A Coherent Single-Hole Spin in a Semiconductor

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- very long hole spin coherence
  T2* > 490 ns (70% confidence)
  1-2 order mag. longer than electron coherence

- coherent population trapping /
electromagnetically induced transparency in quantum dot

- first condensed matter system with full transmission in EIT

- very narrow feature:
  “ushering semi. optical spectroscopy
  into the domain of atomic physics”
  line width ~ 0.35 meV / 85 MHz
Coherent Population Trapping

electromagnetically induced transparency (EIT)
Simulations

\[ \frac{\Gamma_{31}}{\Omega_{\text{probe}}} \]

\( T_2 = 1 \, \mu s \) (black line),
\( T_2 = 10 \, \text{ns} \) (red line).

Rabi energies \( \hbar \Omega_{\text{pump}} = 1.0 \, \mu \text{eV} \), \( \hbar \Omega_{\text{probe}} = 0.45 \, \mu \text{eV} \),

radiative decay rates \( \hbar \Gamma_{31} = \frac{1}{2} \hbar \Gamma_r = 0.50 \, \mu \text{eV} \)
Experiment: EIT

The measured Rabi energies are $\hbar \Omega_{\text{pump}} = 0.75 \pm 0.25 \ \mu\text{eV}$ and $\hbar \Omega_{\text{probe}} = 0.34 \pm 0.15 \ \mu\text{eV}$; radiative decay time, 0.4 ± 0.2 ns; magnetic field, 2.3 T; integration time per point, 5 s; temperature, 4.2 K.

linewidth of just 0.35 \mu\text{eV} (85 MHz)

full transparency on two-photon resonance
Experiment: detuning

Two photon resonance!
$T_2 \geq 490 \text{ ns with 70\%}$
Theory: hole spin – nuclear spin coupling

\[ H = \sum_k A_k^h S_z I_k^z, \]

\[ h_1^k = \frac{\mu_0}{4\pi} \frac{8\pi}{3} \gamma_S \gamma_{j_k} \delta(r_k) S \cdot I_k, \]

\[ h_2^k = \frac{\mu_0}{4\pi} \gamma_S \gamma_{j_k} \frac{3(n_k \cdot S)(n_k \cdot I_k) - S \cdot I_k}{r_k^3(1 + d/r_k)} \]

\[ h_3^k = \frac{\mu_0}{4\pi} \gamma_S \gamma_{j_k} \frac{L_k \cdot I_k}{r_k^3(1 + d/r_k)} \]

Fermi contact hyperfine interaction

dipole-dipole-like interaction

an-isotropic hyperfine interaction

coupling of electron orbital angular momentum to the nuclear spin

pling coefficient of the heavy hole dipole-dipole hyperfine interaction is by no means negligible (28), but the interaction has an Ising form. For
Conclusions

• very long hole spin coherence
  \( T^{*} > 490 \text{ ns (70\% confidence)} \)
  > 1 order mag. longer than electron

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• very narrow feature:
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  line width \( \sim 0.35 \text{ meV / 85 MHz} \)