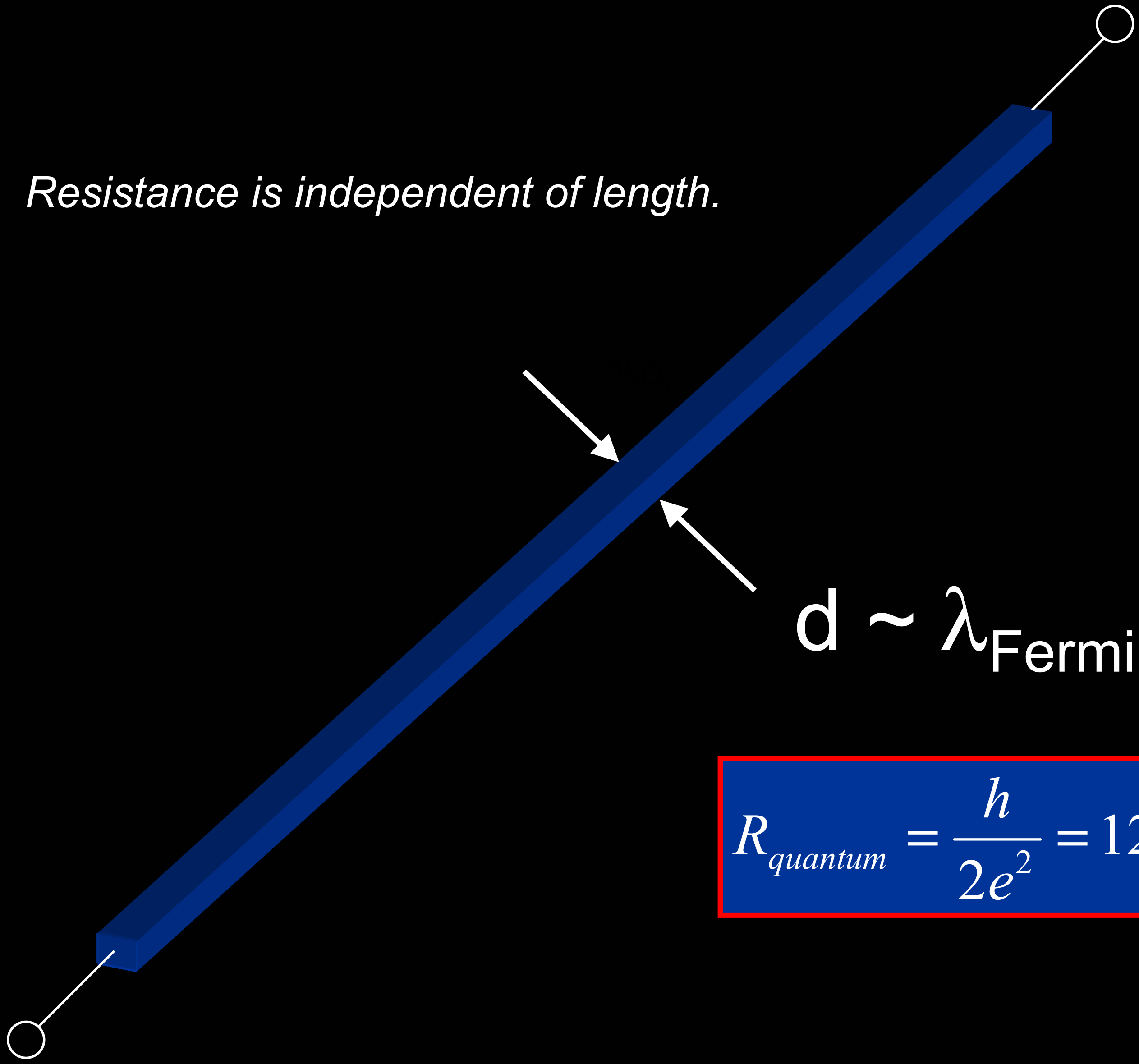
Lecture 11: Quantum point contact



Resistance is independent of length.

