Quantum stochastic resonance in optically detected single electron tunneling

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Stochastic resonance is a long-known phenomenon in a variety of fields, ranging from the periodicity of ice ages to the dynamics of neurons. Stochastic resonance can enhance the sensitivity of signal detection by the addition of noise. Quantum stochastic resonance, even though predicted some 30 years ago [1] has only recently been investigated experimentally [2, 3]. Here, we study stochastic resonance in the charge occupation statistics of a single self-assembled quantum dot (Qd). Single electron transport is detected by resonance fluorescence of the exciton transition (Fig. 1b)). By analysing the transport statistics for different modulation frequencies, we find a strong decrease of the Fano factor ($> 60\%$) in the frequency range that corresponds to the tunneling rate. This is a clear indication for stochastic resonance [2].

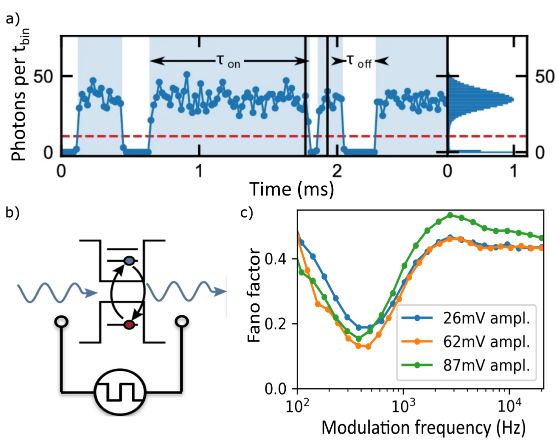

Fig. 1. (a) The telegraph photon signal, (b) the optically-driven QD with gate modulation and (c) the Fano factor for different modulation frequencies.

The system investigated is a quantum dot, embedded in a diode structure, where a gate voltage V_g can be applied to fine-tune the Qd charge. For the present experiment, we adjust V_g so that the dot is occupied by an electron $\approx 50\%$ of the time. The uncharged Qd will be in resonance with the exciton transition while the charged state will be out of resonance. To determine the charging state, the fluorescence photon stream is binned and –after choosing a suitable binning time and threshold [4]– converted into a binary telegraph signal, see Fig. 1a). Here, τ_{on} and τ_{off} are the times the Qd light emission is on and off, respectively.

For the stochastic resonance experiment, the gate voltage is weakly modulated by a square pulse and the optical telegraph signal is monitored. Following the approach of Hänze et al. [2], we evaluate the Fano factor as a function of the modulation frequency. The Fano factor is defined as $F = \sigma^2/\mu$ with the standard deviation σ and the mean μ of the number of tunneling events per modulation period. It is a direct measure of how closely the electron transport follows Poisson statistics. As seen in Fig. 1c) the Fano factor exhibits a clear minimum around $500\,\mathrm{Hz}$, where it drops to roughly $1/3$ of its expected value of 0.5 in the case of no modulation [5]. This drastically reduced standard deviation of the probability distribution is a clear indication for stochastic resonance [3]. The drop in the Fano factor is expected to occur in a frequency range ω that corresponds to the tunneling rate Γ. With an in-depth evaluation of the tunneling dynamics, we indeed find $\omega \approx \Gamma$, which further supports that the tunneling dynamics in our driven quantum dot system is governed by quantum stochastic resonance.

References

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