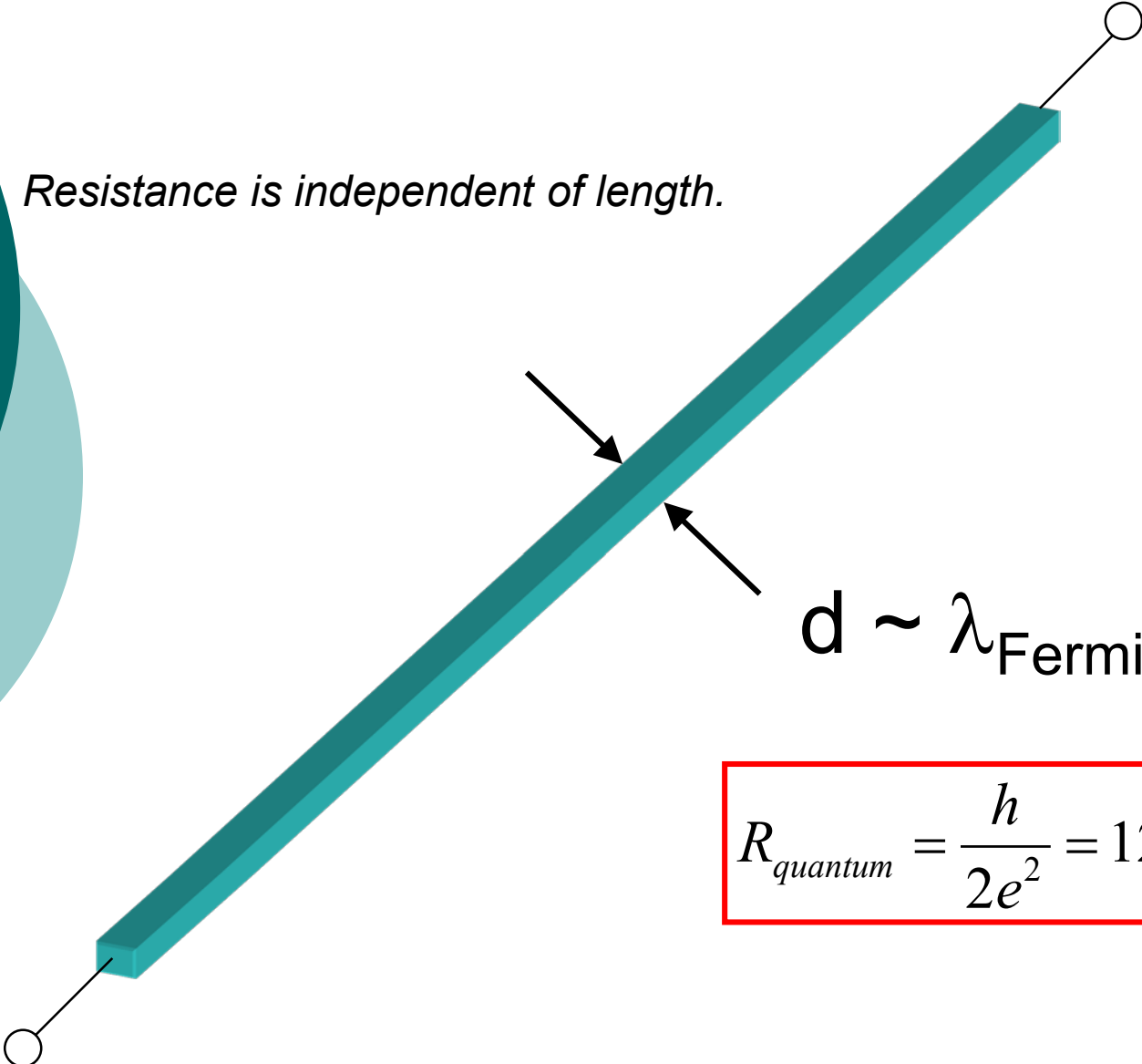


Lecture 11: Quantum point contact

Resistance is independent of length.



A diagram of a quantum point contact (QPC) structure. It shows a long, narrow, teal-colored rectangular channel oriented diagonally from the bottom-left to the top-right. At each end of the channel, there is a small white circle representing an electrical contact, connected to the channel by a thin line. Two black arrows point towards the channel from the right, indicating its width. To the left of the channel, there are two overlapping circular regions, one dark teal and one light teal, representing gates used to create the point contact. The text 'Resistance is independent of length.' is written in italics above the channel. The equation $d \sim \lambda_{\text{Fermi}}$ is placed to the right of the channel, with arrows pointing to the width. A red-bordered box at the bottom right contains the equation for quantum resistance.

