Assessing the charging energy of GaAs/AlGaAs tunable-barrier single-electron pumps by two-gate turnstile operation

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Tunable-barrier single-electron pumps (SEPs) are promising candidates for a direct realization of the unit ampere in the recently revised SI. They have shown the highest potential for generating relatively high currents with reasonable accuracy and are based on quantum dots (QD) that are defined by tunable energy barriers imposed by electrostatic gate electrodes (see Fig. 1 for an exemplary realization) [1]. Periodic modulation of these barriers causes a clocked transfer of electron without need of a bias voltage, which results in a current $I = \langle n \rangle ef$. Here $\langle n \rangle$ is the average number of electrons transferred per transport cycle, e the electron charge and f the repetition rate of the transport cycles. GaAs/AlGaAs based tunable-barrier SEPs have shown robust and accurate single gate operation when imposing a large magnetic field [2,3], whereas accurate pumping at zero magnetic field has only been demonstrated with additional error mitigation by more complex two-gate operation with two tailored RF signals and at lower frequency [4].

For a better understanding of the SEP operation and of the increased robustness in magnetic field, a characterization of the charging energy for a dot with single (or few) electron occupation near resonance to a lead is highly desirable. However, to suppress cotunneling the SEPs are designed such, that one of the barriers always shows complete blockage when bringing the lowest electron states into resonance with one of the lead chemical potentials. Therefore, the charging energy is not accessible by conventional dc Coulomb blockade (CB) diamond measurements. We circumvent this using periodic pi-shifted two-gate driving of the QD entrance and exit barriers in turnstile mode [5], sequentially opening and closing the source and drain barriers with an applied bias voltage V_{sd}, see Fig. 1 for a typical measurement result. This allows us to assess the charging energy in analogy to the analysis of conventional CB diamonds. Using this method we have examined the change of the charging energy with varying perpendicular magnetic fields from 0 to 10 T, observing an increase by approximately 40 % for the device shown in Fig. 1, thereby promoting the accuracy of quantization of the SEP current in a large perpendicular magnetic field.

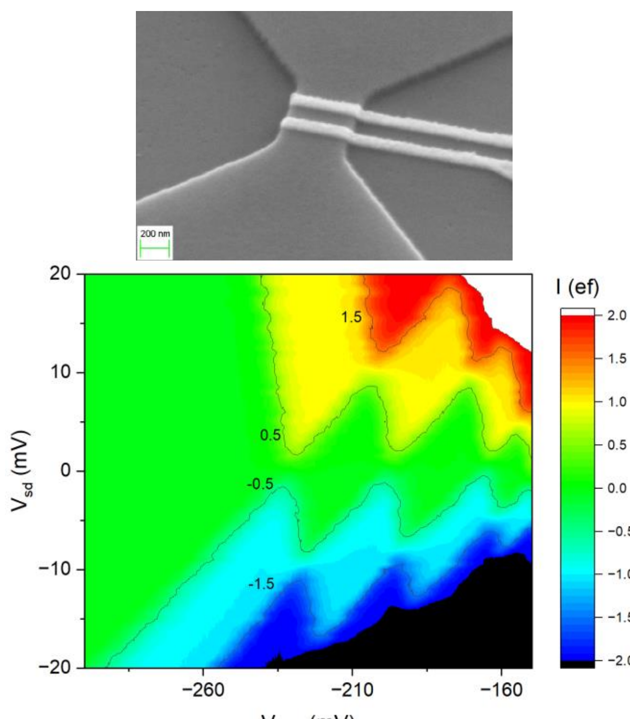

Fig. 1. Top: SEM picture of a similar single-electron pump device. Bottom: Measured normalized current when operating the single-electron pump as turnstile, applying pi-shifted sine signals with $f = 200$ MHz to both gates while applying a bias voltage V_{sd} to one lead ($B = 0$ T). The charging energy for the second electron is estimated to 10 meV.

References

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