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 $G \approx 0.7 \times 2e^2/h$, and we can definitely rule out zero-dimensional structures as the underlying origin of the 0.7 structure.

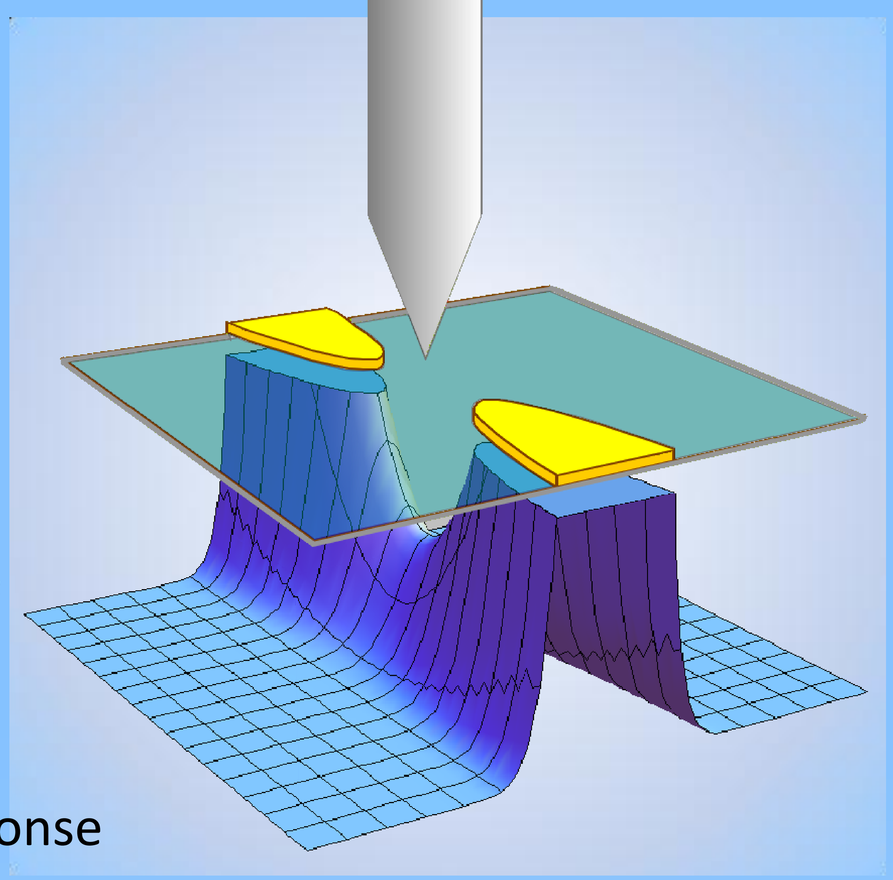
The experiment

- The devices:

GaAs/AlGaAs heterostructures
in Quantum Point Contact geometry
2DEG depth 55-110 nm
$n=1\text{-}5\times10^{11}$ cm^{-2}, $\mu=2\text{-}10\times10^{6}$ cm^2/Vs

- The SGM technique:

Low T (300 mK) AFM, nm-size resolution
Voltage-biased tip is scanned over the device while the conductance G(x,y) is recorded.



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 can act in two ways:

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

Localized defects produce sharp potential variations [3], which are imaged as dark spots in an SGM map and detected for a wide range of experimental parameters (V_{tip}, V_{gate}, T).

