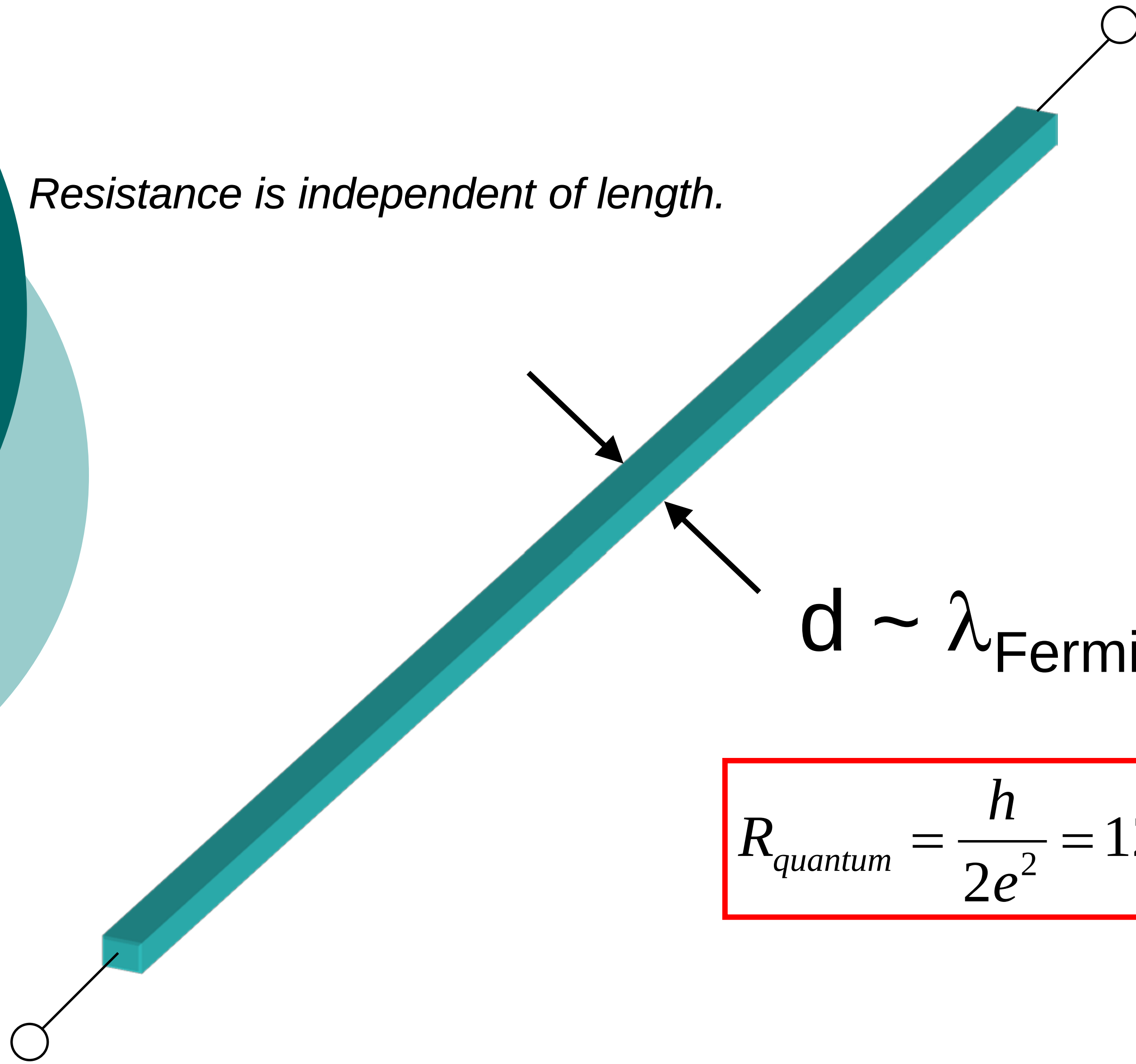
Lecture 12: Quantum point contact

Resistance is independent of length.