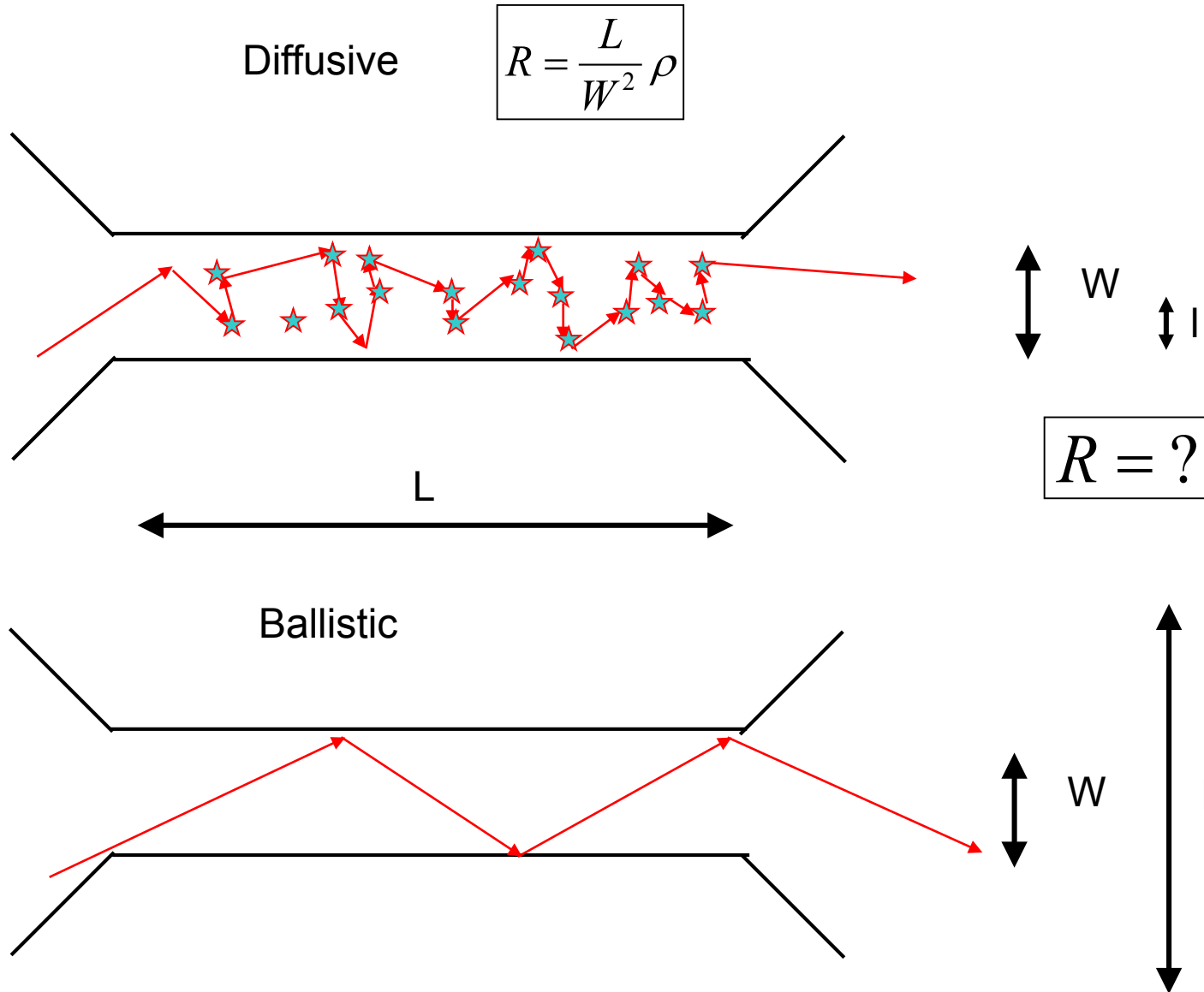
$$d \sim \lambda_{\text{Fermi}}$$

$$R_{\text{quantum}} = \frac{h}{2e^2} = 12.5 \text{ k}\Omega$$

Readings this lecture covers

- Ferry pp. 124-139
- Van Wees PRL (reading packet)
- Marcus APL (reading packet)
- Zhou APL (reading packet)