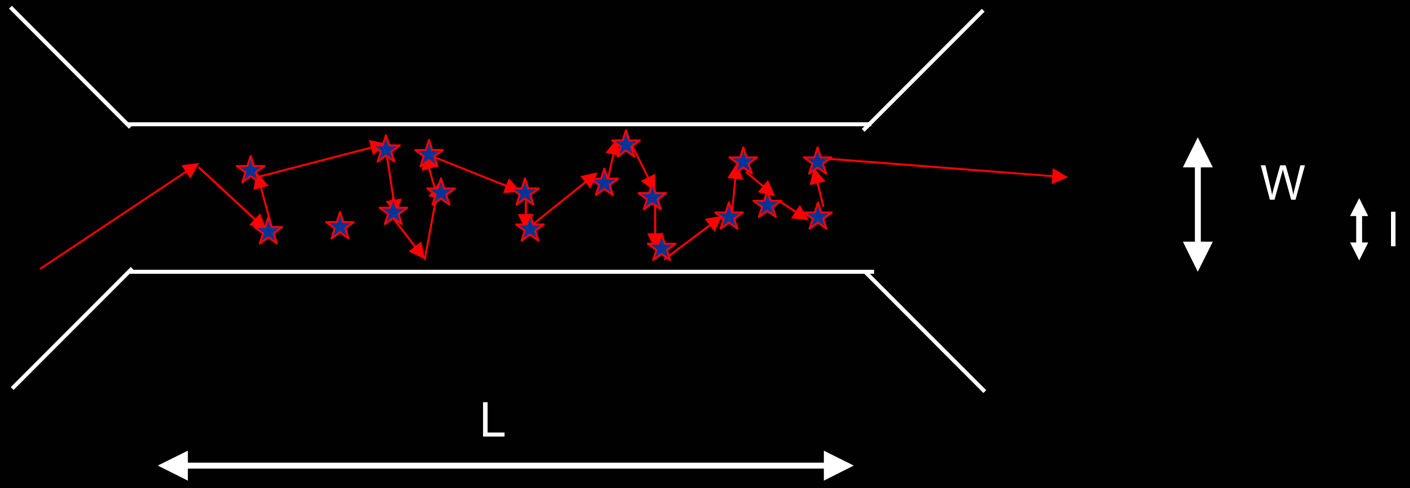
d ~ λ_{Fermi}

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

Ballistic vs. diffusive transport

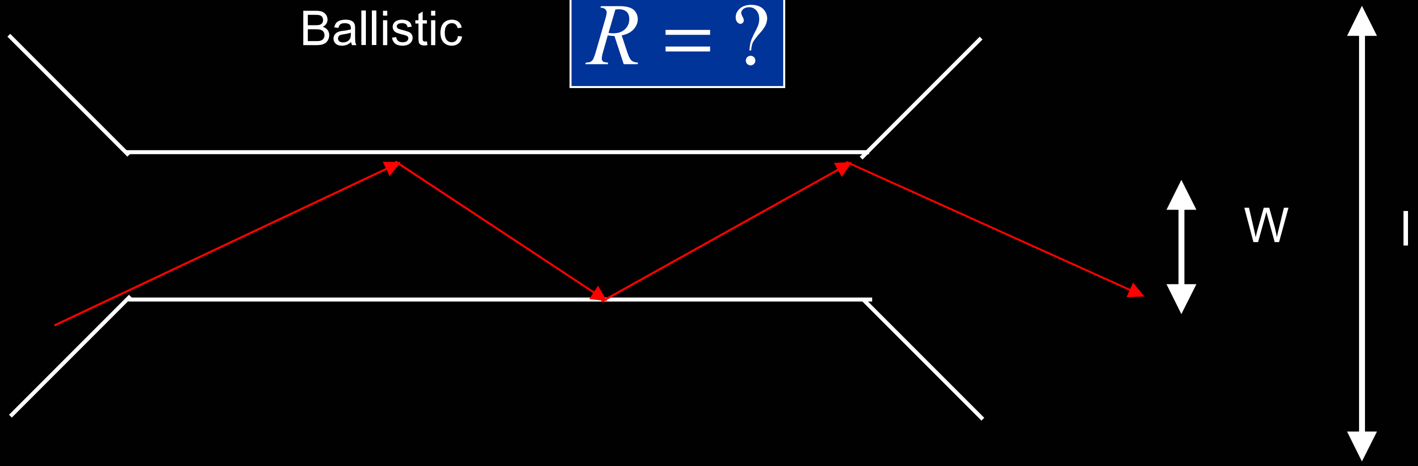
Diffusive

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



Ballistic

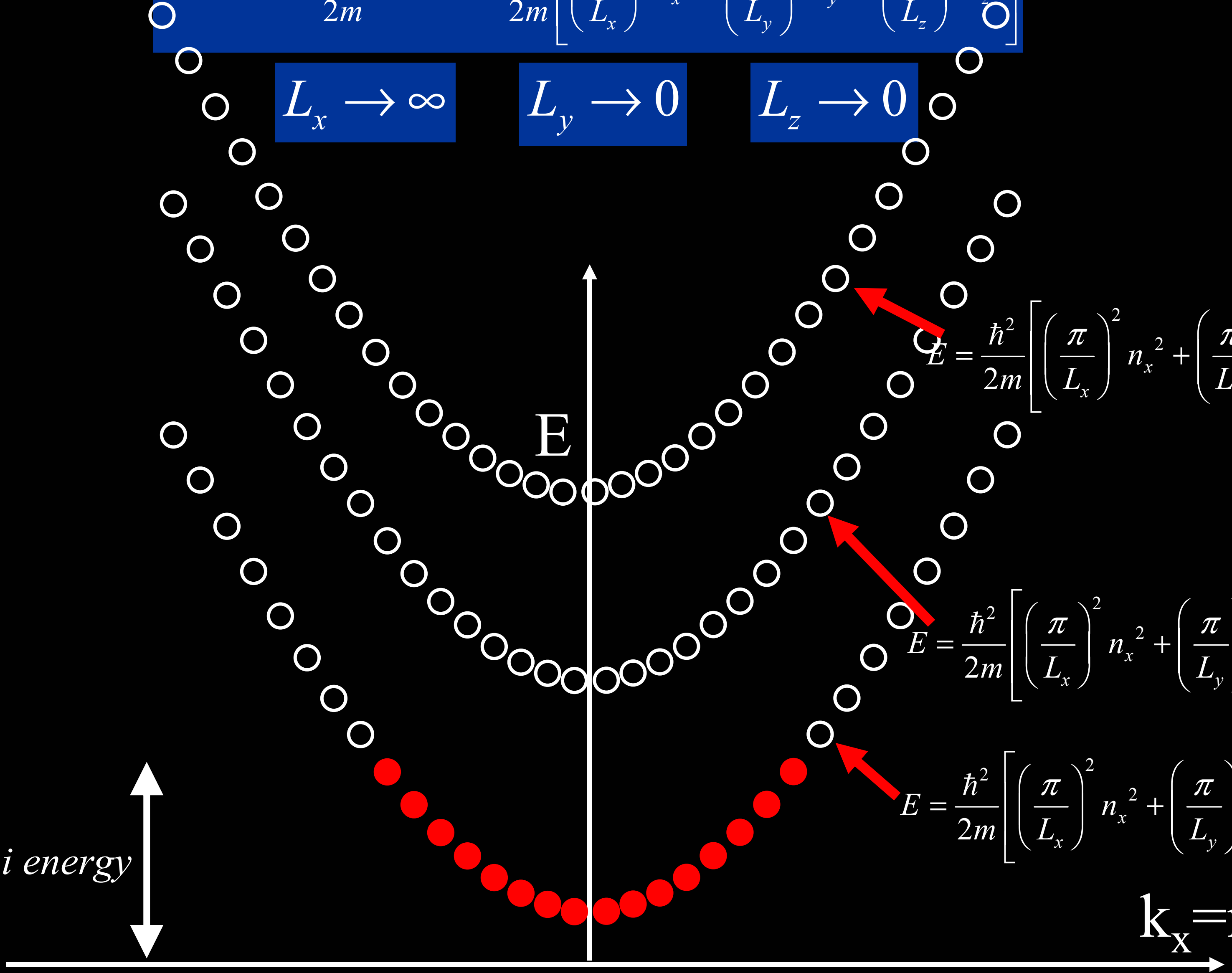
$$\boxed{R = ?}$$



1d system:

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

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



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

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

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

Fermi energy

$k_x = n_x \pi / L_x$

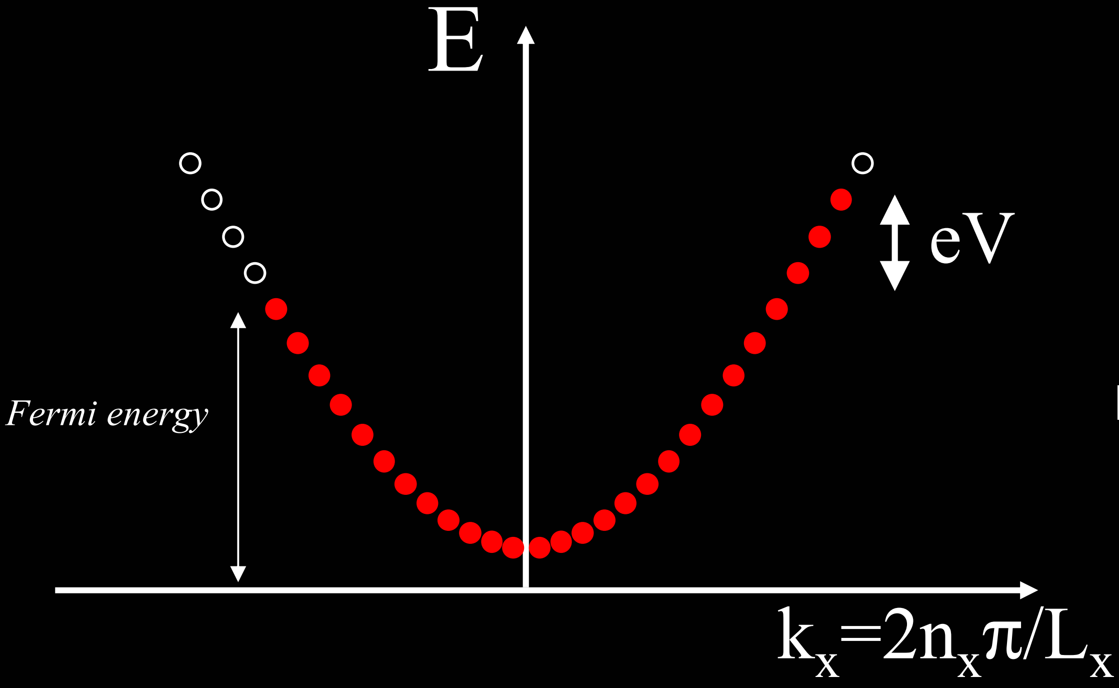
Resistance quantum

Ballistic conductor

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

With spin:

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



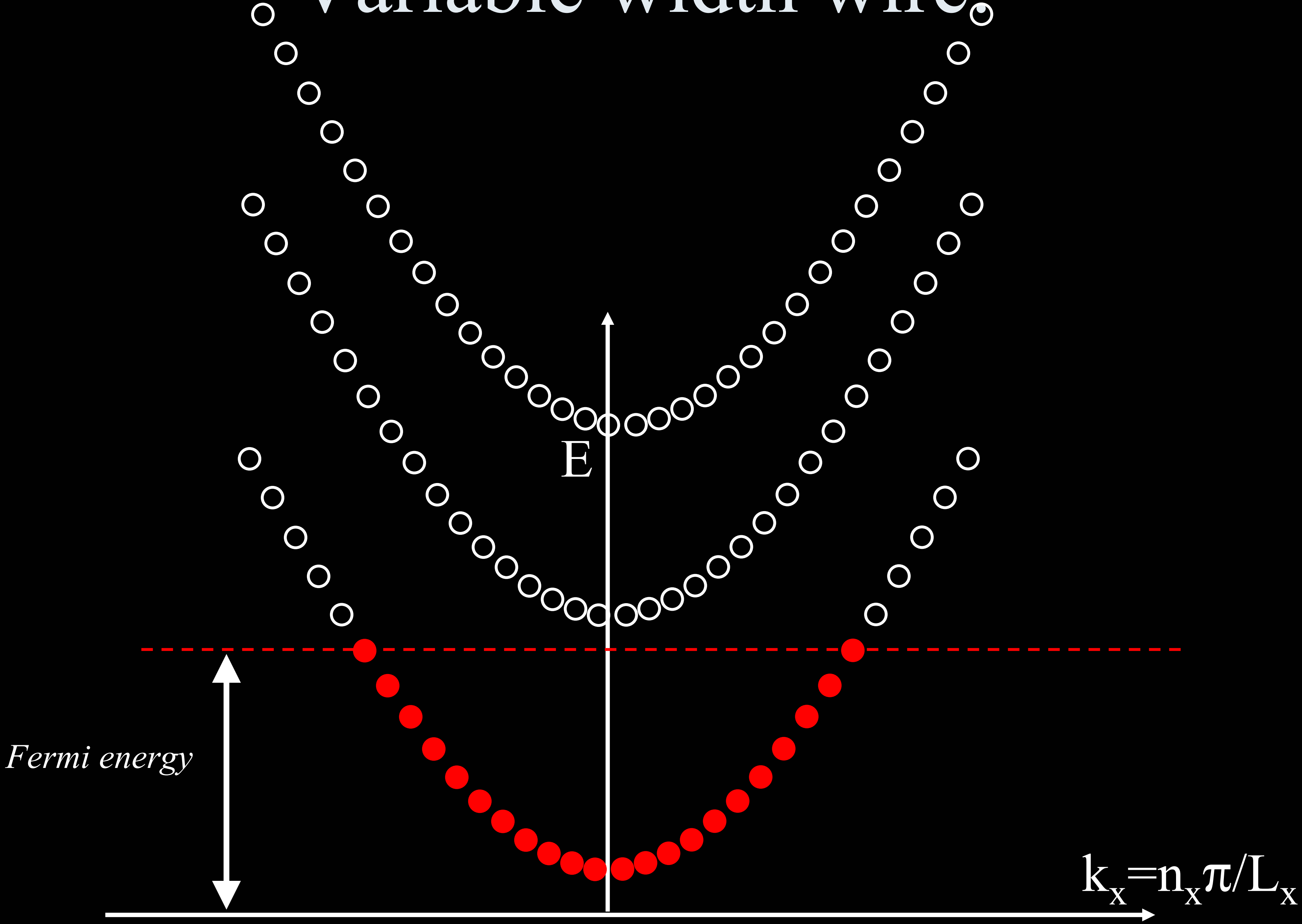
$$G_{quantum} = \frac{2e^2}{h}$$

If injection from leads is not perfect:

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

T is the transmission probability.

