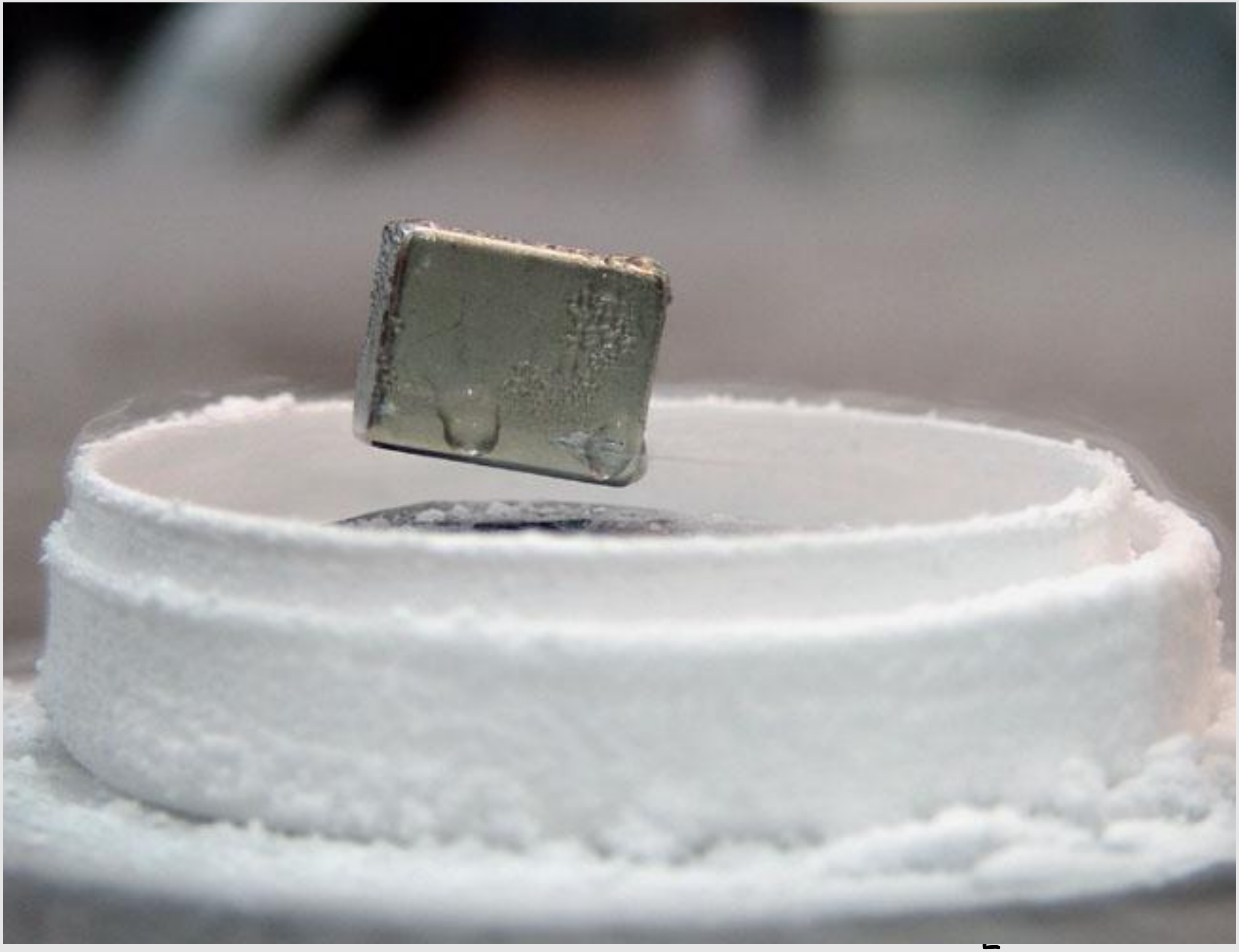
Interaction betweeen Superconductivity and Ferromagnetism in SC/FM nanocomposites

