Superconducting Wire Network under Spatially Modulated Magnetic Field

Hirotaka Sano, Akira Endo,
Shingo Katsumoto, Yasuhiro Iye

Institute for Solid State Physics, University of Tokyo, Japan

Overview

- Previous studies
  - Critical temperature →Little-Parks oscillation
  - *I*-*V* Characteristics →The nature of phase transition

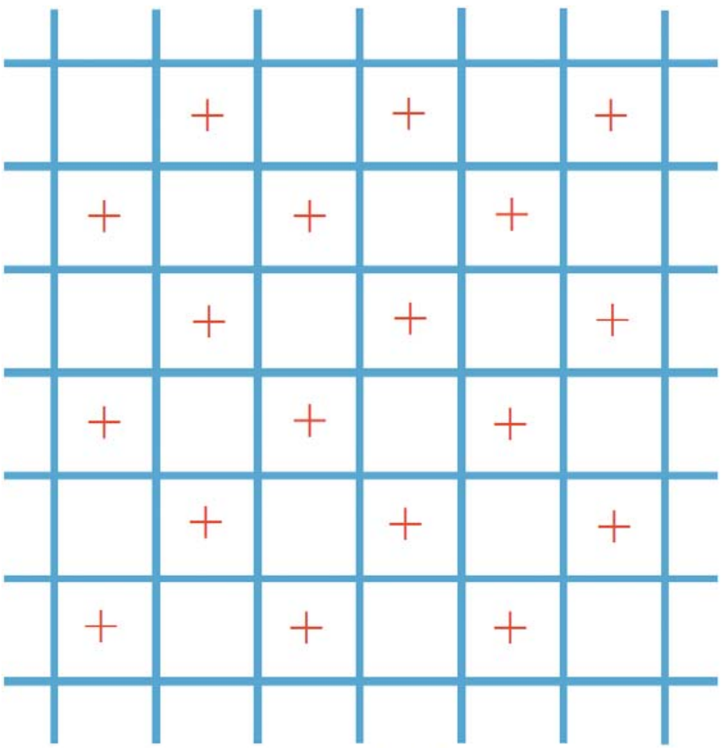
<u>All studies = under uniform field</u>

Uniform Field + Modulated Field

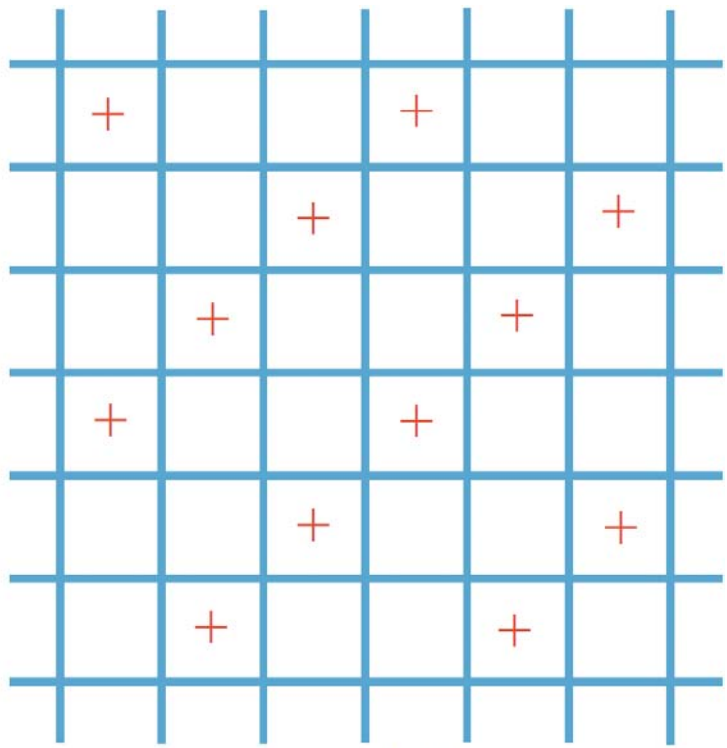
New aspects of superconducting wire network