Variable width wire:



Landauer formula:

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

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

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

Experimental realizations:

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

Quantum point contact

In class we will show images from:

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

0.7 anomaly

In class we will show images from:

http://marcuslab.harvard.edu/spinfilters.jpg

Break junction

In class we will show images from:

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

Electroplating

In class we will show images from:

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

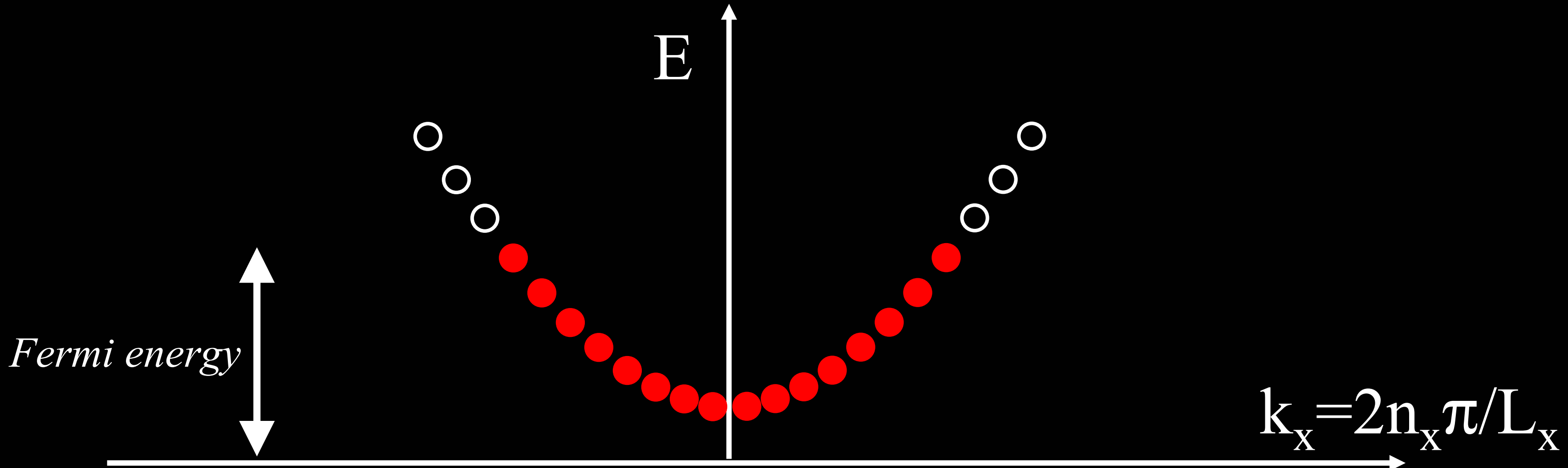
Positive and negative k-vectors:

Particle in a box: (positive k-vectors only)

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

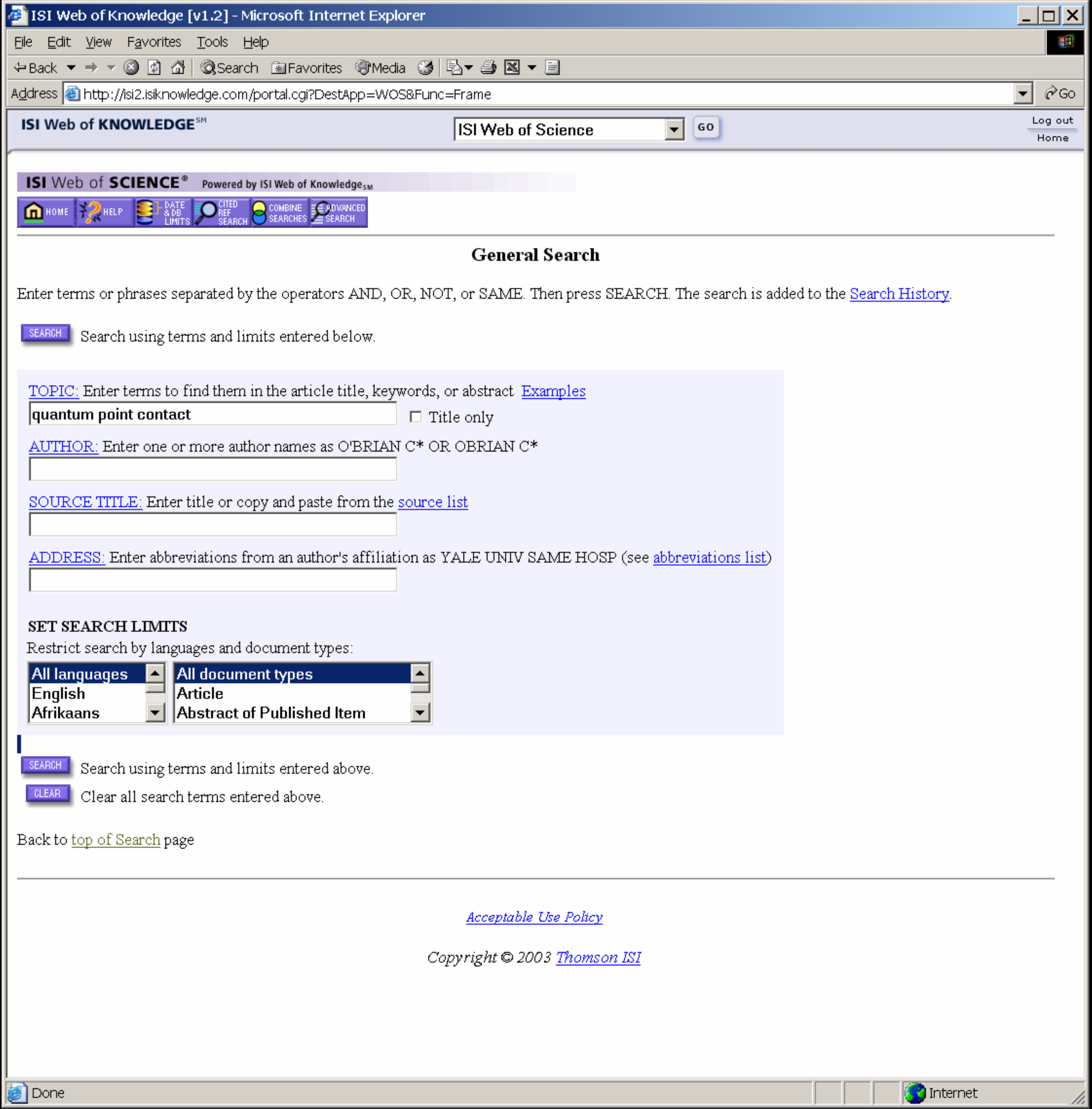
“Born-Von Karman” boundary conditions: (positive *and* negative k-vectors)