Yutao Xing

IF-UFF

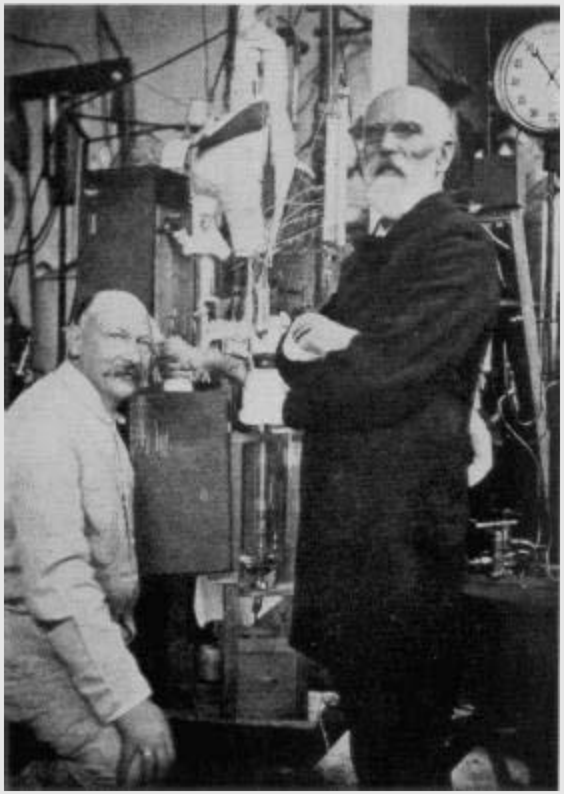
Supercondutor e ferromagneto

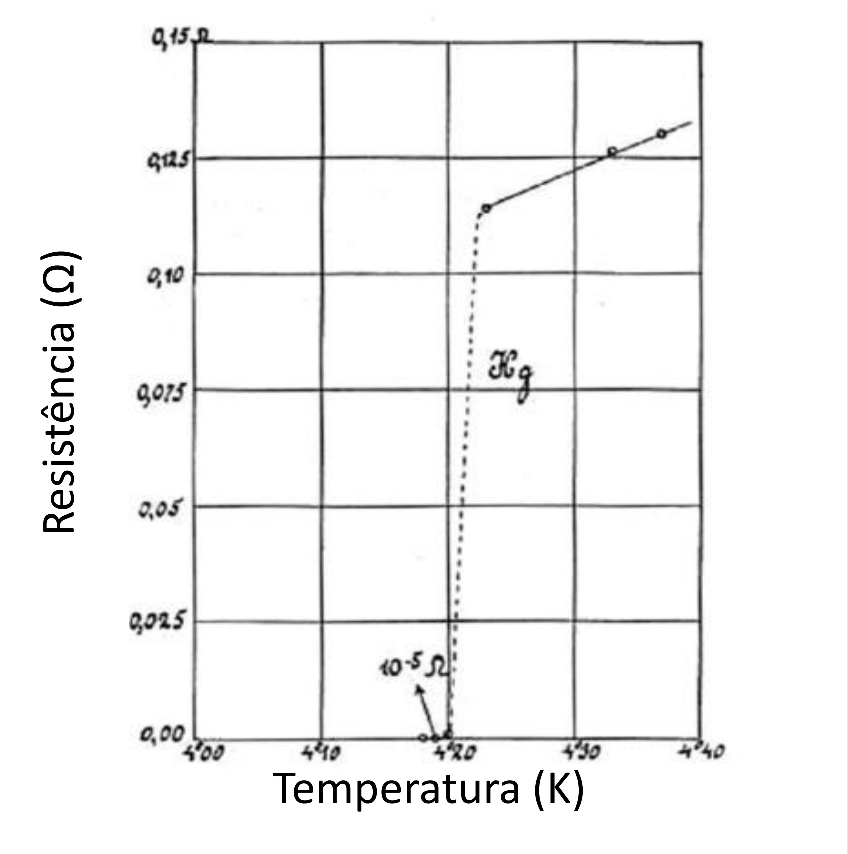


Supercondutor e ferromagneto


鳳凰網 論壇
bbs.ifeng.com

Supercondutividade





Kammerling Onnes (em 1911)

