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Bloch oscillations in lateral periodic nanostructure arrays: a possible new source/detector in far-infrared frequency range

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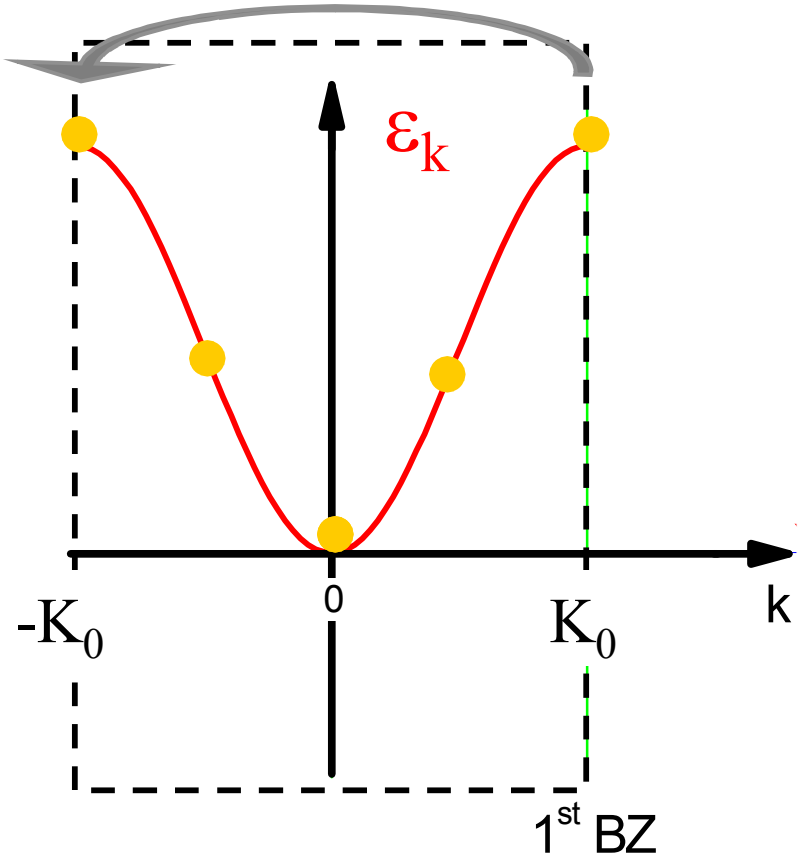
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Project goal
- What's Bloch oscillation?
- Sample fabrication
- Evidence of Bloch oscillation
  - ✓ I-V measurements
  - ✓ Edge magneto-plasmon resonance like behavior

What's Bloch oscillation?