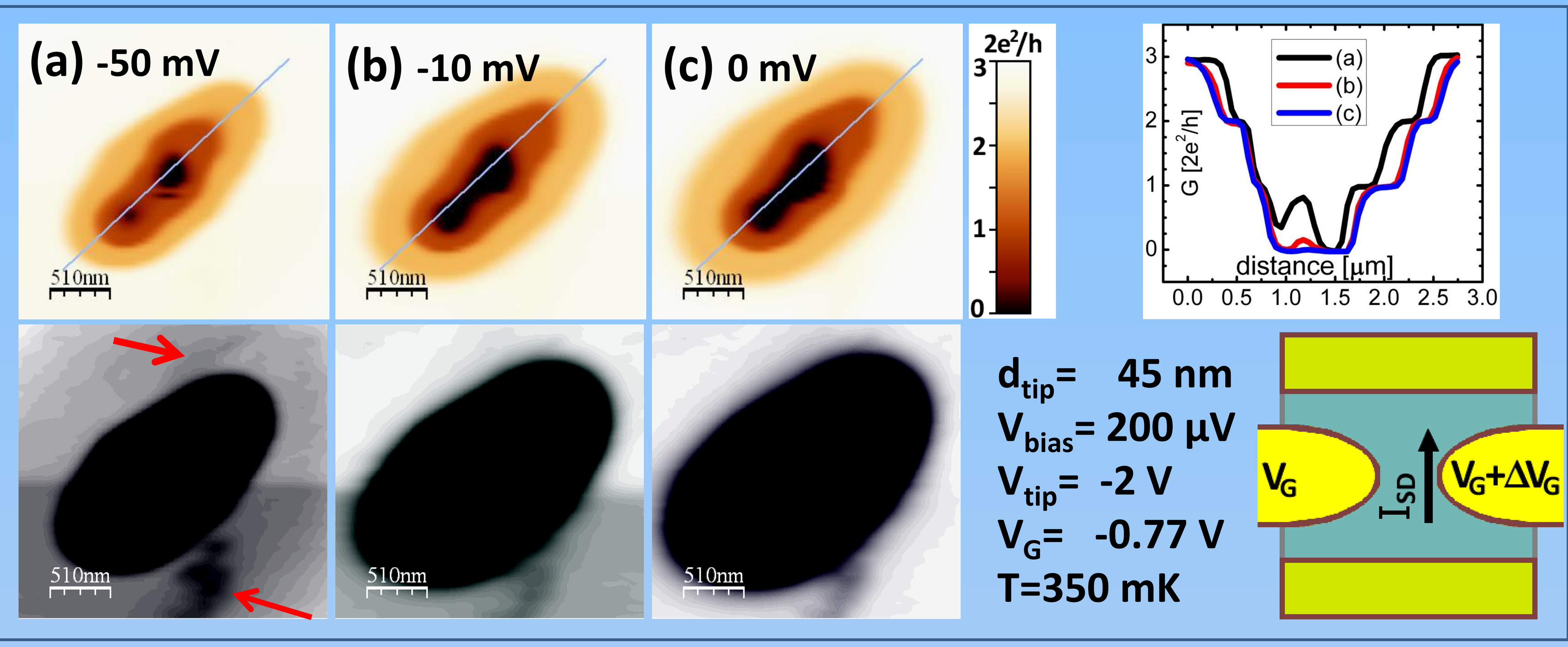
SGM detects **unequivocally** localized charged structures.

Charged defects at pinch-off

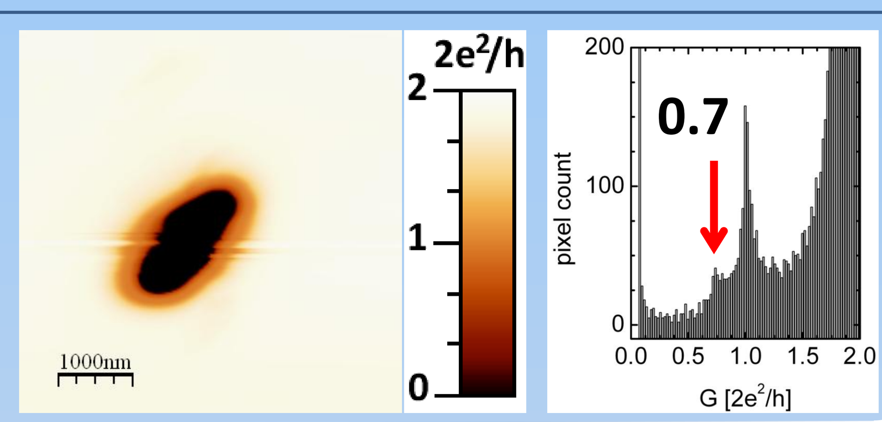
- We observed the plateau at $G \approx 0.7 \times (2e^2/h)$, typical of the 0.7 anomaly, in several devices with localized defects in proximity to the constriction. The sharp features induced by these defects are inevitably detected by SGM.
- The existence of the 0.7 anomaly is not precluded by the presence of localized defects.

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).
- By changing the gate bias difference ΔV_G, the depletion spot can be increased or shifted, enhancing the visibility of the defect.



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



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.

