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Re-entrant Negative Coulomb Drag in a 1D Quantum Circuit

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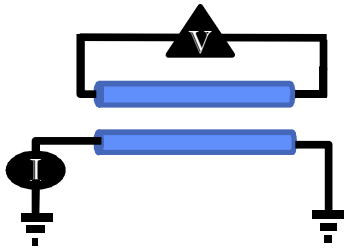
Motivation

Goal : Study electron interactions in 1 dimensional systems

- Address multiple 1D subbands regime
- Electron hole asymmetry
- Luttinger liquid theory

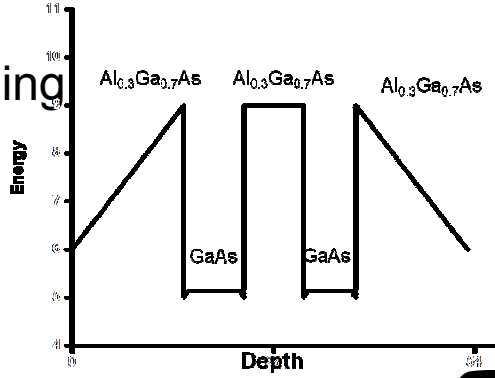


Tool : Coulomb Drag measurement

- Direct probe of electron-electron interactions

How : Independent and vertically-coupled quantum wires

- Direct control of the 1D subband occupancy in each wire independently
- Smaller inter-wire separation without tunnelling
  - Stronger drag signal
  - Stronger coupling between the wires
  - Smaller influence of phonon drag



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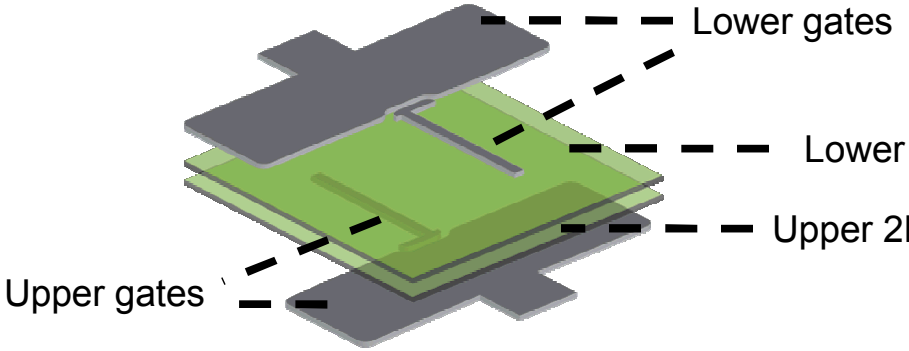
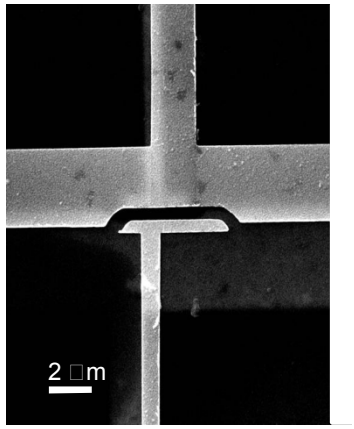
Sample design and fabrication

- Use 18 nm wide double quantum well heterostructures with a 15 nm barrier.
- Fabricated through an Epoxy-Bound And Stopped-Etch technique*
- Fabricate 4.2 □m long vertically-coupled quantum wires

Gates design





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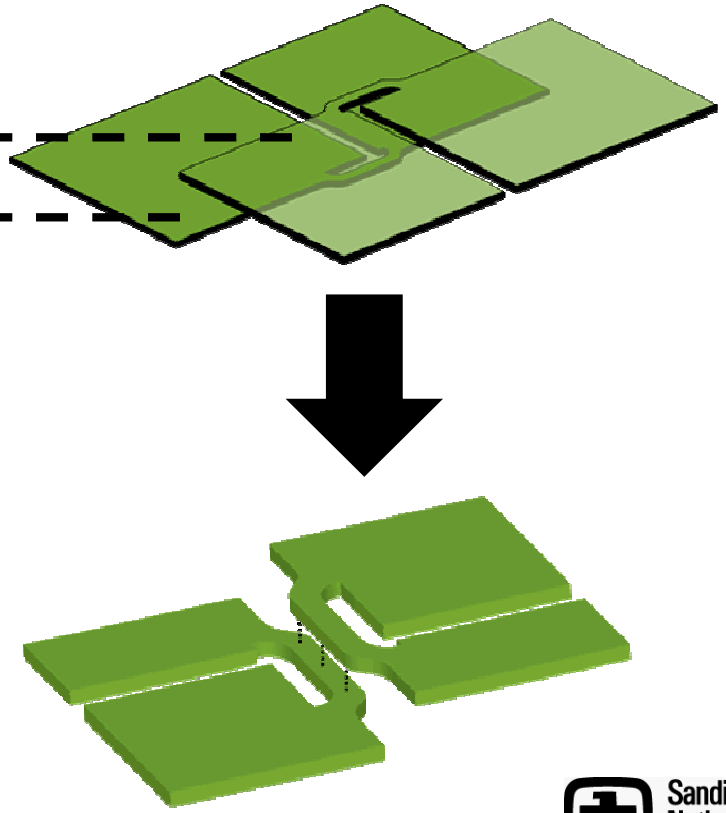

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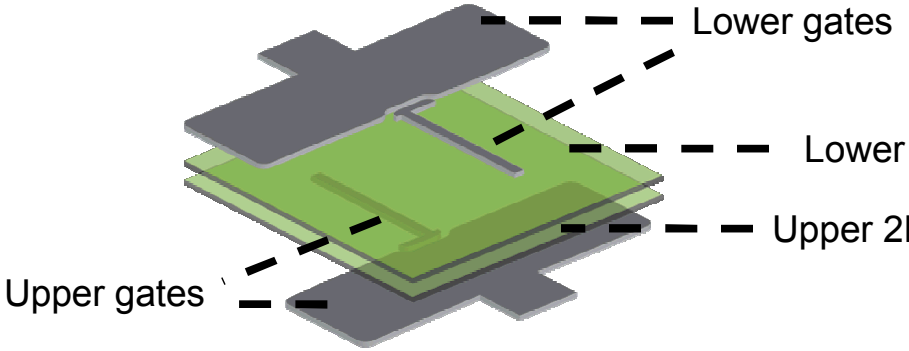