Bloch, Z. Phys. 1928



$K_0 = \pi/a$

Under a DC electric field E

$$\hbar\, dk/dt = -eE$$

$$\varepsilon_k \sim 1 - \cos(ak)$$

$$v \sim \partial\varepsilon_k/\partial k \sim \sin(aeEt/\hbar)$$

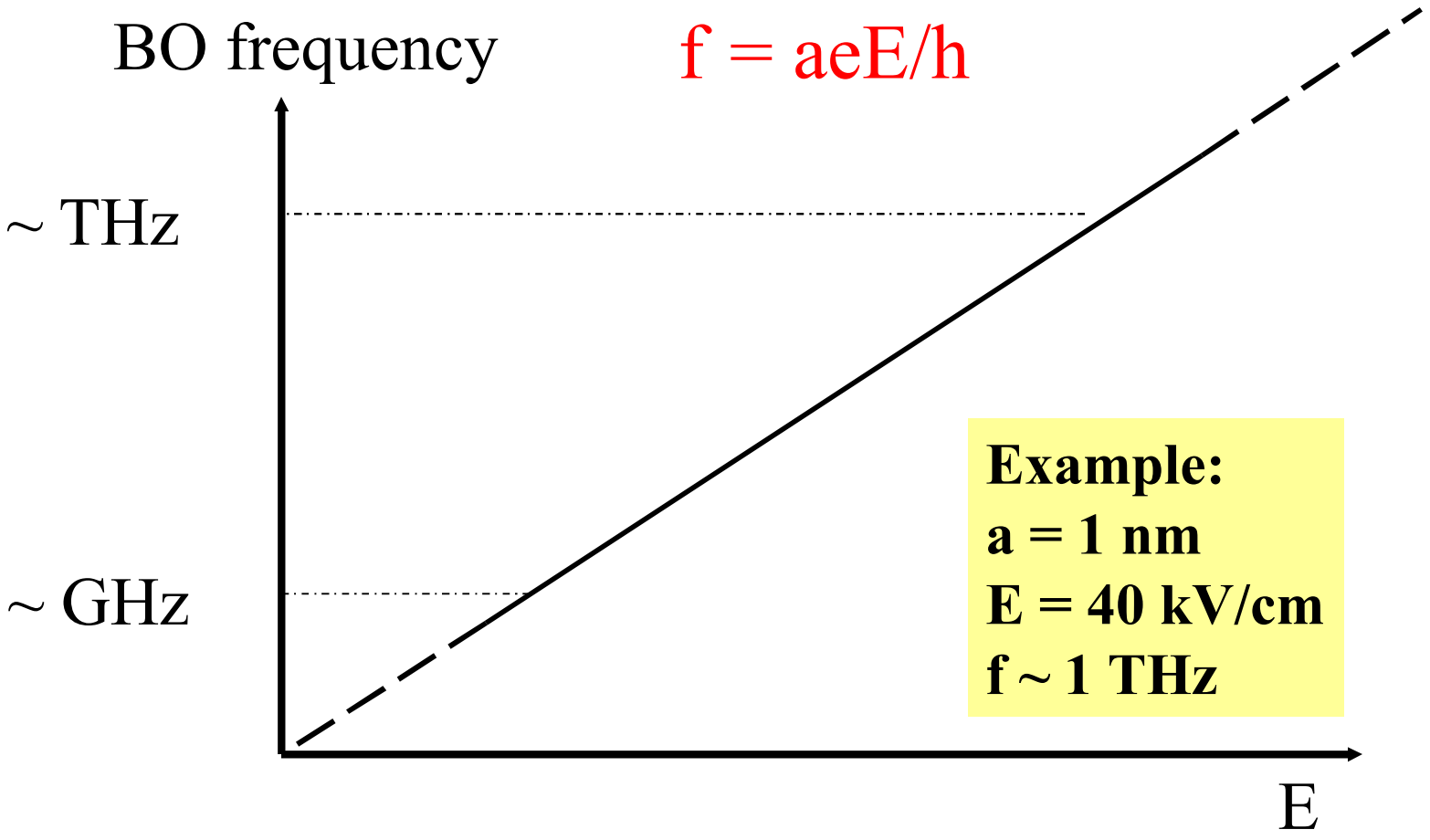
$$\mathbf{r \sim \cos(aeEt/\hbar) = \cos(2\pi ft)}$$

$$\mathbf{f = aeE/h}$$

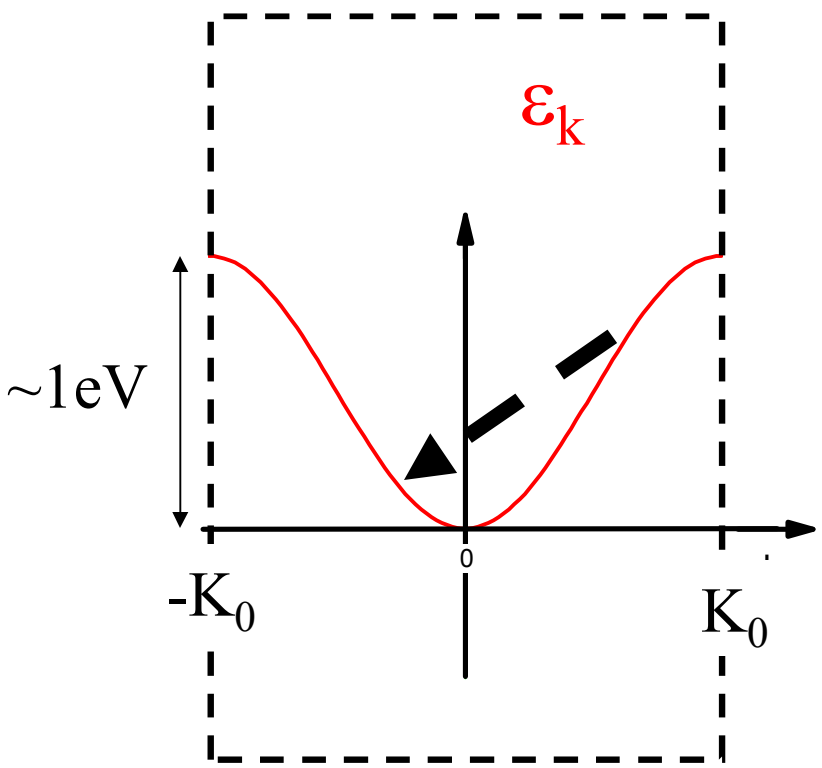
a: lattice constant

Why Bloch oscillation?