Magnetic Frustration

Frustration α = Number of flux through a unit cell



$\alpha = 1/2$



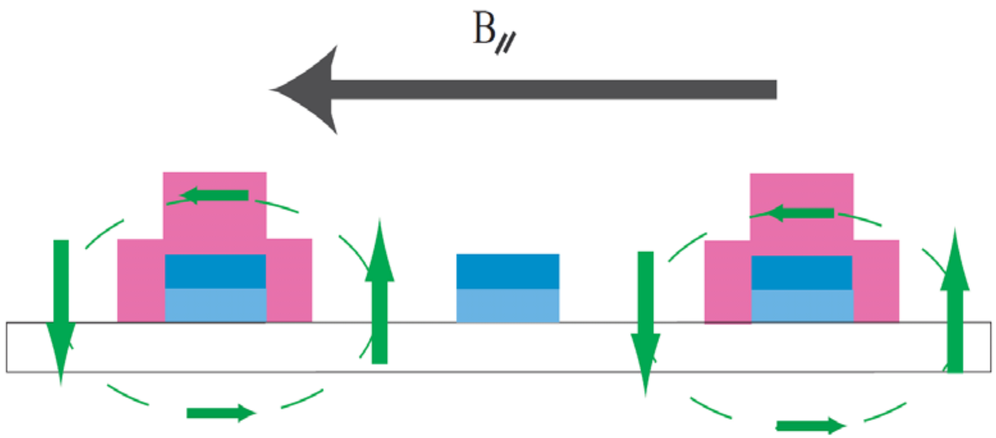
$\alpha = 1/3$

Field Modulation

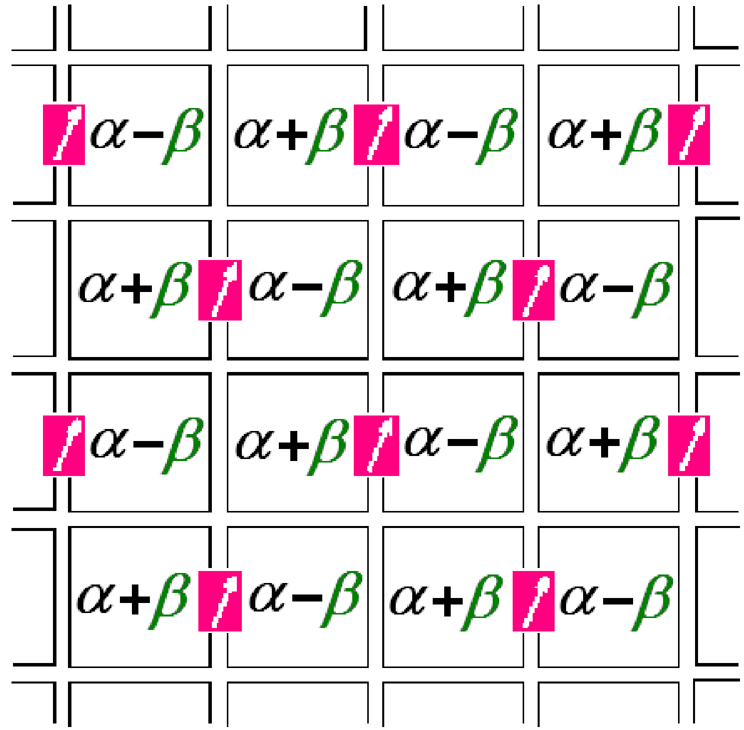
- SC/FM Hybrid System

Stray field from FM dot

field modulation

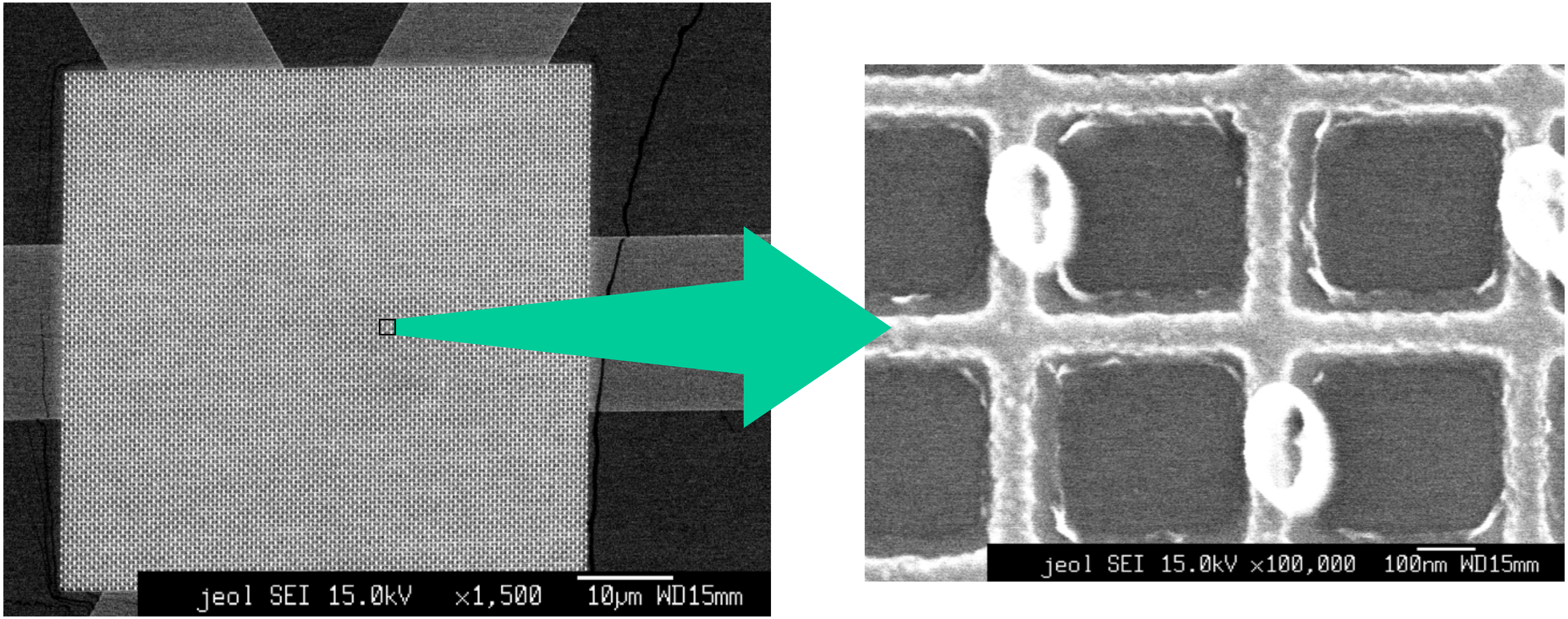


Checkerboard Pattern



Control β by <u>rotating</u> magnetization ($B_{//}$=const.)

