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I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

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Research Workshop on Condensed Matter Physics
30 June - 22 August 1997
MINIWORKSHOP ON
QUANTUM WELLS, DOTS, WIRES
AND SELF-ORGANIZING NANOSTRUCTURES
11 - 22 AUGUST 1997

"Magneto-Acoustic Phonon Antiresonances in Wannier-Stark Superlattices"

PART II

L. EAVES
The University of Nottingham
Department of Physics
University Park
NG7 2RD Nottingham
U.K.

Magneto-Acoustic Phonon Antiresonances

in Wannier-Stark Superlattices

Speaker : L. Eaves
Lecture 2

Alain Nogaret
Laurence Eaves
Peter Main
Mohamed Henini
} Dept. of Physics University of Nottingham

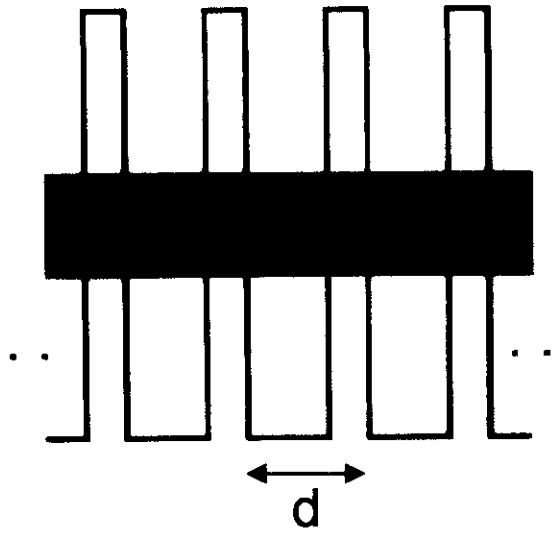
Duncan Maude — *HMFL Grenoble*
Jean-Claude Portal

