Scanning Gate Imaging of the 0.7 anomaly

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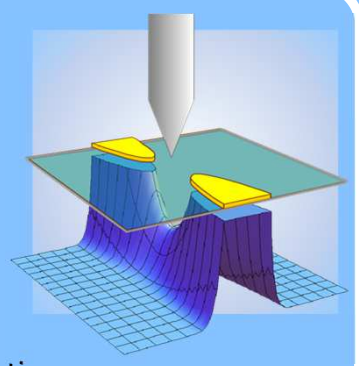
Motivation

The origin of the so called “0.7 structure" in the transport characteristics of 1D mesoscopic devices represents a long standing puzzle, yet showing a continuously renewed interest for possible applications in spintronics [1]. Though several mechanisms have been proposed to explain such anomaly, a general consensus has not been achieved so far. Among the proposed explanations are quantum **interference** from **scatterers** within the electron phase coherence length from the constriction, and **Kondo** effect due to zero-dimensional systems inside the constriction itself, acting as **quantum dots** [2]. These explanations involve the presence of point defects, such as charged impurities. The investigation of the spatial distribution of charge and potential is thus essential in discussing these mechanisms, and is not possible with traditional measurement schemes. In this work, we exploit the high spatial resolution allowed by the Scanning Gate Microscopy technique to correlate the presence of localized defects (e.g. charged defects, impurities or antidots) with the occurrence of the anomalous plateau at G≈0.7 □ e^2/h, and definitely ruled out zero-dimensional structures as the underlying origin of the 0.7 structure.

The experiment

- The devices:
  GaAs/AlGaAs heterostructures
  in Quantum Point Contact geometry
  2DEG depth 55-110 nm
  n=1 - 5 □ 10^{11} cm^{-2}, μ=2 - 10 □ 10^6 cm^2/Vs



- The SGM technique:
  Low temperature (300 mK) AFM, nm-size resolution
  Voltage biased tip is scanned over the device while the transport properties are recorded: G(x,y)

  Local effect ⇒ Global response

- Correlate **local** information to macroscopic properties (conductance).
- Strong gating effect **AND** mapping of potential landscape.

According to proposed explanations of the 0.7 anomaly [2], localized defects act in two ways:

- As **quantum dots**, they can provide the physical systems for the explanation of the 0.7 structure based on the **Kondo effect**.
- As charge **scatterers**, they cause quantum **interference** phenomena with electrons reflected from the constriction, which produce plateaus at G<(e^2/h).

Localized defects produce sharp potential variations, which are imaged as dark spots in a SGM map. The presence of these structures is detected for a wide range of experimental parameters (V_{tip}, V_{gate}, T).

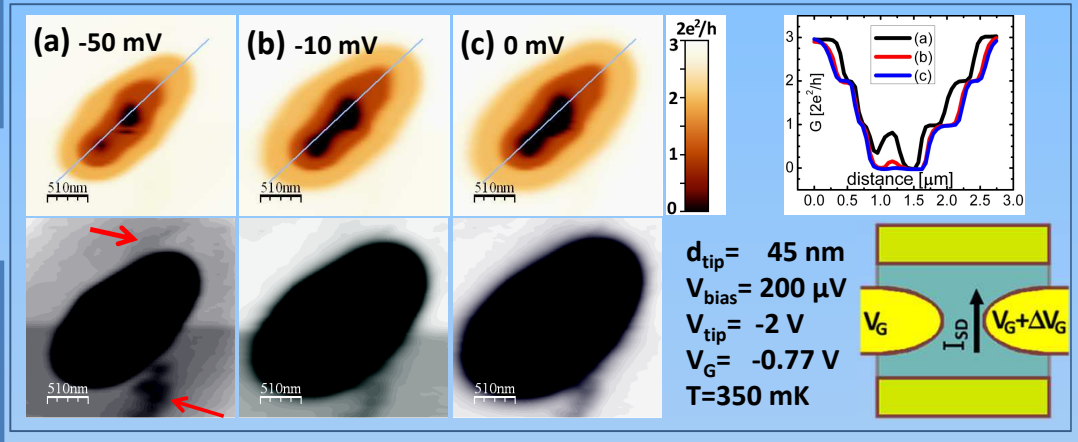
Only method to detect **unequivocally** localized charged structures

Charged defects at pinch-off

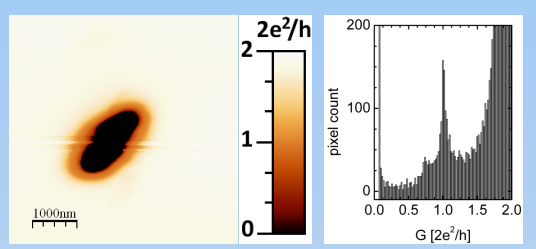
- We observe the plateau at G≈0.7□(e^2/h), typical of the 0.7 anomaly, in several devices with localized defects in proximity to the constriction.

