electric-dipole spin resonance. The $g$ factors are extracted from the spin resonance condition as a function of the magnetic field direction, allowing determination of the full $g$ tensor. Electric and magnetic field tuning can be used to maximize the $g$-factor difference and in some cases altogether quench the electric-dipole spin resonance response, allowing selective single spin control.
Motivation

- Spin qubits: Fast control of single electron spins
  - ESR: Spin rotation via $B_{RF}$ pulses

Motivation

- Spin qubits: Fast control of single electron spins
  - EDSR: Electric dipole spin resonance via $E_{RF}$, mediated by
    - Hyperfine interactions to nuclei (Overhauser field)
    - Spin-Orbit fields $B_{SO}$
    - Local B-field gradients (nanomagnets)
  - Simpler setup/device design
  - Experiments done in GaAs\textsuperscript{1}, but rotations too slow

  \textup{\textsuperscript{1}}K. C. Nowack et al., Science 318, 1430 2007
InAs Nanowire DQD

- InAs nanowire (d=50 nm) deposited onto:
  - Silicon substrate
  - Ti/Au gates, spaced 60 nm
  - Ti/Au sidegates
  - 20 nm SiNₓ isolation layer
- Ohmic contacts
DQD Stability Diagram

- $(1, 1) \leftrightarrow (2, 0)$ transition
  - Positive bias (+4mV)

(1, 0) → (2, 0) → (1, 1) → (1, 0)
(1, 1) ↔ (2, 0) transition

- Negative bias (-4mV)

- Small "leakage current" due to
  - Spin flips
  - cotunneling
EDSR Measurements

- For $B=0$: hyperfine mediated spin flips

- For finite $B$: resonance peaks for $hf = g\mu_B|B|
  - One for each QD (different $g$-factor)
- $B=80\text{mT}$, rotating field direction
- g-factor varies spatially
  - as a function of external $B$-direction
  - between QDs
- Resonance intensity also shows angle dependence

\[
B_{so}(t) = 2B \times (\Omega_0 \sin \omega_{ac} t)
\]

\[
I_{EDSR} = \frac{e\Gamma_i |B_{so}|^2}{2B^2_N}
\]
g-factor Anisotropy

- Lower values compared to bulk (14.7)
- Cylindrical anisotropy
- Not aligned to nanowire axis
g-factor Anisotropy

- Same measurements for “unbalanced” case:
  - Change in confinement potential
  - Indicator: coupling to leads
  - Asymmetric cotunneling peak in the leakage current
  - Influence on g-factor mainly in one QD due to change in confinement potential

| Dot | $|g_1|$ | $|g_2|$ | $|g_3|$ | $\alpha$ | $\beta$ | $\gamma$ |
|-----|-------|-------|-------|--------|--------|--------|
| Balanced    | A      | 9.1   | 7.8   | 7.5    | 1.9    | 2.1    | -0.25 |
|            | B      | 8.4   | 7.3   | 7.0    | -0.81  | 1.0    | 1.5   |
| Unbalanced  | A      | 22    | 12    | 8.0    | 1.8    | 1.9    | -0.21 |
|            | B      | 8.8   | 7.6   | 7.4    | -1.2   | 1.0    | 0.73  |
Quantitative Analysis

- g-factor
  - in bulk: 14.7
  - in QDs: 7.4 – 22, highly anisotropic

- SOI strength
  - from $l_{\text{EDSR}} = \frac{e\Gamma_i|B_{so}|^2}{2B_N^2}$, with $\Gamma = 220\text{MHz}$ and $B_N = 3\text{mT}$
    $\rightarrow B_{so} \approx 1\text{mT}$
  - and from $l_{so} = \frac{B}{B_{so}} \frac{2\hbar^2e|E|}{m_e\Delta^2}$
    $\rightarrow l_{so} \approx 170\text{nm}$
Summary

- Spin sensitive measurements in Pauli blockade regime
- EDSR-induced spin rotations measured in (3d) rotating B-field
  - Spatial variations of g-factor
  - Anisotropy highly correlated to confinement potential of applied E-fields rather than 1d-structure of nanowire

- Quantitative Analysis:
  - $B_{SO} \approx 1\text{mT}$
  - $B_N \approx 3\text{mT}$
  - $l_{SO} \approx 170\text{nm}$

- Large g-factor differences for each QD in DQD allows fast and selective single spin rotations