



Subsecond nuclear spin dynamics in *n*-GaAs

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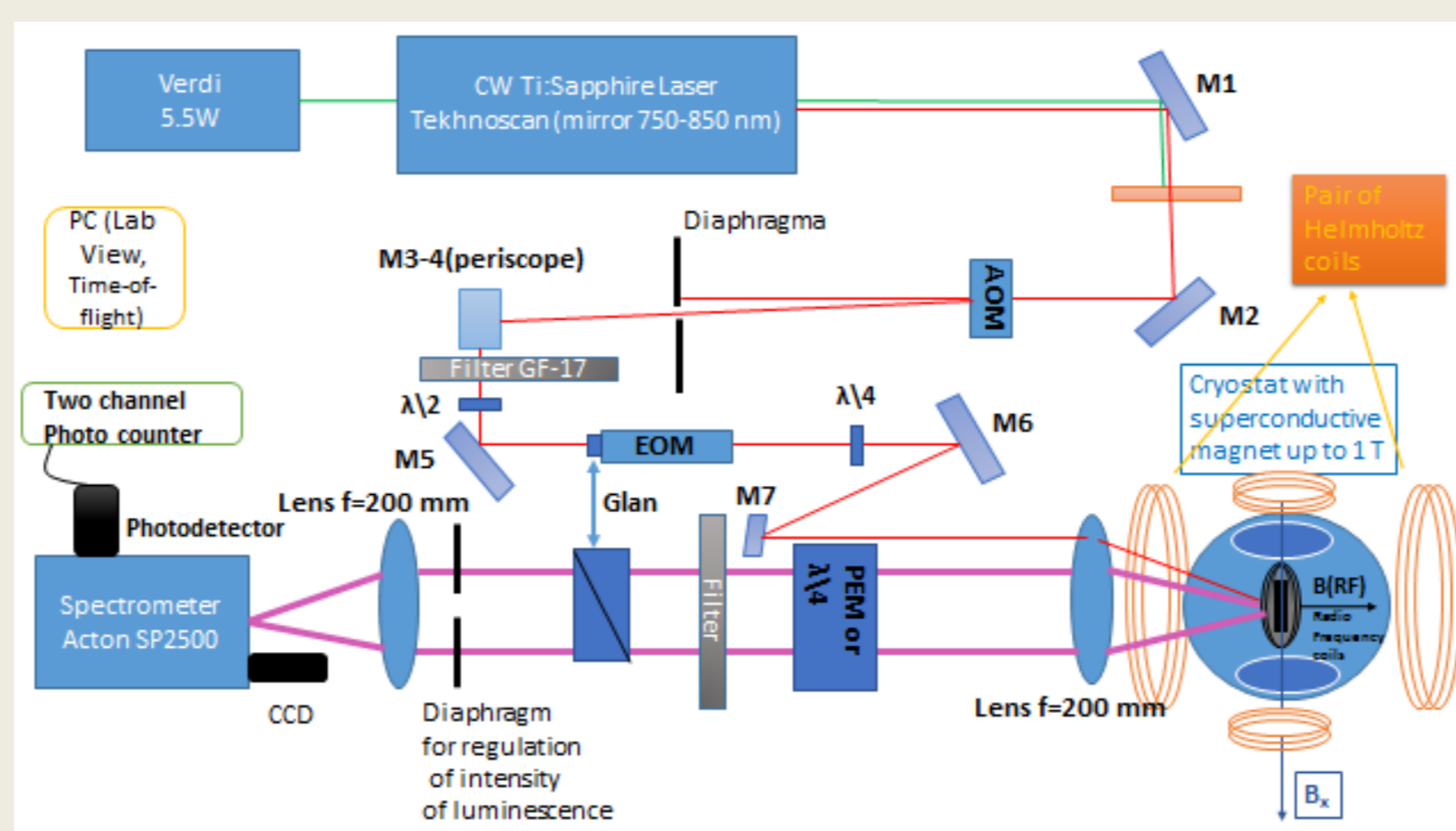
