

# Lecture 12: Quantum point contact

*Resistance is independent of length.*



The diagram shows a long, thin, teal-colored rectangular bar representing a quantum point contact. The bar is oriented diagonally from the bottom-left to the top-right. At each end of the bar, there is a small white circle connected to the bar by a thin black line, representing electrical contacts. Two black arrows point towards the bar from the right side, indicating its width. To the left of the bar, there are two overlapping circular shapes, one dark teal and one light teal, representing a gate structure. The text 'Resistance is independent of length.' is written in italics above the bar. The equation  $d \sim \lambda_{\text{Fermi}}$  is written to the right of the bar, with two arrows pointing to the width of the bar. A red-bordered box at the bottom right contains the equation  $R_{\text{quantum}} = \frac{h}{2e^2} = 12.5 \text{ k}\Omega$ .

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

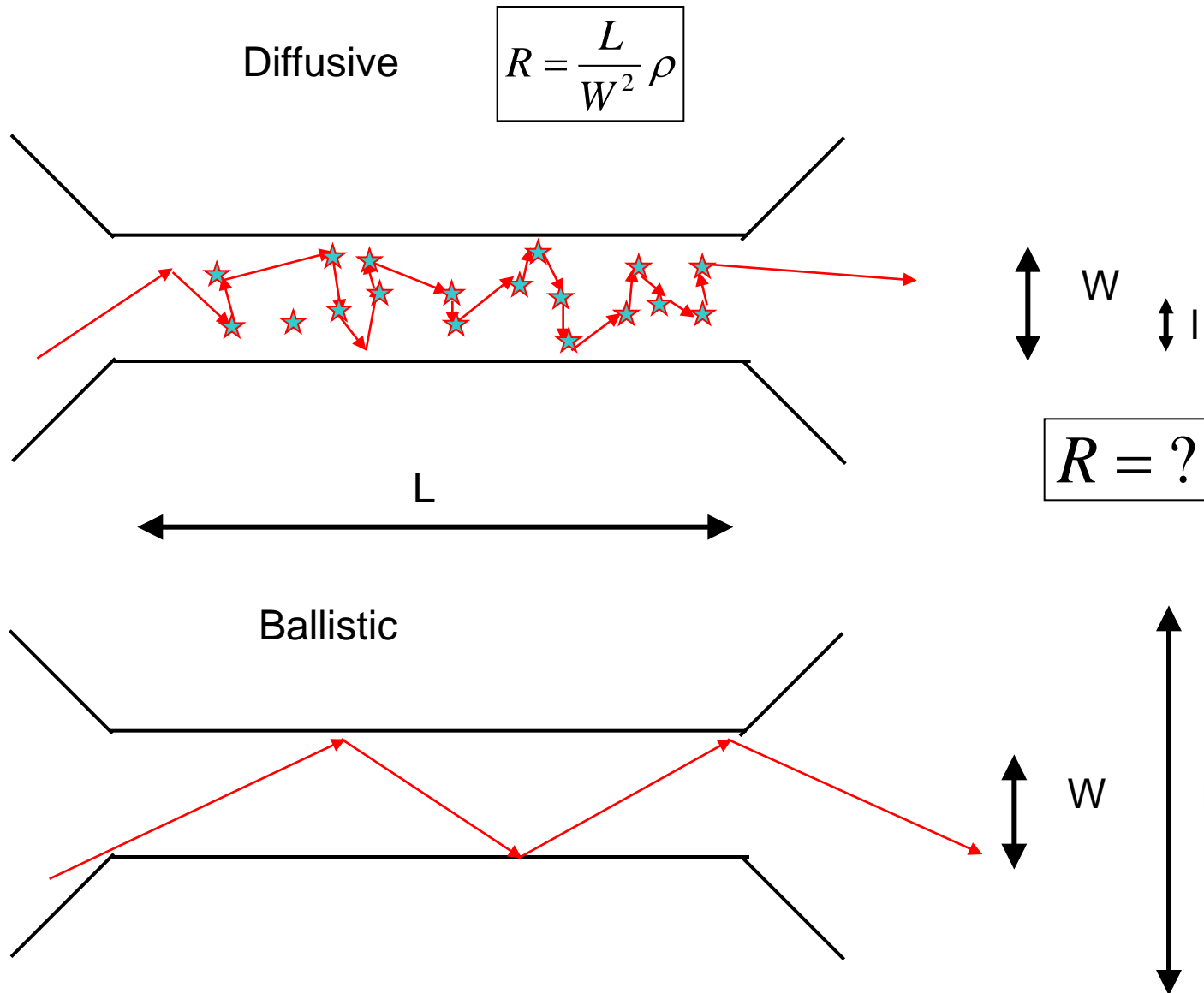
$$R_{\text{quantum}} = \frac{h}{2e^2} = 12.5 \text{ k}\Omega$$