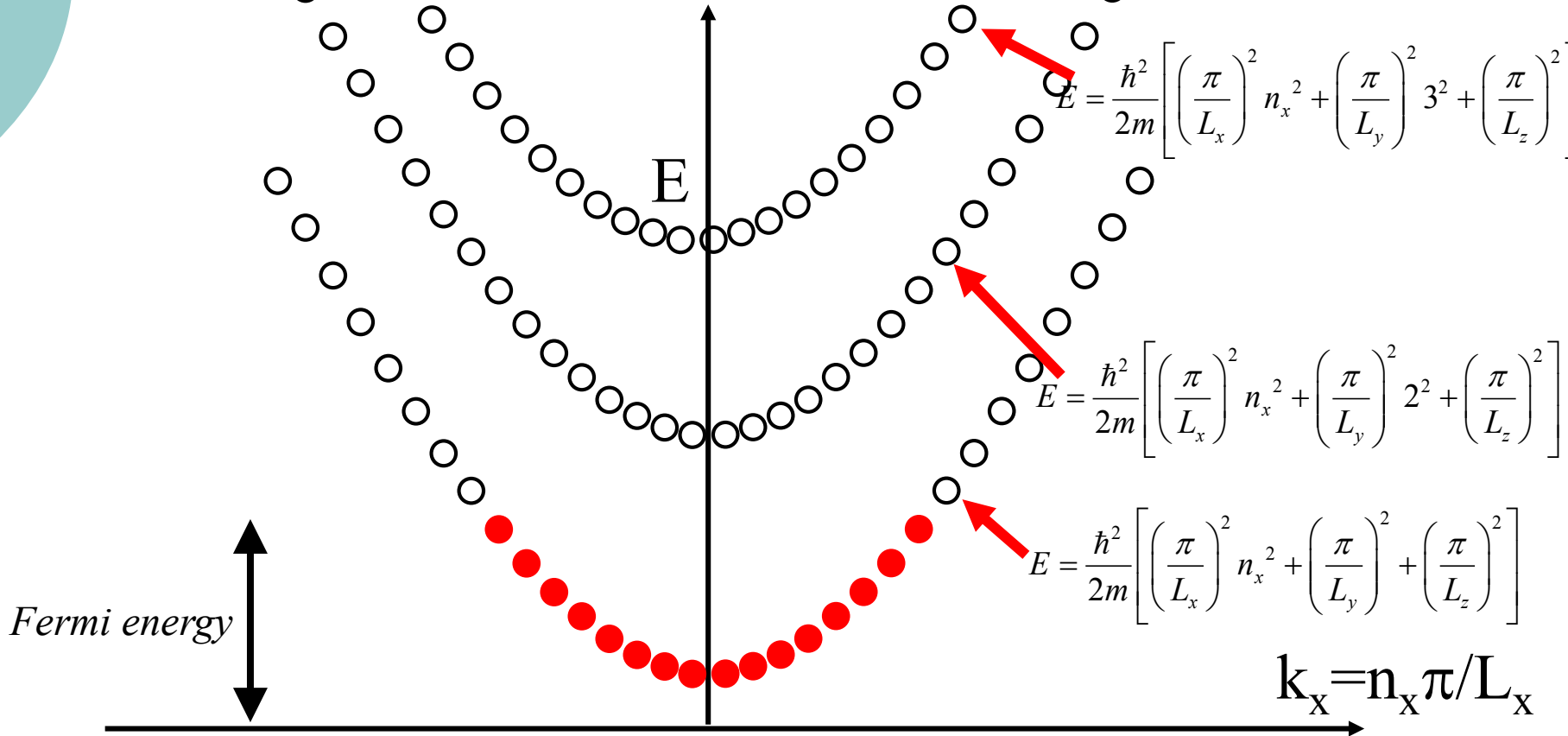
Ballistic vs. diffusive transport



1d system:

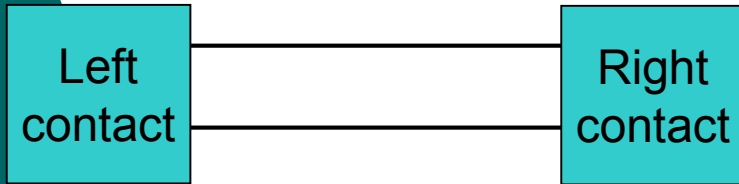
$$E = \frac{\hbar^2(k_{n_x}^2 + k_{n_y}^2 + k_{n_z}^2)}{2m} = \frac{\hbar^2}{2m} \left[\left(\frac{\pi}{L_x} \right)^2 n_x^2 + \left(\frac{\pi}{L_y} \right)^2 n_y^2 + \left(\frac{\pi}{L_z} \right)^2 n_z^2 \right]$$

$$L_x \rightarrow \infty \quad L_y \rightarrow 0 \quad L_z \rightarrow 0$$



Resistance quantum

Ballistic conductor



$$R_{\text{quantum}} = \frac{h}{e^2} = 25 \text{ k}\Omega$$

With spin:

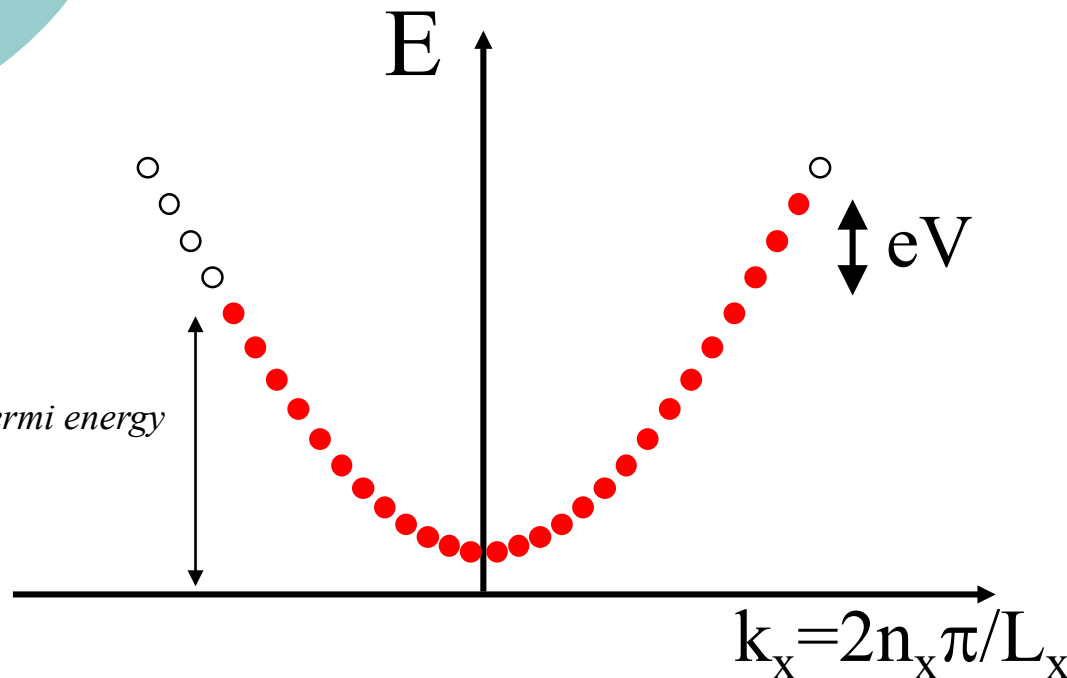
$$R_{\text{quantum}} = \frac{h}{2e^2} = 12.5 \text{ k}\Omega$$