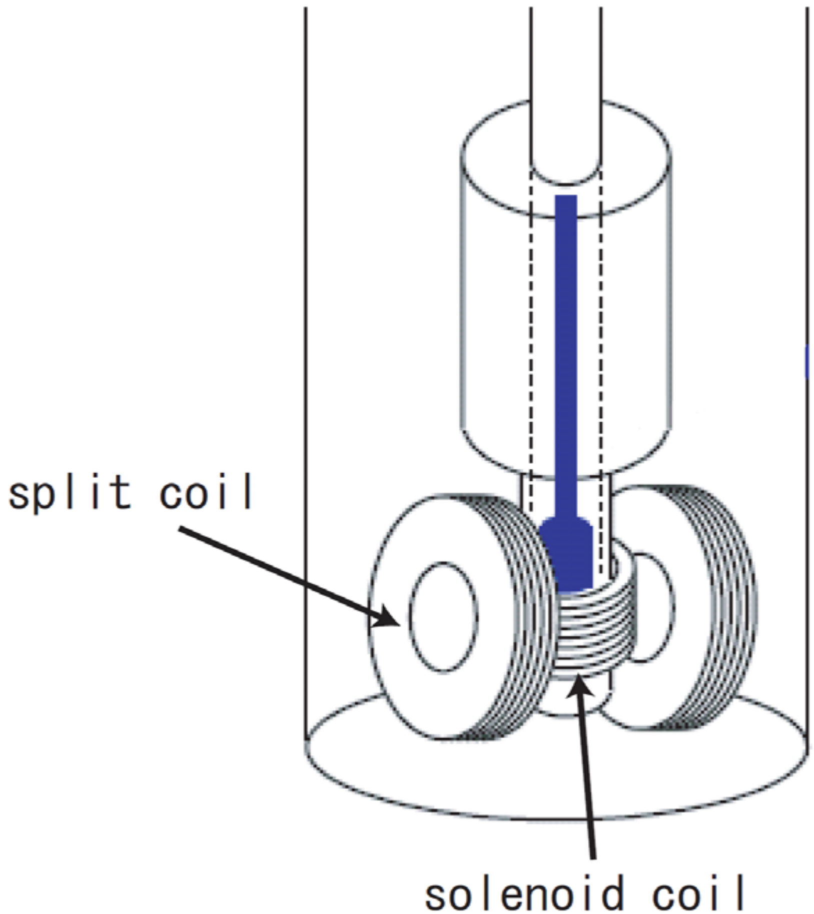
Sample



Al network
- 70 nm wide
- 35 nm thick
- Period = 500 nm
- 120 ×120 cells

Co dots
- 200 nm × 130 nm
- 80 nm thick

Experiment



- Magnetic Field

  Cross coil magnet system

  Sample ⊥ solenoid coil

  Solenoid coil→ α

  Split coil → β

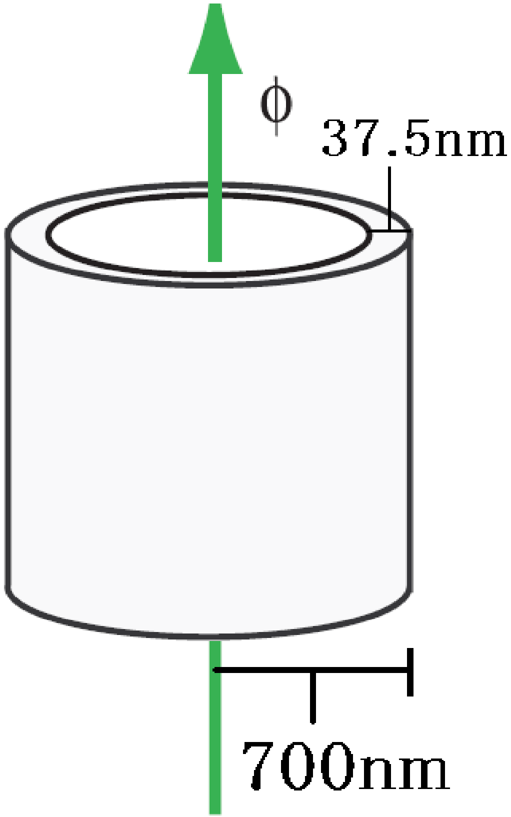
- Temperature

  Liq. ^{4}He + RP