# Readings this lecture covers

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

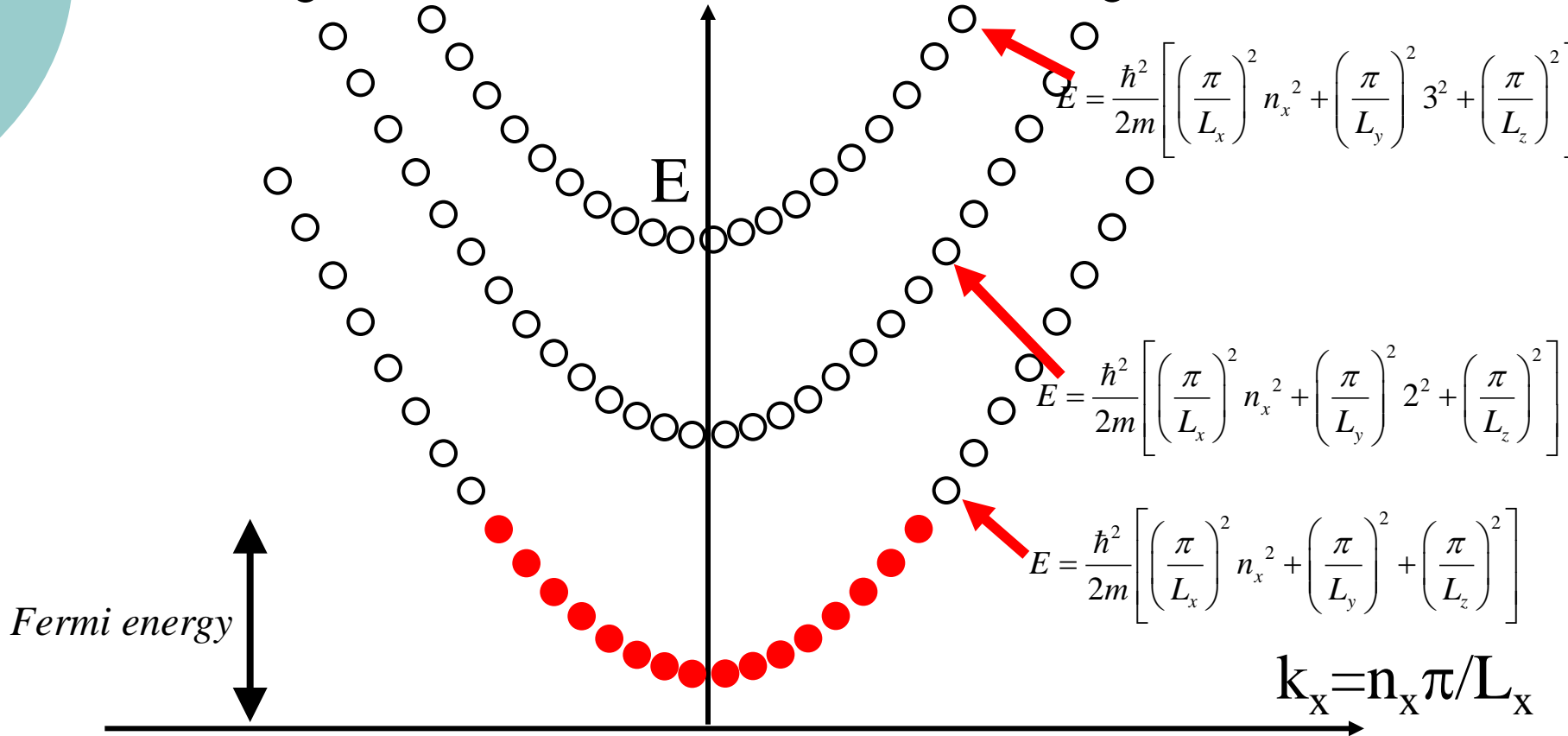
# Ballistic vs. diffusive transport



# 1d system:

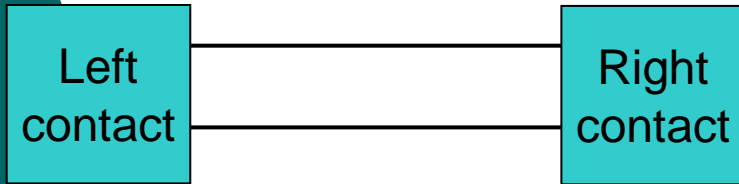
$$E = \frac{\hbar^2(k_{n_x}^2 + k_{n_y}^2 + k_{n_z}^2)}{2m} = \frac{\hbar^2}{2m} \left[ \left( \frac{\pi}{L_x} \right)^2 n_x^2 + \left( \frac{\pi}{L_y} \right)^2 n_y^2 + \left( \frac{\pi}{L_z} \right)^2 n_z^2 \right]$$

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



# Resistance quantum

Ballistic conductor



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

With spin:

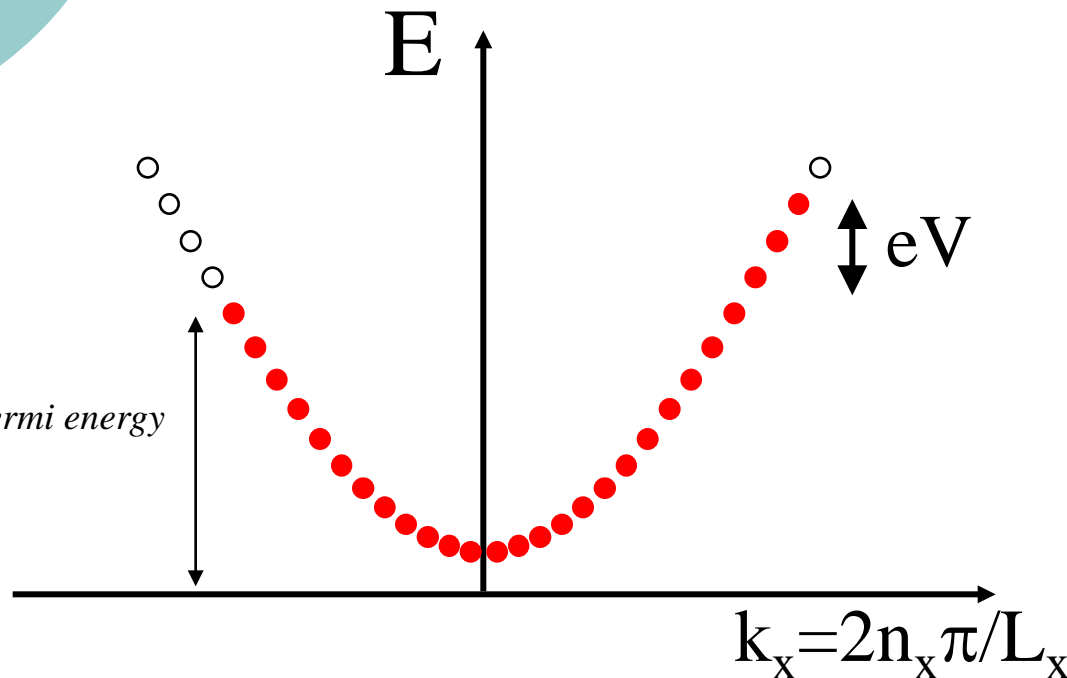
$$R_{\text{quantum}} = \frac{h}{2e^2} = 12.5 \text{ k}\Omega$$

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

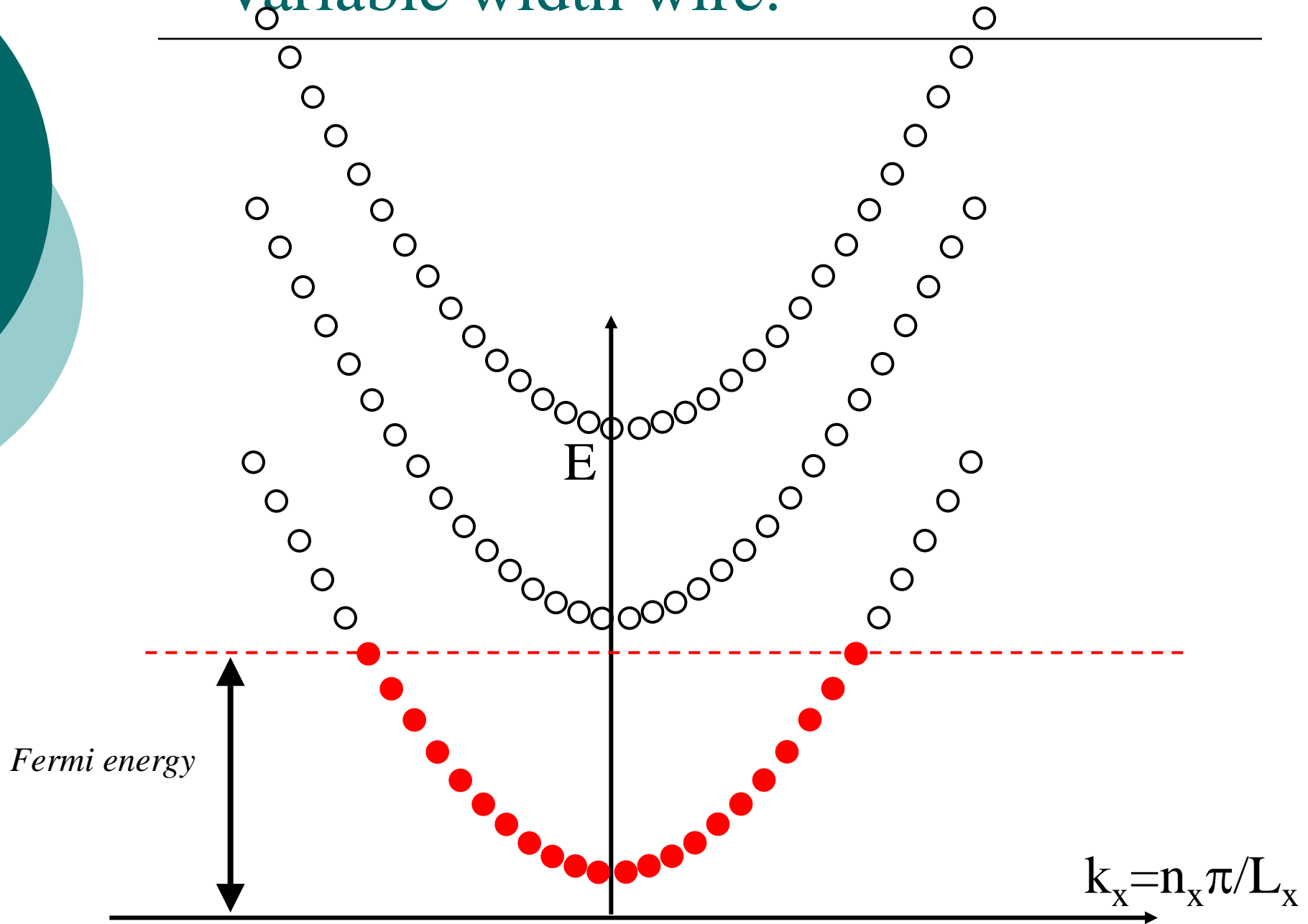
If injection from leads is not perfect:

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

T is the transmission probability.



# Variable width wire:



# Landauer formula:

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

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

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

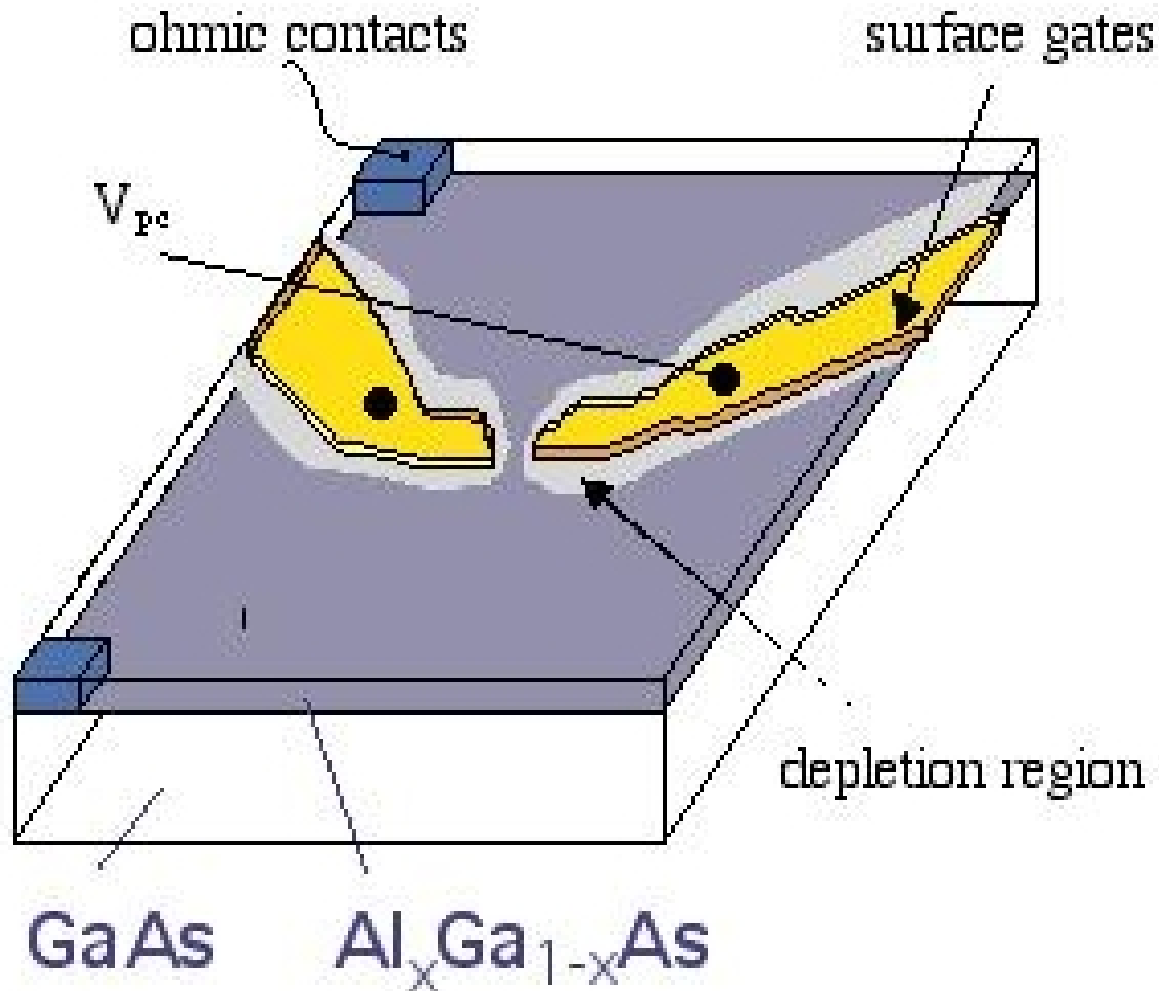
# Experimental realizations:

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- 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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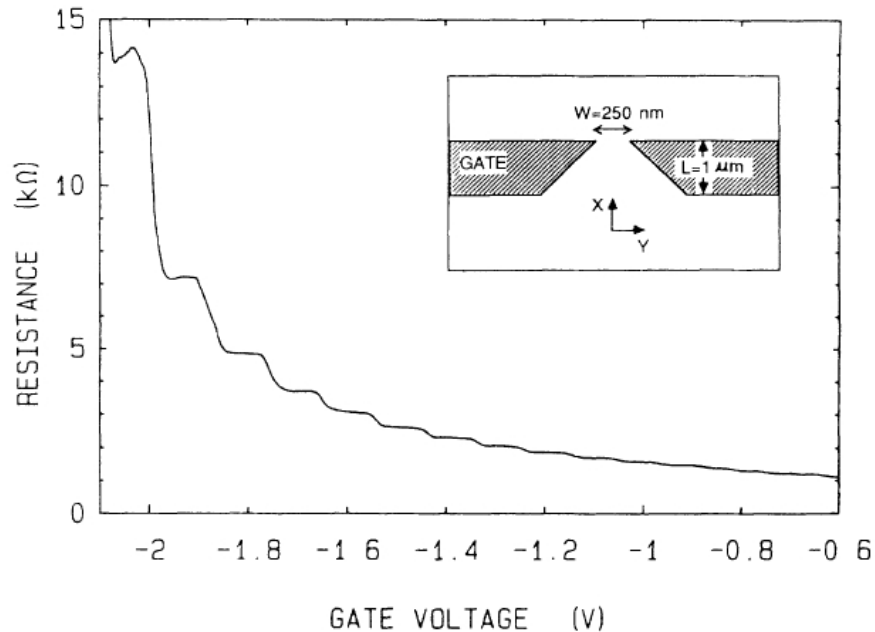


FIG. 1. Point-contact resistance as a function of gate voltage at 0.6 K. Inset: Point-contact layout.

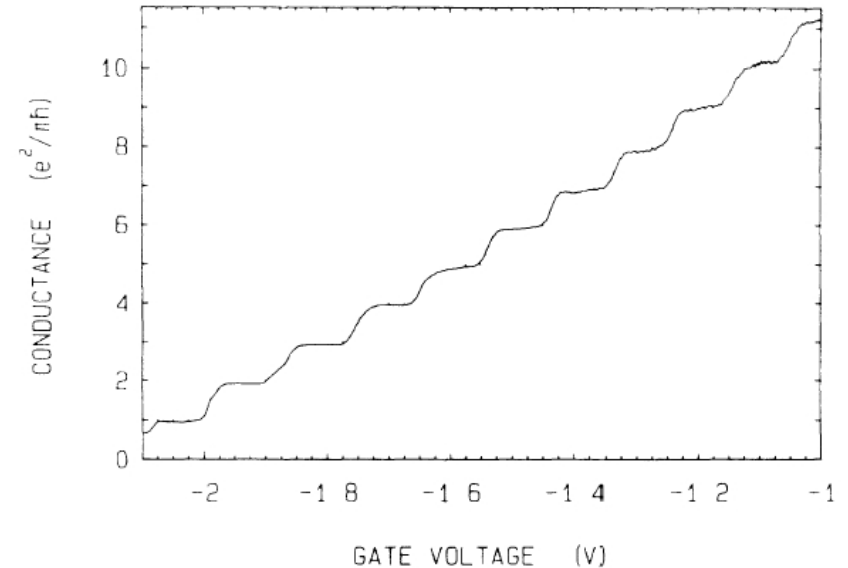


FIG. 2. Point-contact conductance as a function of gate voltage, obtained from the data of Fig. 1 after subtraction of the lead resistance. The conductance shows plateaus at multiples of  $e^2/\pi h$ .