- **Far-infrared application – frequency tunable**



Problems in achieving Bloch oscillation



3D crystal

- Very high electric field
- Electron is scattered before it can complete a full oscillation

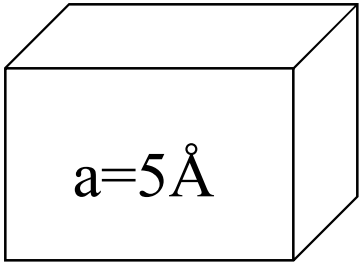
Scattering mechanisms:

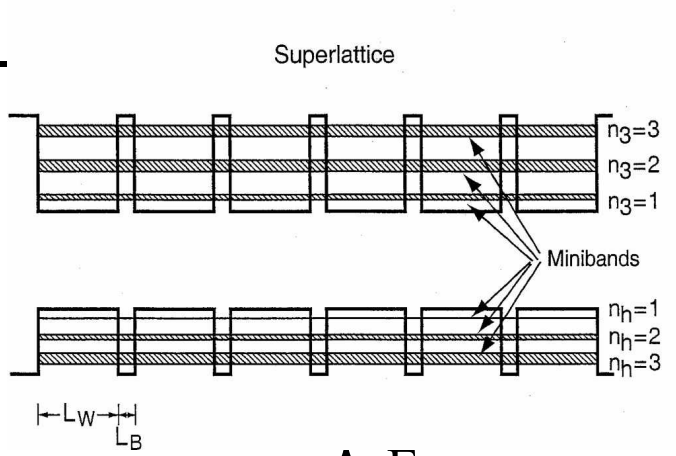
- Impurities
- Phonons

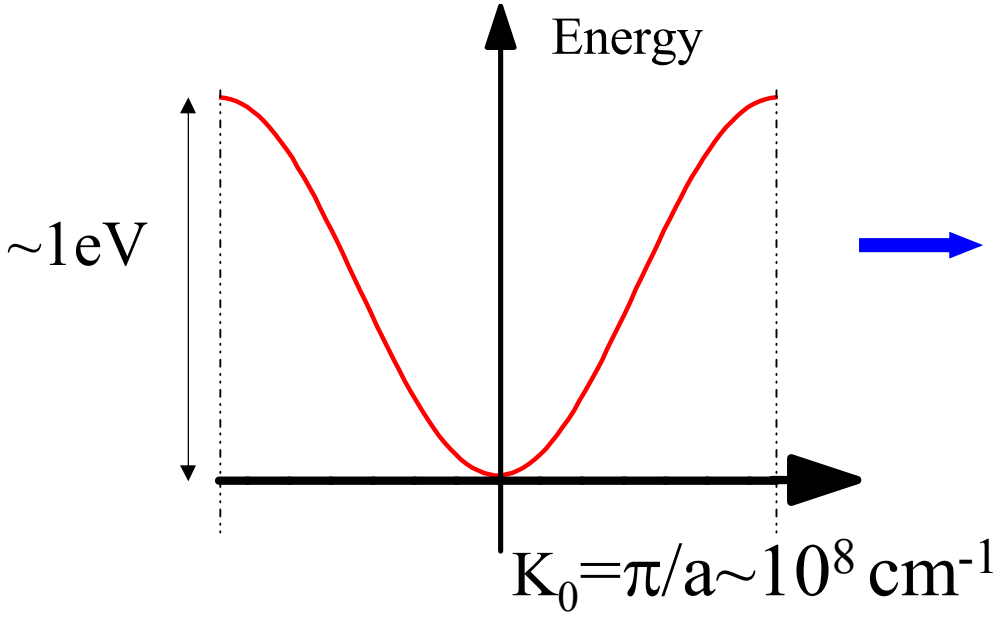
1D vertical superlattice

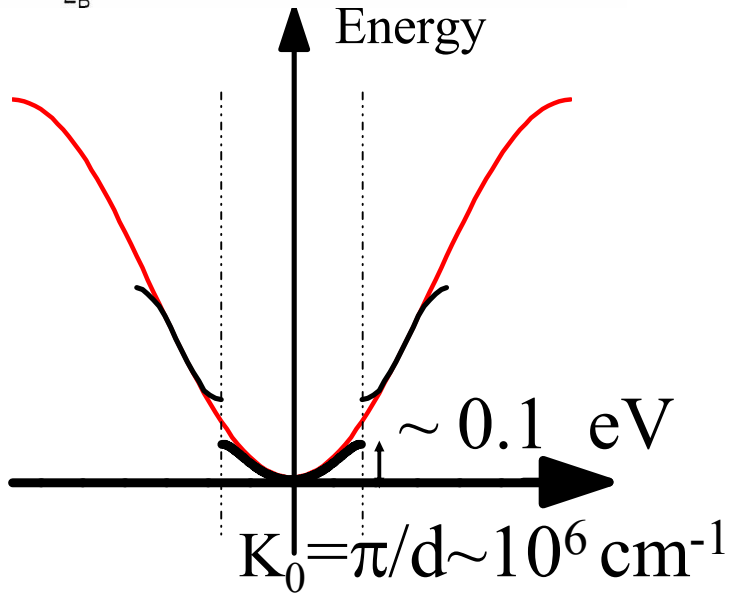
Esaki and Tsu, 1975

3D crystal









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Many progresses made in 1D superlattice

However, issues in 1D vertical superlattice:

- **formation of high electric field domains**
- **electron – phonon scattering**
- **impurity scattering**