  $T_{\mathrm{min}} \sim 1.3\,\mathrm{K}\quad \Delta T \sim 1\,\mathrm{mK}$

Little-Parks Oscillation

W. A. Little *et al.*, *Phys. Rev. Lett.* **14**, 2239 (1976).



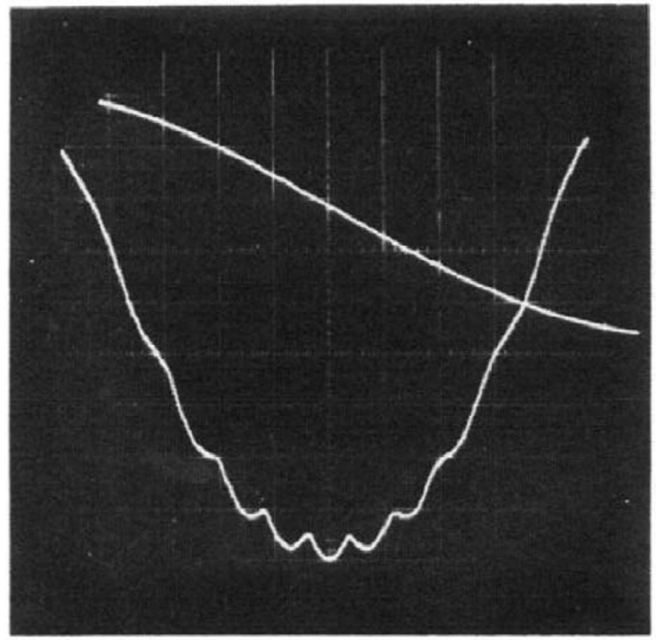


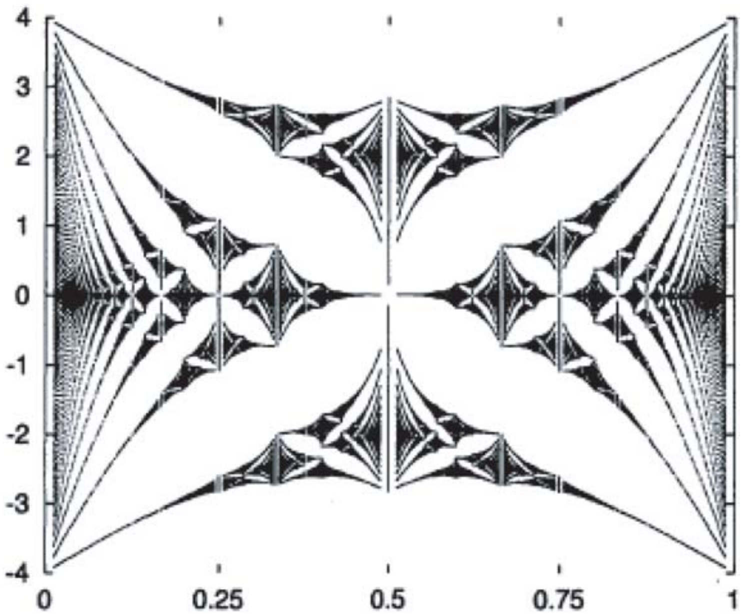
FIG. 6. Lower trace: variation of resistance of tin cylinder at its superconducting transition temperature as a function of magnetic field. Upper trace: magnetic field sweep.