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

# 0.7 anomaly

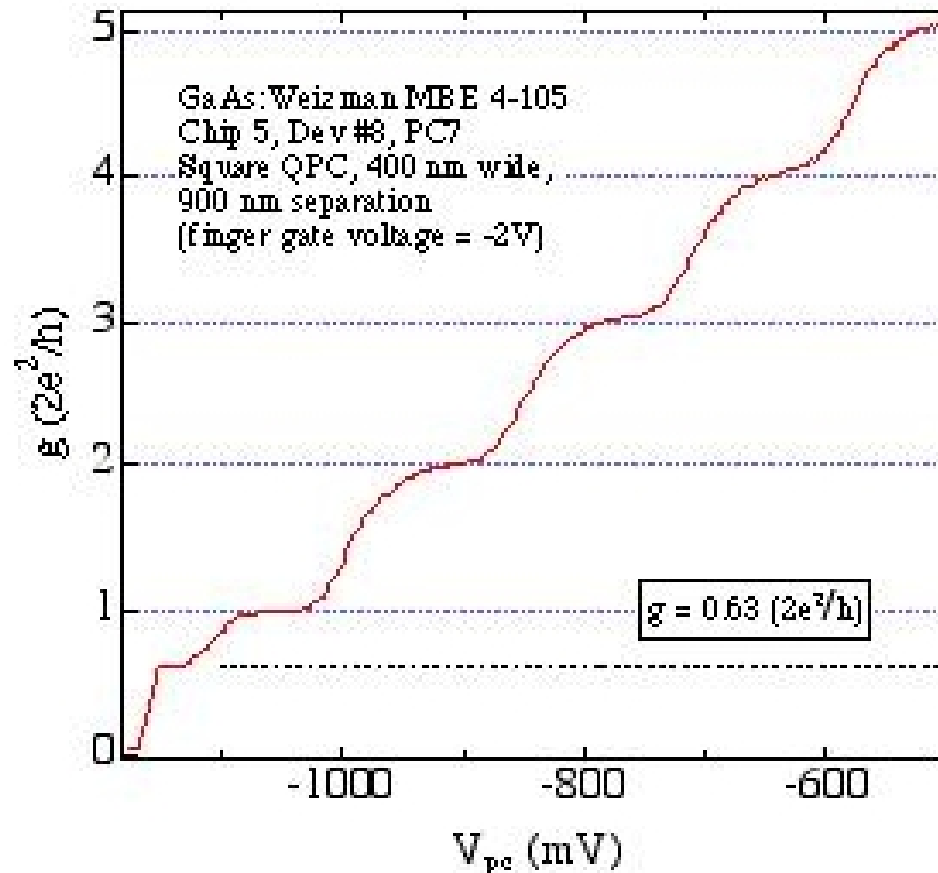
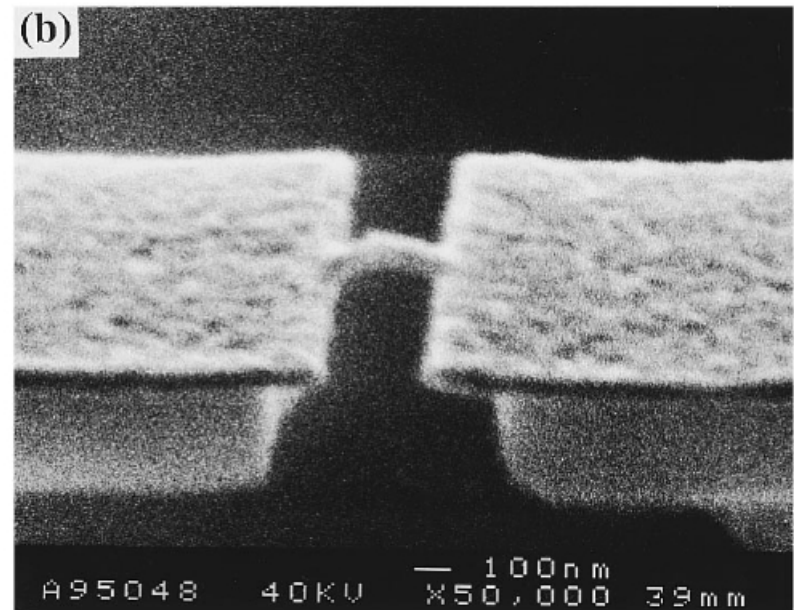
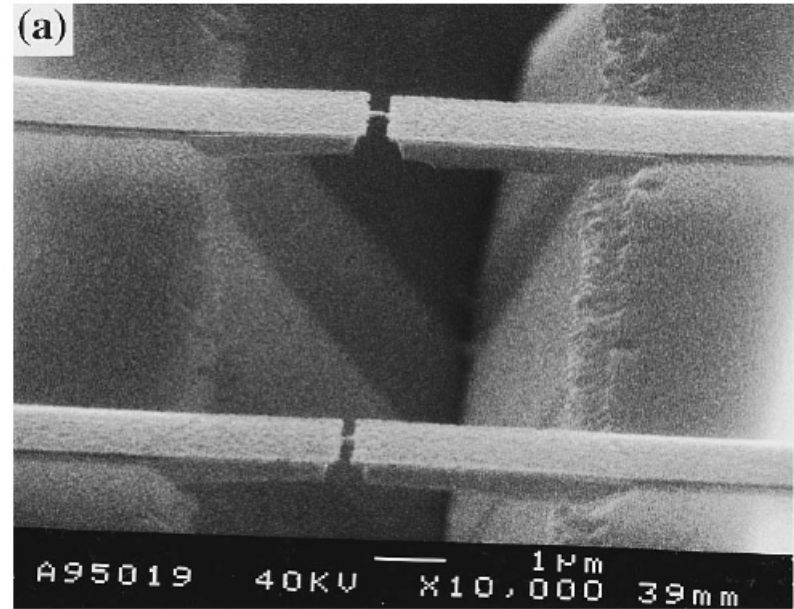
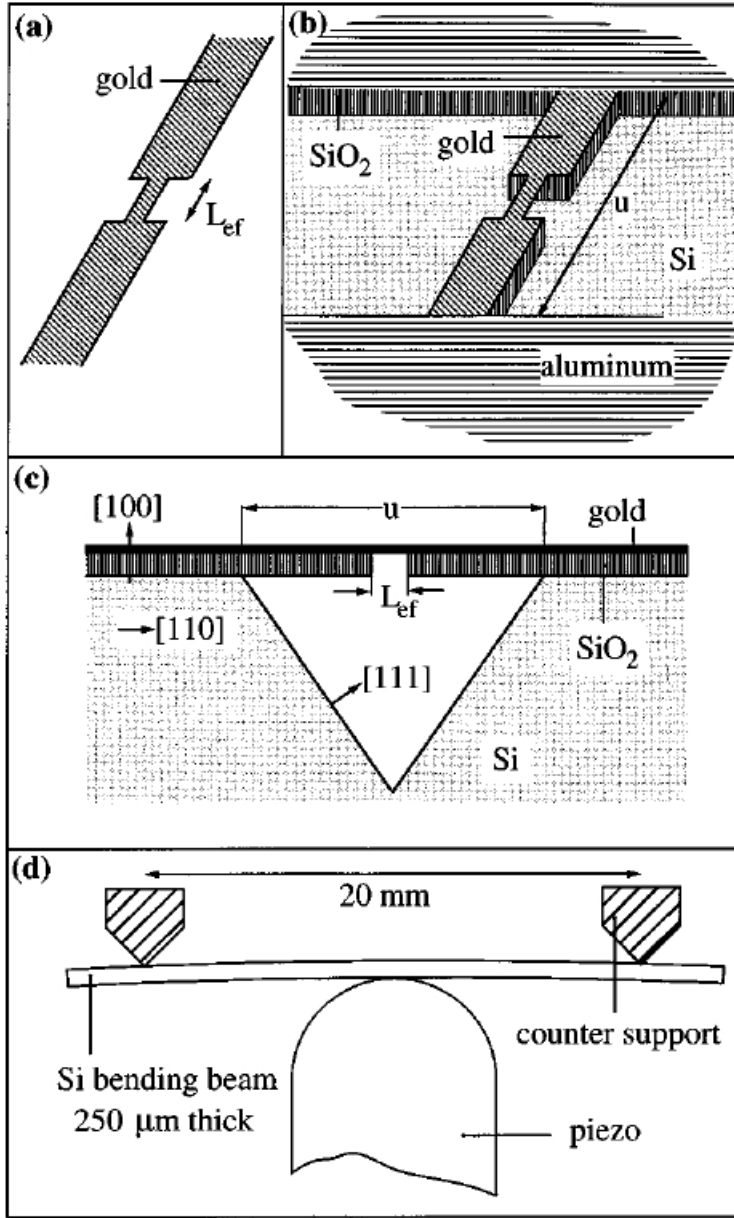


