Bismuth donor hyperfine state populations studied by optical transitions of donor bound excitons in enriched ^{28}Si

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The electron and nuclear spins of neutral donor impurities (D^0) in Si have received much attention as promising qubit candidates for Si-based quantum computing schemes. Enriched ^{28}Si has been used in the more recent studies, since the elimination of the ^{29}Si (with the I = 1/2 nuclear spin) present in natural Si (^{nat}Si) can result in greatly increased electron and nuclear spin coherence times [1], but also because optical transitions in ^{28}Si are much sharper than in ^{nat}Si. More recently, attention has focused on the deepest Group V donor, Bismuth (^{209}Bi), which has a very large hyperfine coupling and a large (I = 9/2) nuclear spin, resulting in a rich hyperfine structure. Our preliminary study of donor bound exciton (D^0X) photoluminescence (PL) in ^{nat}Si doped with ^{209}Bi showed that under an applied magnetic field the envelope of the unresolved hyperfine multiplets revealed a strong nuclear hyperpolarization towards I_z = -9/2, resulting from the intense above-gap excitation used to produce the PL.[2]

We report on the first optical studies of Bi D^0X in ^{28}Si, using absorption rather than emission spectroscopy, and a new noncontact photoconductivity method which has much higher sensitivity and spectral resolution than PL spectroscopy. Individual hyperfine components of this potential semiconductor qubit can be resolved under an applied magnetic field, and we find that strong nonresonant optical hyperpolarization towards both the I_z = +9/2 and -9/2 hyperfine states can be observed, depending on the intensity of the above-gap excitation.

[1]. M. Steger et al., Science 336, 1280-1283 (2012).
[2]. T. Sekiguchi et al., Phys. Rev. Lett. 104, 137402 (2010).

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