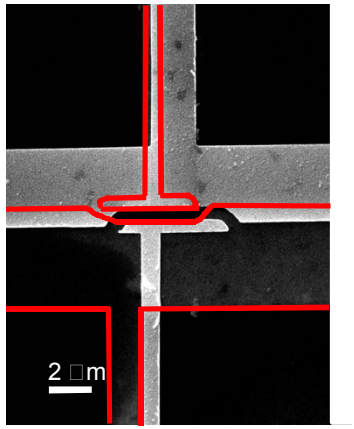

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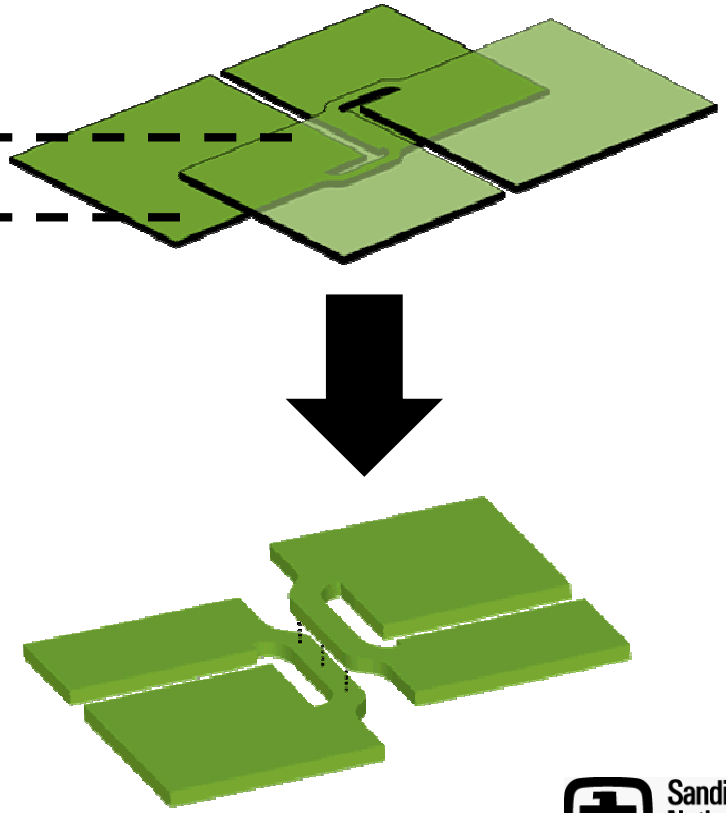

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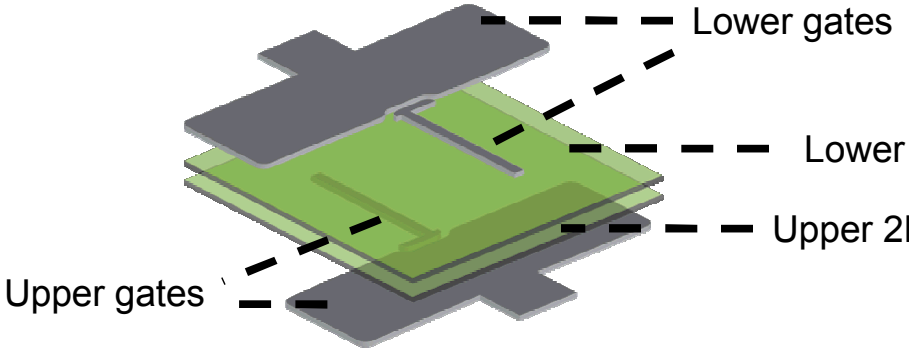

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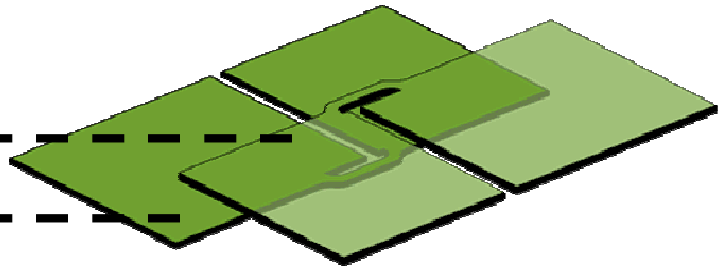

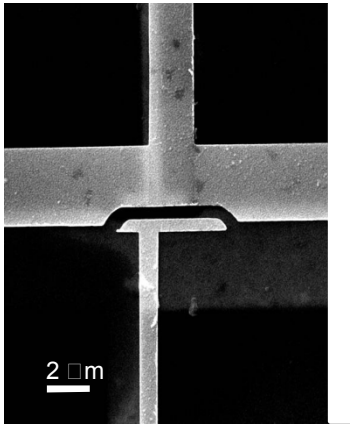

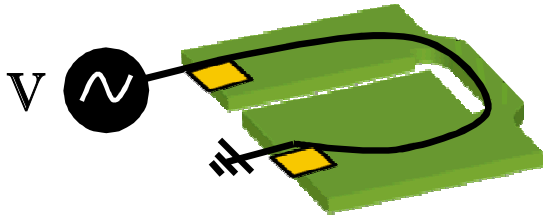

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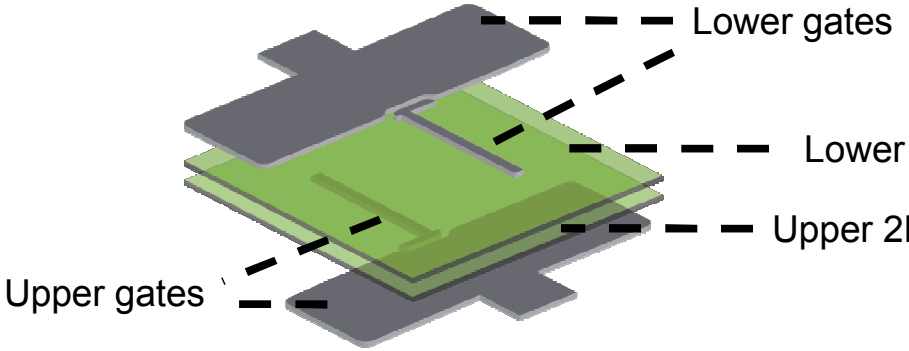

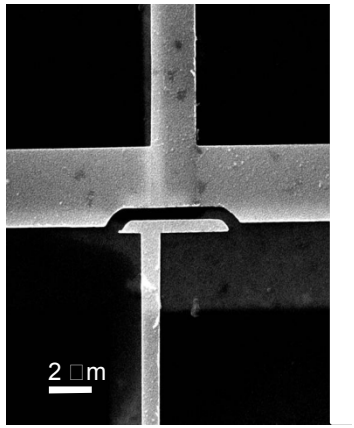

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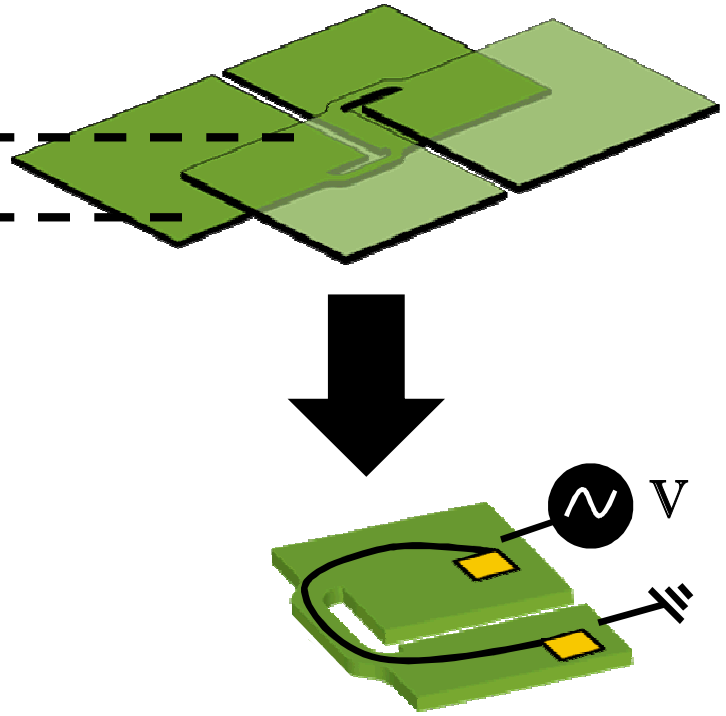