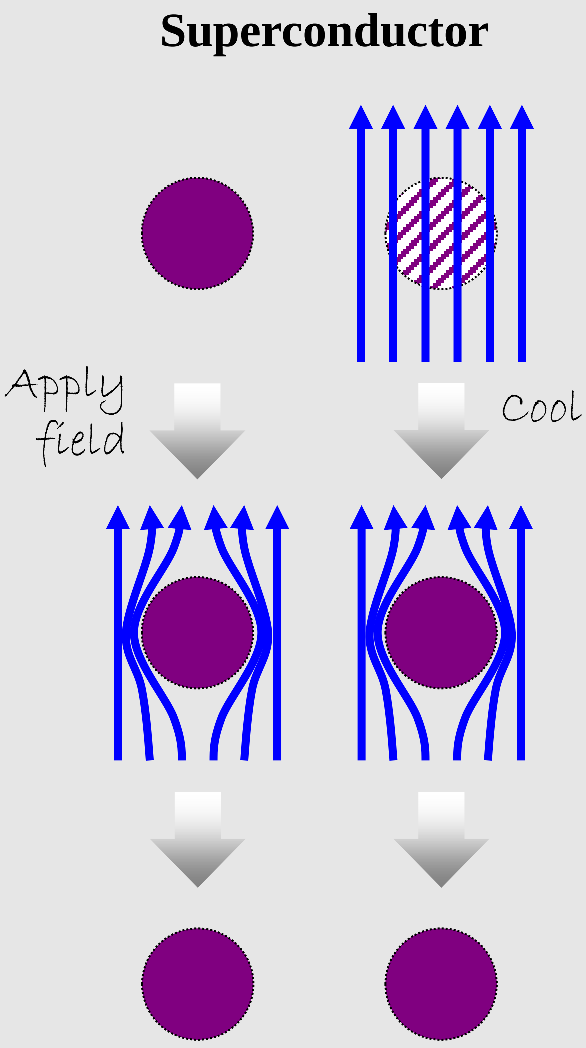
Meissner Effect

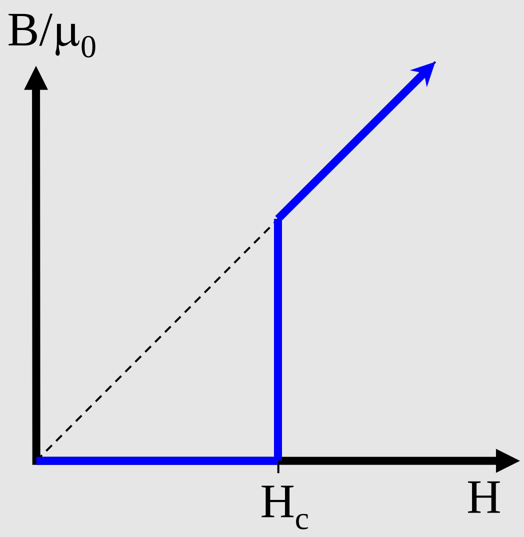
- B = 0 → perfect diamagnetism: χ_M = -1

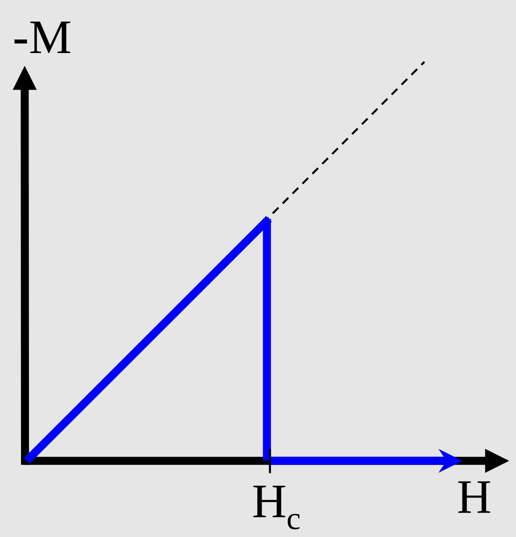
$$B = \mu_0(H + M) = 0$$

$$M = \chi H = -H$$

- Field expulsion unexpected; not discovered for 20 years.