$$G_{\text{quantum}} = \frac{2e^2}{h}$$

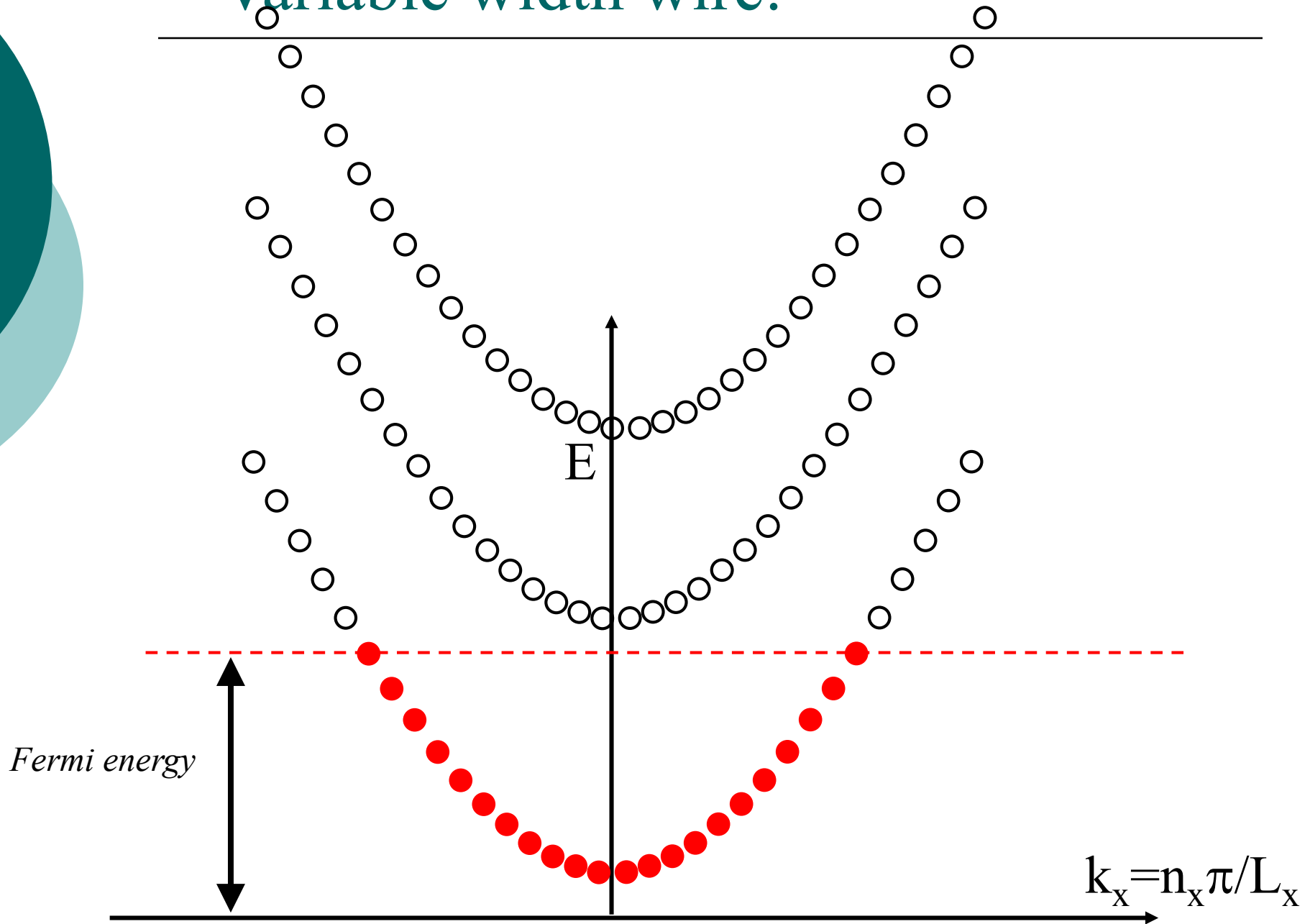
If injection from leads is not perfect:

$$G = T \frac{2e^2}{h}$$

T is the transmission probability.



Variable width wire:



Landauer formula:

$$G = n \frac{2e^2}{h}$$

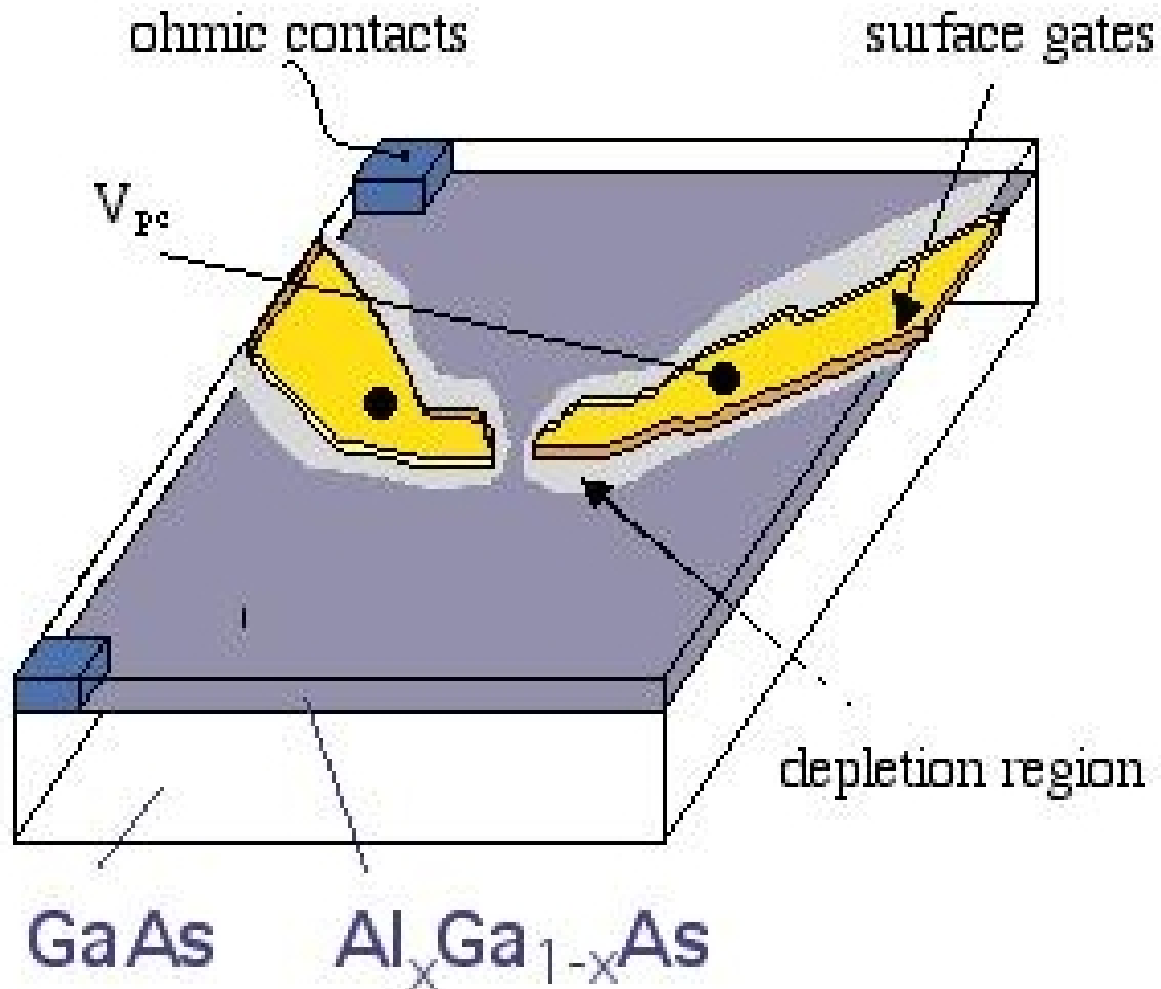
If the leads are not perfect injectors into each “channel” then:

$$G = \frac{2e^2}{h} \sum T_n$$

Experimental realizations:

- Pinch-off gate in semiconductor 2DEG (QPC)
- Break junction
- Electrochemical addition of atoms
- Scanning tunneling microscope

Quantum point contact



Quantum point contact

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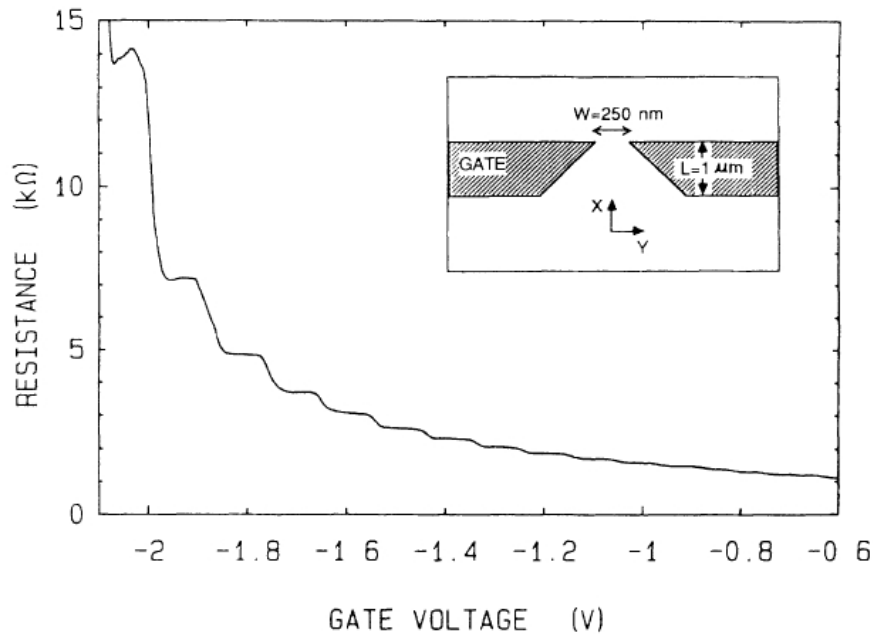


FIG. 1. Point-contact resistance as a function of gate voltage at 0.6 K. Inset: Point-contact layout.

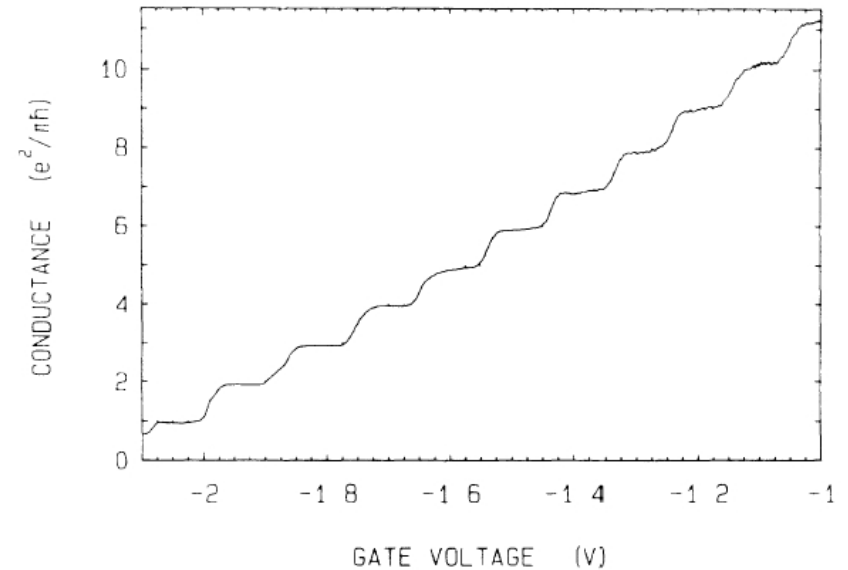


FIG. 2. Point-contact conductance as a function of gate voltage, obtained from the data of Fig. 1 after subtraction of the lead resistance. The conductance shows plateaus at multiples of $e^2/\pi h$.

B.J. van Wees et al. (1988), Phys. Rev. Lett., **60**, 848.