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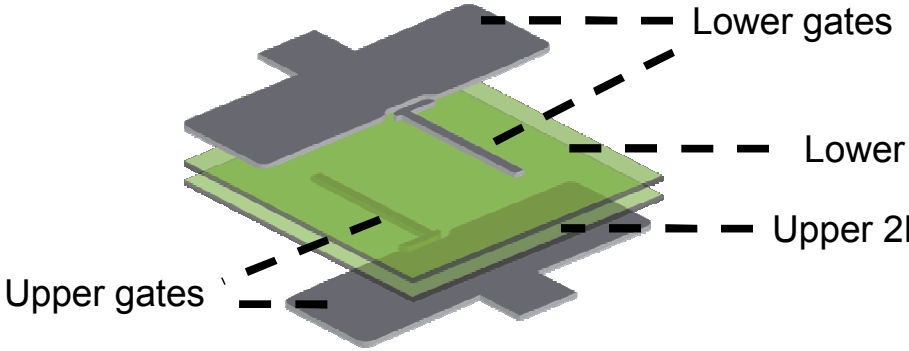

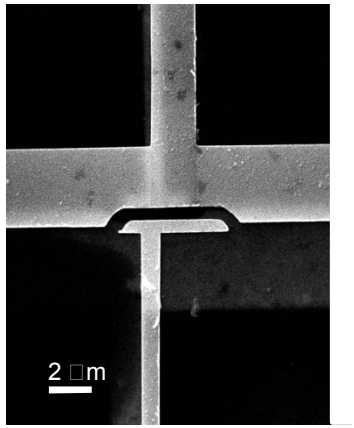

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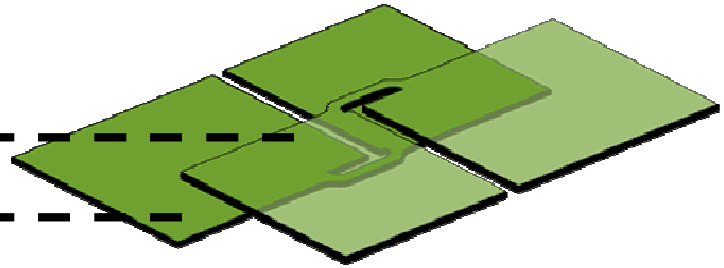

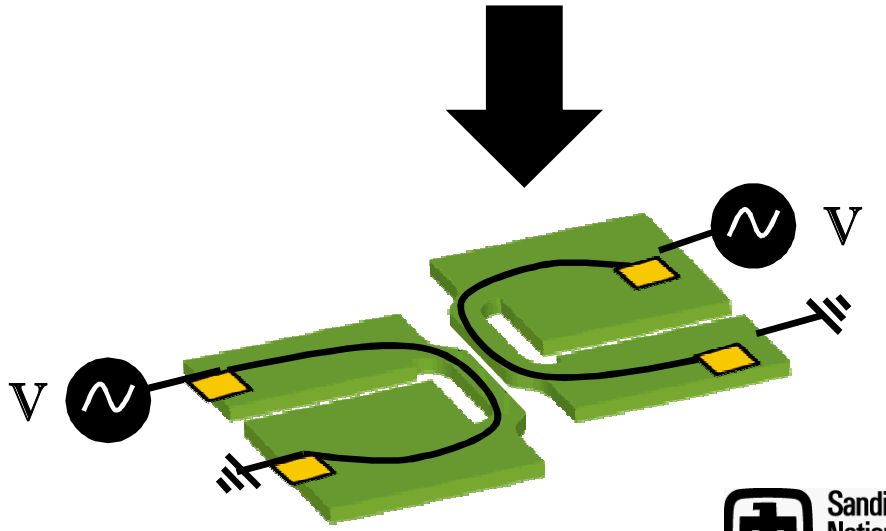

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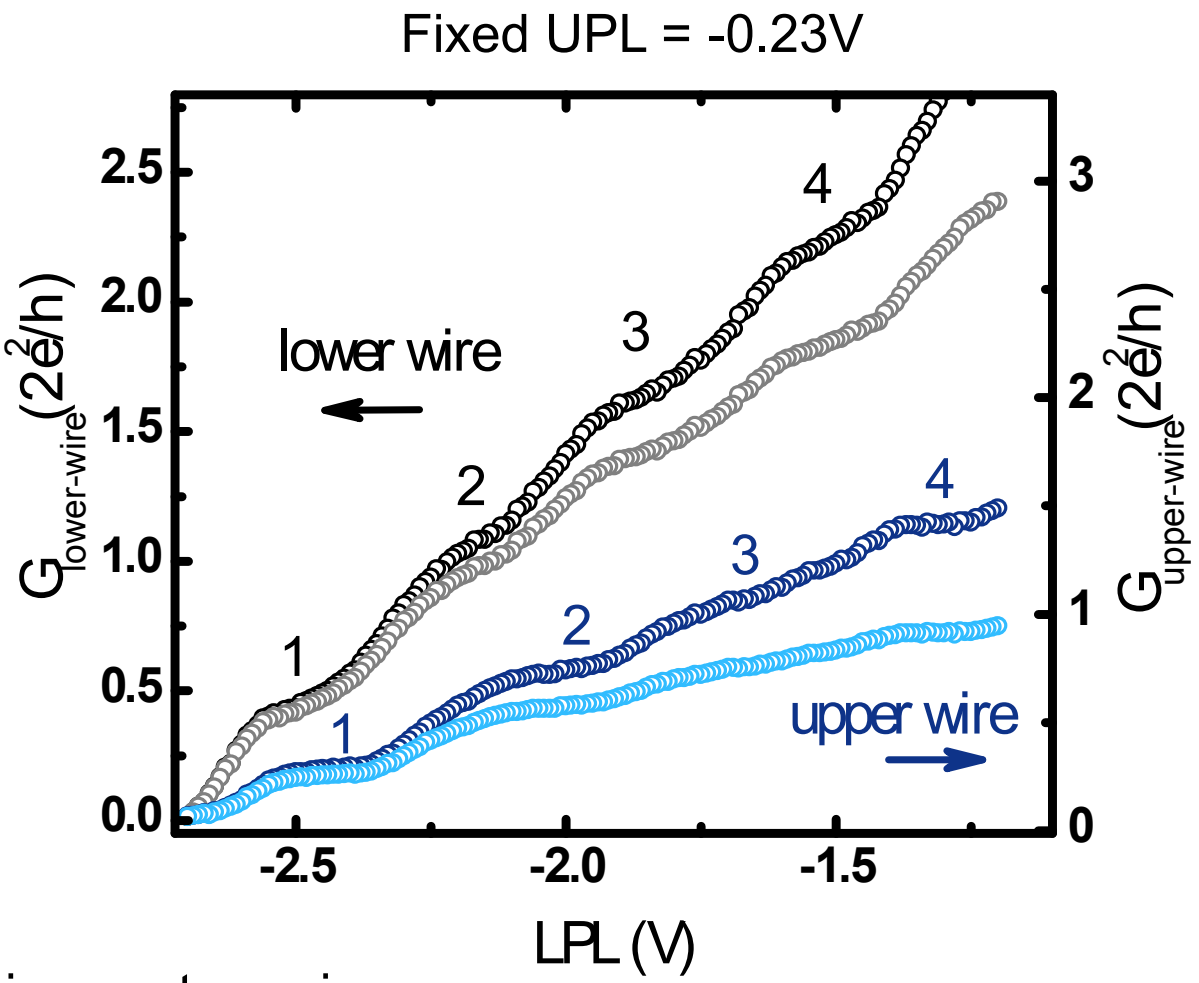
Wires characterization