- **….**

New approach – 2D quantum dot superlattice

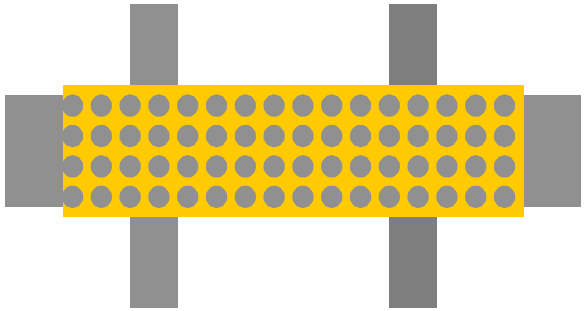
Dmitriev and Suris, Semiconductors 35, 212 (2001)

- 3D-quantum confinement, suppress electron-phonon scattering
- High sample quality, reduce disorder scattering
- 2D dimensionality, prevent formation of electric field domains
- Compatible with existing techniques, interferometric lithography

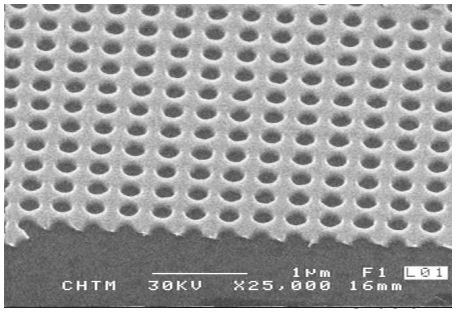
Sample fabrication

Though e-beam lithography is commonly used in nanometer scale fabrication, yet, for devices of *cm^2 size*, **interferometric lithography** is the best choice. It also provides *fast turn-around time* in new device fabrication, which is essential for explorative research.