0.7 anomaly

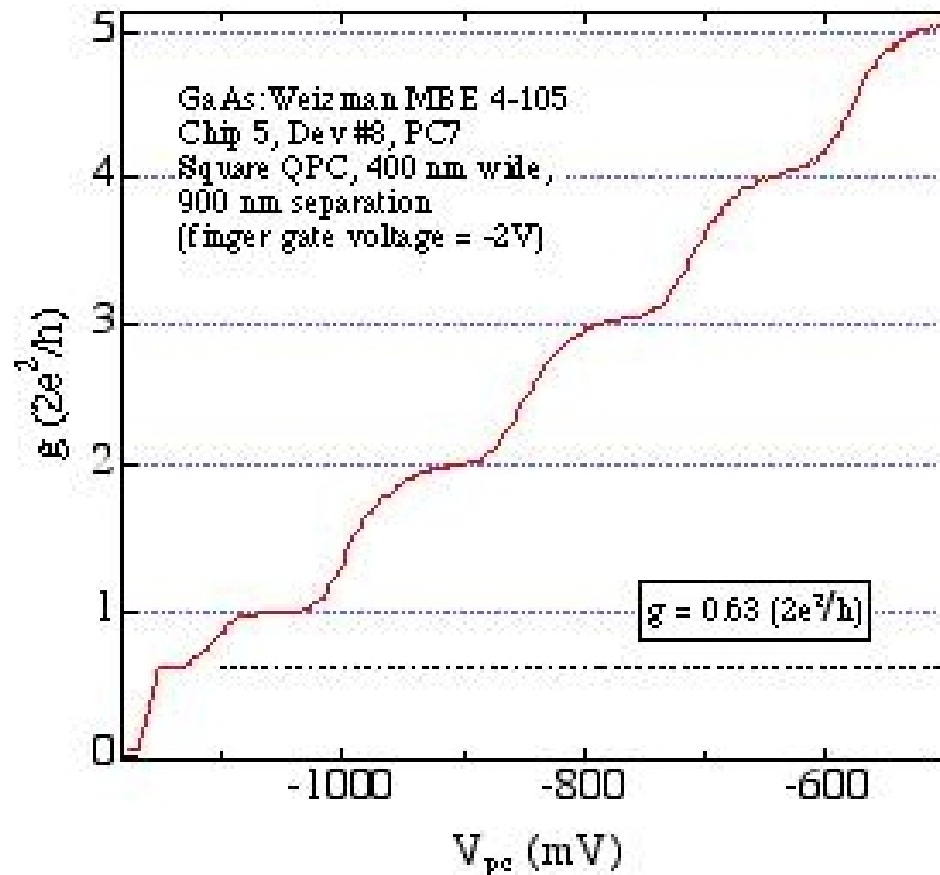
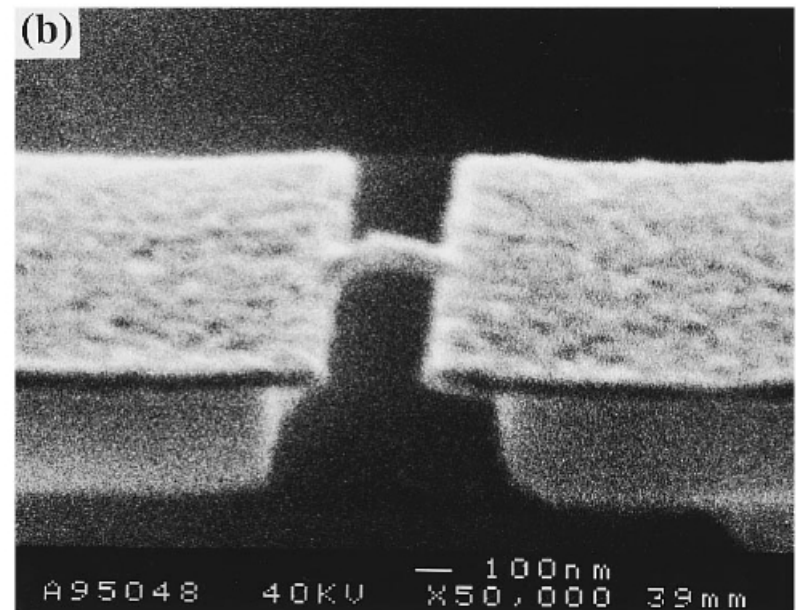
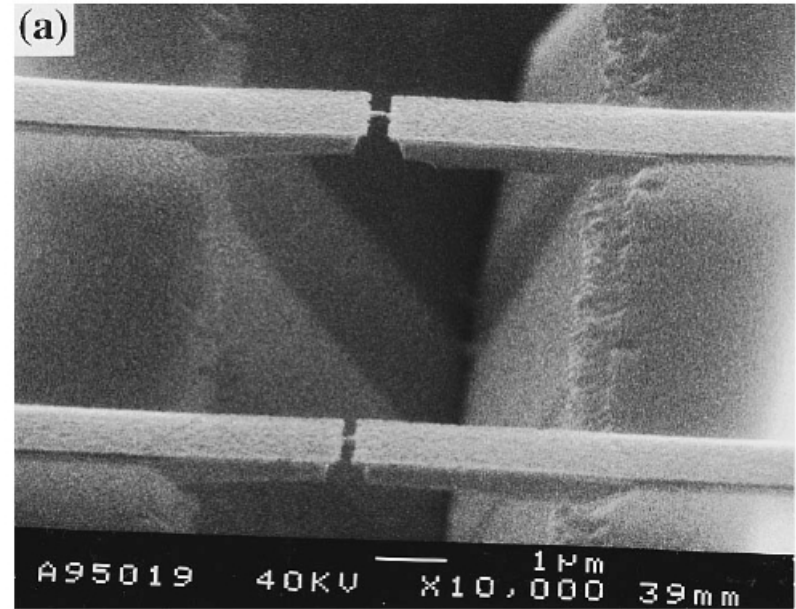
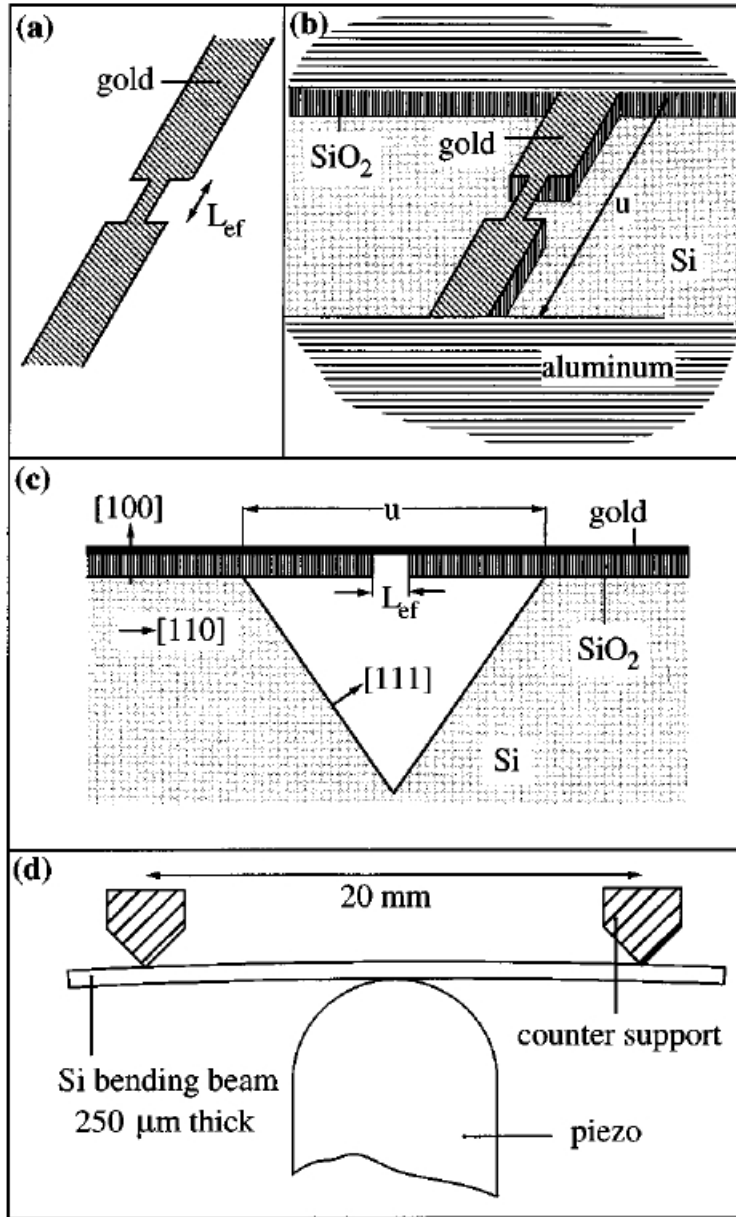