- Non-ballistic quantum wires
  - ➢ After substracting a series resistance, even plateau-like features spa

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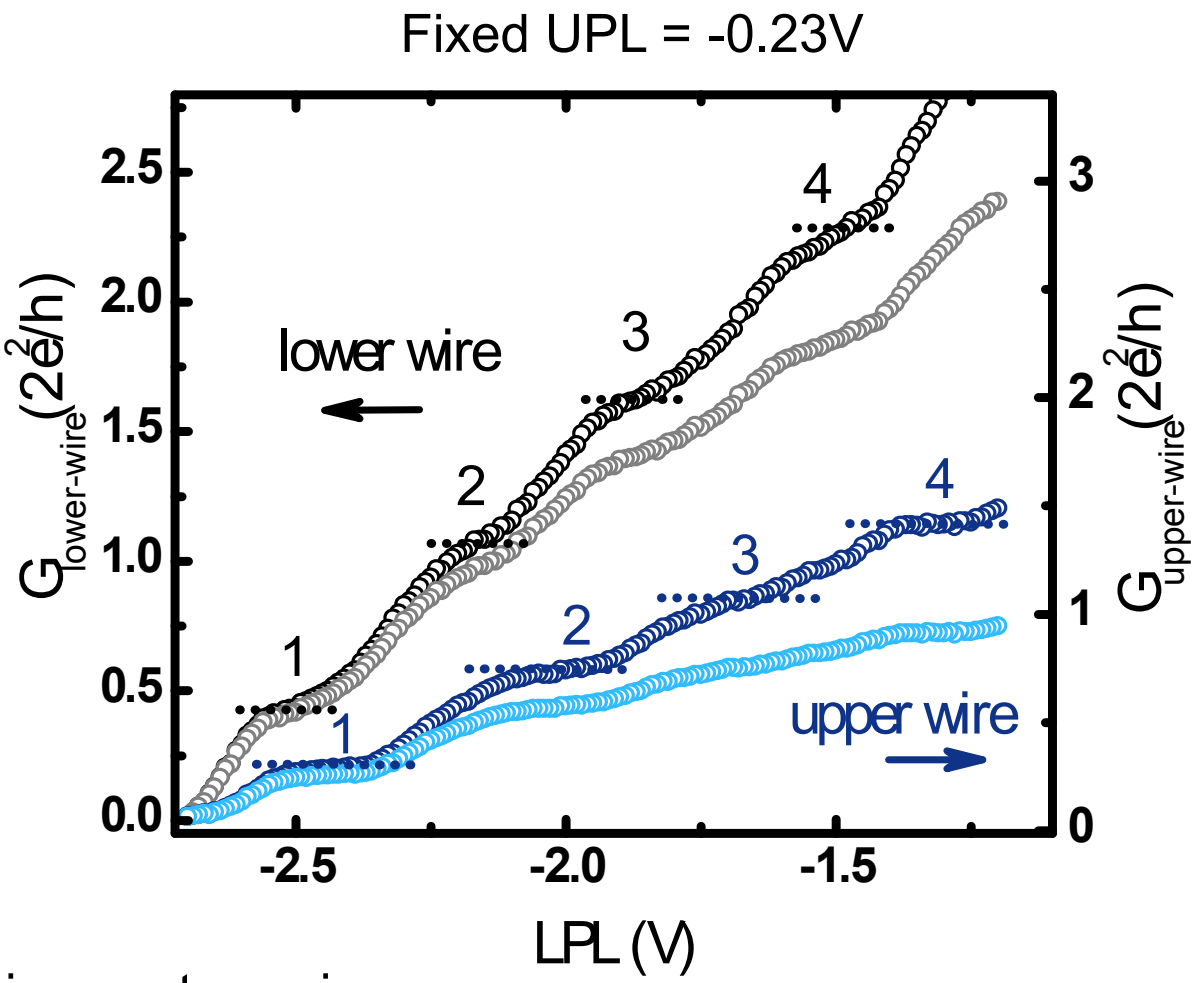

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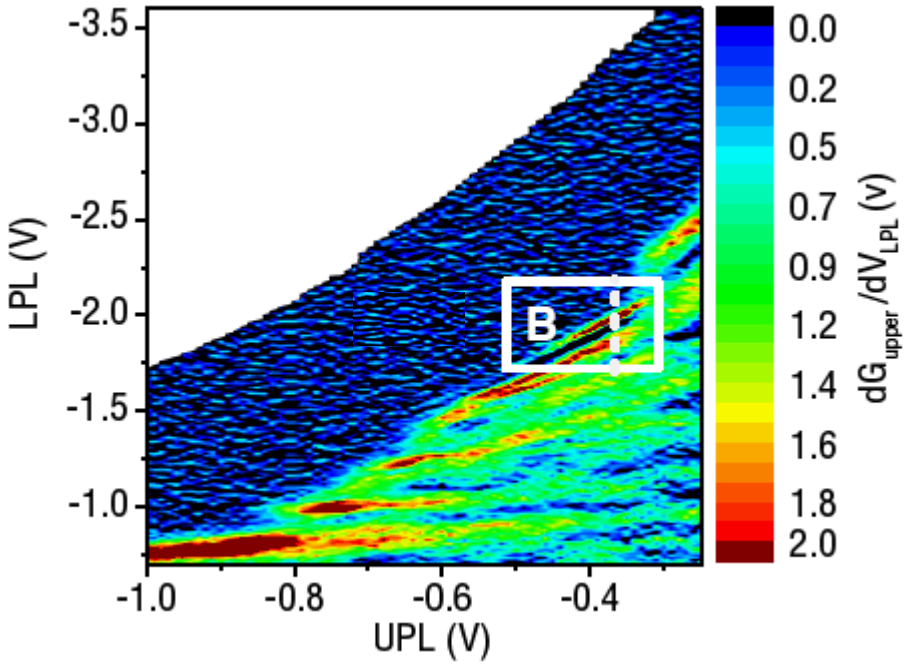
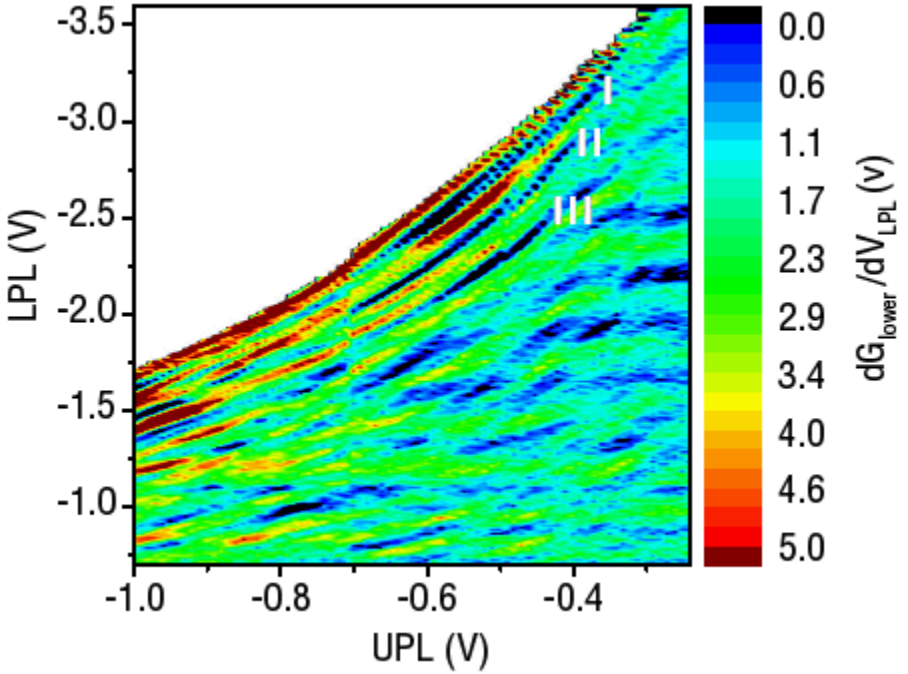
Wires characterization

