Shortcuts to adiabaticity for efficient population transfer in a quantum dot exciton under phonon-induced dephasing

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Semiconductor quantum dots are promising platforms for quantum information technologies. The two qubit states are typically encoded in the ground and exciton states of a quantum dot. An important step for quantum information processing is the efficient controlled population transfer from the ground to the exciton state, despite the presence of dephasing and dissipation. In modeling the effect of the environment on the ground to exciton population transfer, the theory, supported by experimental results, suggests that the major dephasing mechanism in the quantum dot system is the coupling to acoustic phonons [1, 2]. Also, quantum control methods have been exploited to successfully achieve the desired population transfer, including the application of resonant pulses and the creation of Rabi oscillations and rapid adiabatic passage [1, 2], which robustly drives the system from the ground to the exciton state along a slower adiabatic path.

To accelerate the slow adiabatic dynamics while maintaining the robustness feature to some extent, a variety of methods called shortcuts to adiabaticity [3] were developed, providing faster paths to the same target states. In the present work, we utilize the transitionless quantum driving shortcut method [3], developed for suppressing non-adiabatic transitions in fast quantum dynamics, to obtain pulses which are then used for the efficient ground to exciton population transfer in a GaAs/InGaAs quantum dot, under the presence of acoustic phonon-induced dephasing. By applying the shortcut pulses to the quantum dot system, as a time-dependent Rabi frequency and detuning, we find using the time-evolving matrix product operator (TEMPO) method [4] that, for temperatures below 20 K and pulse duration up to 10 ps, a very good transfer efficiency is obtained in general. For the detailed explanation of the results, we employ a set of Bloch-like equations obtained from a generalized Lindblad equation, which can sufficiently describe the quantum dot dynamics at these lower temperatures. For higher temperatures, the transfer performance is degraded except for pulses of subpicosecond duration, where the shortcut Rabi frequency essentially degenerates to a delta-like pulse achieving a fast population transfer.

A typical set of results is shown in Fig. 1, where we display the efficiency of the population transfer to the exciton state obtained with TEMPO after the application of specifically designed pulses with maximum value of the Rabi frequency $\Omega_0 = 1$ ps^{-1}, as a function of pulse duration up to 10 ps and for temperatures in the range $0 - 20$ K (left plot) and $20 - 100$ K (right plot). We observe that for temperatures up to 20 K and shorter pulses, with duration below 1 ps, a high transfer efficiency is achieved. The performance is degraded for pulses with duration in the range around $1 - 2$ ps, while it is improved for longer durations, especially for temperatures below 10 K.

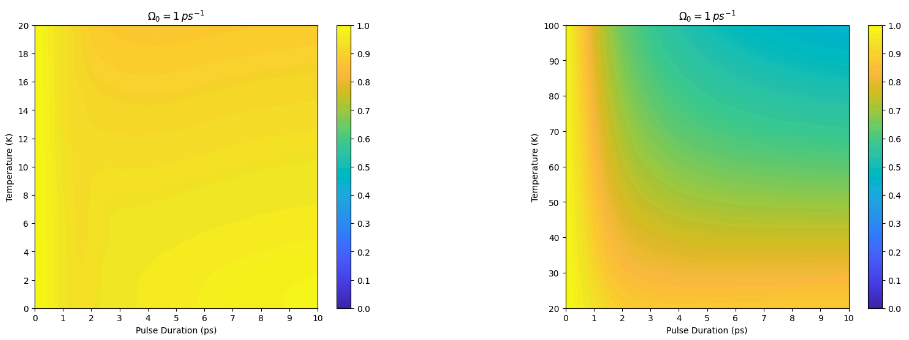

Figure 1: Efficiency of the population transfer to the exciton state after the application of pulses obtained with the method of shorcuts to adiabaticity, as a function of pulse duration and temperature.

References

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