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High Field ESR of Phosphorus Donors in Silicon under Optical Excitation

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Introduction

Shallow donors in semiconductor crystals such as the phosphorus impurity in silicon are promising candidates for solid-state spin qubits due to their long coherence times. It will be necessary to develop such atomic-scale qubits for future larger-scale solid-state quantum processors and sensors. The phosphorus-doped silicon (Si:P) system is also a promising platform for studying atomic and molecular physics in a solid-state environment. While the control and characterization of phosphorus donor spins in silicon has been extensively studied, both in the bulk and at the single donor level, particularly at magnetic fields below 1 T, their spin physics continues to reveal new phenomena at high magnetic fields. For example, recent experiments have shown that above-band gap optical excitation can result in strong hyperpolarization of the donor nuclear spins [1, 2].

Experimental

We performed both continuous wave (CW) and pulsed electron spin resonance (ESR) of several samples of Si:P with different donor concentrations at 8.5 T using the 12.5 T SC magnet of the EMR Facility. The experiments were performed both in the dark and under different forms of optical excitation.

Results and Discussion

We observed that the sign of nuclear spin hyperpolarization of the phosphorus donors appears to depend on the doping concentration. Additionally, we observed that low-power, above-band-gap optical excitation of Si:P can also *extend* the phase memory time of the donor electron spins in a low-concentration (~3.3 - 3.5 × 10^{15} cm^{-3}) phosphorus-doped natural abundance silicon sample. A two-pulse Hahn echo experiment at 8.5T and 4K was used to measure the decay of the echo amplitude with time. The non-exponential decays (~$\exp(-(t/T)^n)$) suggest that the phase memory time is dominated by spectral diffusion due to the ^{29}Si spins [3]. T_{SD} was measured to be 110 μs in the dark and with sub-bandgap excitation, rising to over 180 μs with 1050 nm laser excitation, as seen in **Fig.1**(a). **Fig.1**(b) shows that, with 980 nm excitation, T_{SD} increases with applied laser power saturating at 200 μs.

Conclusions

While the physical mechanism underlying them remain unknown, such phenomena suggest that there remain many unexplored avenues for improving control of shallow donor qubits.

Acknowledgements

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References

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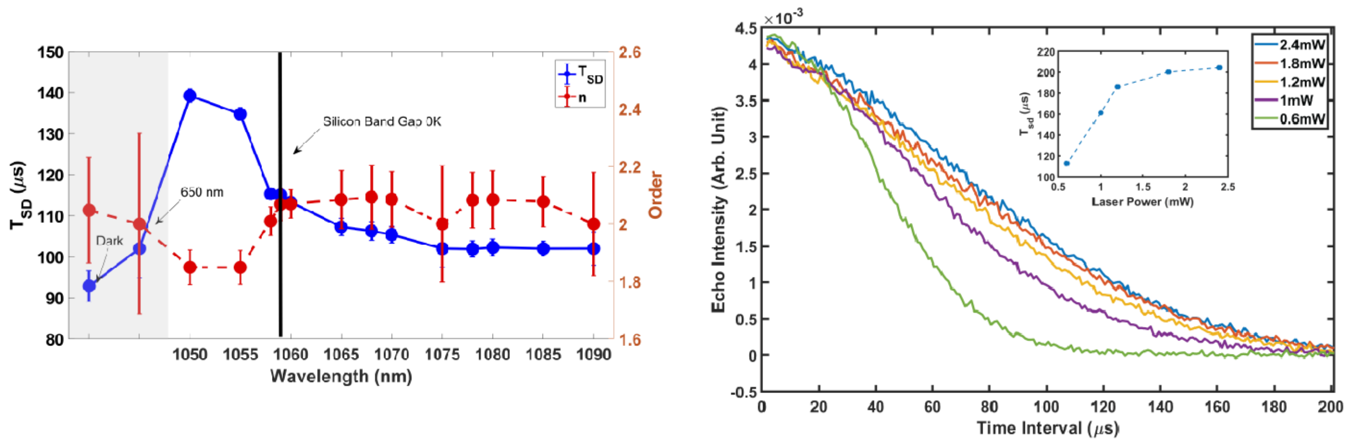

Fig.1 (a) Plot of T_{SD} and n as a function of the wavelength of the applied optical excitation. No excitation (dark) and 650 nm excitation are shown in the shaded area. (b) Change in echo decay at different applied laser powers at 980 nm**.**