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

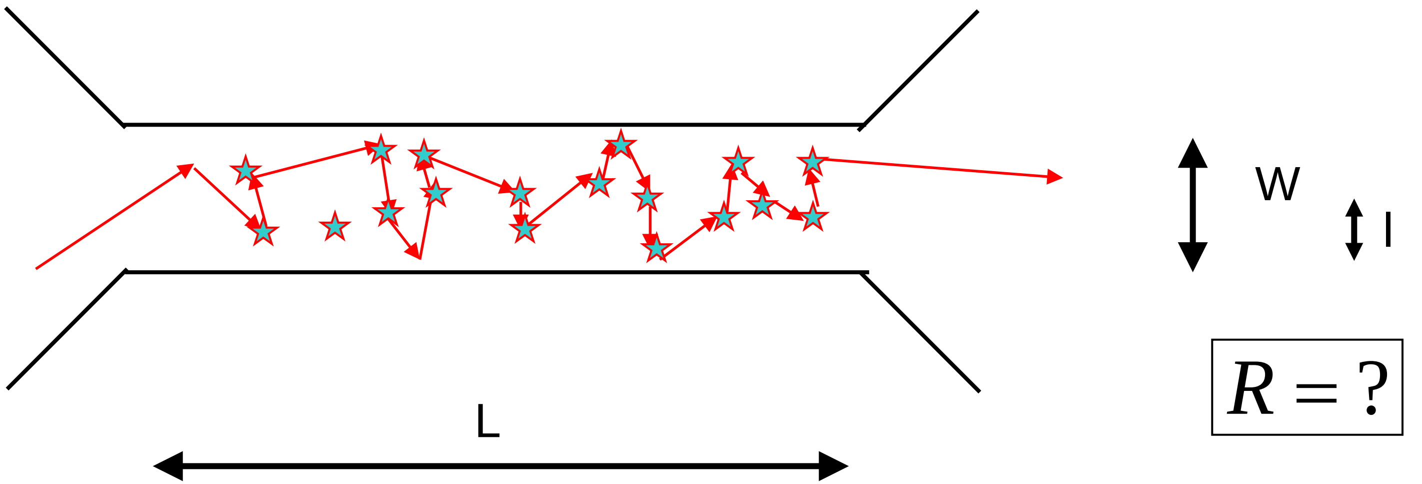
Readings this lecture covers

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

Ballistic vs. diffusive transport

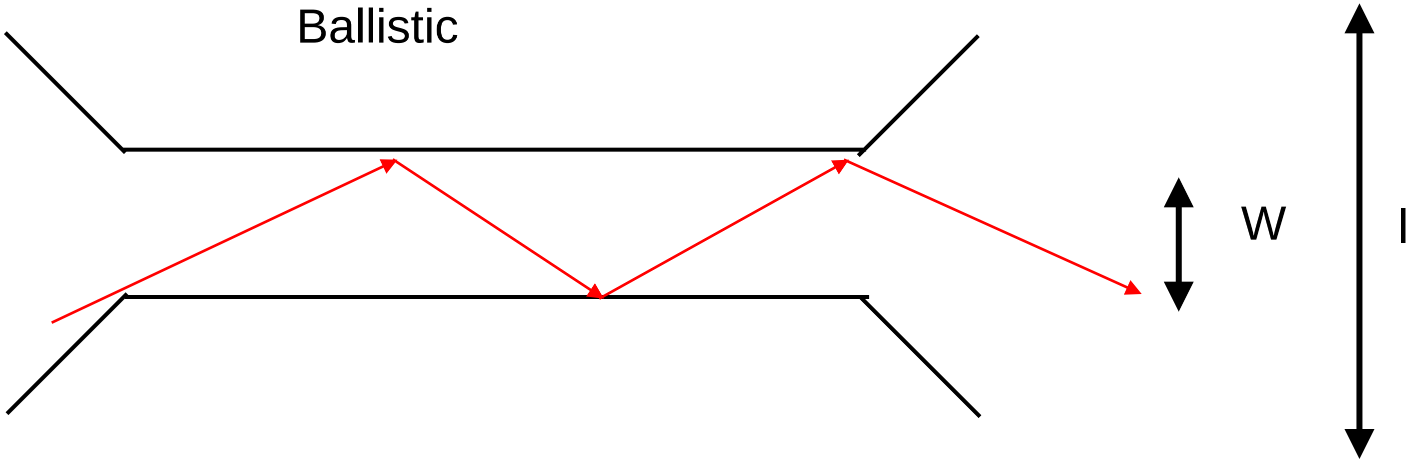
Diffusive

$$R = \frac{L}{W^2}\rho$$



$$R = ?$$

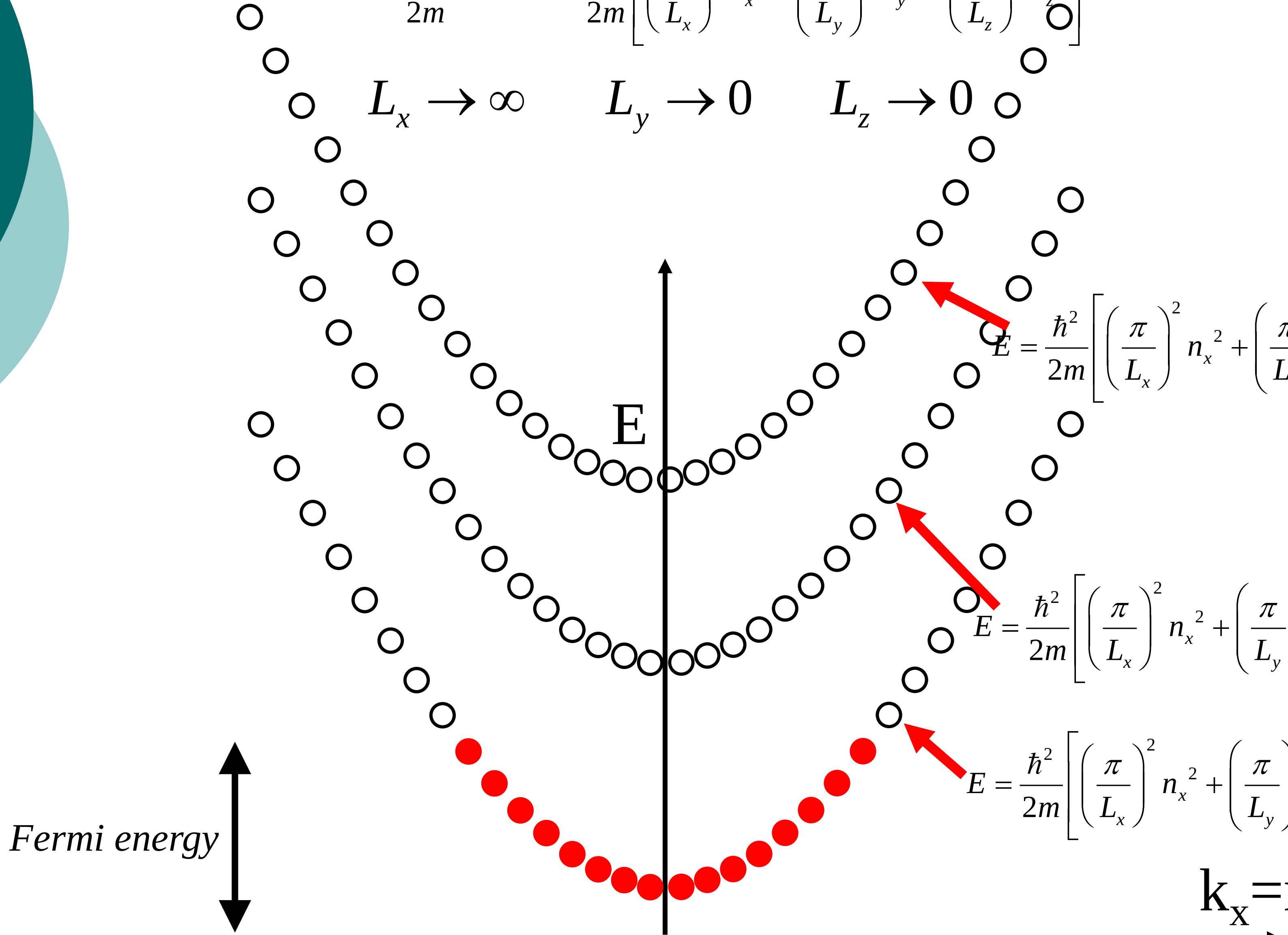
Ballistic



1d system:

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

$$L_x \to \infty \qquad L_y \to 0 \qquad L_z \to 0$$



