Dynamics of a Spin Qubit in an Optical Dipole Trap

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Laser-cooled atoms, confined in far off-resonant optical dipole potentials, offer an original experimental platform for quantum computing and quantum simulation. We present a theoretical investigation of coherent dynamics of a spin qubit encoded in hyperfine sublevels of an alkali-metal atom in a far off-resonant optical dipole trap. The qubit is prepared in the "clock transition" utilizing the Zeeman states with zero projection of the spin angular momentum Fig. 1(a). We focus on various dephasing processes such as the residual motion of the atom, fluctuations of the trapping field and its incoherent scattering, and their effects on the qubit dynamics. We implement the most general fully quantum treatment of the atomic motion, so our results remain valid in the limit of close-to-ground-state cooling with a low number of vibrational excitations. We support our results by comparison with an experiment showing reasonable correspondence with no fitting parameters Fig. 1(b,c) [1].

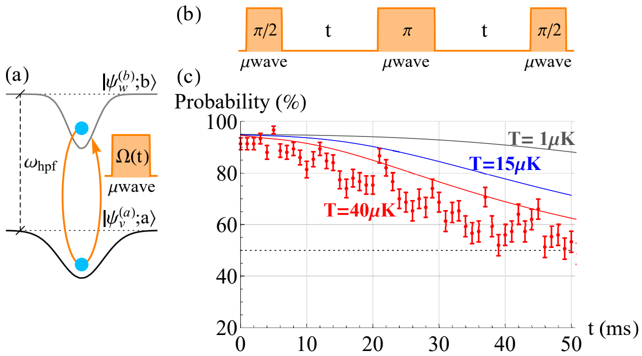

Figure 1: (a) Schematic of the qubit preparation: the trapping potentials are slightly different for the spin states, which induces dephasing in the qubit dynamics, (b) Pulse sequence for the spin-echo detection protocol, (c) Experimentally measured population of the signal state vs its theoretical estimate

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References

[1] L V Gerasimov, R R Yusupov, I B Bobrov, D Shchepanovich, E V Kovlakov, S S Straupe, S P Kulik and D V Kupriyanov, Phys. Rev. A (2021), accepted; arXiv:2105.11833 (2021)