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



Time permitting:

- Landauer-Buttiker
- Web of Science



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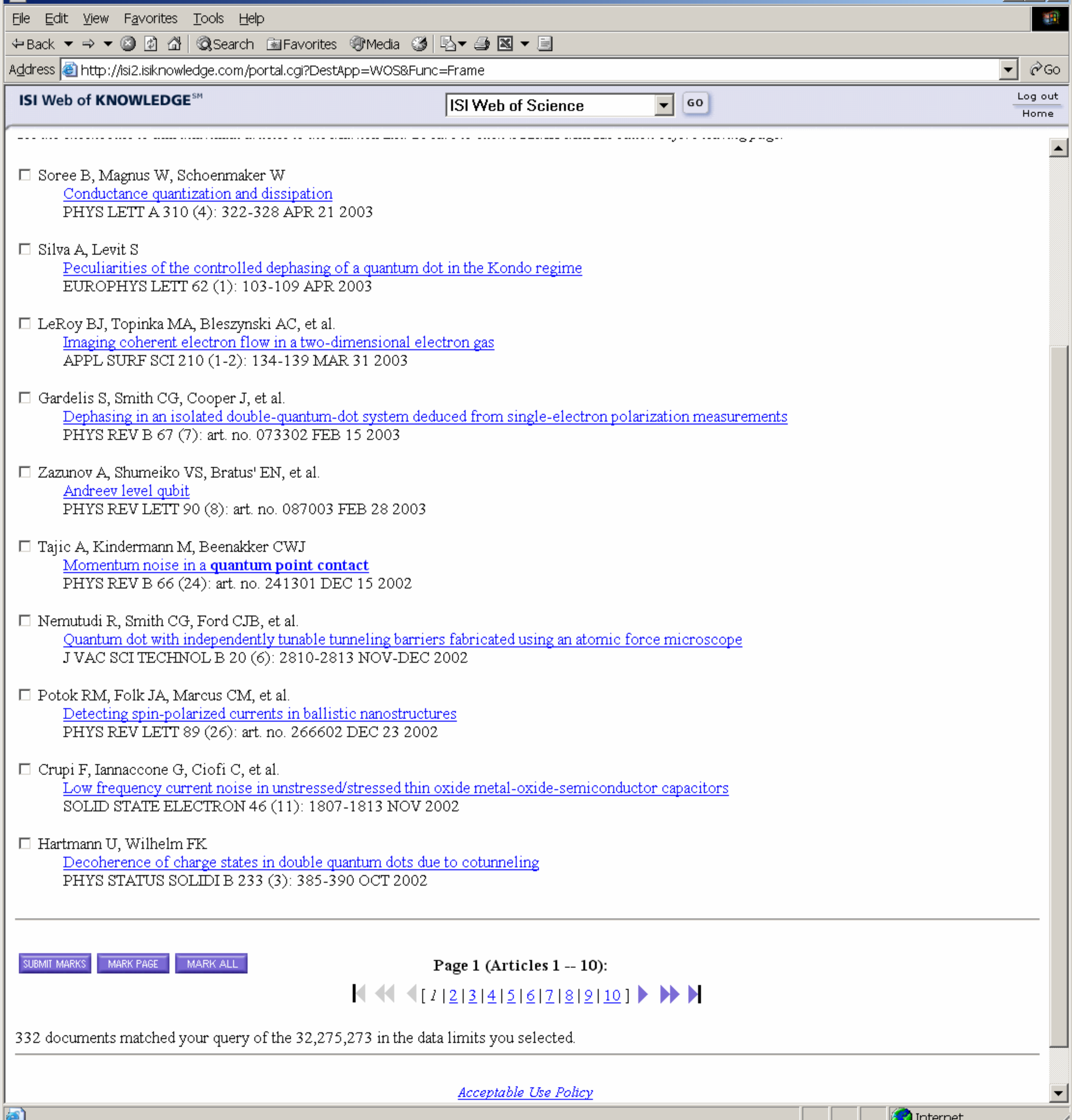

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PHYS REV LETT 89 (26): art. no. 266602 DEC 23 2002

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Low frequency current noise in unstressed/stressed thin oxide metal-oxide-semiconductor capacitors
SOLID STATE ELECTRON 46 (11): 1807-1813 NOV 2002

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Decoherence of charge states in double quantum dots due to cotunneling
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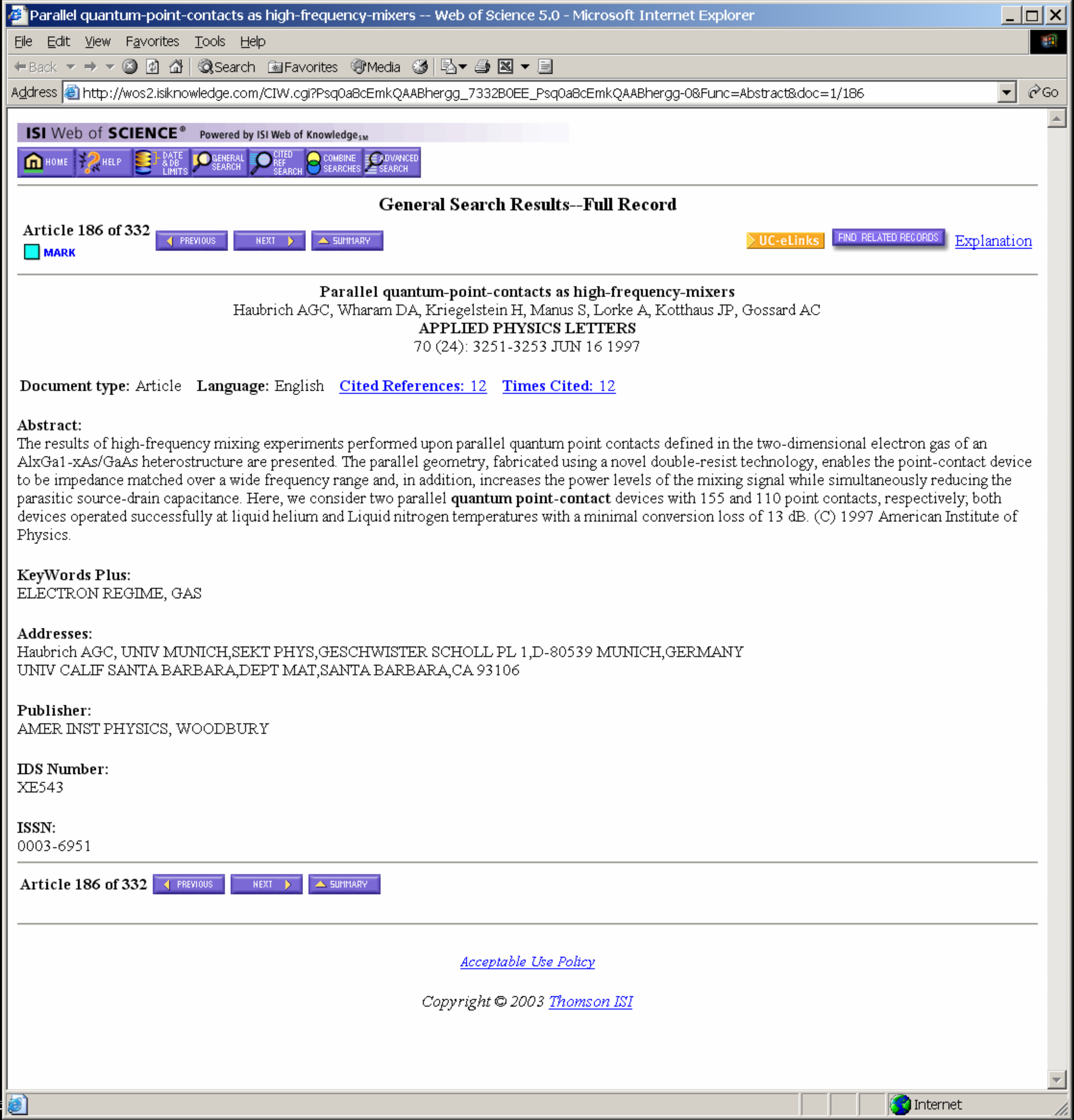