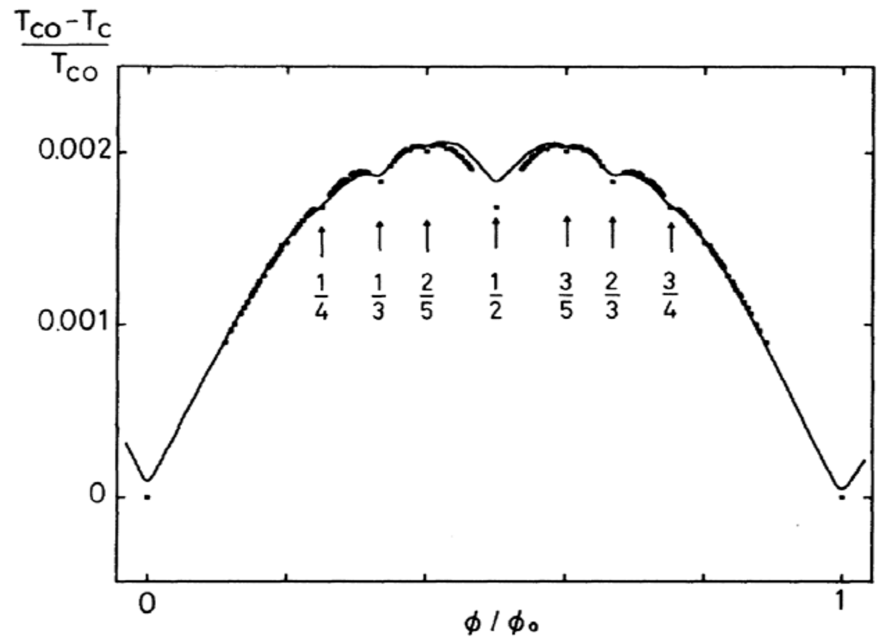
$$\text{Period}: \phi_0 = \frac{2\pi\hbar}{2e} = 2.07\times10^{-15}\ \text{Tm}^2$$

Square Lattice

$$T_c(B) = T_{c0}\left(1 - \left(\frac{\xi(0)}{l}\arccos\left(\frac{\varepsilon_{\max}}{4}\right)\right)^2\right)$$

Hofstadter butterfly
(tight binding energy spectrum)

