Single-Electron Screening Versus Controlled Dephasing

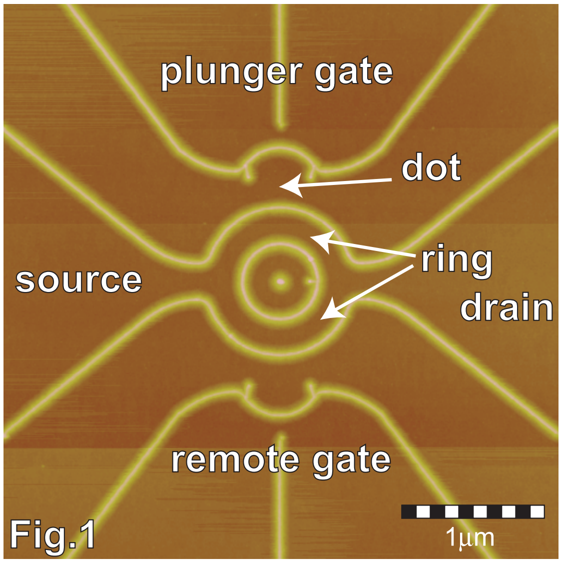
L. Meier[1], A. Fuhrer[1], T. Ihn[1], K. Ensslin[1], W. Wegscheider[2], M. Bichler[3]

[1] *Solid State Physics Laboratory, ETH Zurich, 8093 Zürich, Switzerland*
[2] *Institut für experimentelle und angewandte Physik, Universität Regensburg, Germany*
[3] *Walter Schottky Institut, Technische Universität München, Germany*

We report an experiment in which two quantum structures, an Aharonov-Bohm ring and a Coulomb-blockaded quantum dot interact electrostatically. The goal of the experiment is to unravel the consequences of the interaction between the two subsystems. From the quantum measurement point of view the quantum dot can be regarded as a 'which path detector' for electrons traversing the quantum ring. The efficiency of this detector can be expected to depend on its quantum state, e.g. if it is blockaded or conducting. Efficient detection of the electron path will lead to a reduction of the interference amplitude in the Aharonov-Bohm ring. From another (equivalent) point of view, the interaction between dot and ring may lead to an entanglement of the states of the two subsystems causing dephasing.

In our experiment the coupled ring-dot structure was realized on a Ga[Al]As heterostructure with a high quality two-dimensional electron gas 34 nm below the surface. Ring and dot were defined by AFM-Lithography (Fig. 1). The whole structure was covered by a top gate giving additional tunability. Experiments were carried out in a dilution refrigerator with a base temperature of 40 mK. The quantum ring structure exhibits pronounced Aharonov-Bohm oscillations as a function of magnetic field. The quantum dot can be tuned from the Coulomb blockade regime to the open regime. The exact states of the two subsystems are tuned by the potential difference between them and by additional in-plane gate electrodes and the top gate. In order to probe the interaction between electrons in the ring and the dot we measure the Aharonov-Bohm oscillations in the ring current I as a function of magnetic field B (Fig. 2 inset) and evaluate their amplitude at different plunger gate voltages which tune the quantum dot through a conductance peak. The measurement is performed with a low-frequency (89 Hz) modulation voltage added onto the DC plunger gate voltage allowing to detect the AC component of the ring current with a lock-in technique. As compared to the blockaded dot, it is found that the amplitude of the Aharonov-Bohm oscillations is significantly suppressed (by up to 40%) when the quantum dot is conducting (Fig. 2). This suppression shifts in plunger gate voltage with the conductance peak if the latter is moved by a remote gate electrode proving the intimate relation between the two effects and providing evidence for the electrostatic dot-ring coupling.

However, in addition to the dephasing arguments presented above we have to take another mechanism into account which may contribute to the observed suppression of the Aharonov-Bohm oscillation amplitude. It involves screening of the modulated plunger gate voltage felt in the ring by single-electron charging in the dot on a conductance peak. We discuss the relative importance of dephasing and single-electron screening in our system based on measurements of the temperature dependence of the effects. We address the question under which conditions charge fluctuations near a quantum ring can obscure the determination of the true dephasing rate.



plunger gate
dot
ring
source
drain
remote gate
Fig.1
1μm

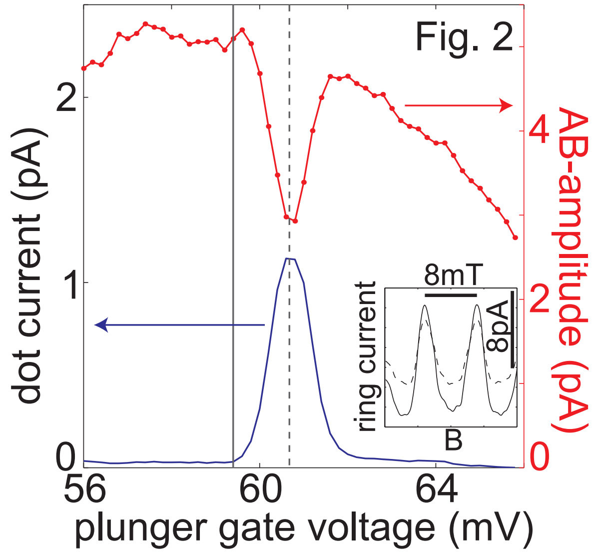


Fig. 2
dot current (pA)
AB-amplitude (pA)
plunger gate voltage (mV)
0
1
2
0
2
4
56
60
64
8mT
8pA
ring current
B