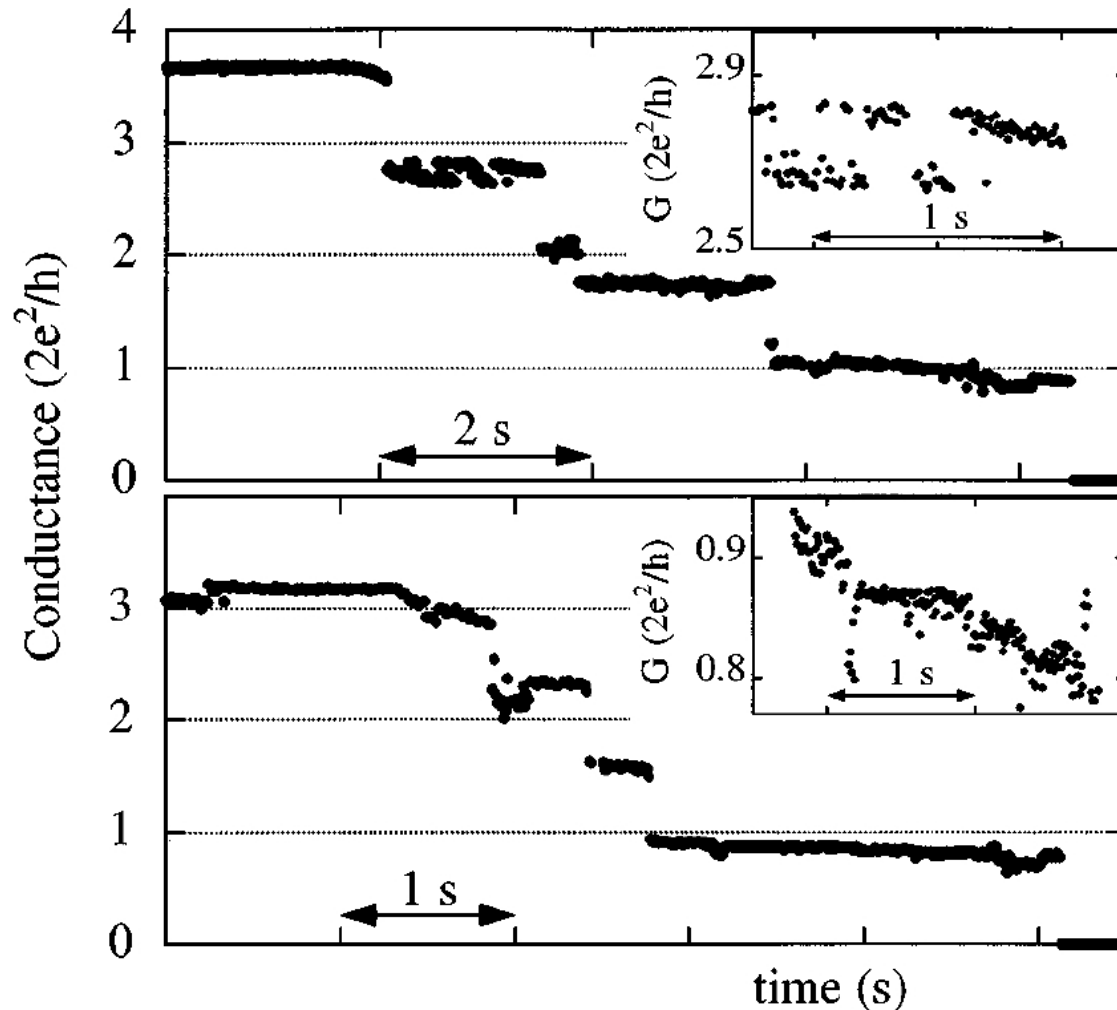
Figure 2: The conductance g through a point contact shows quantized plateaus at integer values of $2e^2/h$ with applied gate voltage, V_{pc} . This QPC shows a very prominent structure at $\sim 0.6 (2e^2/h)$. The gates of this QPC are 400 nm wide and 900 nm apart.