Top view



SEM picture



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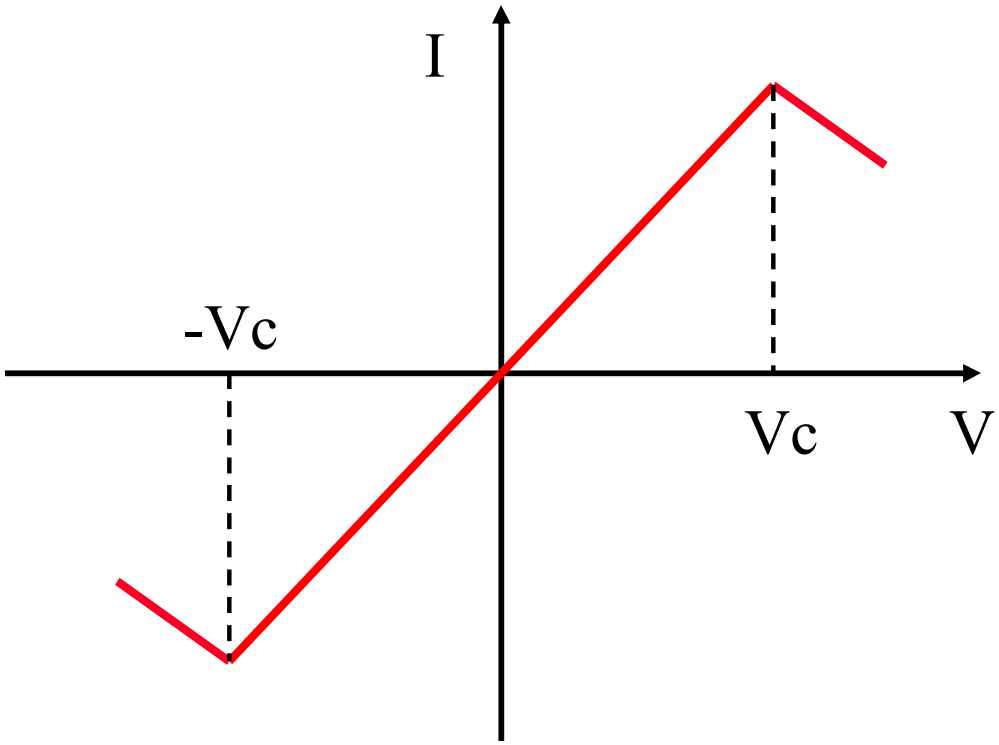
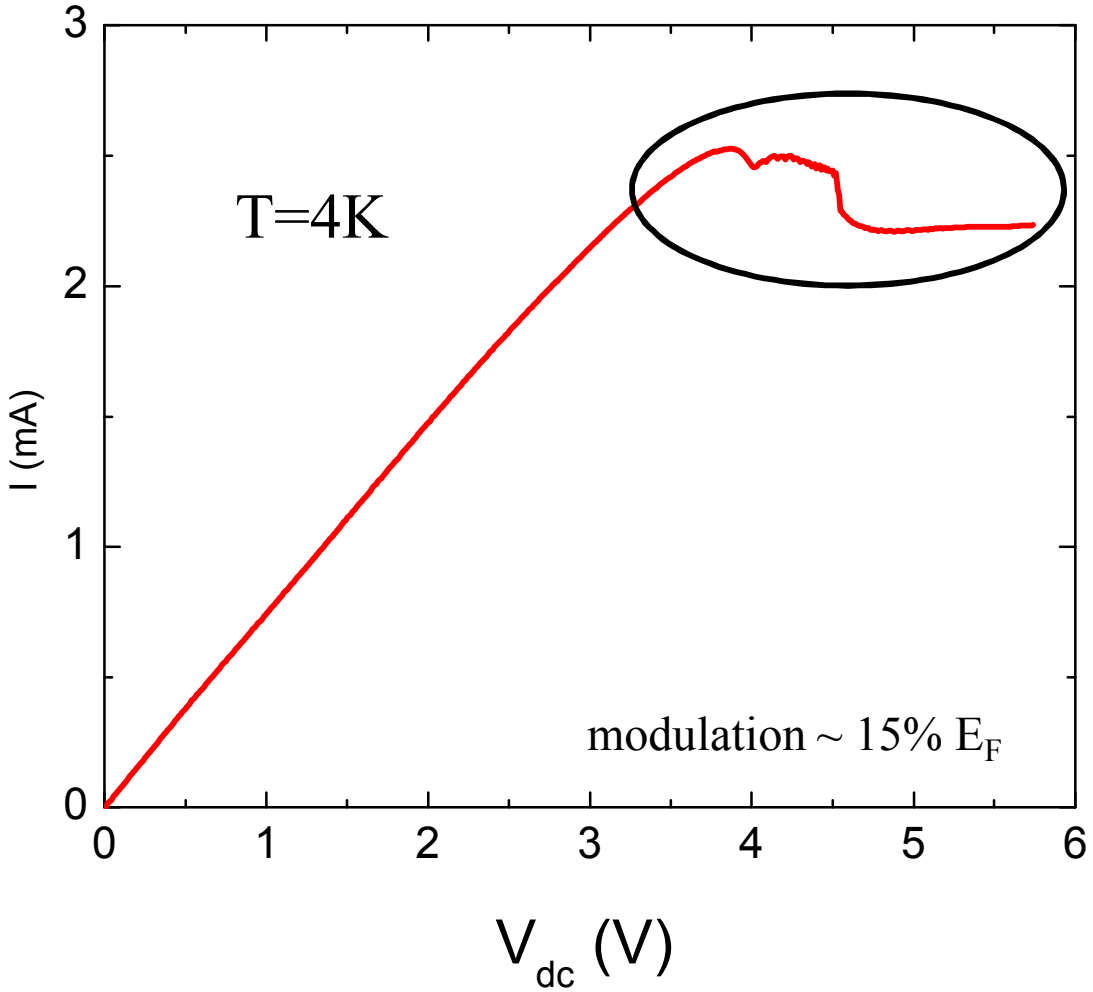
Evidence of Bloch oscillation