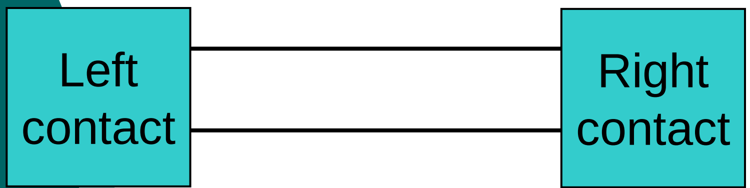
$$E = \frac{\hbar^2}{2m}\left[\left(\frac{\pi}{L_x}\right)^2 n_x{}^2 + \left(\frac{\pi}{L_y}\right)^2 3^2 + \left(\frac{\pi}{L_z}\right)^2\right]$$

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

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

Resistance quantum

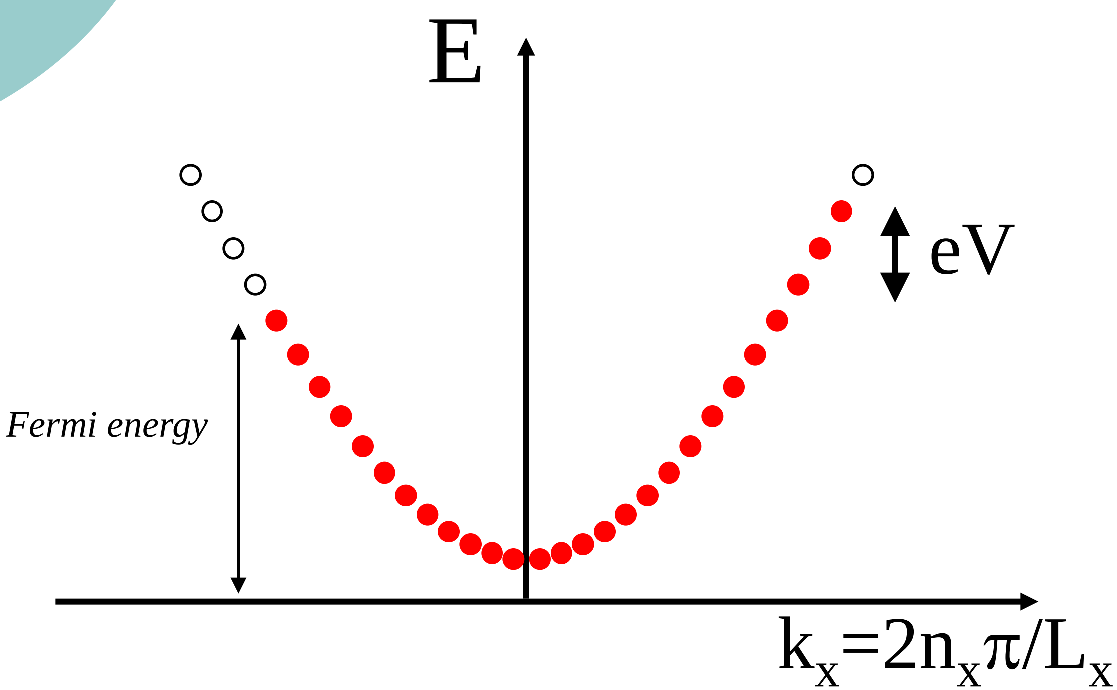
Ballistic conductor



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

With spin:

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



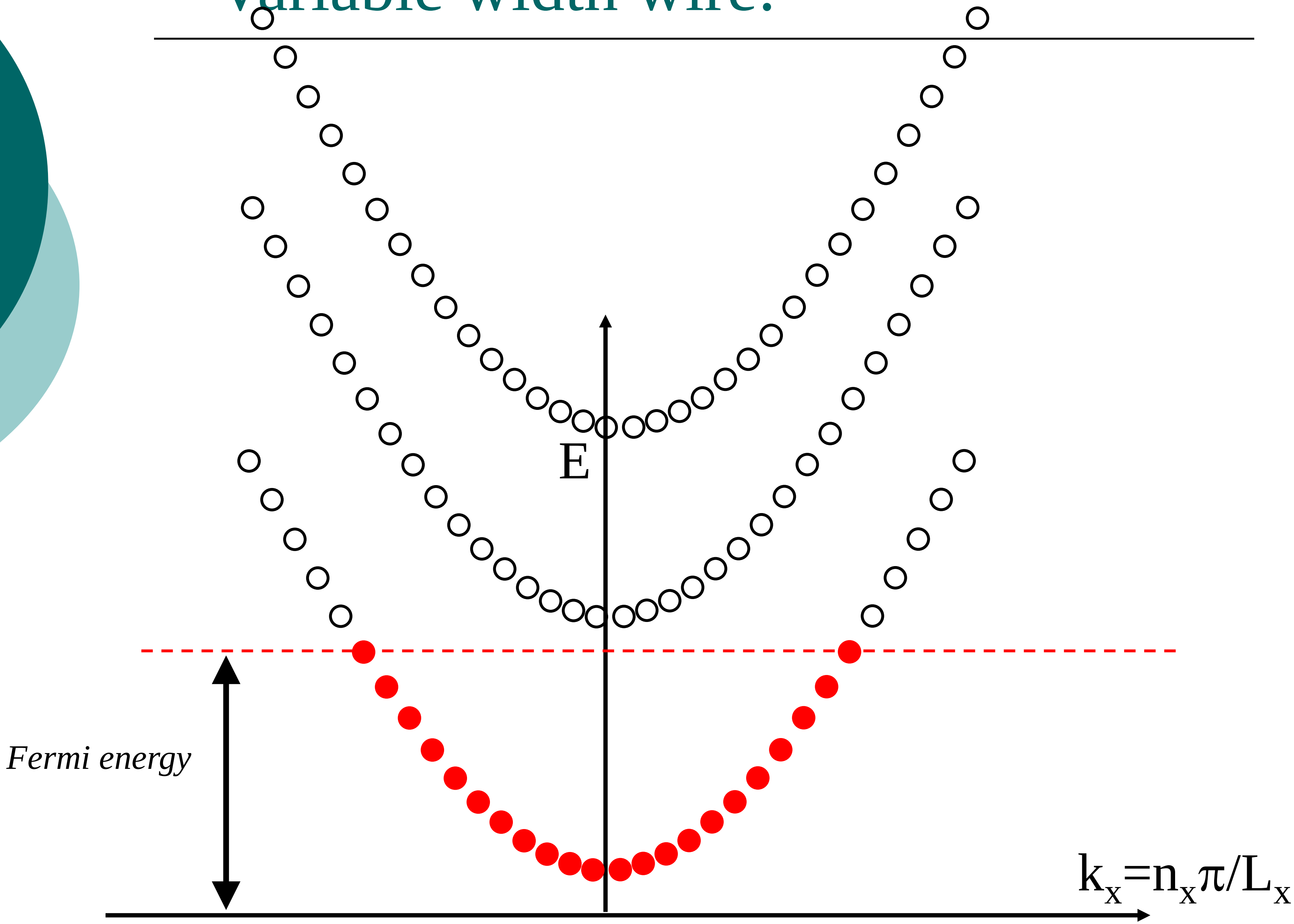
$$G_{quantum} = \frac{2e^2}{h}$$

If injection from leads is not perfect:

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

T is the transmission probability.

Variable width wire:



Landauer formula:

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

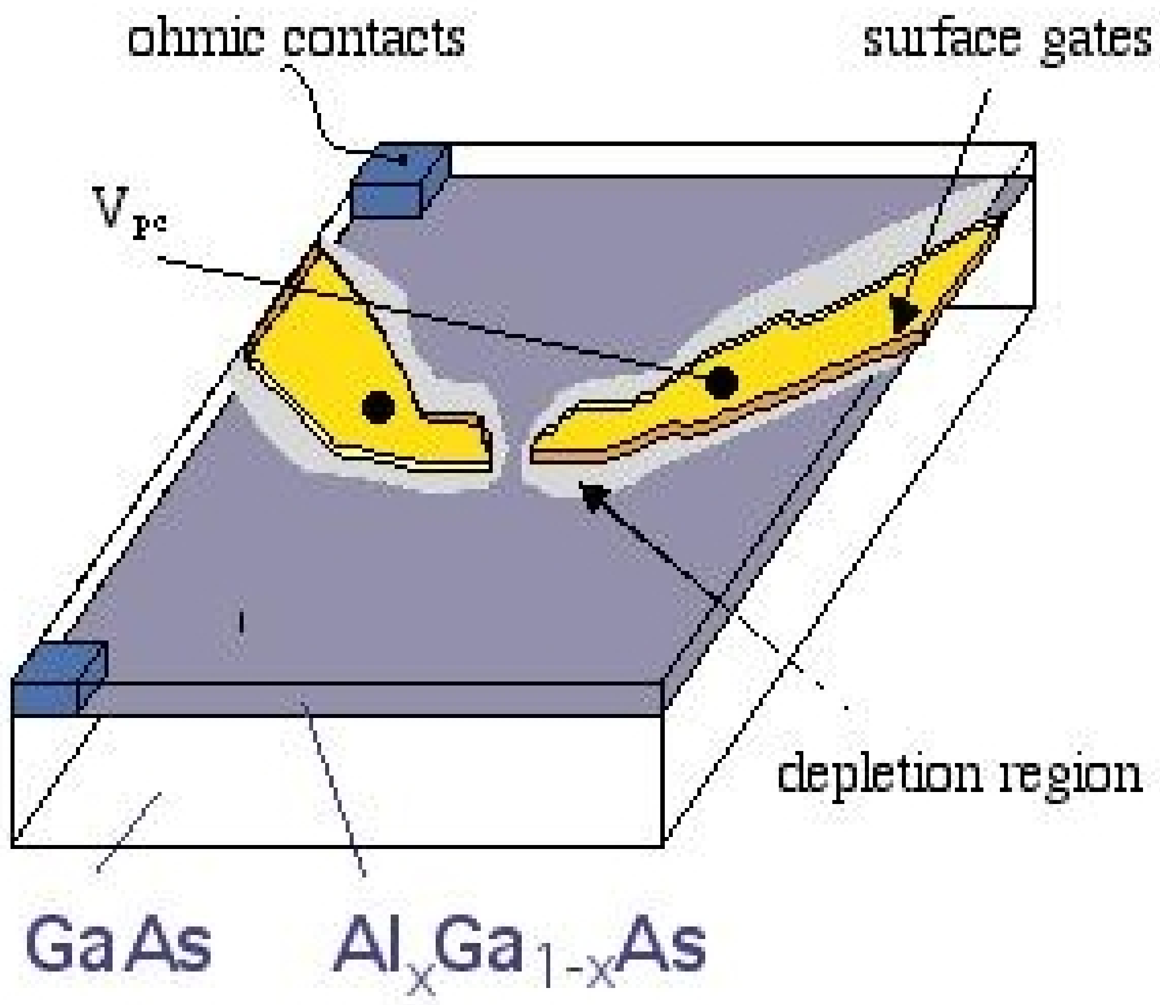
If the leads are not perfect injectors into each "channel" then:

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

Experimental realizations:

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

Quantum point contact



Quantum point contact

VOLUME 60, NUMBER 9 PHYSICAL REVIEW LETTERS 29 FEBRUARY 1988

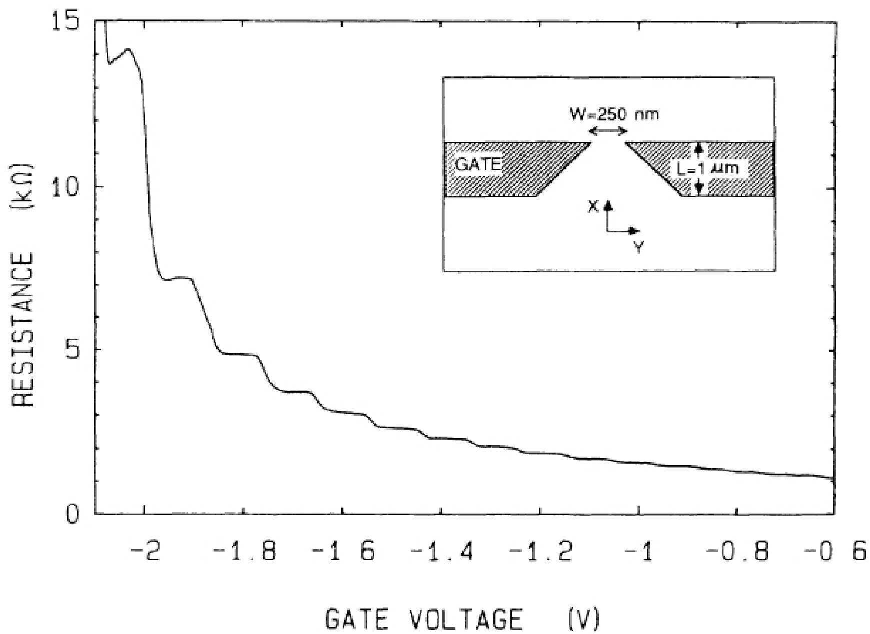


FIG. 1. Point-contact resistance as a function of gate voltage at 0.6 K. Inset: Point-contact layout.

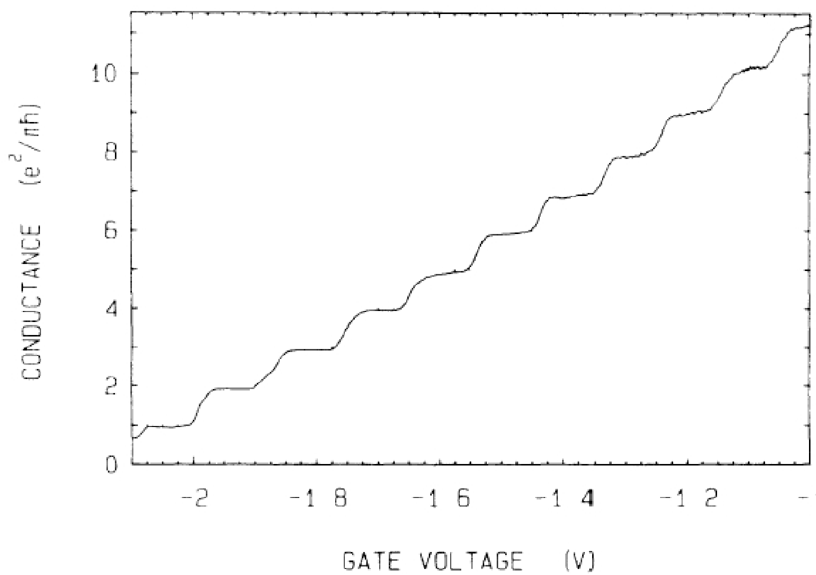


FIG. 2. Point-contact conductance as a function of gate voltage, obtained from the data of Fig. 1 after subtraction of the lead resistance. The conductance shows plateaus at multiples of $e^2/\pi\hbar$.