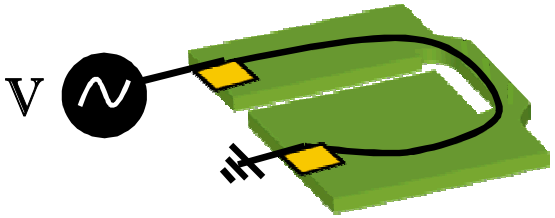
Tracking of the 1D subbands over a large range of gates voltage

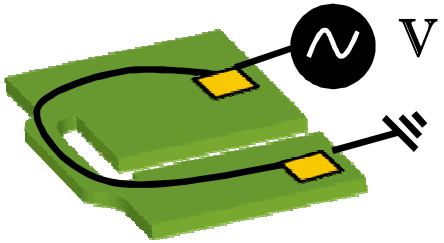
Upper wire derivative



Lower wire derivative







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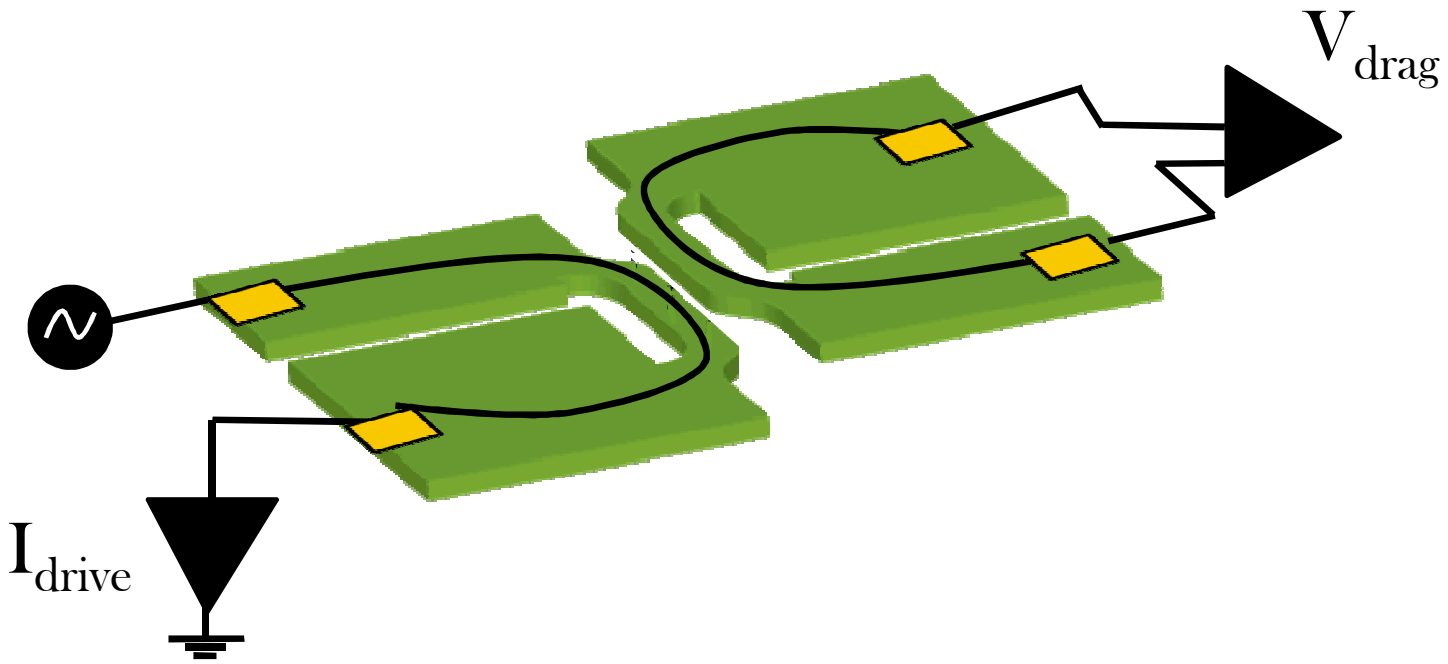
General Coulomb drag measurements



Measured quantity : transresistance

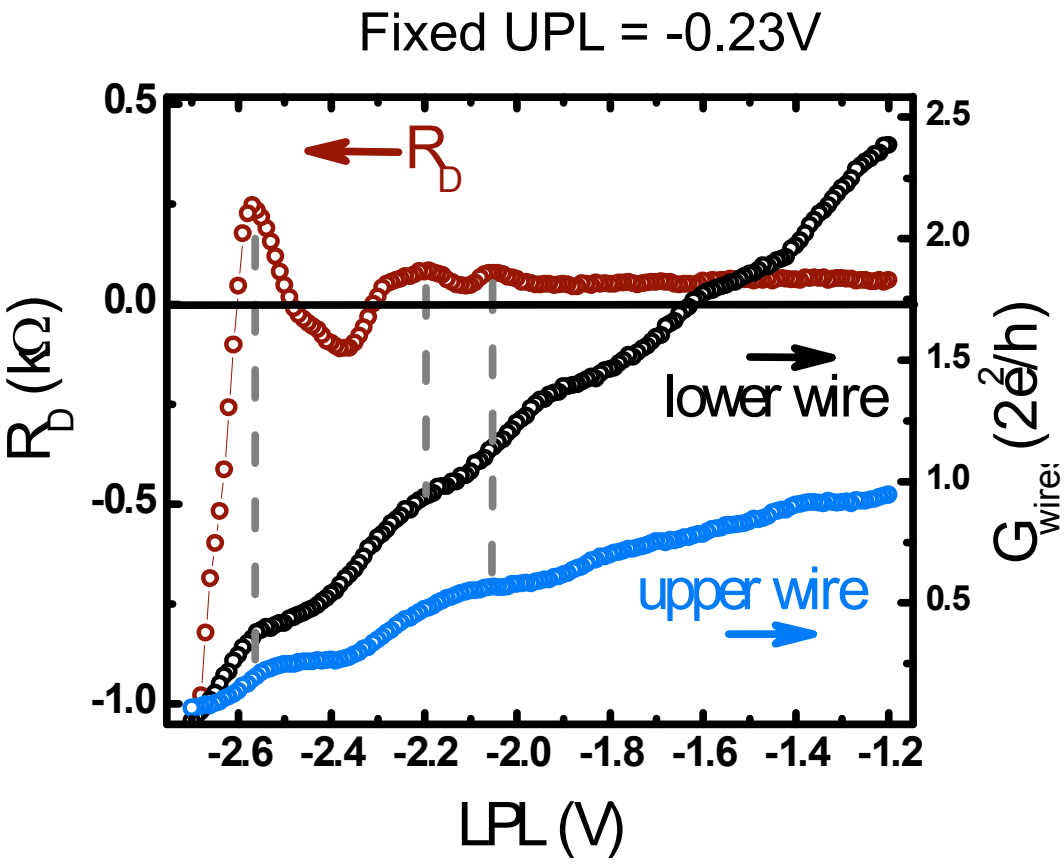
$$R_D = -\frac{V_{drag}}{I_{drive}}$$

Coulomb drag results

- Peaks in the drag signal as 1D subbands gets depleted. (Previously observed by Debray *et. al.*[1])

- Low-density negative drag observed when $N_{wires} < 1$ (Previously observed by Yamamoto *et. al.*[2])

- Re-entrant negative drag at the 1st plateau-like feature of the drag wire



➢ Never observed previously !