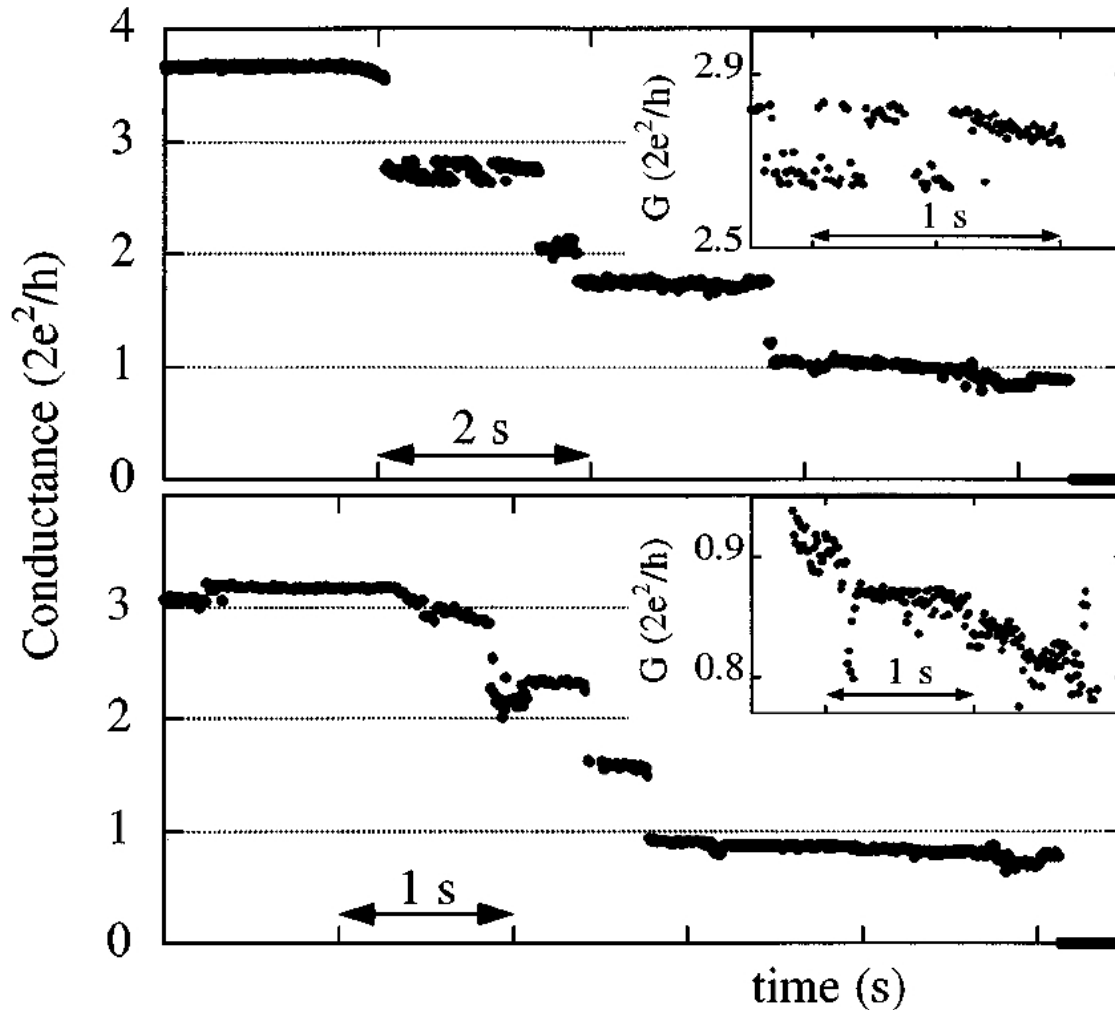
Figure 2: The conductance  $g$  through a point contact shows quantized plateaus at integer values of  $2e^2/h$  with applied gate voltage,  $V_{pc}$ . This QPC shows a very prominent structure at  $\sim 0.6 (2e^2/h)$ . The gates of this QPC are 400 nm wide and 900 nm apart.