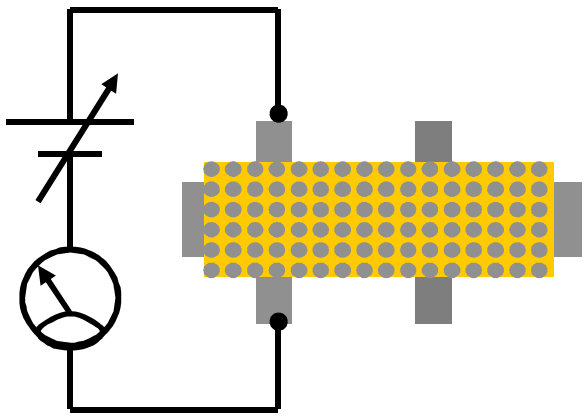
One signature for Bloch oscillation
--- negative differential conductance (NDC)



I – V measurement in 2D QDSL

NDC in QDSL!





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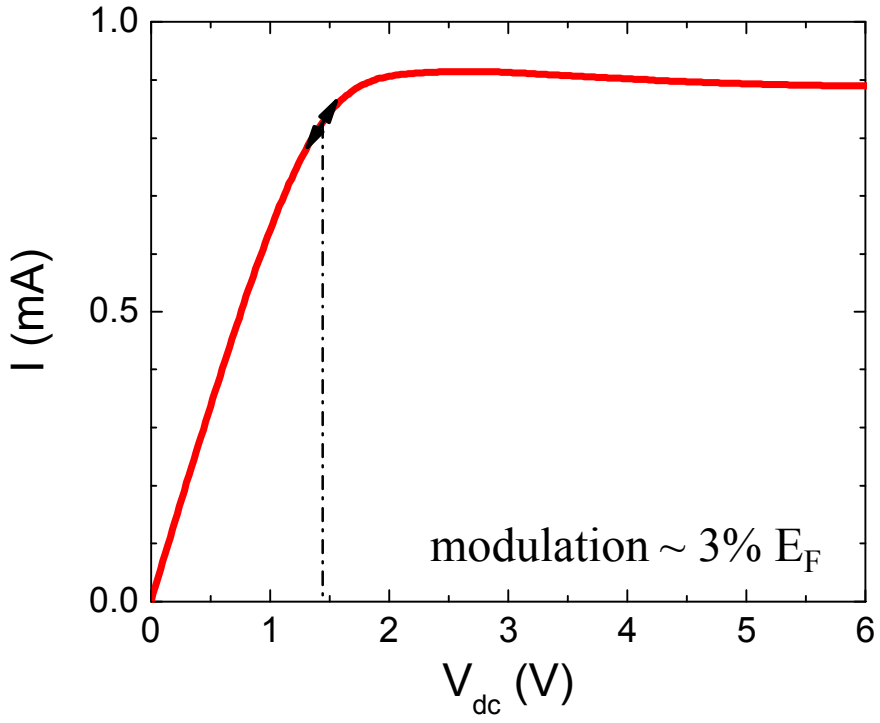
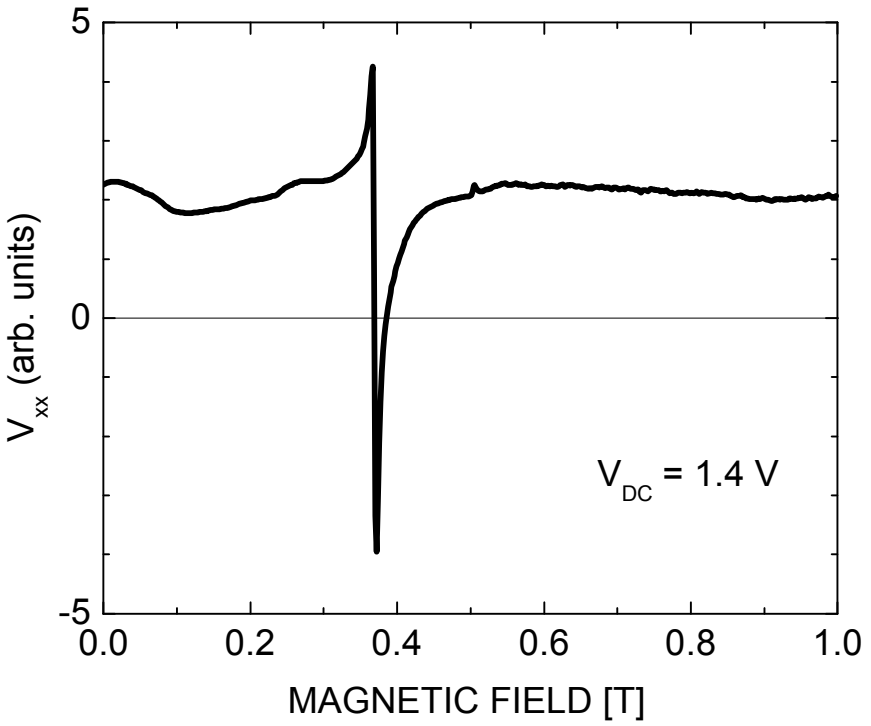
Physical origin of NDC ?