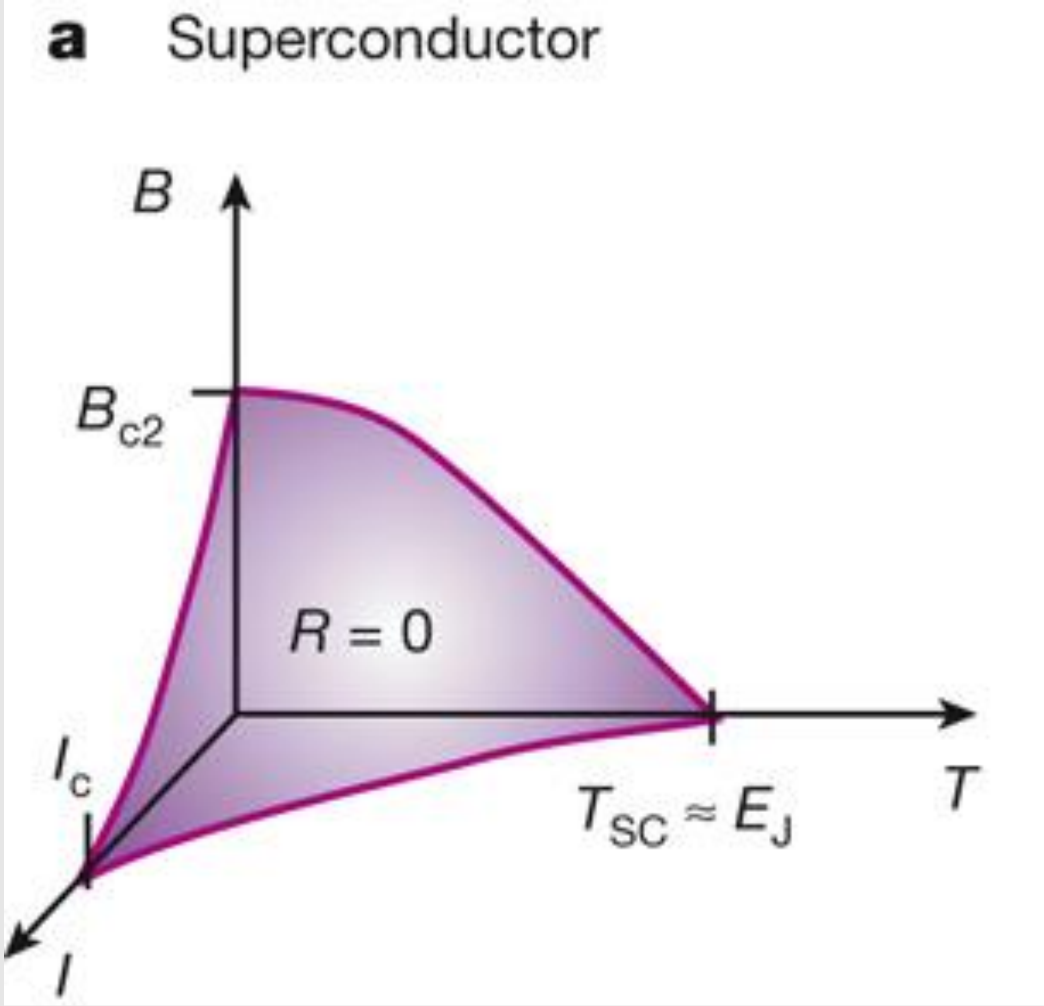


Critical Parameters for SC

T_c

B_c

I_c



Type I and type II SC

- London Theory ⇒ magnetic penetration depth λ
- Ginzburg-Landau Theory ⇒ coherence length ξ

$\lambda + \xi$ ⇒ two kinds of superconductors!

Conductors in a Magnetic Field

$$\vec{\nabla} \cdot \varepsilon \vec{E} = \rho$$

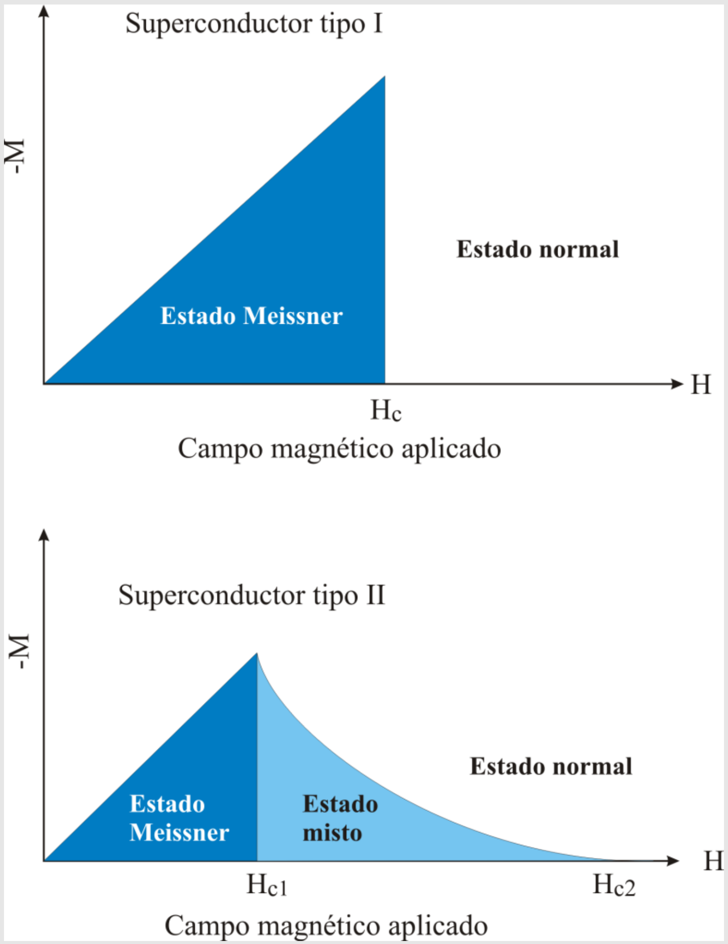
$$\vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\vec{\nabla} \times \vec{B} = \mu_0 J + \frac{\partial \vec{E}}{\partial t}$$