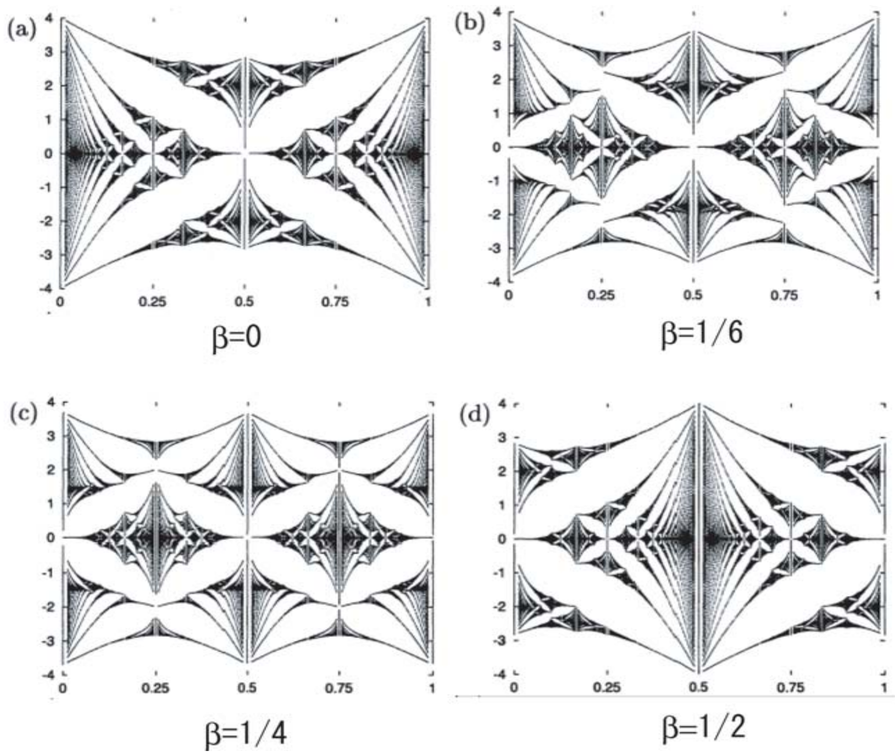




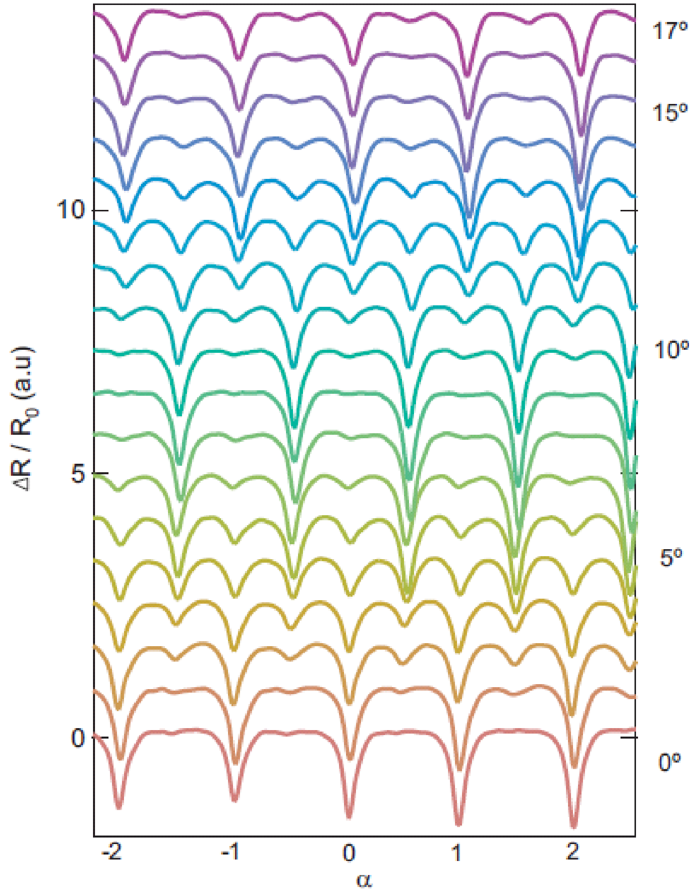
D.R. Hofstadter, *Phys. Rev. B* **14**, 2239 (1976). B. Pannetier *et al., Phys. Rev. Lett.* **53,** 1845

Under Checkerboard Modulation

Y. Iye *et al., Phys. Rev. B* **70**, 144524 (2004).



Hofstadter butterfly
under checkerboard modulation



Change of magnetoresistance

T_c Measurement

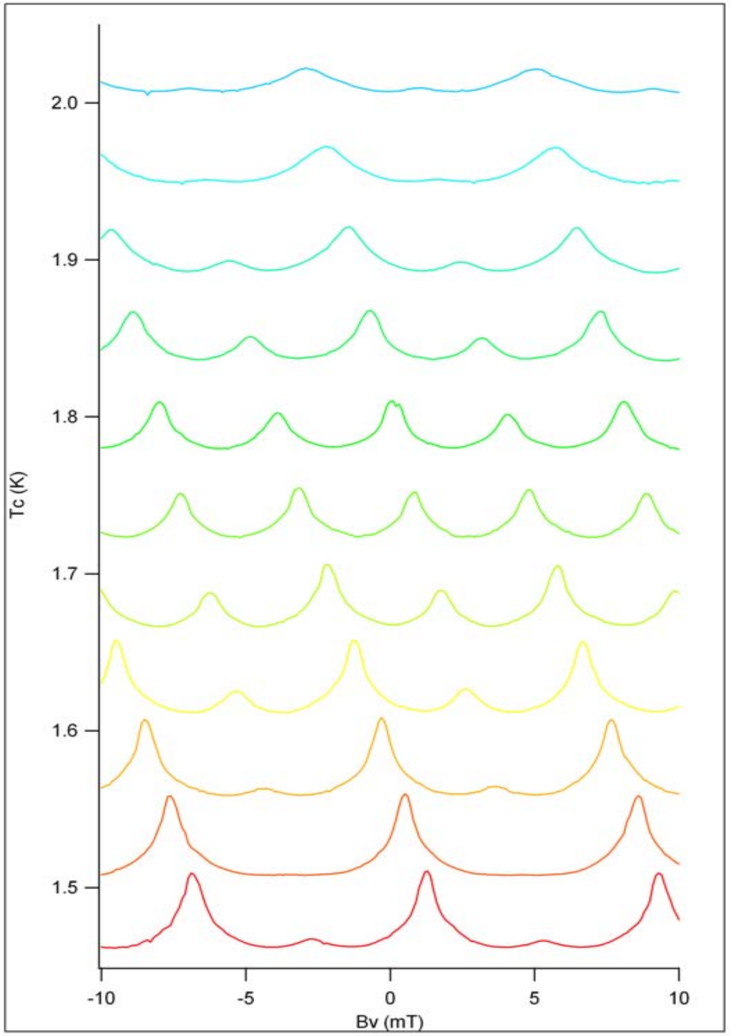
1. Measure $R(B)$ at fixed T, β
2. Repeat with sweeping T