# Break junction



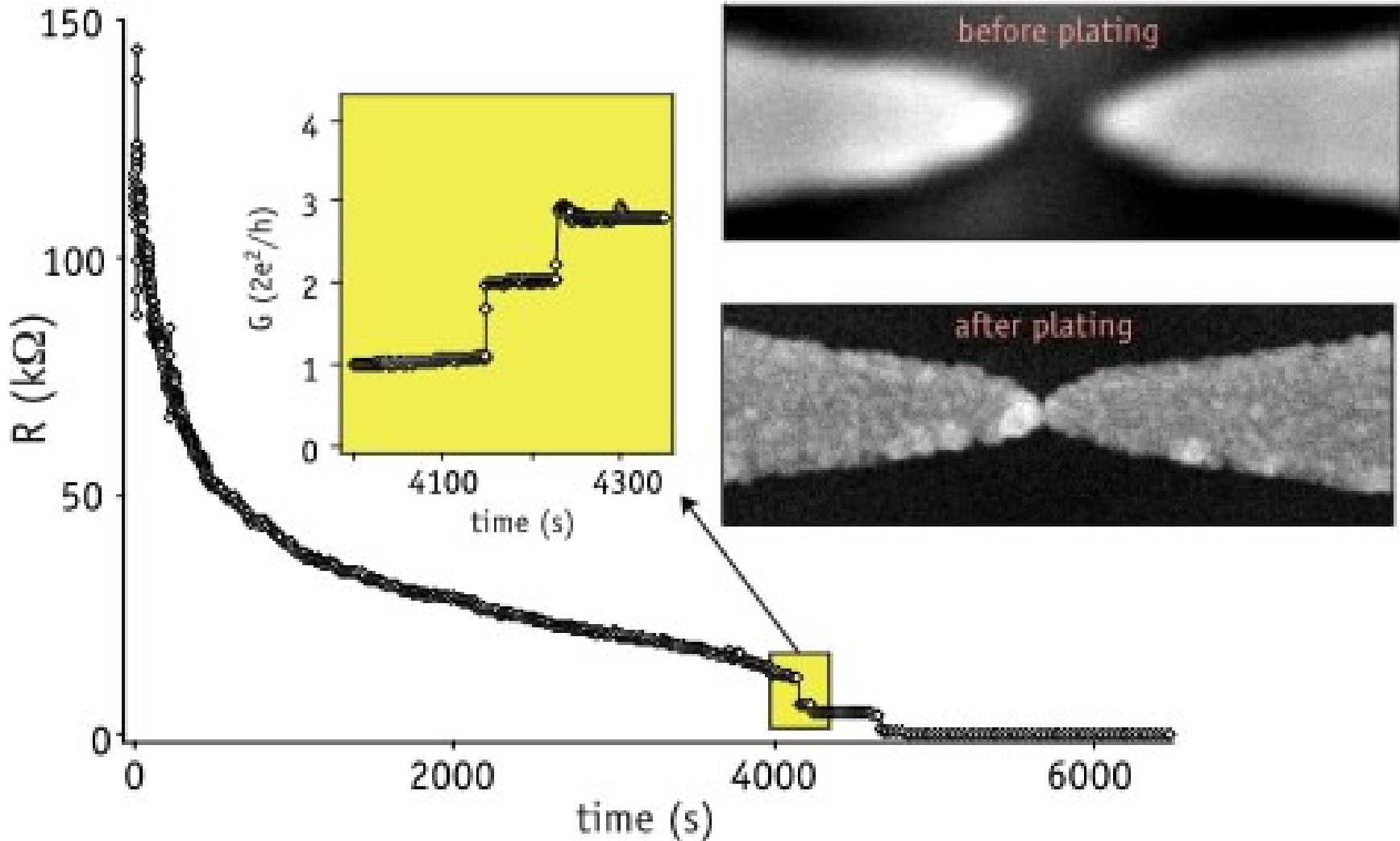
# Microfabrication of a mechanically controllable break junction in silicon

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).