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

0.7 anomaly

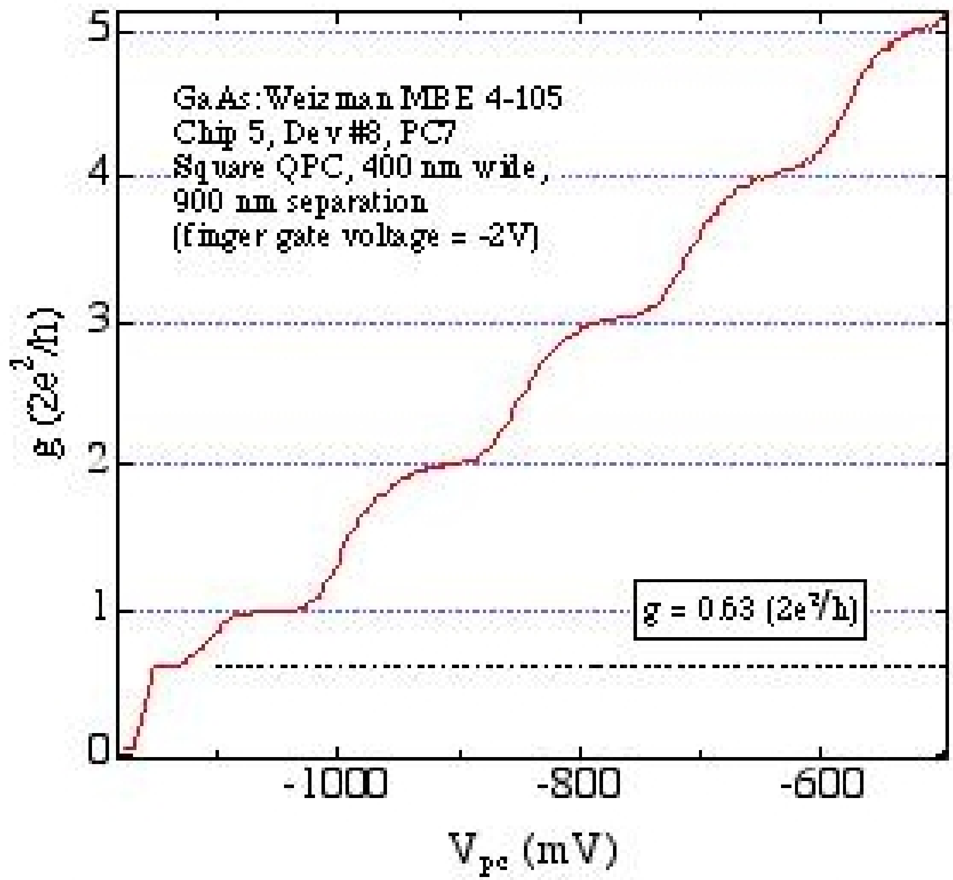
