# Superadiabatic Landau-Zener transitions during spin shuttling

Guido Burkard

*Department of Physics, University of Konstanz, Germany*

As a quantum dot carrying an electron spin qubit is shuttled along a disordered hetero-interface in silicon-based structures, the time-dependent valley splitting can cause inter-valley transitions (Fig.1a). In combination with the valley-dependent g-factor and non-deterministic valley relaxation, this effect may lead to spin decoherence. While at first sight, the transition probability $P$ seems to be governed by the Landau-Zener (LZ) model, we find the LZ model to be inadequate because both the valley splitting and the valley phase are essential (Fig.1b). We find a generalization of the Landau-Zener (LZ) model characterized by distinct paths of the instantaneous (valley) eigenstates as the system evolves in time, describing inter-valley transitions during shuttling and determining $P$. This often leads to superadiabatic (SA) behavior, i.e., to a substantial reduction of $P$, and therefore to an improvement of the shuttling fidelity.

*Figure 1: Superadiabatic (SA) vs. Landau-Zener (LZ) transitions. (a) Energy splitting landscape as encountered, e.g., in electron shuttling with valley splitting $E_{VS} = 2|\Delta|^2$. The splitting $E_{VS}$ between the two low-lying energy levels depends on the center position $d$ of a localized electron, where $d = vt$ during electron shuttling at velocity $v$ [1]. Starting in the lower level at $t = 0$, $P$ denotes the excitation probability into the higher valley state. (b) Concomitant trajectory of the inter-valley coupling matrix element $\Delta$ in the complex plane. While the three highlighted minima of $E_{VS}$ in (a) look similar, their different character becomes apparent as LZ-like (red), SA (blue), elliptic (green). For comparison, a standard LZ trajectory with energy gap $\Delta_0$ is shown (dashed red line). (c) Transition probability $P$ as a function of $\alpha$ and $\beta$, where $\alpha$ corresponds to the level velocity in the LZ model. The LZ case corresponds to $\beta = 0$ (vertical red line). For increasing $\beta > 0$, the decrease of $P$ indicates the SA behavior (SA regime bounded by red and white lines), until at $\beta = \alpha$ (dashed white line), the unconditionally adiabatic case $P = 0$ is reached.*

[1] J. R. F. Lima and G. Burkard, Phys. Rev. Materials **8**, 036202 (2024)
[2] J. R. F. Lima and G. Burkard, arXiv:2408.03173