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70 (24): 3251-3253 JUN 16 1997

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Abstract:
The results of high-frequency mixing experiments performed upon parallel quantum point contacts defined in the two-dimensional electron gas of an AlxGa1-xAs/GaAs heterostructure are presented. The parallel geometry, fabricated using a novel double-resist technology, enables the point-contact device to be impedance matched over a wide frequency range and, in addition, increases the power levels of the mixing signal while simultaneously reducing the parasitic source-drain capacitance. Here, we consider two parallel **quantum point-contact** devices with 155 and 110 point contacts, respectively; both devices operated successfully at liquid helium and Liquid nitrogen temperatures with a minimal conversion loss of 13 dB. (C) 1997 American Institute of Physics.

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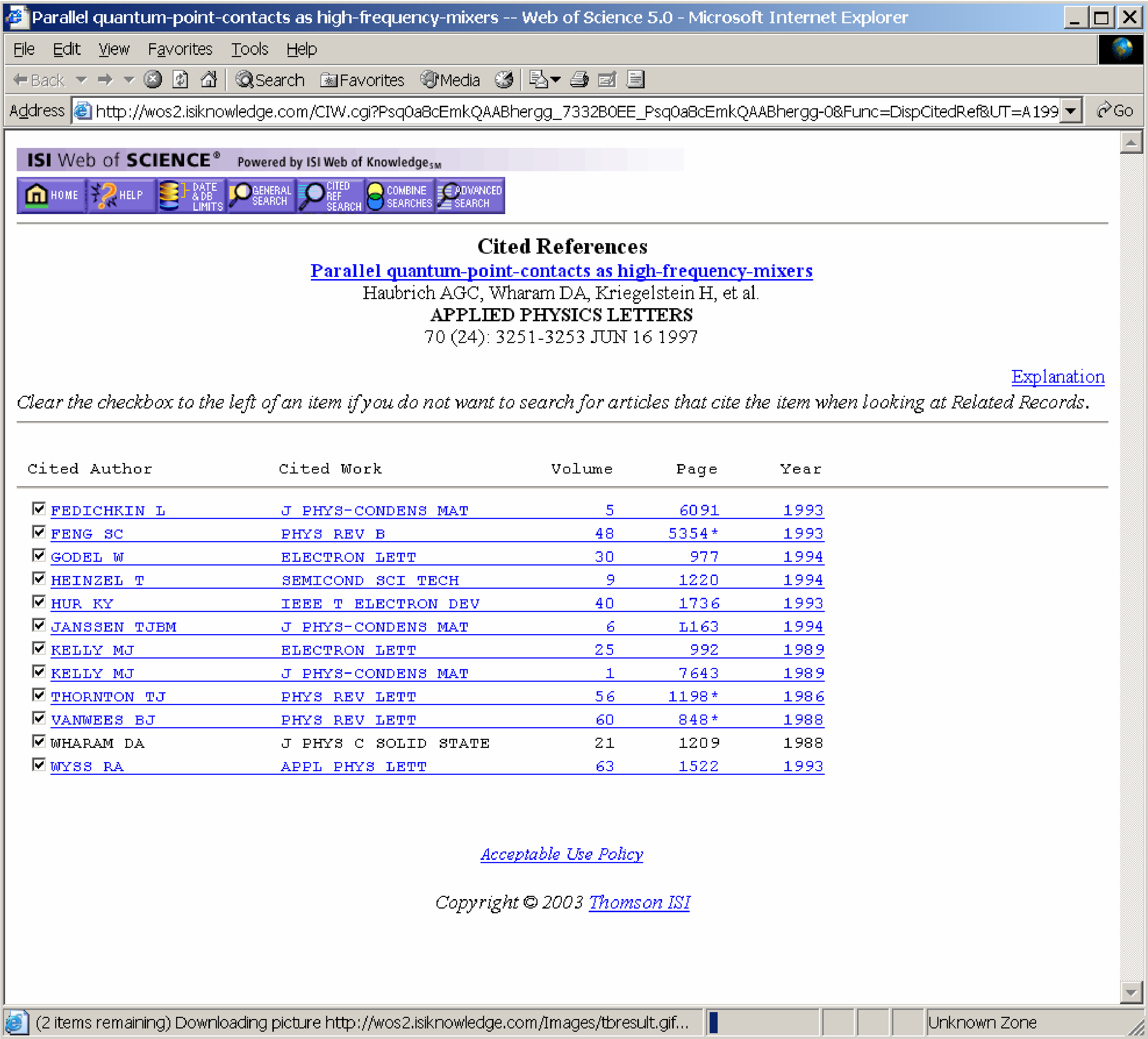