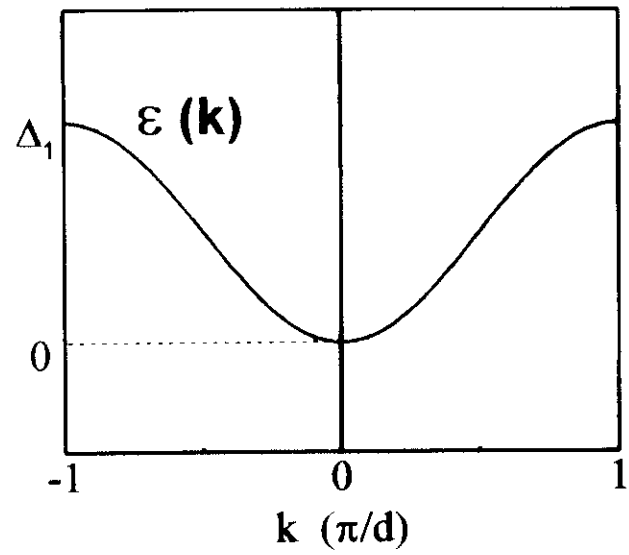
Elisa Molinari — *Universita di Modena*

Steve Beaumont — *Glasgow University*

Wannier's Effective Hamiltonian

F=0



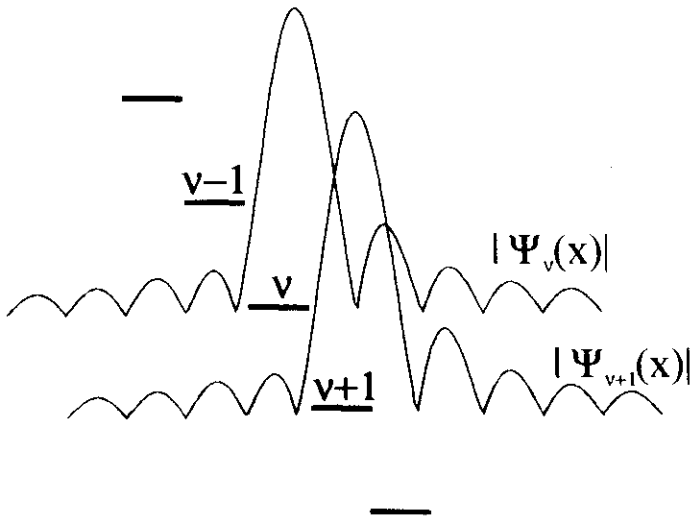


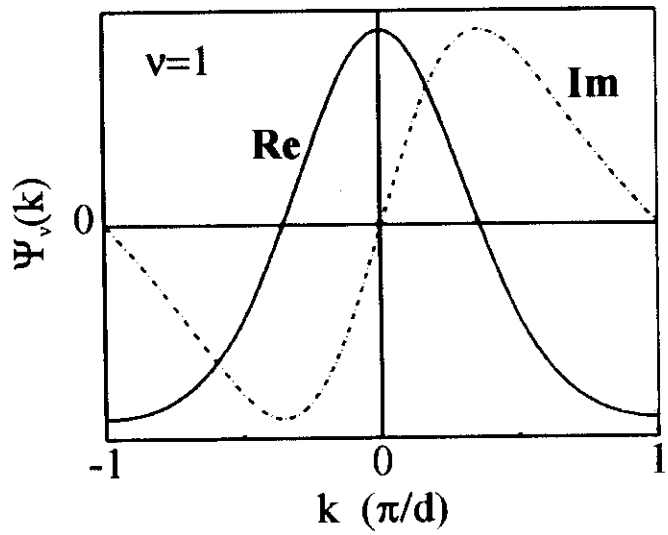
F>0

Wannier 1960

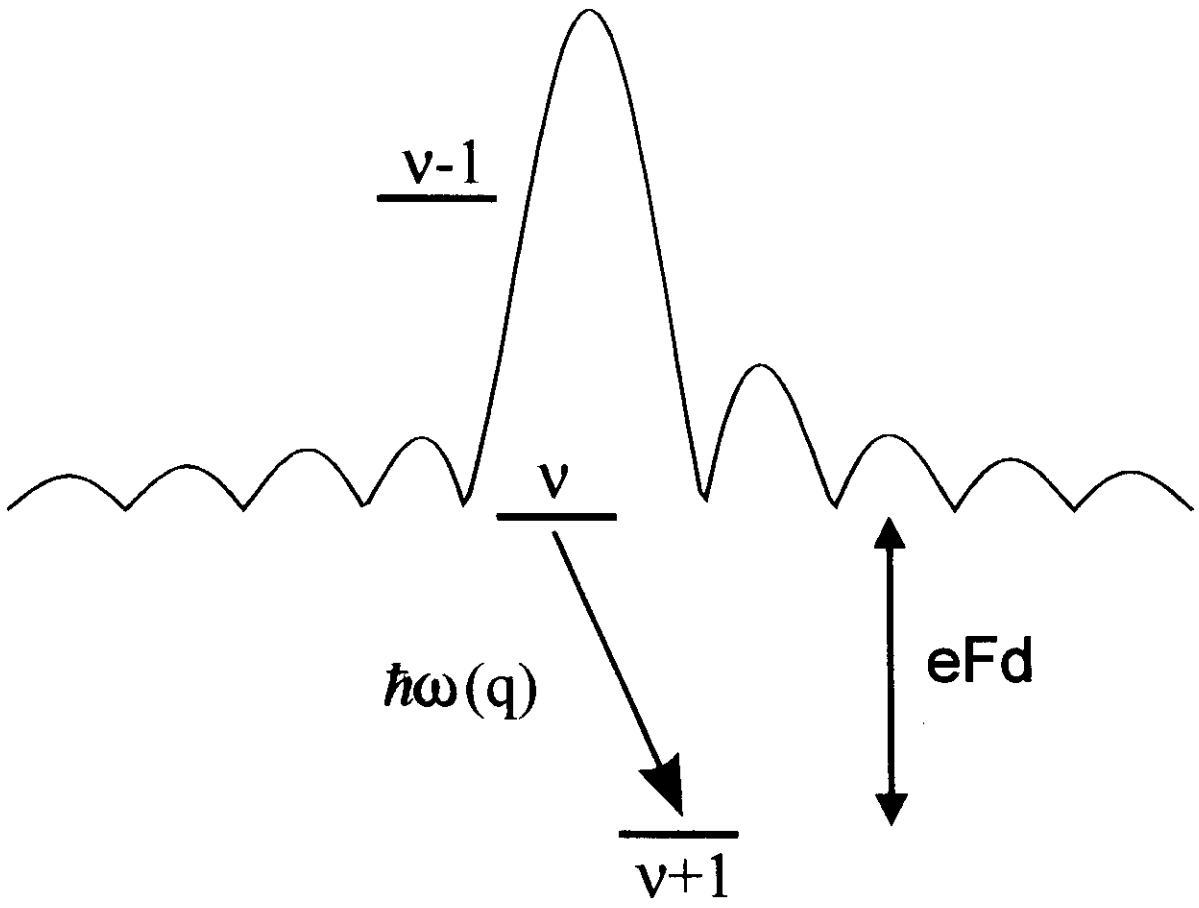
$$\left[\varepsilon(k) - ieF\frac{\partial}{\partial k}\right]\Psi(k) = \varepsilon\,\Psi(k)$$