[1] P. Debray *et al.*, J. Phys. Condens. Matter 13, 3389 (2001).

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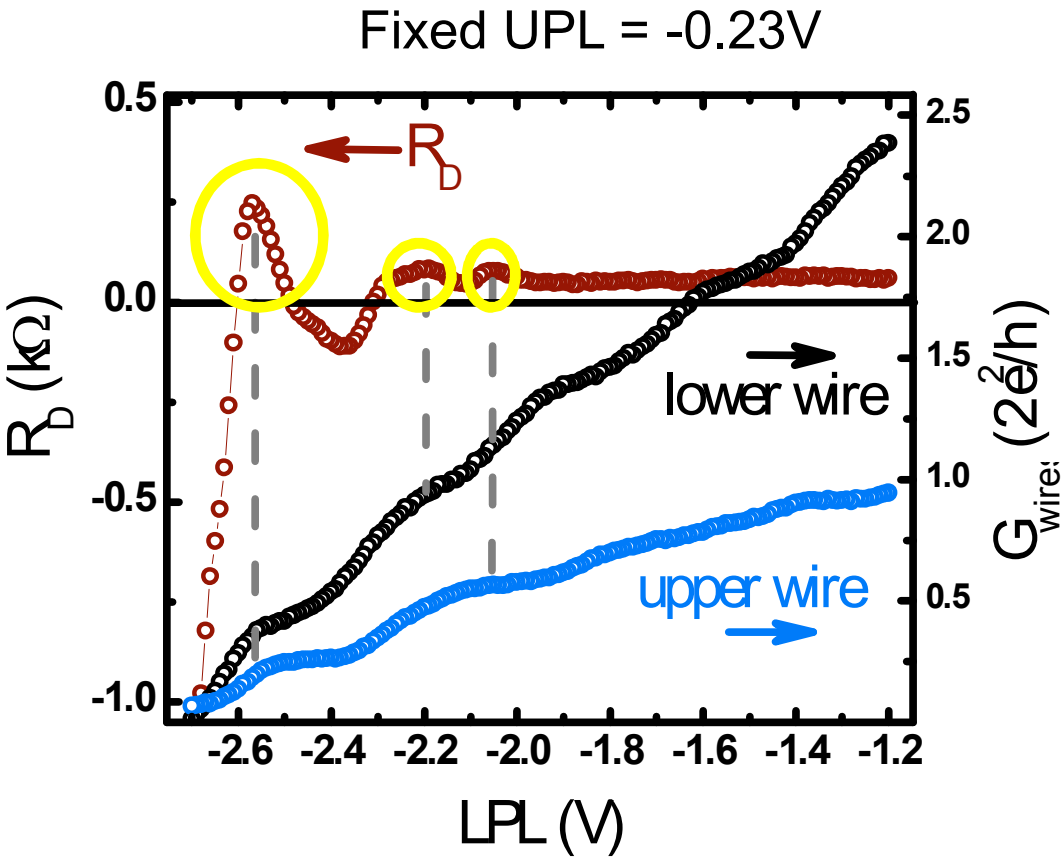

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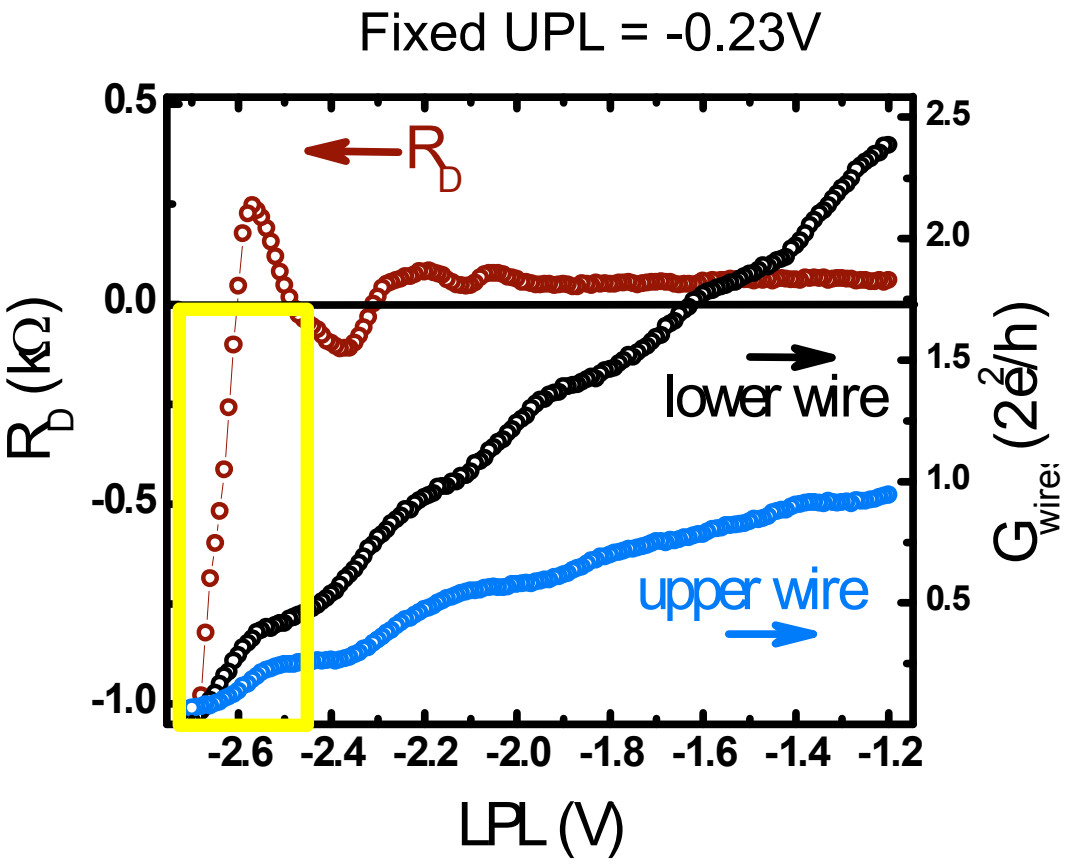