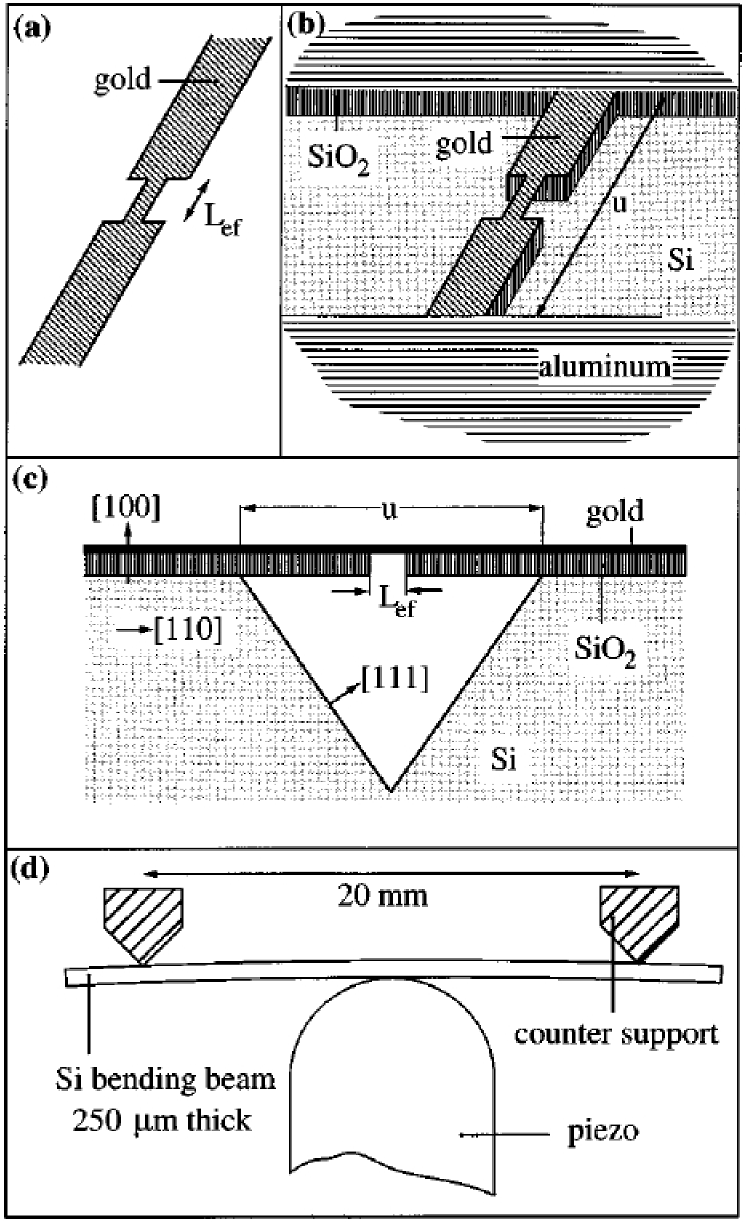
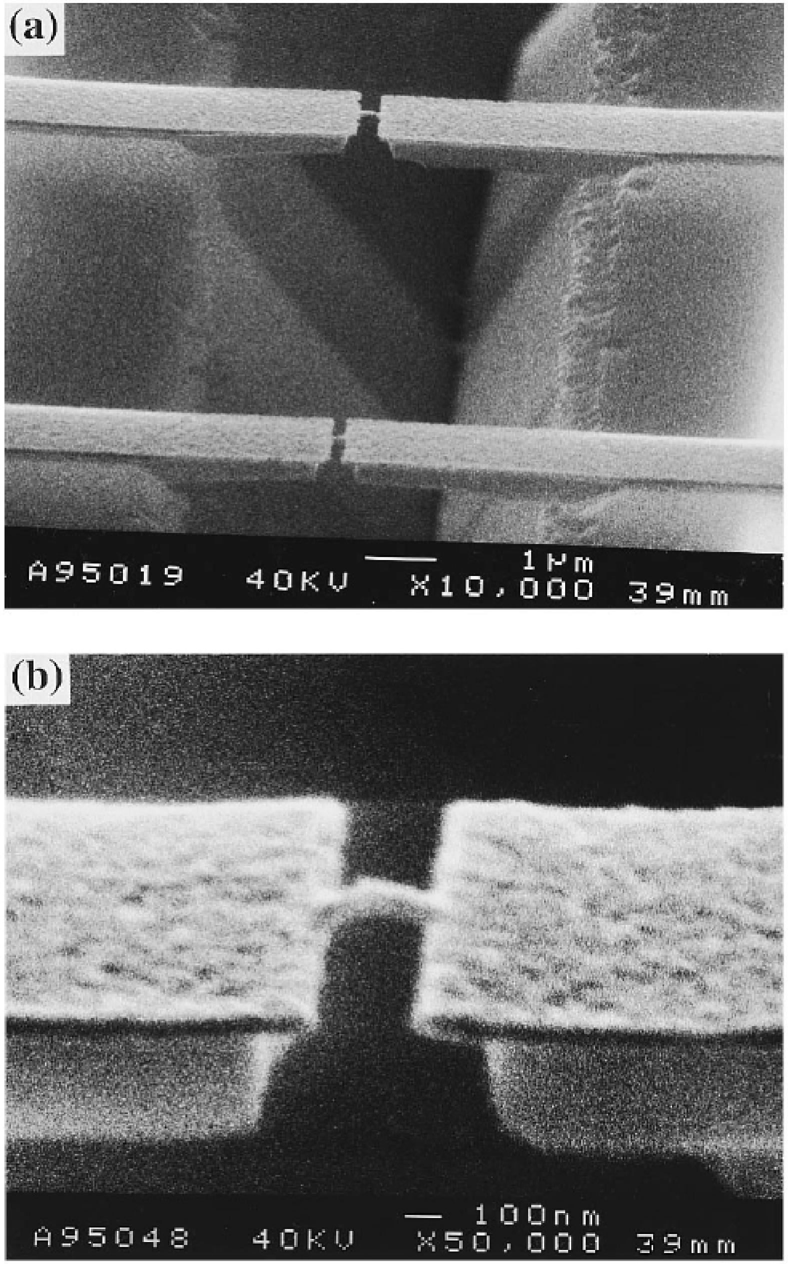