Comportamento diferentes

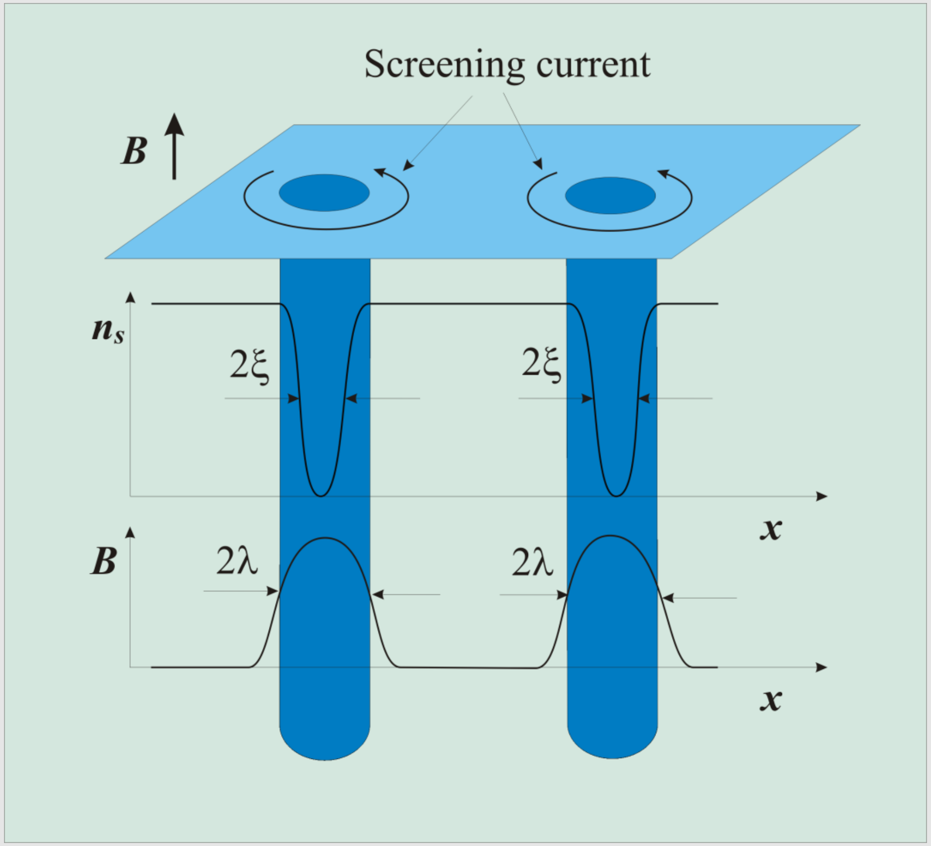
Supercondutores dos tipo I e tipo II:



B = 0

Estado misto:
B □ 0

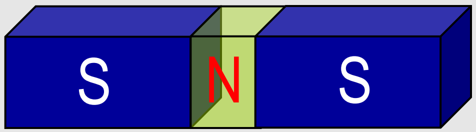
Vórtices



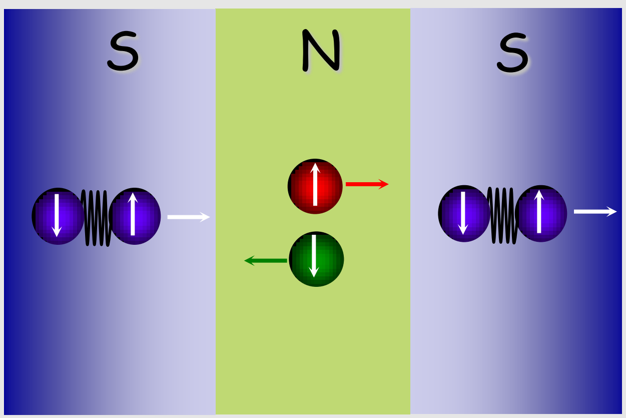
Estado misto de um SC do tipo II, quando (H) é $H_{c1} < H < H_{c2}$, formam-se tubos de vórtices, a variação da densidade dos pares de Cooper (n_s) e a variação da densidade de fluxo.

