Unraveling Timing Noise-Induced Decoherence in Single-Electron Sources

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Understanding decoherence in electronic excitations is pivotal for advancing solid-state devices in quantum technologies. The single-electron sources (SESs), which generate narrow nonequilibrium electron excitations as potential flying qubits, are particularly sensitive to external noise. Previous experiment using high-energy SES [1] has shown that the electron excitations suffer a strong decoherence, measuring the quantum purity low as 0.04. This cannot be explained by traditional mechanisms such as electron-electron or electron-phonon interactions, because the high-energy excitations are effectively isolated from the Fermi sea and the phonons [2].

We propose timing noise [3] as a universal model, consistent with Ref. [1], to explain strong decoherence of ultrafast SES pulses, without resorting to any specific microscopic mechanism. The timing noise generates a stochastic ensemble of wave packets which are temporally translated, see Fig.1. The timing noise induces pure dephasing effect in energy basis. Namely, the coherence in energy components is suppressed when the time uncertainty of the noise is much larger than that of the wave packet, see Fig.2. We also propose a protocol to identify the timing noise, i.e., to decide whether a SES involves timing noise and to obtain its noise distribution. Finally, we show that an energy filtering can recover the coherence when the time elongation due to the filtering is larger than the time uncertainty of the timing noise. Our theory and protocol are applicable for any SESs with ultrafast voltage pulses.

References

[1] J. D. Fletcher et al., Nat. Commun. 10, 5298 (2019)
[2] N. Johnson et al., Phys. Rev. Lett. 121, 137703 (2018)
[3] S. Ryu et al., arXiv:2310.03728.

Figures

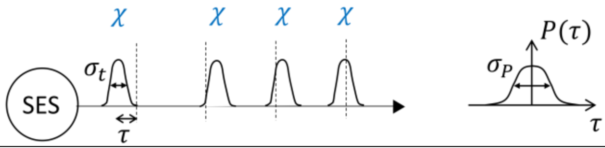

Figure 1: Single-electron sources with timing noise. At each emission (dashed lines), electron state χ is temporally translated by random timing shift τ, governed by probability distribution P(τ).

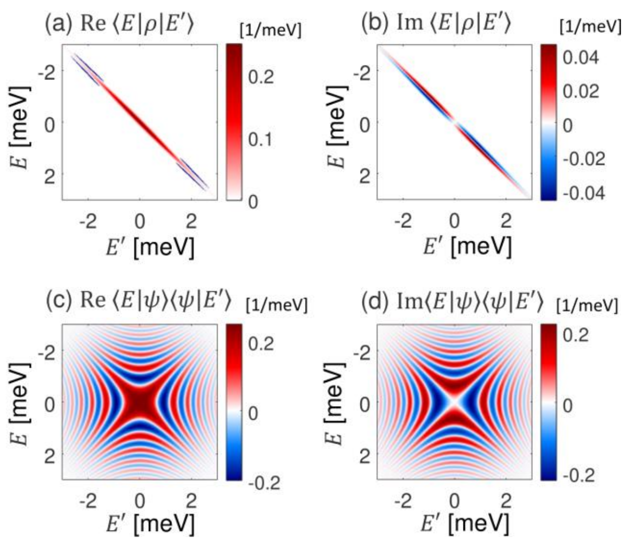

Figure 2: Timing noise identification. (a)–(b) The density matrix in energy basis for the state detected in Ref. [1]. Our protocol shows that this state is the result of noisy SES emitting pure-state wave packet ψ, (c)–(d).