- Bloch oscillation?
- high field domains?
- ~~thermal runaway?~~

More evidence of Bloch oscillation





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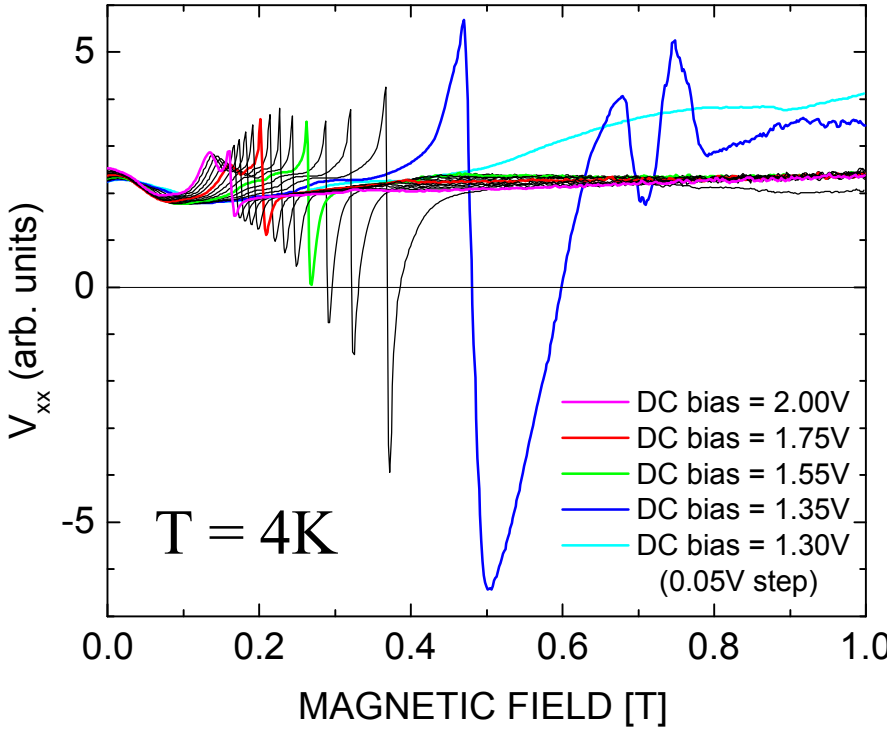
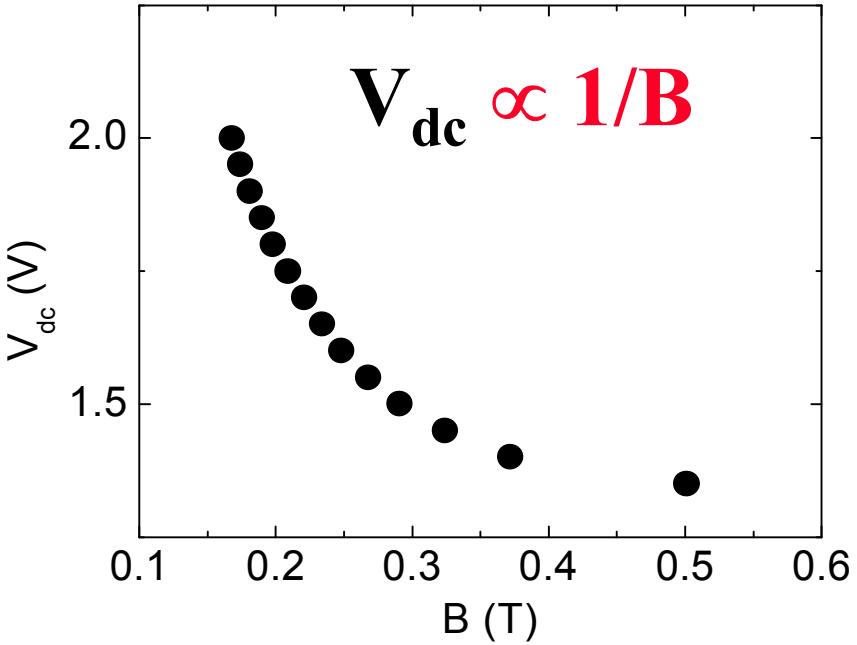
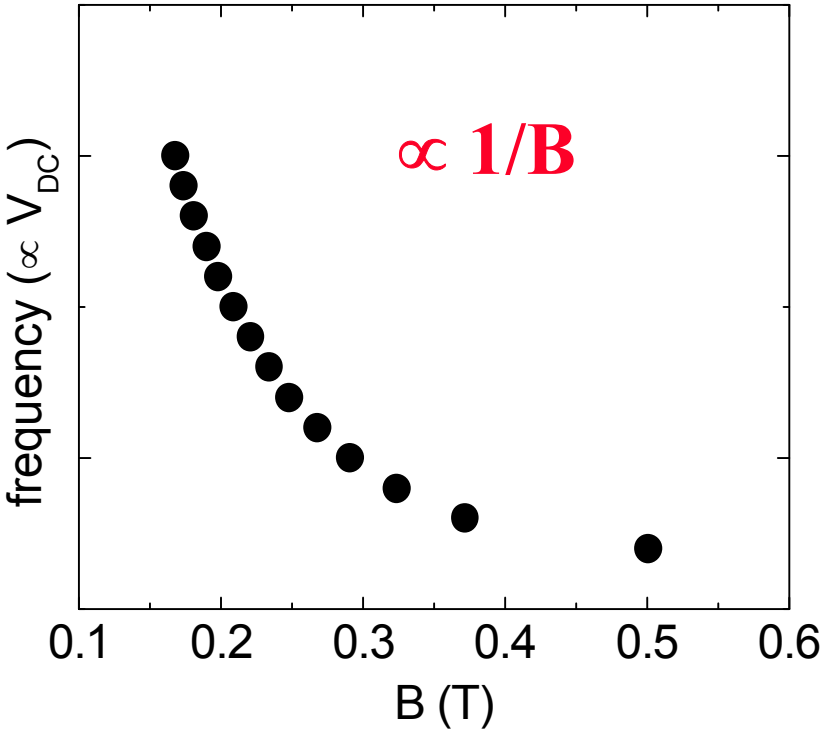