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Haubrich AGC, Wharam DA, Kriegelstein H, et al.
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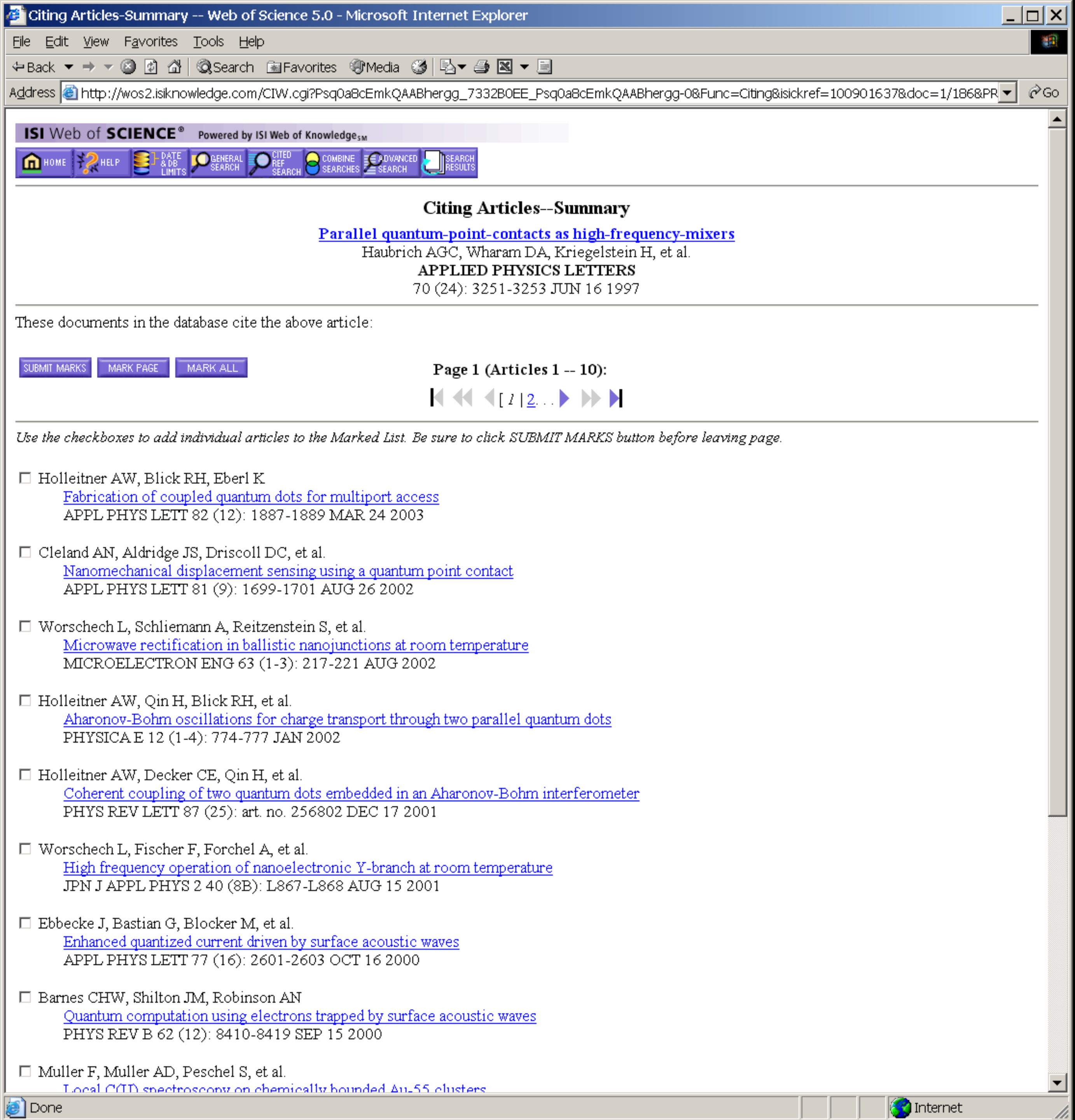

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Aharonov-Bohm oscillations for charge transport through two parallel quantum dots
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Quantum computation using electrons trapped by surface acoustic waves
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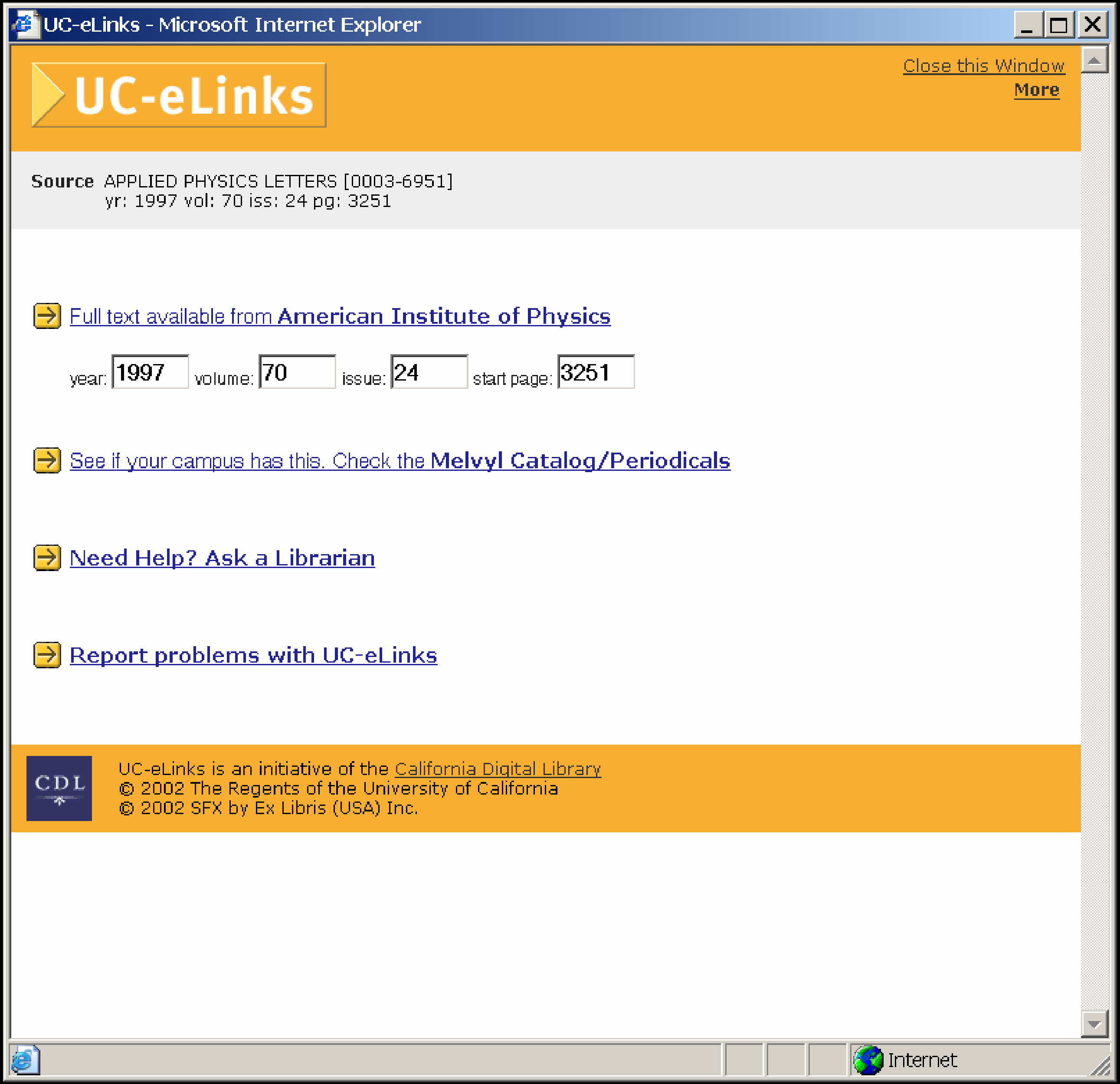