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

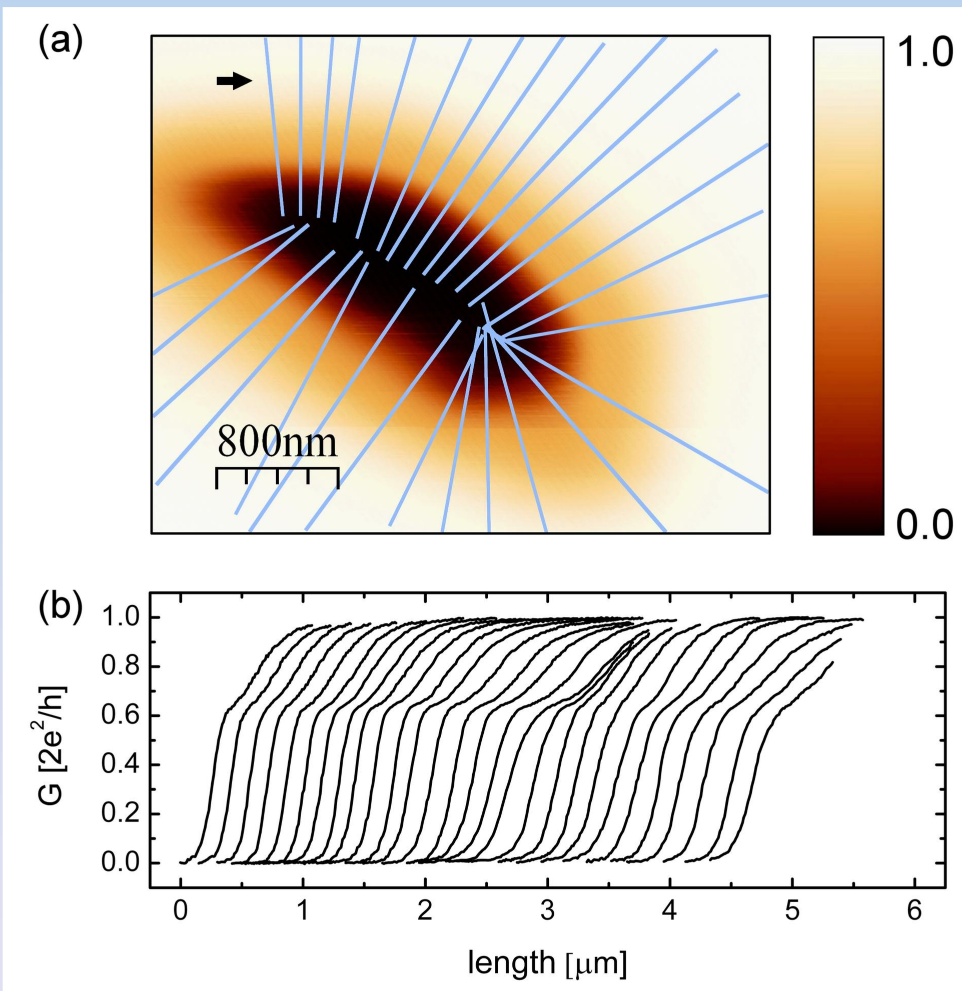
- Cross-sections of the SGM scan indicate uniform value for the "0.7" anomaly.

The 0.7 anomaly arranges spatially in an annular structure of constant conductance $G<(2e^2/h)$ around the QPC centre.

0.7 anomaly a clean constriction.

(a) SGM scan of device B measured for T = 0.7 K, V_g = -0.471 V, V_{tip} = -5 V, showing the low conductance range. The conductance is given in units of $G_0 = (2e^2/h)$.

(b) Conductance cross-sections obtained from the SGM scan in (a), offset for clarity. The traces, from left to right, are cuts along the lines in (a), starting at the arrow and following the clockwise direction. The 0.7 anomaly is at the same conductance value G = 0.63 G_0 in all traces.



Conclusions

We performed a systematic study of constrictions on GaAs 2DEG heterostructures, both with and without sharp defects. We observe the 0.7 structure in both "clean" and "dirty" constrictions, with an annular symmetry around the depleted spot at the QPC centre. Our results thus disregard explanations based on localized defects (i.e. on interference and Kondo effects) as the main underlying mechanism for the 0.7 phenomenology.

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