$$\Psi(k) = \Psi(k+2\pi/d)$$





Phonon Assisted Hopping



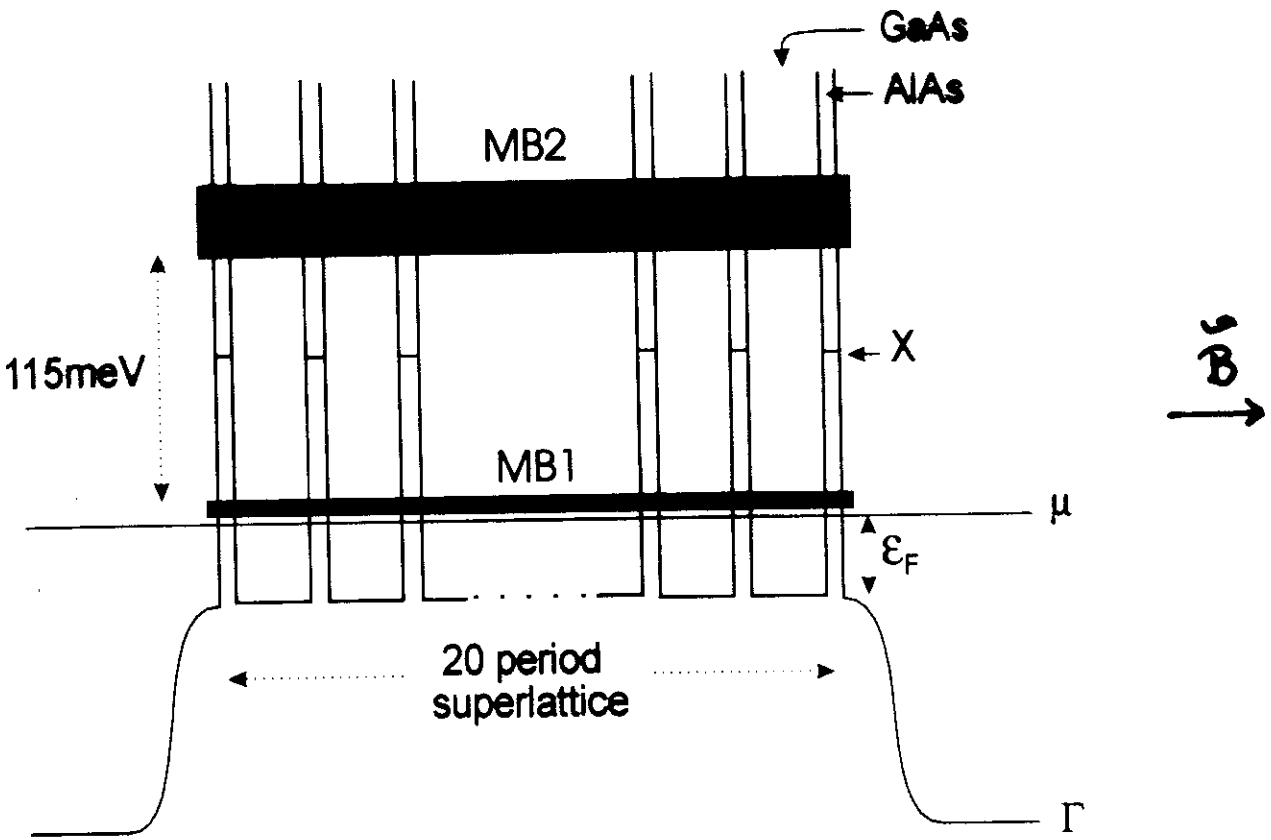
Bragg Reflection: $q=2\pi n/d$, $n=1,2,3...$

