Exploring the potential of two-gate operation of tunable-barrier single-electron pumps

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Single-electron pumps based on tunable-barrier quantum dots are the most promising candidates for a direct realization of the unit ampere in the recently revised SI: they are simple to operate and show good precision of the quantized current I = e·f at high operation frequencies. The current understanding of the residual transfer errors at low temperature is based on the evaluation of backtunneling effects in the decay cascade model. This model predicts a strong dependence on the ratio of the time dependent changes in the quantum dot energy and the tunneling barrier transparency. Trading the simplicity of the usual single-gate operation for the increased flexibility of a two-gate operation scheme we have verified predictions of the decay cascade model and demonstrated the control of the backtunneling error. As experimental model system we have used a single-electron pump realized by a quantum dot hosted in a GaAs/AlGaAs heterostructure. We have derived and experimentally verified a quantitative prediction for the error suppression, thereby confirming the basic assumptions of the backtunneling (decay cascade) model. We have used this scheme to demonstrate a controlled transition from the backtunneling dominated regime into the thermal (sudden decoupling) error regime. The predicted suppression of transfer errors by several orders of magnitude at zero magnetic field was also verified by a sub-ppm precision measurement [1]. We furthermore have recently explored a simplification of the scheme used in [1] for two-gate error suppression at increased frequency and therefore current and also have used additional parameters like source-drain bias to explore the transition to turnstile operation and to further characterize the the characteristics of the quantum dot used for single-electron pumping.

[1] F. Hohls et al., PRB **105**, 205425 (2022).

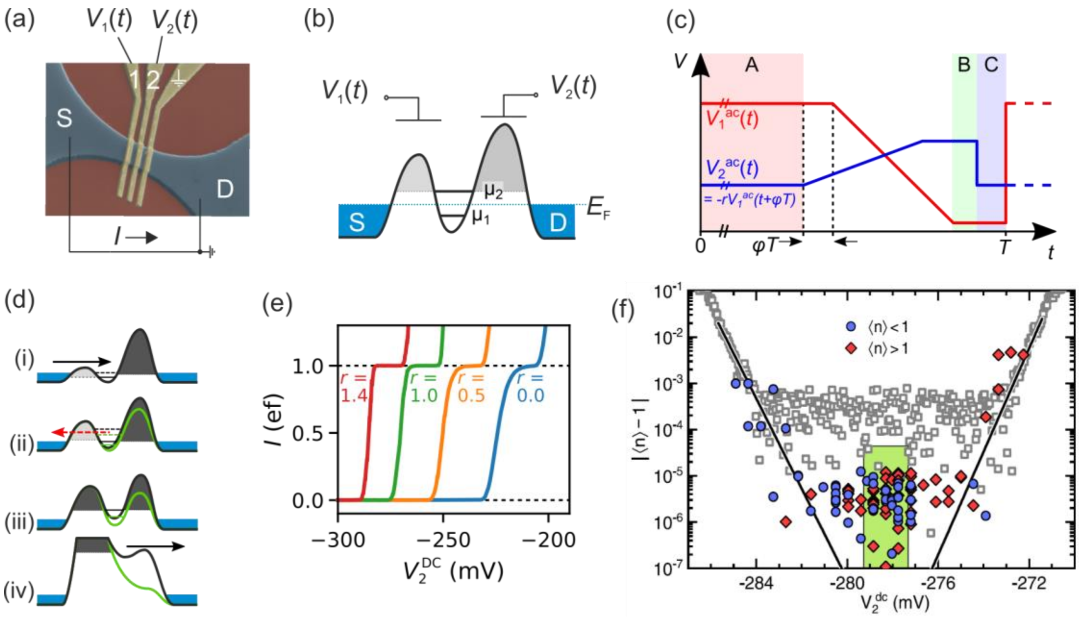

Fig.1. a) Exemplary device. b) Schematic of QD barrier control by gate voltages. c) Voltage waveforms used in [1] and for (e) and (f). d) Schematic of pumping phases for single drive (black) and two-gate drive (green). e) Effect of compensation ratio r on quantization step sharpness (f = 85 MHz). f) Deviation from quantized value I = e·f (squares: fast measurement, lines: exponential fits, filled symbols: precision measurement with typical 5 ppm uncertainty)