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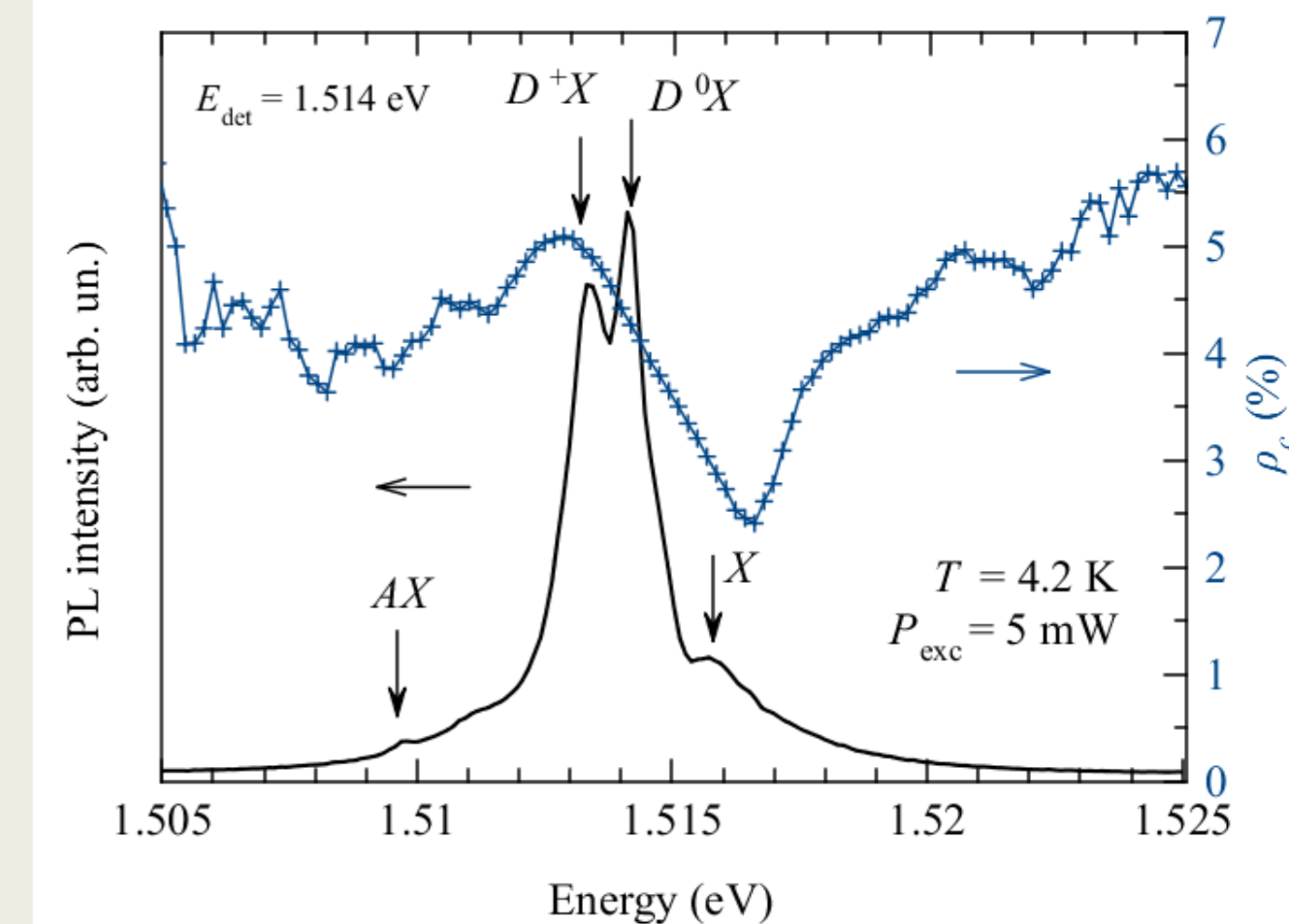
Introduction