$$\Psi_\nu(k+q) = \Psi_\nu(k)$$

Ψ_ν orthogonal to all $\Psi_{\eta\neq\nu}$

Hopping matrix element vanishes
due to Selection Rule on Momentum

Y.Lyanda-Geller and J.P.Leburton 1995
R.Tsu and G.Dohler 1975

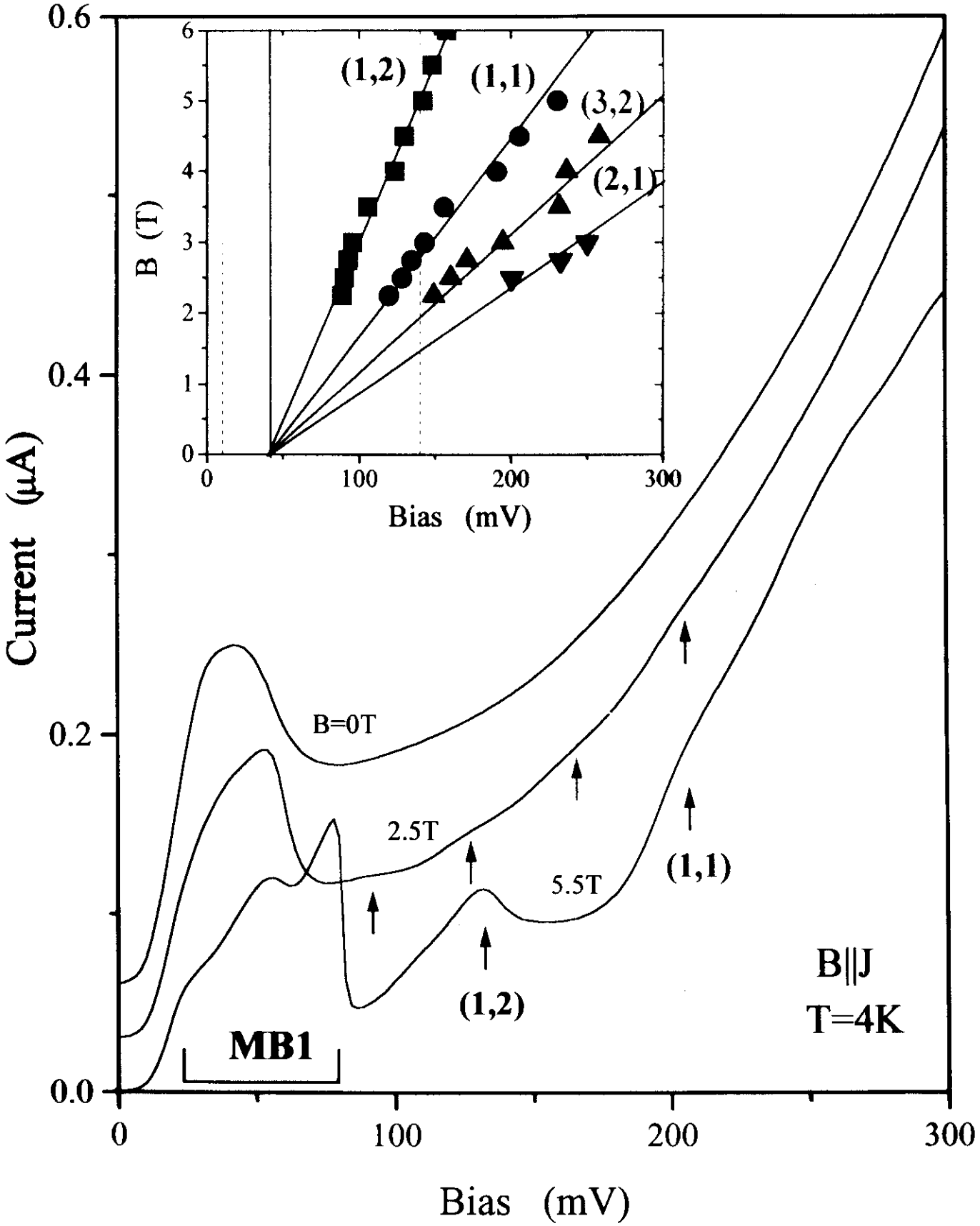


B

period = 10.6nm (38ML)
spacer = 10.2nm

GaAs = 9.3nm (33ML)
AlAs = 1.3nm (5ML)