   $\rightarrow R(B,T)$ at fixed β
3. Convert to $T_c(B)$ as $R(B, T_c) = R_c$
4. Repeat with changing β

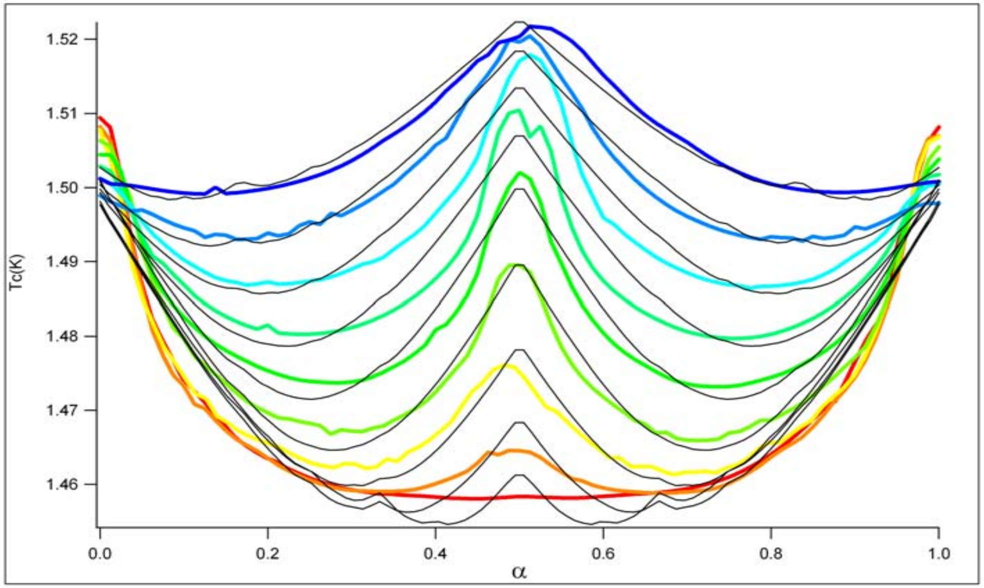
   $\rightarrow T_c(B, \beta)$
5. Pick up one period and compare with calculation

Result

$R(B,T) \rightarrow T_c(B)$



Comparison with calculation



Main feature : consistent
detail : inconsistent

I-V Characteristics

- Superconducting state $R \to 0 \ (I \to 0)$
  - No free vortex without current

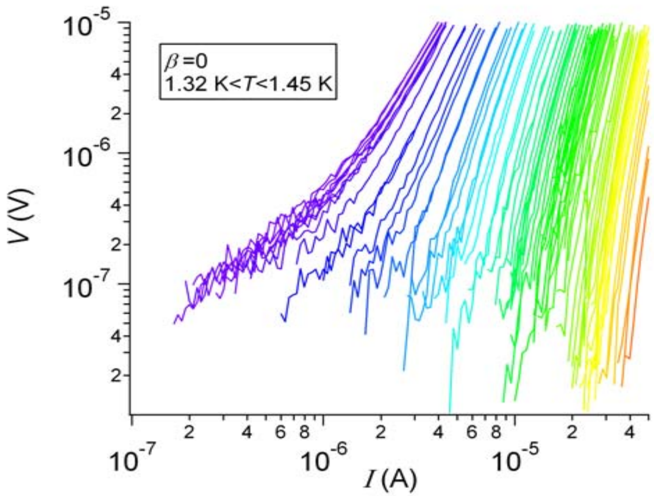
Phase transition
→Change of vortex dynamics