We use time-resolved detection of the Hanle effect and polarized photoluminescence with dark intervals to investigate the buildup and decay of the spin polarization of nuclei interacting with donor-bound electrons in *n*-doped GaAs. Strong hyperfine coupling defines the millisecond time scale of the spin dynamics of these nuclei, as distinct from the nuclei far from impurity centers, characterized by a thousand times longer spin-relaxation time. The dynamics of spin polarization and relaxation attributed to the nuclei inside the donor orbit is observed on the time scale from 200 to 425 ms.

Experimental setup

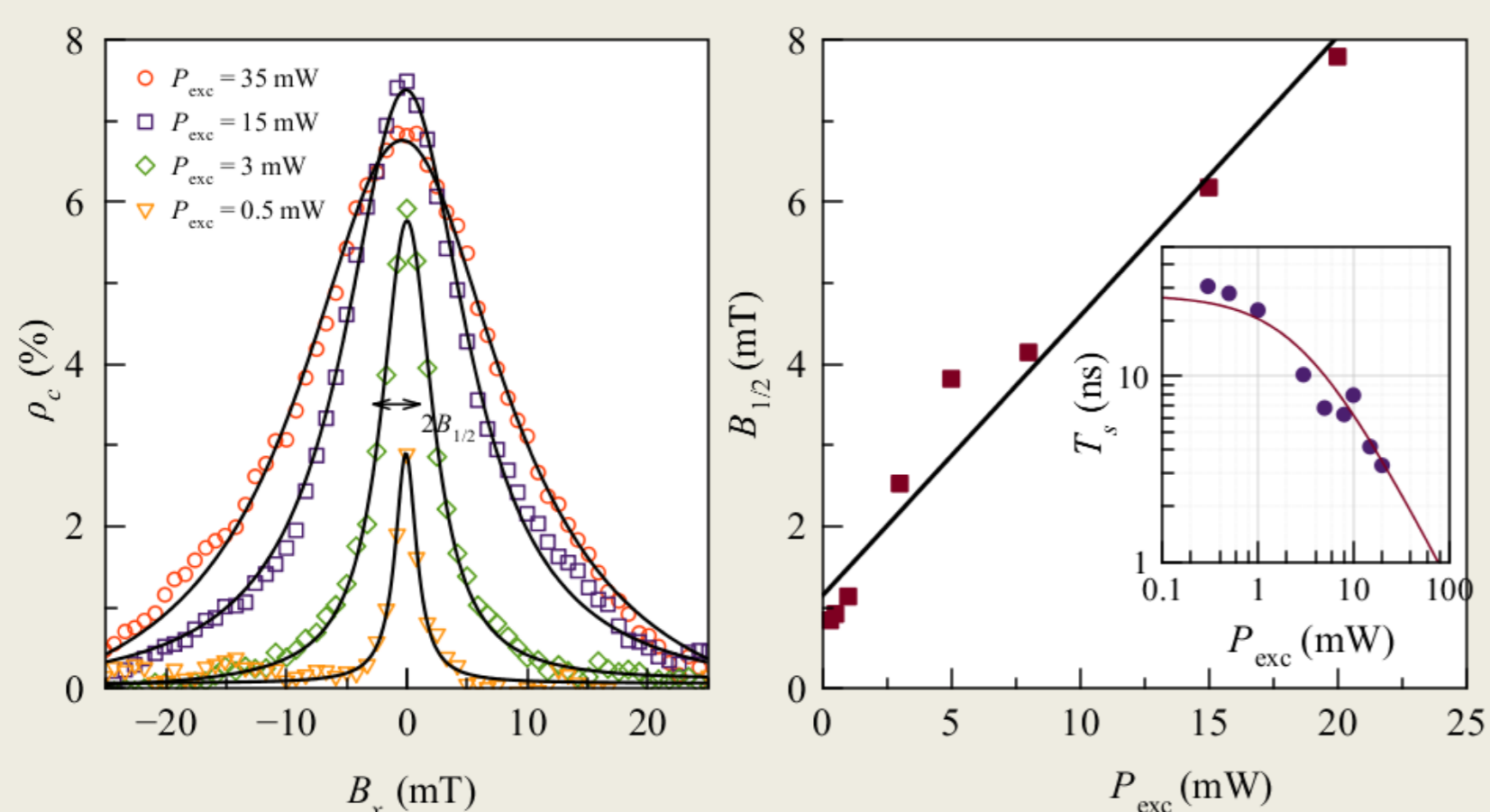


$$\rho_c = \frac{I_{co} - I_{cross}}{I_{co} + I_{cross}}$$



The PL spectrum of *n*-doped GaAs measured at $B = 0$ (solid line) and the spectral dependence of the PL circular polarization degree (crosses).

Spin relaxation times of localized electrons



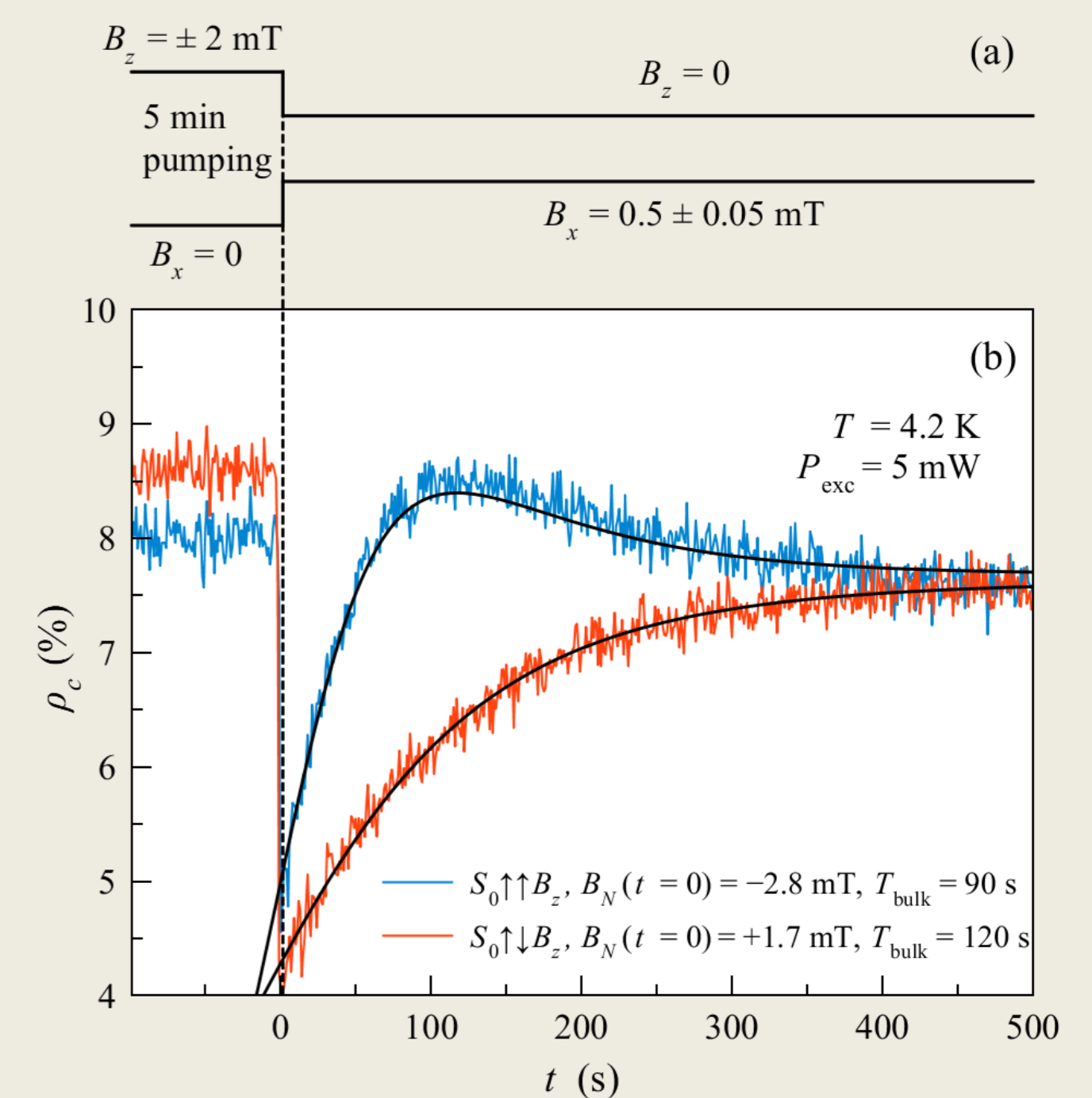
The Hanle curves of D_{0X} line measured for fast polarization modulation $f_{mod} = 50$ kHz at various pumping powers.