Low Magnetic Field Regime

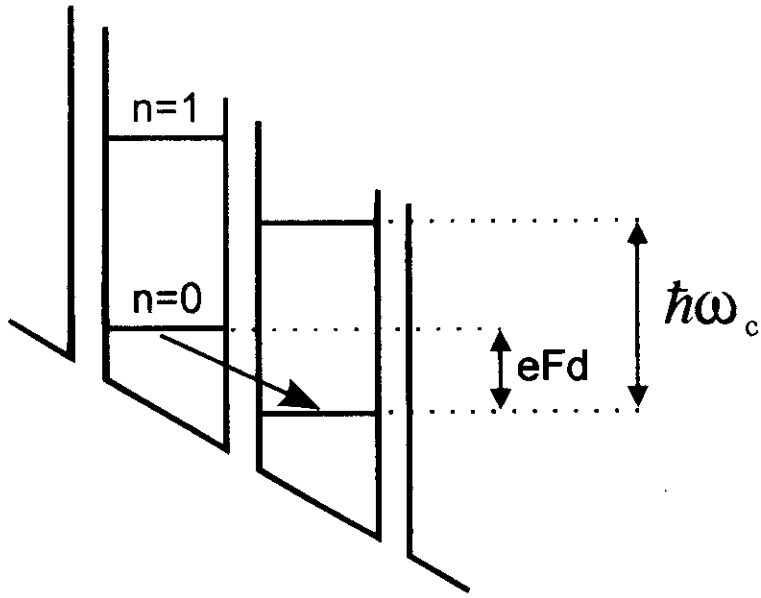


Electrical Conduction in a quasi-1D Superlattice

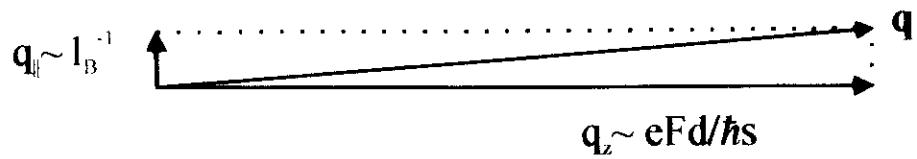
- High Magnetic Field Regime -

1D W-S

$$\hbar\omega_c > eFd > \Delta_1$$

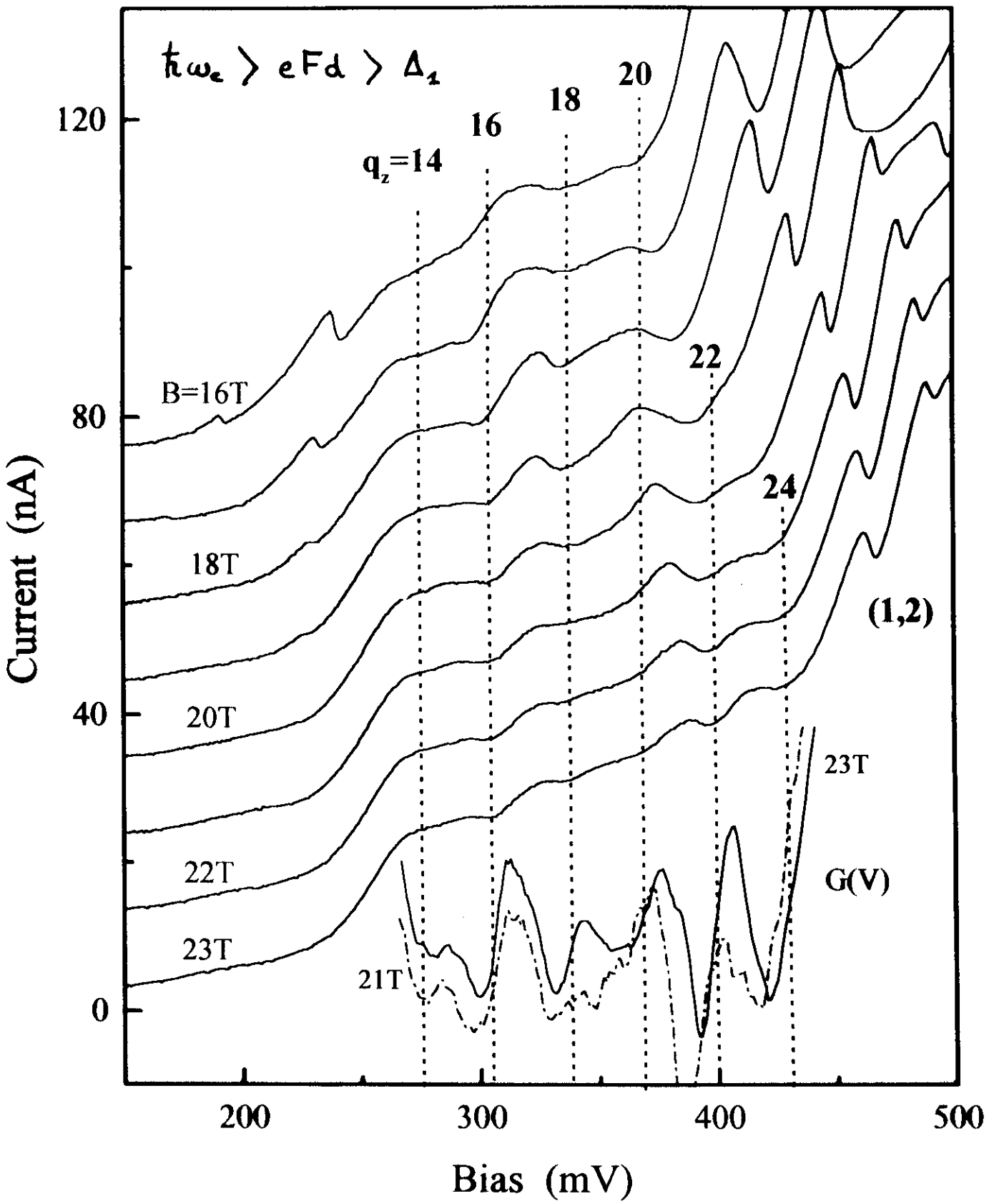


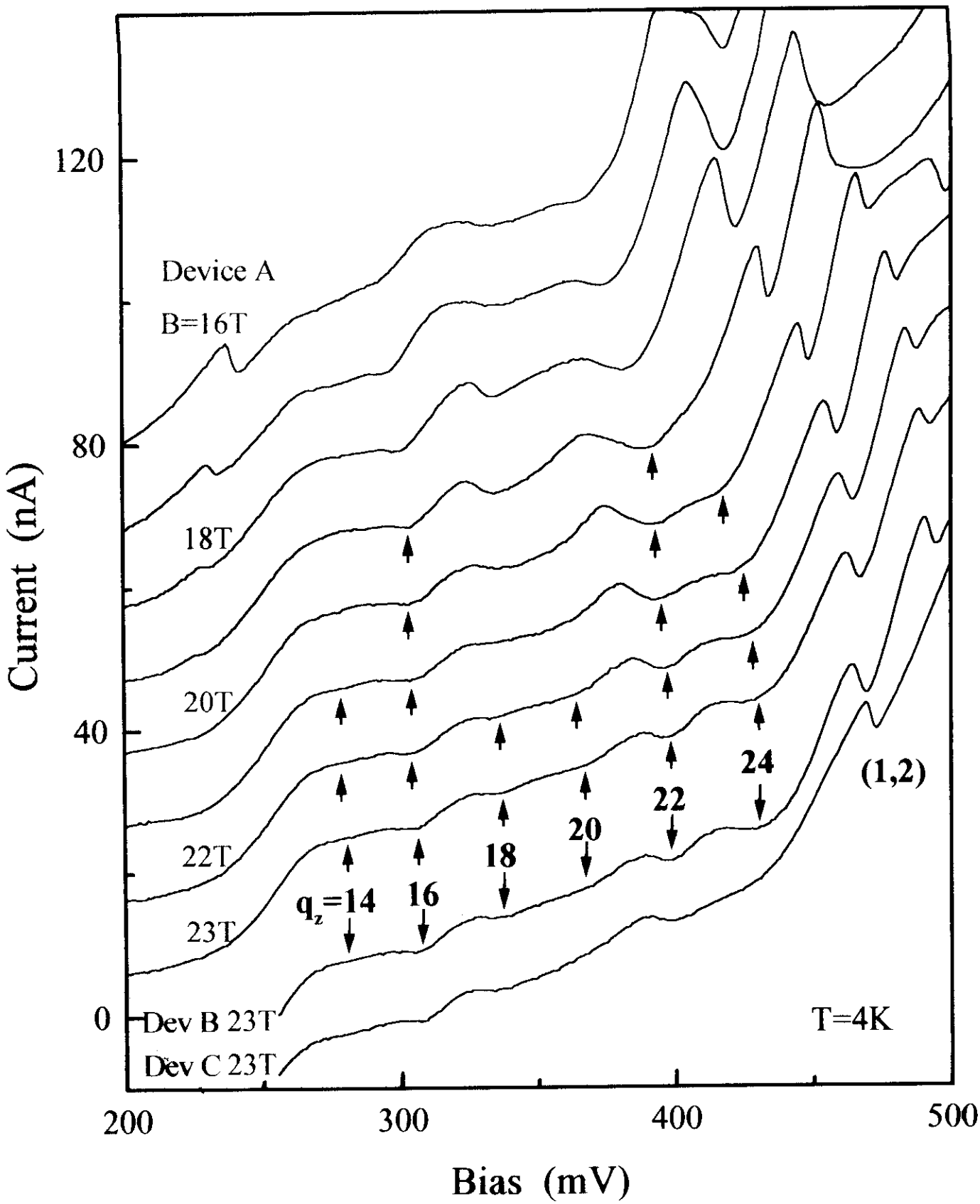
$$|\langle 0|\exp(i\mathbf{qr})|0\rangle|^2 \;\alpha\; \exp(-q_{\|}^{\,2} l_B^2)$$