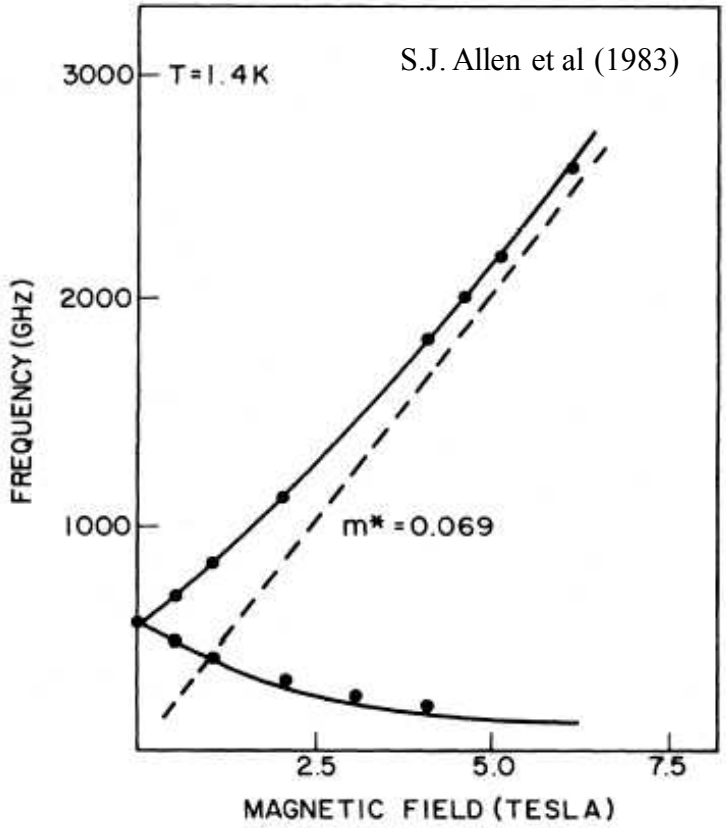
More evidence





Edge magnetoplasmon resonance?





$\omega = -\hbar\omega_c/2 + [(\hbar\omega_c/2)^2 + \omega_0^2]^{1/2} \propto 1/B$ at high B fields

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