Coherence recovery of electron spin qubit described by the central spin model in spin echo experiment

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Decoherence is one of the toughest problems that has to be overcome to build a solid state quantum computer. In the Loss-Divincenzo proposal, when electron spin of an impurity atom in semiconductor serves as a qubit, hyperfine coupling to surrounding nuclear spins is one of the main sources of decoherence. In the central spin model for small systems (with $N \sim 10$ nuclear spins) it has been observed that single π-pulse can almost completely reverse the electron spin decoherence. In our work we provide theoretical description of this effect for an arbitrary system size and pulse delay time.

It was found that the near perfect coherence recovery is achieved if eigenfunctions of the system Hamiltonian H and the spin-flipped Hamiltonian $\tilde{H} = R_\pi H R_\pi^\dagger$, where R_π is 180°-rotation around x-axis operator in the electron spin space, are nearly identical (up to some small quantity, which is inversely proportional to external magnetic field strength). In the case when eigenfunctions of these two operators coincide, full coherence recovery is achieved. This takes place if the system Hamiltonian commutes with the 180°-rotation operator.

To proof that eigenfunctions of H and $\tilde{H}$ for an arbitrary central spin system are almost identical perturbative approach with inverse field strength as a small parameter can be used but only if all hyperfine coupling constants are significantly different. For a more realistic case, when some hyperfine constants can be close or equal to each other perturbative theory series diverge. It was found that more general approach to the proof can be devised from a Bethe-ansatz for eigenfunctions of both Hamiltonians in the central spin model. The Bethe-ansatz provides a system of non-linear algebraic equations for components of eigenfunctions and using perturbation theory on these equations allowed us to find near identical pairs of eigenfunctions for the corresponding Hamiltonians.