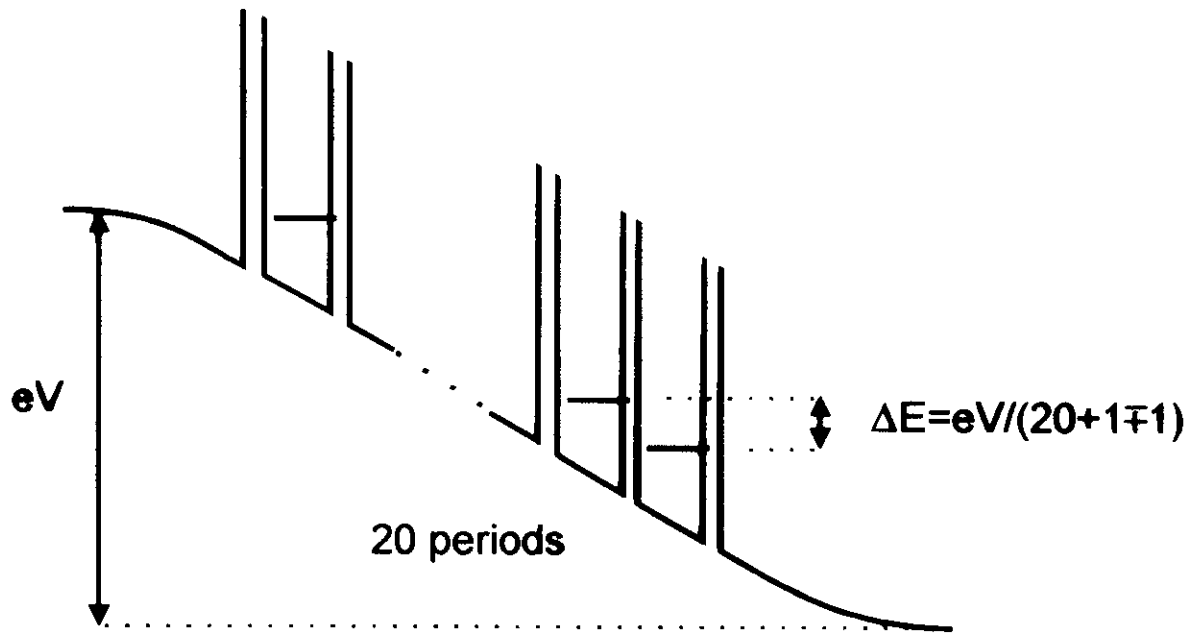
A given eFd corresponds to the emission of a *single* phonon mode: q_z

Magneto-Acoustic Antiresonances




Device A
B=16T
18T
20T
22T
23T
Dev B 23T
Dev C 23T
T=4K
(1,2)
q_z=14
16
18
20
22
24
Current (nA)
Bias (mV)
0
40
80
120
200
300
400
500

Periodicity of the Antiresonances



q_z =	**14**	**16**	18	20	22	24	(π/d)
ΔE =	12.9	14.2	15.7	17.1	18.5	20.1	(meV)