Dependence of $B_{1/2}$ (squares) and its linear fit (line). Inset shows the power dependence of the electron spin lifetime (circles) $T_s = \frac{h}{\mu_B g_e B_{1/2}}$

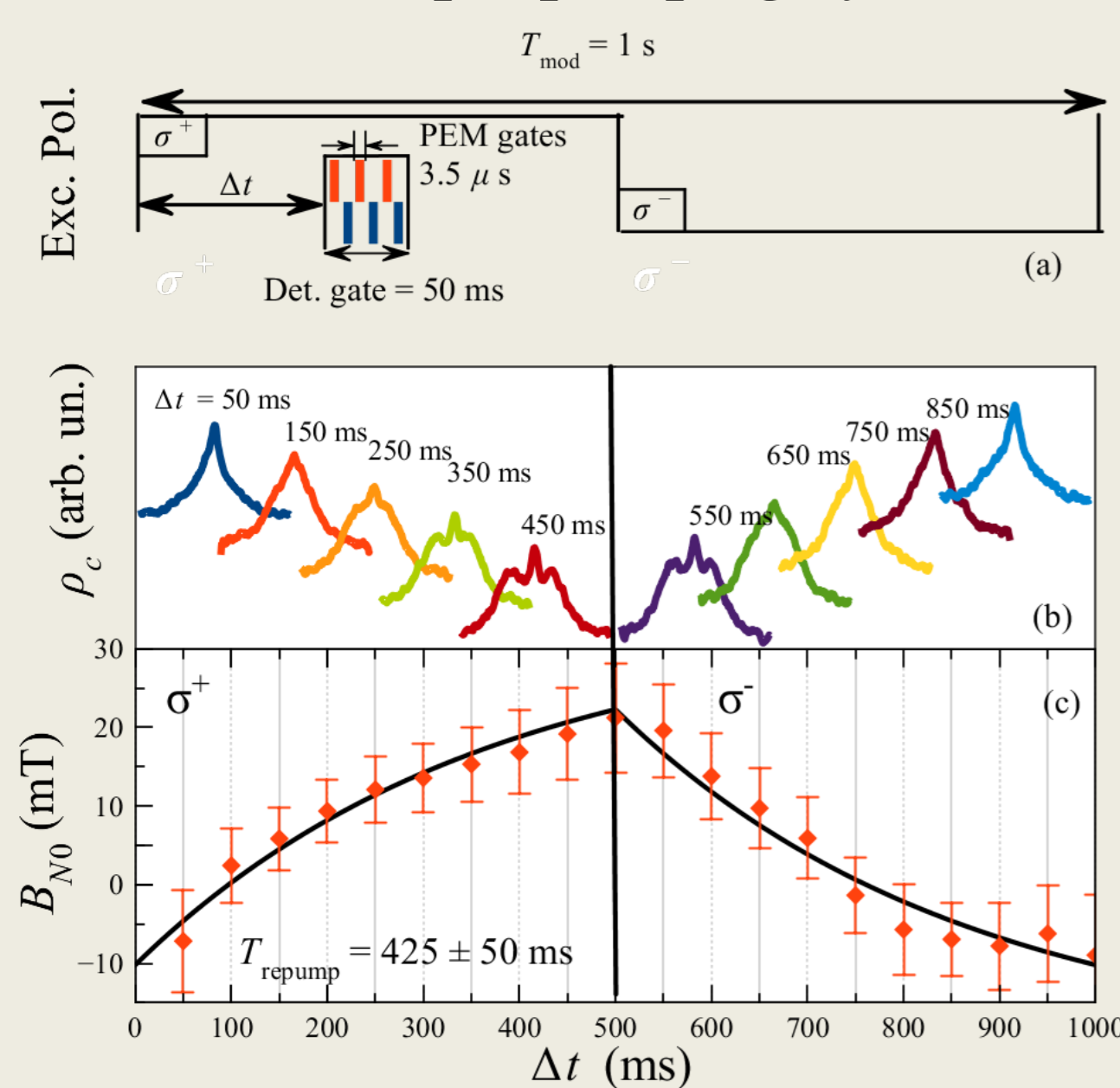
Time dependence of the PL circular polarization degree after demagnetization from the longitudinal $B_z = +2$ mT (blue curve) and $B_z = -2$ mT (red curve) fields in a small transverse magnetic field $B_x = 0.5 \pm 0.05$ mT and its fitting (solid lines) with equation:

$$\rho_c \propto \left[1 + \frac{(B_x + B_N(t=0))e^{-t/T_{bulk}}}{B_{1/2}^2} \right]^{-1}$$

Spin relaxation time of the bulk nuclei



Fast nuclear spin pumping dynamics



(a) Schematic of the measurement protocol.

(b) Hanle curves corresponding to the gated detection in the time intervals shown in panel (a).

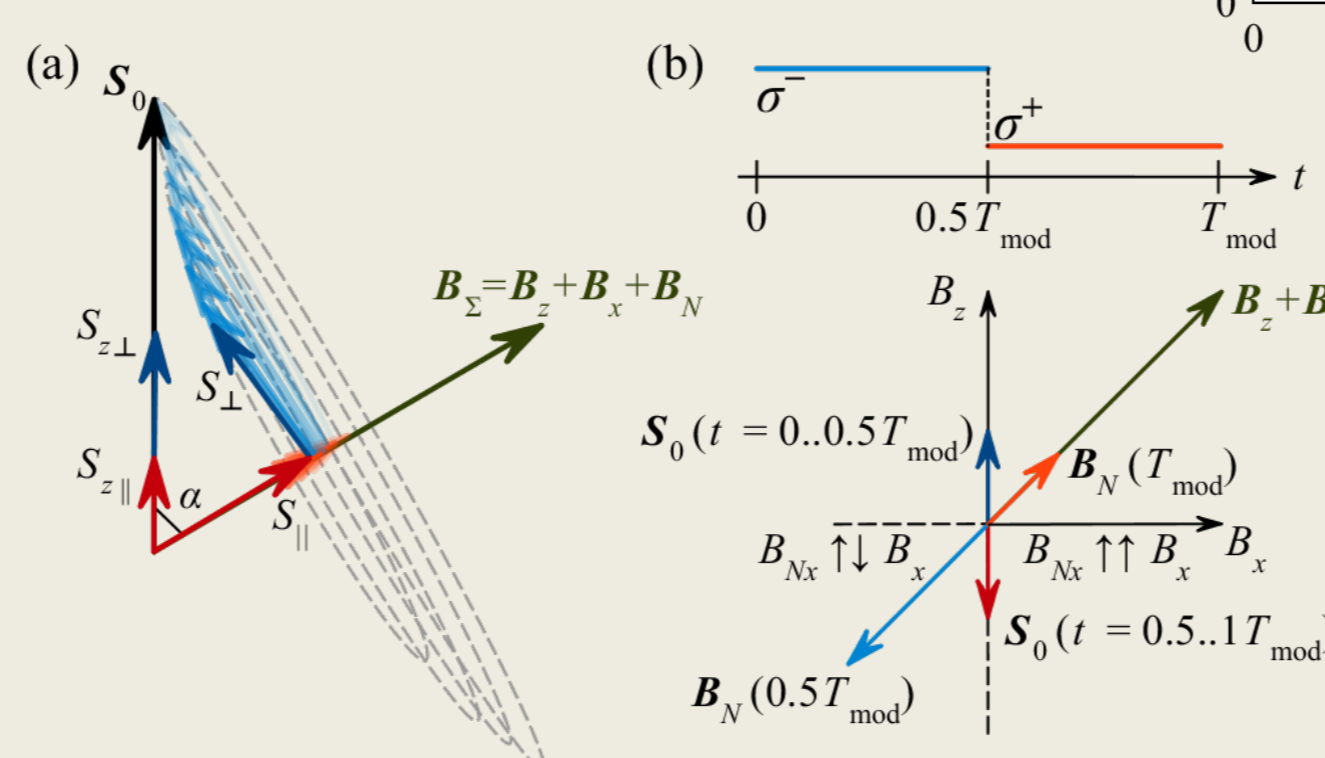
(c) Magnitude of the Overhauser field, B_{N0} , extracted from fitting the Hanle curves

$$S_z(B) = S_{z\parallel} + S_{z\perp} = S_z(0) \frac{(B_z + B_{Nz})^2}{B_{\Sigma}^2} + S_z(0) \frac{(B_x + B_{Nx})^2}{B_{\Sigma}^2} \frac{1}{1 + B_{\Sigma}^2/B_{1/2}^2}$$