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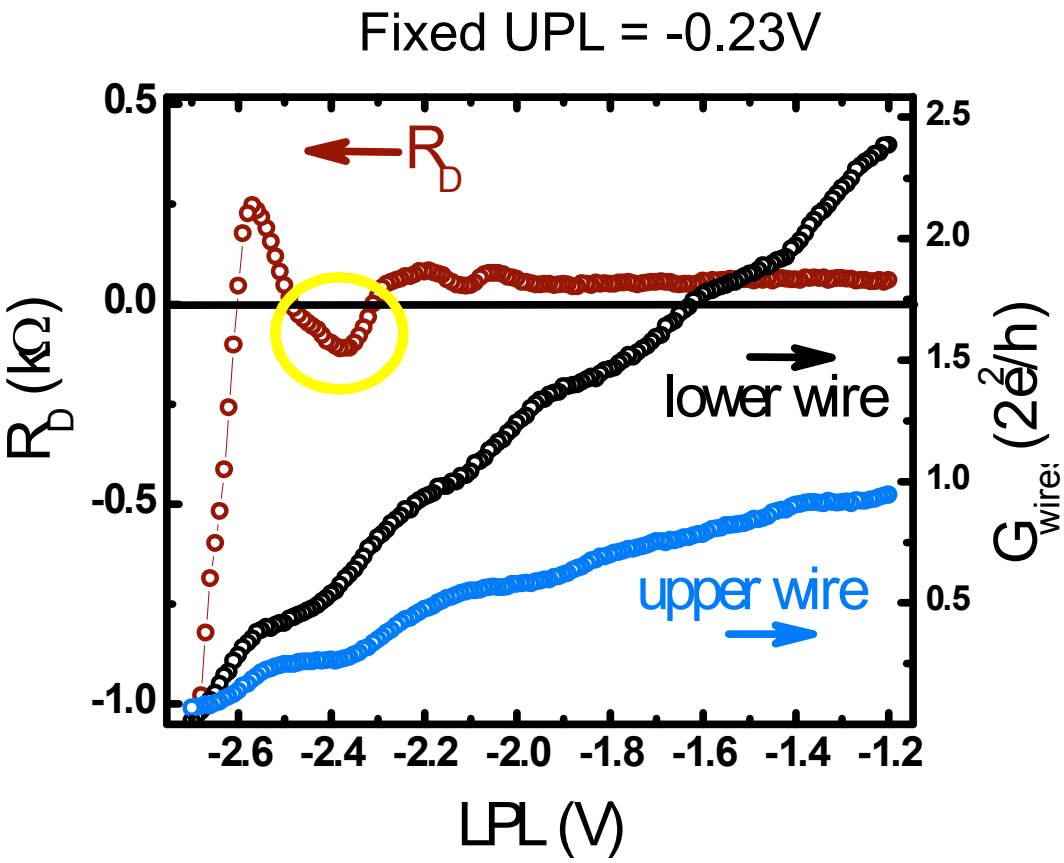

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- Re-entrant negative drag at the 1st plateau-like feature of the drag wire

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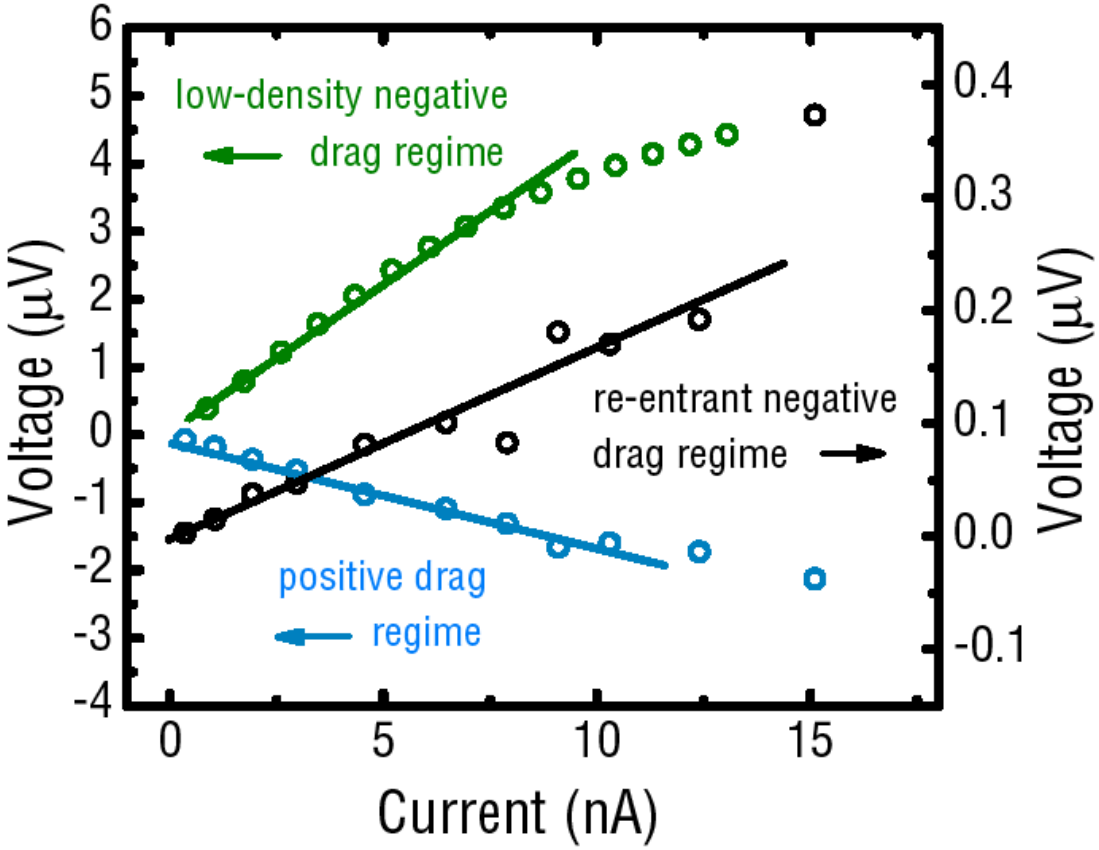
Consistency test for Coulomb drag



- Linear with drive current
- Drag resistance is independent of frequency
- No DC response is measured in the drag wire while sending an AC drive current