0.7 vs gate unbalancing ΔV_G

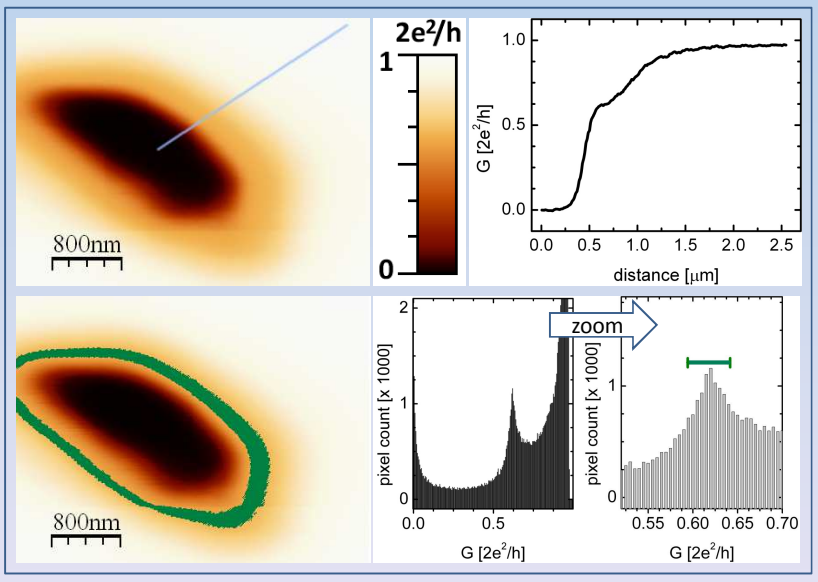
- Charged structures strongly perturb the saddle point potential produced by the metallic gates, and induce areas of lower charge density. (Arrows)
- Increasing the gate bias difference ΔV_G, the depletion spot is increased until the impurity merges with the features of the quantized conductance.



High resolution SGM map of the same device. The 0.7 anomaly produces a peak in the amplitude histogram at G<(e^2/h).

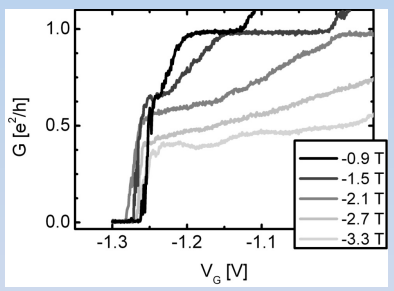


Top: typical SGM image of a clean QPC constriction, and conductance profile along the blue line. Bottom: annular structure obtained from the FWHM of the peak in the amplitude histogram. The data are obtained with: d_{tip}= 45 nm, V_{bias}= 40 μV, V_{tip}= -3.1 V, V_G= -0.47 V, T=5 K



Clean constrictions

- We investigated several devices with clean constrictions. In these devices, **no** trace of **charged spots** is detected: no impurities, localized defects or sharp density variations are present within tens of μm from the constriction. Transport measurements (see Right) show the plateau-like feature associated to the 0.7 anomaly.



The 0.7 structure is present even in the absence of localized charged structures or potential fluctuations on a nm scale.

- SGM measurements (see Left) show that the quantized conductance displays **annular symmetry**.

The 0.7 structure arranges spatially in an annular structure of constant conductance G<(e^2/h). This structure has a **closed** loop shape, centered around the QPC centre.

Conclusions

In conclusion, we performed a systematic study of constrictions on GaAs 2DEG heterostructures, both clean and containing charged defects . We observe the 0.7 structure in both clean and dirty constrictions, and it shows annular symmetry around the depleted spot at the QPC centre. As a result, we disregard the explanations based on fixed defects (i.e., Interference effects and Kondo effect due to localized quantum dots) as underling mechanism for the 0.7 structure.

[1] A. M. Burke, O. Klochan, I. Farrer, D. A. Ritchie, A. R. Hamilton, and A. P. Micolich, Nano Letters **12**, 4495 (2012).
[2] A. P. Micolich, J. Phys.: Condens. Matter **23** (2011).
[3] N. Paradiso, S. Heun, S. Roddaro, G. Biasiol, L. Sorba, D. Venturelli, F. Taddei, V. Giovannetti, and F. Beltram, Phys. Rev. B 86, 85326 (2012).