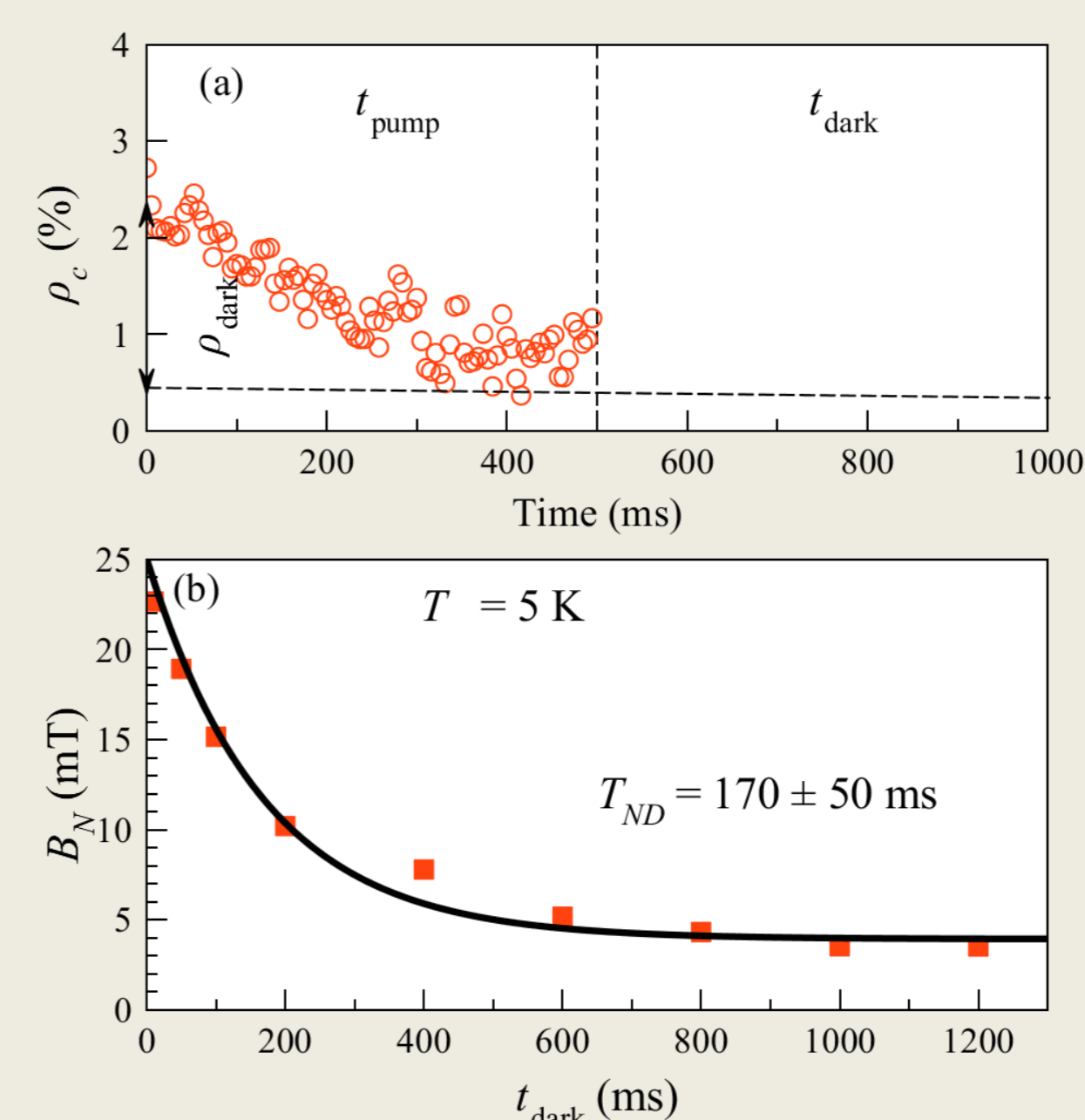
$$B_{\Sigma}^2 = (B_z + B_{Nz})^2 + (B_x + B_{Nx})^2$$

$$B_{Nx} = \frac{B_z B_x}{B_z^2 + B_x^2} B_{N0}(t)$$

$$B_{Nz} = \frac{B_z^2}{B_z^2 + B_x^2} B_{N0}(t)$$



Nuclear spin relaxation mediated by the hyperfine interaction with donor bound electrons in the absence of illumination



a) Time dependence the ρ_c in the presence of circularly polarized pump.

(b) The Overhauser field values calculated for different dark time intervals evaluated using equation

$$B_N = B_{1/2} \sqrt{\frac{\rho_0 - \rho_{dark}}{\rho_{dark} - \rho_0 \sin^2 \theta} - \sqrt{B_x^2 + B_z^2}}$$

See PRB **99**, 075307 (2019); PRB **96**, 205205 (2017).

Conclusion: The nuclear spin dynamics has been experimentally studied in *n*-GaAs with donor concentration $n_D = 4 \times 10^{15} \text{ cm}^{-3}$ by measuring the Hanle effect with millisecond time resolution under time-varying optical pumping. Two time-scales of nuclear buildup and relaxation have been observed. One of them is slow $T_{bulk} \approx 10^2$ s (on the order of hundreds of seconds) relaxation of bulk nuclei via spin diffusion from (buildup) or to (relaxation) donor centers. At the same time, a faster dynamics is observed on the time scale from 200 to 425 ms, which is attributed to the spin dynamics of nuclei inside the donor orbit. It means that the charged donor centers play the role of the "killer" centers for the spatially distributed nuclear spin.

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