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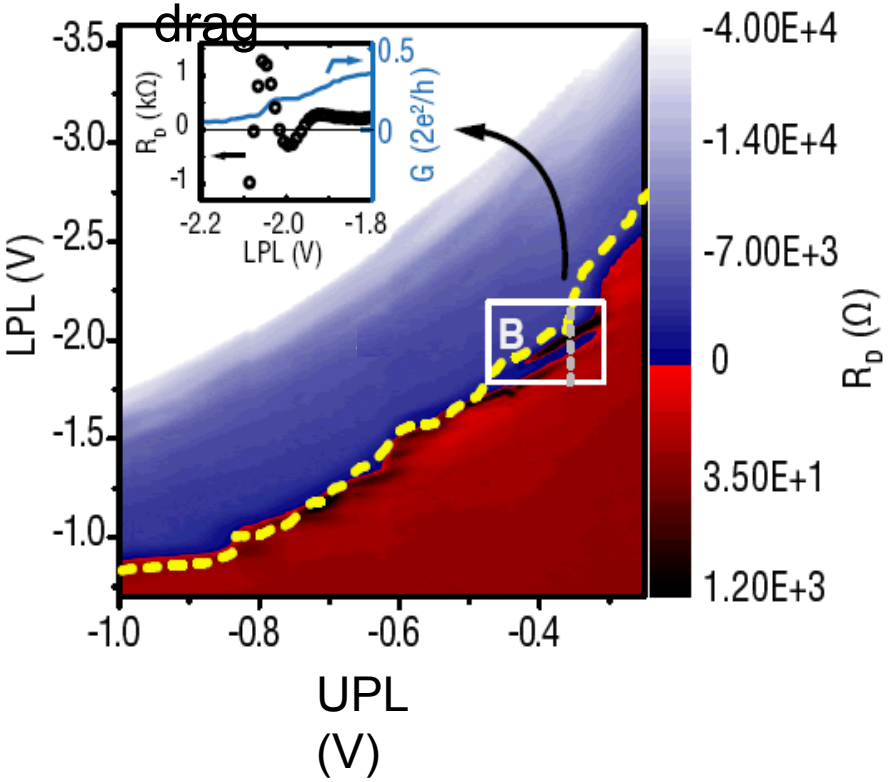
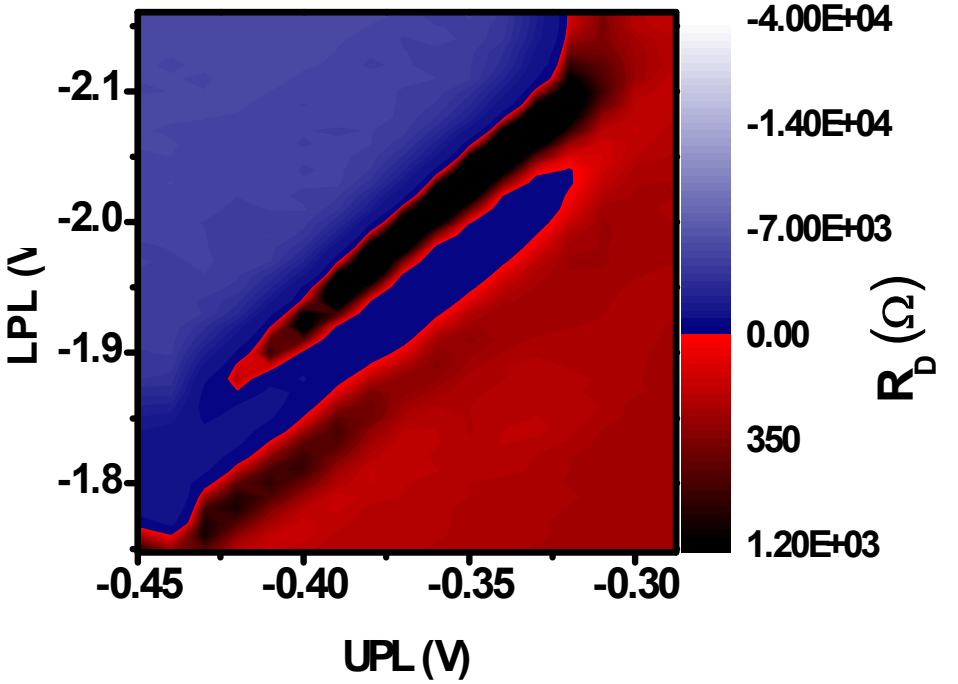
Mapping of the Coulomb drag

Coulomb drag



Zoom on re-entrant negative Coulomb d



- Features in the drag signal can be tracked over large range of gate volta
- Line up with subband occupancy mapping of the wires

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Interpretation of re-entrant negative drag

- Low-density negative drag : heuristically attributed to Wigner crystallizatior
  - Re-entrant negative drag occurs at density too high for typical Wigner crystallization

- Possible explanations :
  - ➢ Gate-dependent enhancement of electron-hole asymmetry coupled with non-monotonic increase in transmission probability of electrons along wire.[1]
  - ➢ Local hole-like dispersion relation in the quantum wires band structure

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[1] A. Levchenko and A. Kamenev, Phys. Rev. Lett. 101, 216806

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Conclusion and future plans

First vertically coupled quantum wires with :

- Independent control over subbands occupancy
- Independent contacts to each wire

Coulomb drag measurements

- Study drag with multiple 1D subbands regime
- Reproduce qualitatively other 1D drag experiments
- Observe a new re-entrant negative drag regime at high density

Future plans

• Measure temperature dependence of Coulomb drag in vertical structures

• Measure Coulomb drag in devices with a smaller interwire separation

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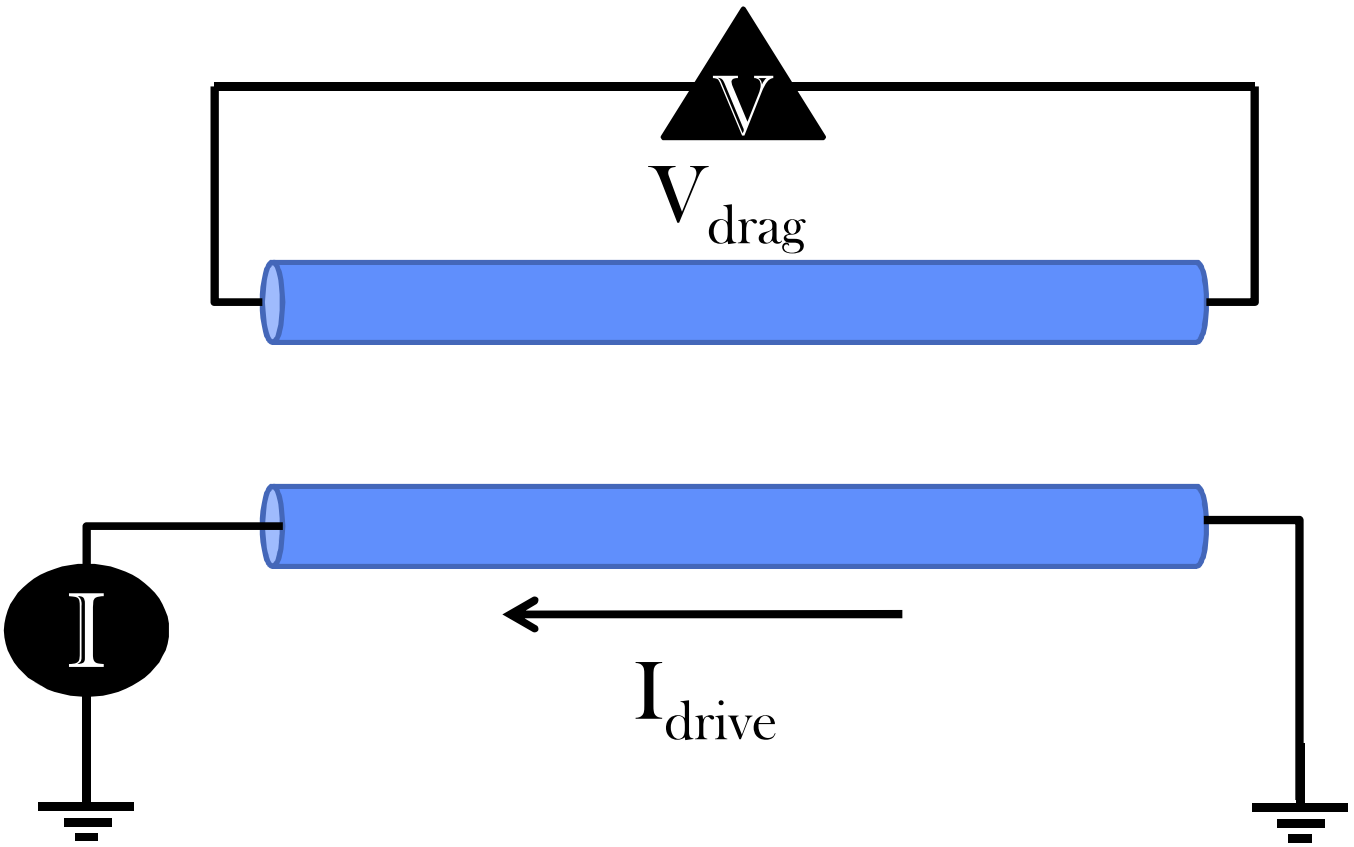
$$R_D = \frac{-V_{drag}}{I_{drive}}$$



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