

# Formation of Transverse Nuclear Field in Single Self-Assembled Quantum Dots: role of quadrupolar splitting

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We studied the formation mechanism of an in-plane nuclear field in single self-assembled  $\text{In}_{0.75}\text{Al}_{0.25}\text{As}/\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$  quantum dots (QDs). In a current theoretical framework for the dynamics in a coupled electron-nuclear spin system of a QD, a *large* nuclear field up to  $\sim 1$  Tesla *orthogonal to a photo-injected electron spin* is impossible to be generated. However, the drastically distorted Hanle curves from a normal Lorentzian shape are observed as shown below and in Ref. 1. The results suggest strongly that a QD electron experiences only a small total transverse field. Then, the formation mechanism of an in-plane field which can compensate the applied field is necessary to be fully revealed. The complete understanding of the mechanism leads directly to the possible applications with the optical manipulation of a nuclear field, and therefore, is very important.

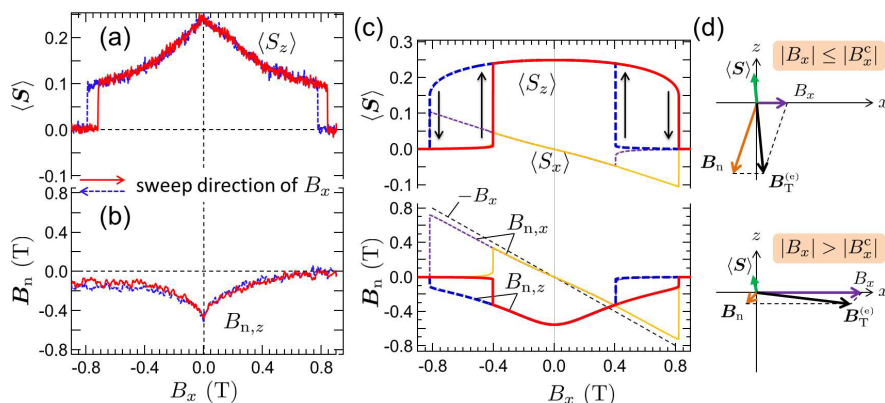


Figure 1: (a) The observed  $\langle S_z \rangle$  and (b) the observed  $B_{n,z}$  in Hanle effect measurements. (c) The calculated results by a proposed model, (d) Schematics of  $\langle \mathbf{S} \rangle$  and  $\mathbf{B}_n$ .

We propose an improved model for dynamic nuclear spin polarization including the nuclear quadrupole interaction (QI). Figure 1(a) indicates the observed anomalous Hanle curve in a single InAlAs QD. Since the  $\sigma^+$  and  $\sigma^-$  PL components from a positive trion were detected under the external transverse field  $B_x$ , also  $B_{n,z}$  could be evaluated experimentally as shown in Fig. 1(b). The calculated results in Fig. 1(c) reproduce well the experimental ones in Fig. 1(a) and (b) at the following characteristic points;

1. a large value of  $\langle S_z \rangle$  is preserved even under a large  $|B_x|$  until the critical field  $B_x^c$ ,
2.  $\langle S_z \rangle$  changes abruptly at  $B_x^c$  and shows the hysteretic (thus, bistable) behavior,
3.  $\langle S_z \rangle$ -curve is almost symmetric with respect to the sweep direction of  $B_x$ ,
4.  $|B_{n,z}|$  reduces gradually with increasing  $|B_x|$ .

In the calculations, the sign inversion of the nuclear g-factors is assumed (i.e.  $g_x^n \cdot g_z^n < 0$ ), and the QI plays a role to stabilize a part of nuclear spins along with  $z$ -axis. As shown in Fig. 1(c) and (d), the transverse component of  $\mathbf{B}_n$  compensates the applied field  $B_x$ , and the total effective field  $\mathbf{B}_T^{(e)}$  that is seen by an electron is determined dominantly by  $B_{n,z}$ . Therefore, a large value of  $\langle S_z \rangle$  is kept under the condition  $|B_x| \leq |B_x^c|$ . On the other hand, in the region of  $|B_x| > |B_x^c|$ , the vector  $\langle \mathbf{S} \rangle$  feels a large transverse field and  $\langle S_z \rangle$  relaxes quickly since the induced  $\mathbf{B}_n$  is quite small [2].

While the model calculations reproduced successfully the observed anomalies in the Hanle curves, further investigations are necessary to improve the quantitative agreement.

[1] O. Krebs et al., Phys. Rev. Lett. **104**, 056603 (2010).

[2] S. Yamamoto, R. Matsusaki, R. Kaji, and S. Adachi, arXiv:1710.00333 (2017).