Break junction



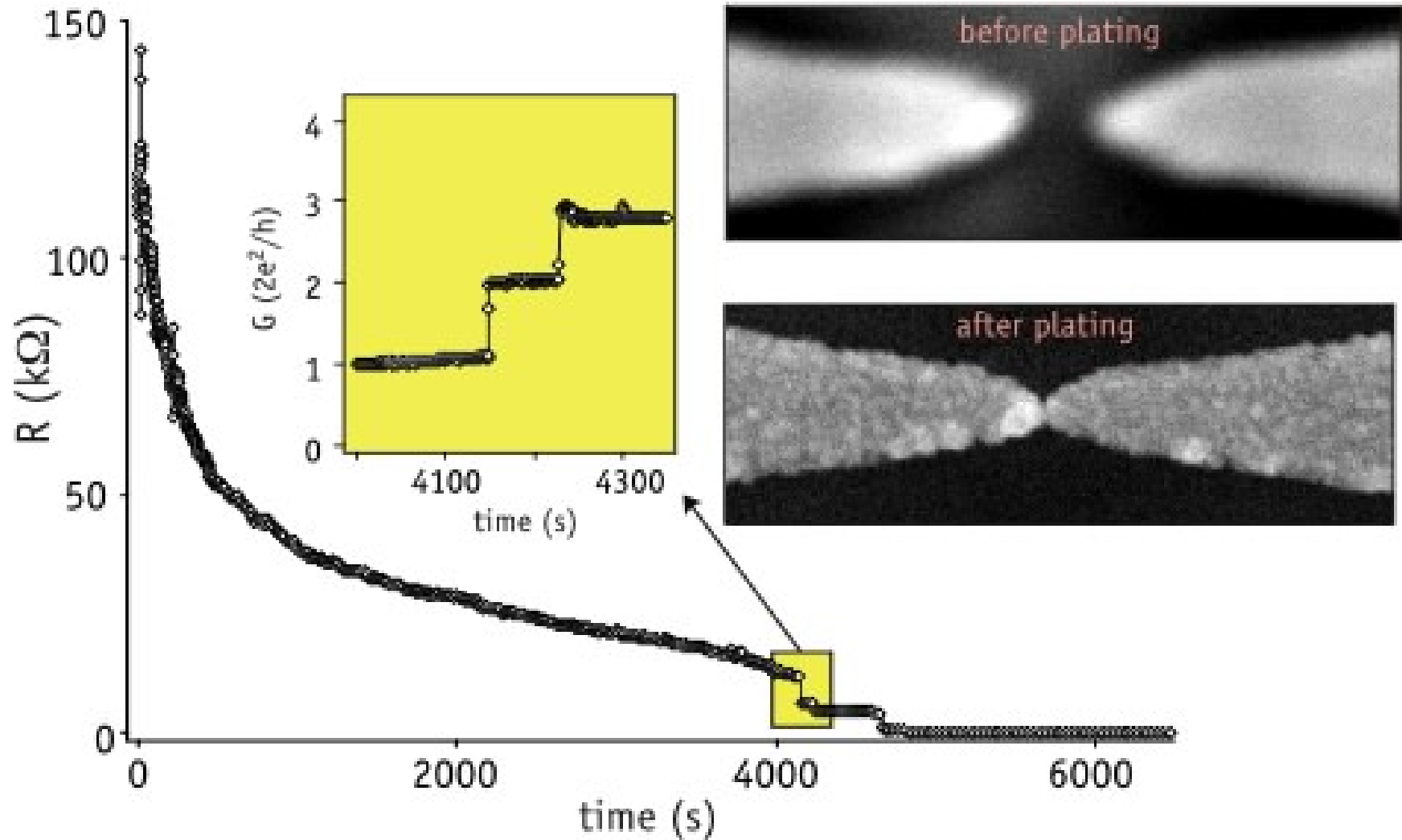
Microfabrication of a mechanically controllable break junction in silicon

C. Zhou, C. J. Muller, M. R. Deshpande, J. W. Sleight, and M. A. Reed
Center for Microelectronic Materials and Structures, Yale University, P.O. Box 208284, New Haven, Connecticut 06520-8284



Zhou, et al, Applied Physics Letters **67**, 8 (1995) p. 1160.

Electroplating



A.F.Morpurgo, C.M.Marcus and D. B. Robinson,
Controlled Fabrication of Metallic Electrodes with Atomic Separation, Appl. Phys. Lett. **74**, 2084 (1999).