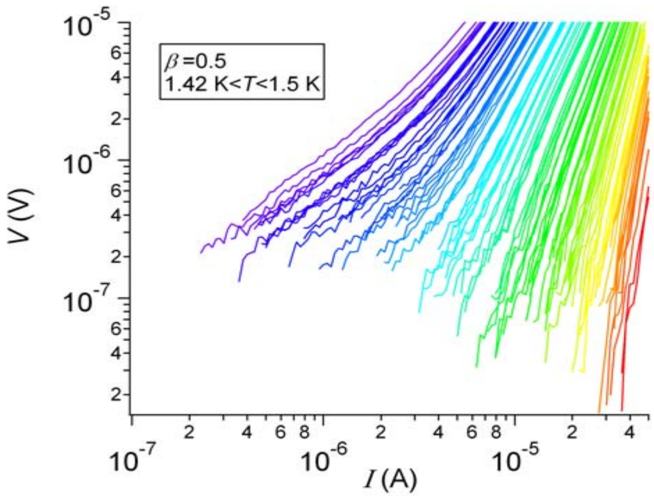
- Resistive state $R \neq 0 \ (I \to 0)$
  - Free vortex exists without current

I-V characteristics = vortex dynamics

nature of phase transition

I-V Measurements





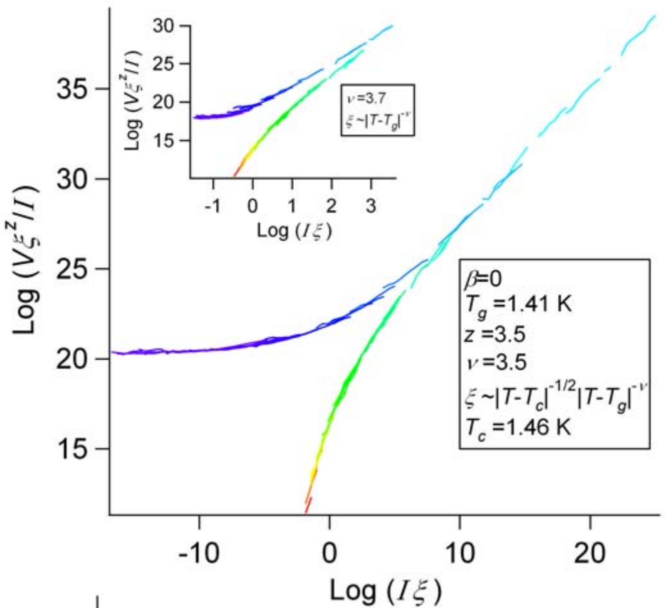
- DC measurement

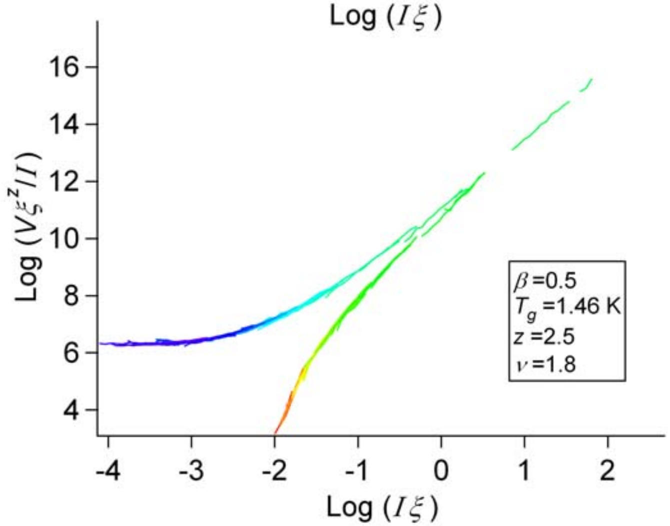
  α =0,0.618,1/2

  β =0,1/2
- α-independent
- Look like vortex glass transition

  → scaling analysis

Scaling Plot





- β =0 : Bad scaling plot
  - T_g is too close to T_c

ξ ~$|T$- $T_c|^{-1/2}$

Good plot

- β =1/2 : Good scaling plot

VG transition at all α and β

(Previous studies : KT at α=β=0)

Conclusion

Under checkerboard field modulation,

- Little-Parks oscillation
  - Consistent with calculation
- *I*-*V* characteristics
  - VG transition is observed at all α and β

Inconsistency --- Lithographical irregularity