Figure 2: The conductance g through a point contact shows quantized plateaus at integer values of $2e^2/h$ with applied gate voltage, V_{pc} . This QPC shows a very prominent structure at ~0.6 ($2e^2/h$). The gates of this QPC are 400 nm wide and 900 nm apart.

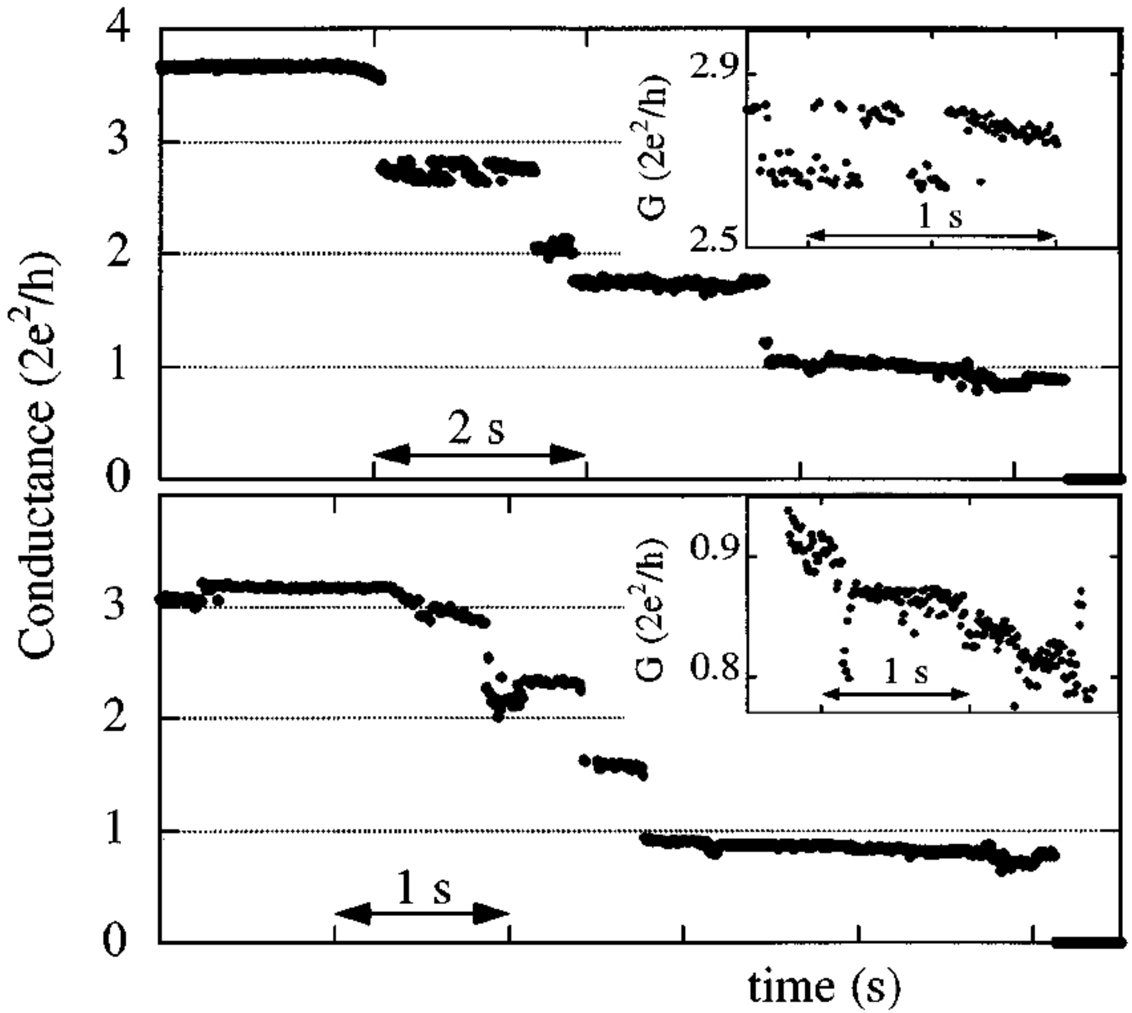
Break junction





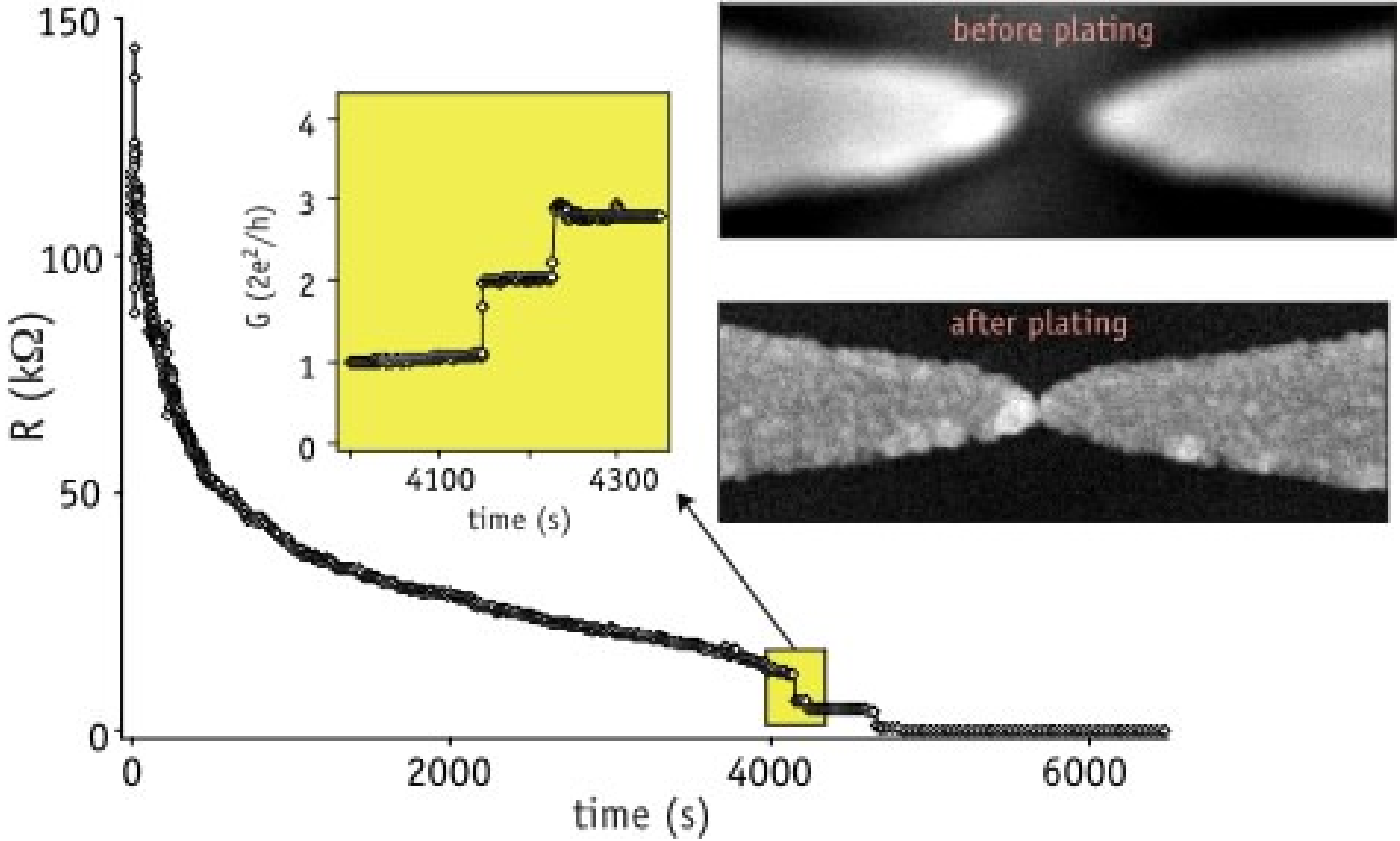
Microfabrication of a mechanically controllable break junction in silicon

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).