$\delta(\Delta E)$

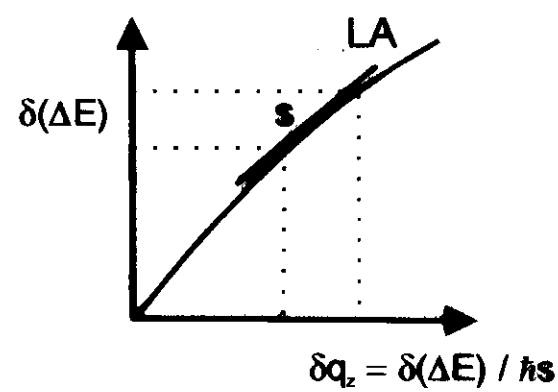
Period: $\delta(\Delta E) = 1.5 \mp 0.1$ meV

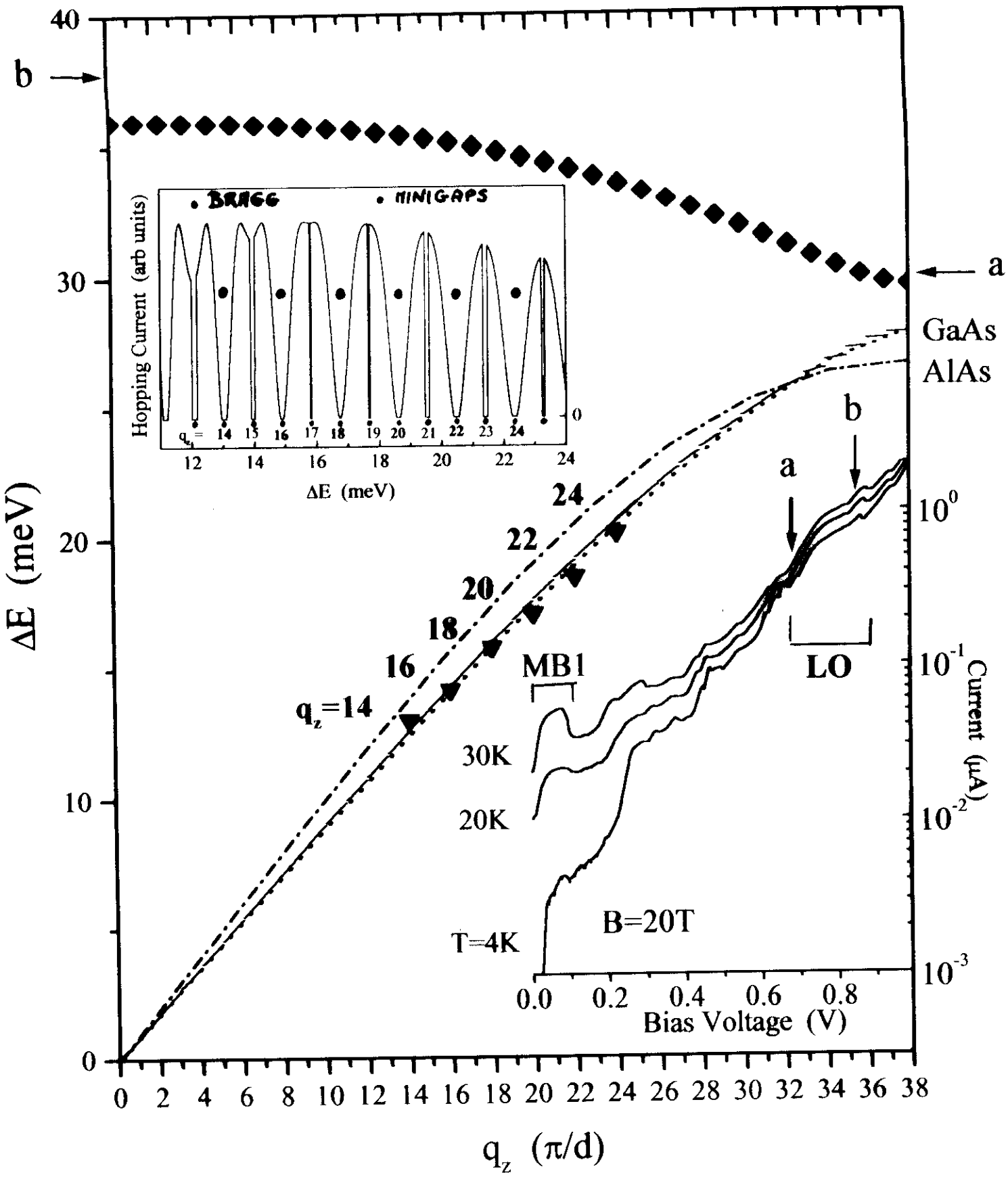
Assume hopping assisted by LA phonons:

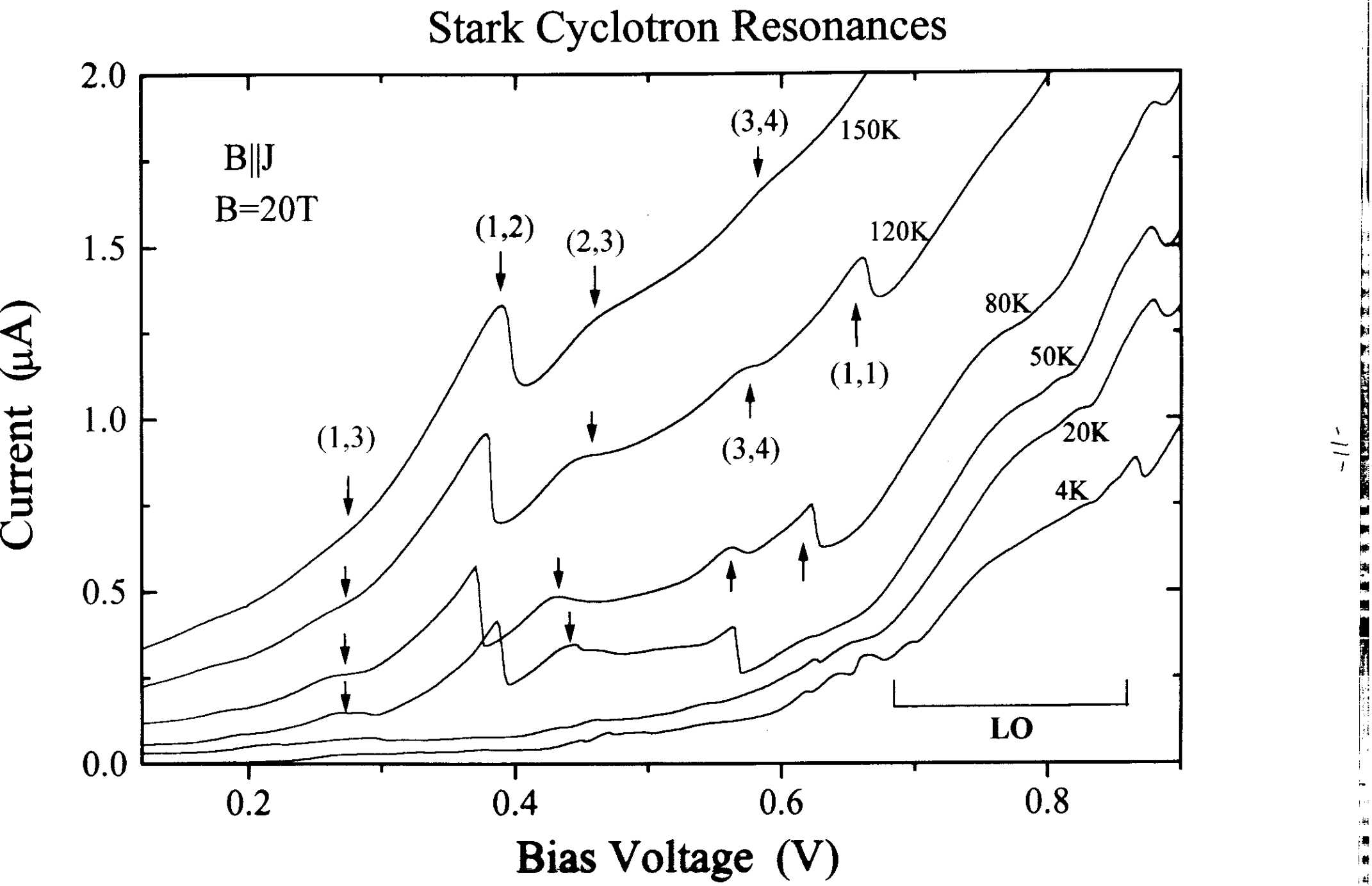
$\hbar\omega_{sc} \sim 15$meV => s = 4100m/s (GaAs)

Period: $\delta q_z = 1.9 \mp 0.1$ (π/d)

Brillouin Minizone !!




40
30
20
10
0
b
a
ΔE (meV)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
q_z (π/d)
GaAs
AlAs
24
22
20
18
16
q_z=14
MB1
LO
30K
20K
T=4K
B=20T
10^0
10^-1
10^-2
10^-3
Current (μA)
0.0 0.2 0.4 0.6 0.8
Bias Voltage (V)
BRAGG
MINIGAPS
Hopping Current (arb units)
q_z = 14 15 16 17 18 19 20 21 22 23 24
12 14 16 18 20 22 24
ΔE (meV)


Stark Cyclotron Resonances
2.0
1.5
1.0
0.5
0.0
Current (μA)
B||J
B=20T
(1,3)
(1,2)
(2,3)
(3,4)
(3,4)
(1,1)
150K
120K
80K
50K
20K
4K
LO
0.2
0.4
0.6
0.8
Bias Voltage (V)

Conclusions

"...This study furnishes an experimental incidental proof that **k**-space is a finite space consisting in its entirety of what is customarily called the first Brillouin zone."

Wannier 1960

This effect provides a new method for measuring the dispersion curves of acoustic phonons in a superlattice by means of simple conductance measurements.