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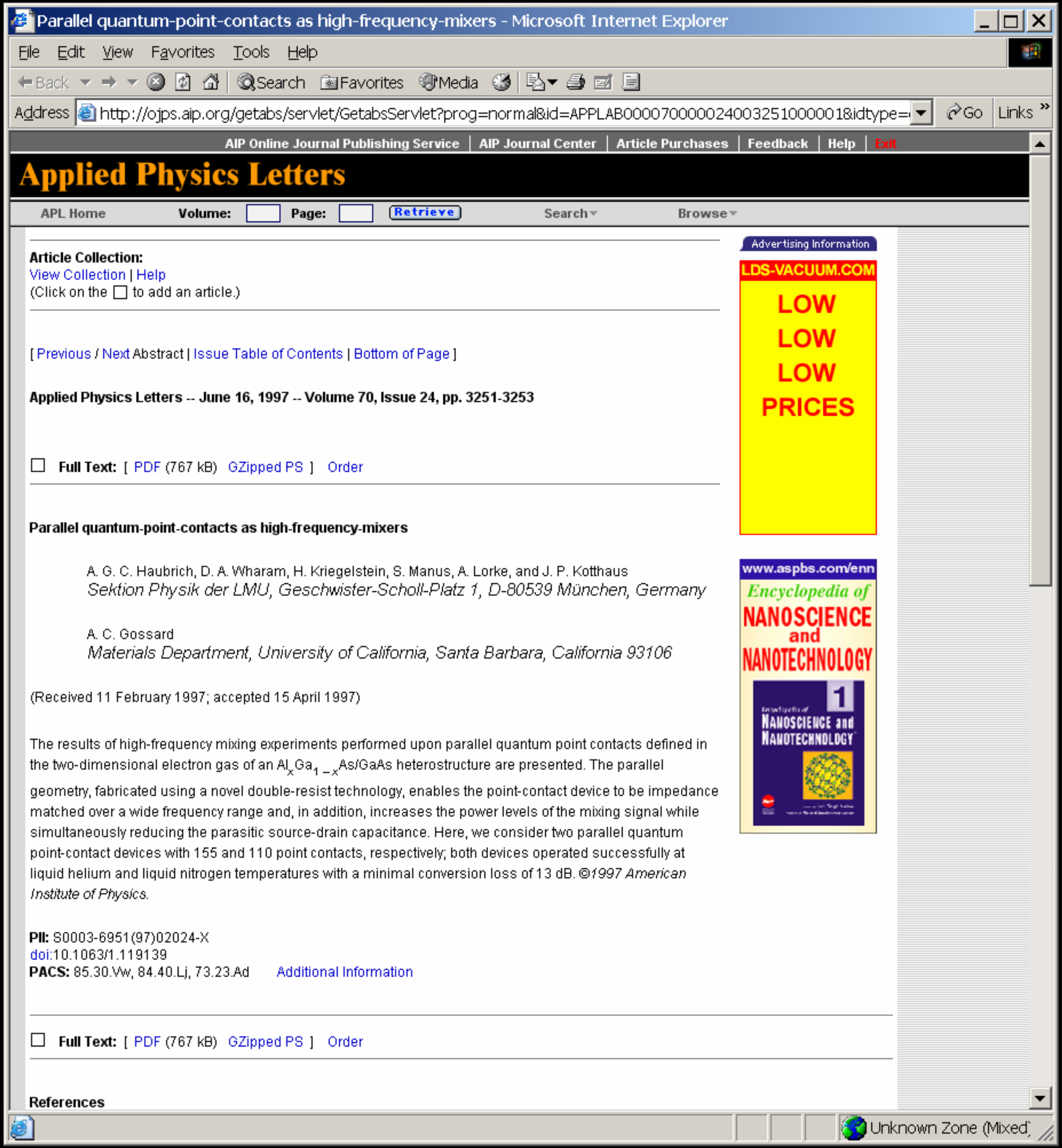

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Parallel quantum-point-contacts as high-frequency-mixers

A. G. C. Haubrich, D. A. Wharam, H. Kriegelstein, S. Manus, A. Lorke, and J. P. Kotthaus
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A. C. Gossard
Materials Department, University of California, Santa Barbara, California 93106

(Received 11 February 1997; accepted 15 April 1997)

The results of high-frequency mixing experiments performed upon parallel quantum point contacts defined in the two-dimensional electron gas of an $Al_xGa_{1-x}As/GaAs$ heterostructure are presented. The parallel geometry, fabricated using a novel double-resist technology, enables the point-contact device to be impedance matched over a wide frequency range and, in addition, increases the power levels of the mixing signal while simultaneously reducing the parasitic source-drain capacitance. Here, we consider two parallel quantum point-contact devices with 155 and 110 point contacts, respectively; both devices operated successfully at liquid helium and liquid nitrogen temperatures with a minimal conversion loss of 13 dB. *©1997 American Institute of Physics.*

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