Efeito de Proximidade

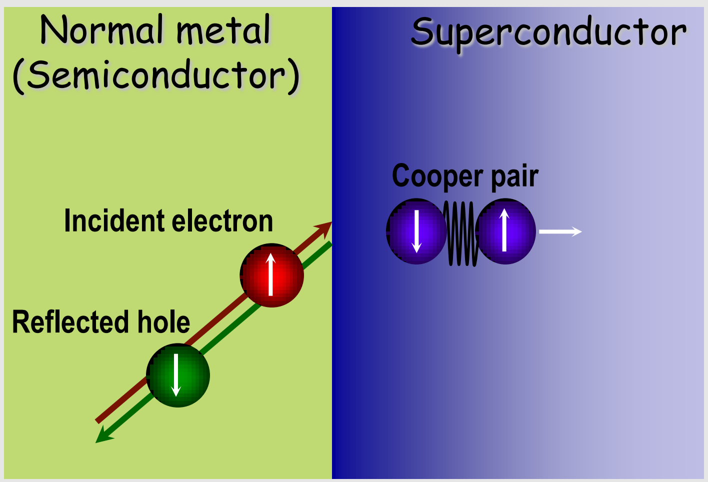
Metallic contact between a normal metal and a superconductor



Electron-hole correlations: proximity effect

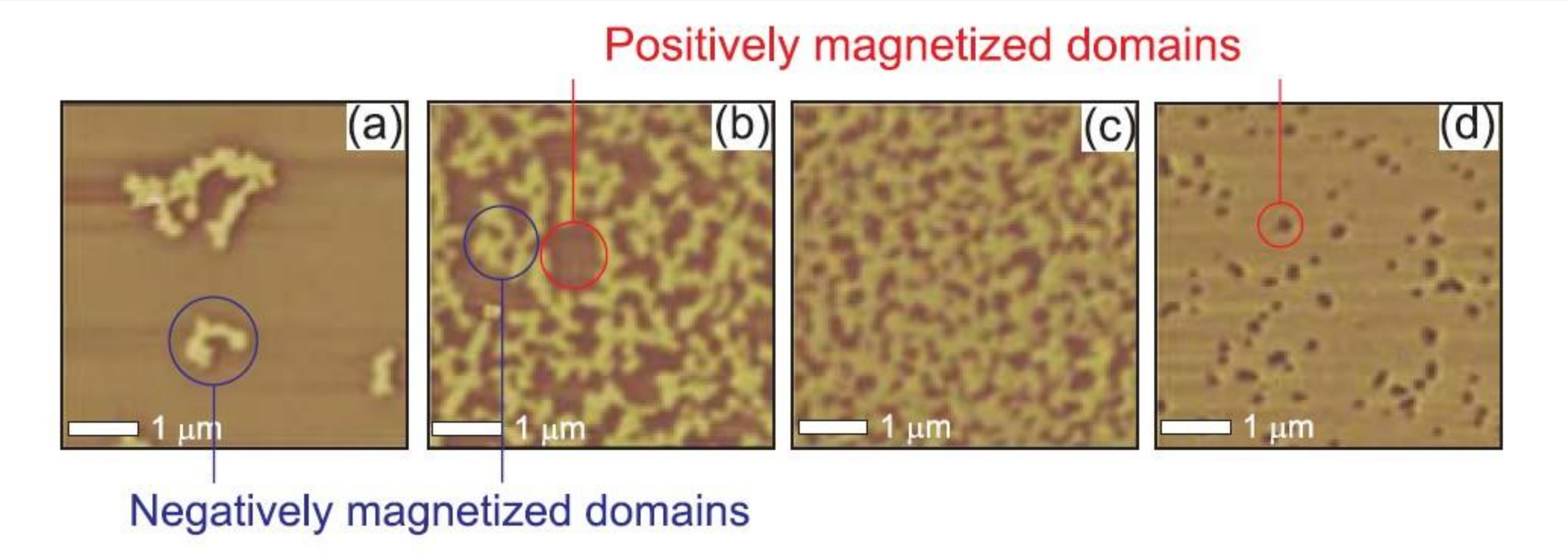


Andreev reflection

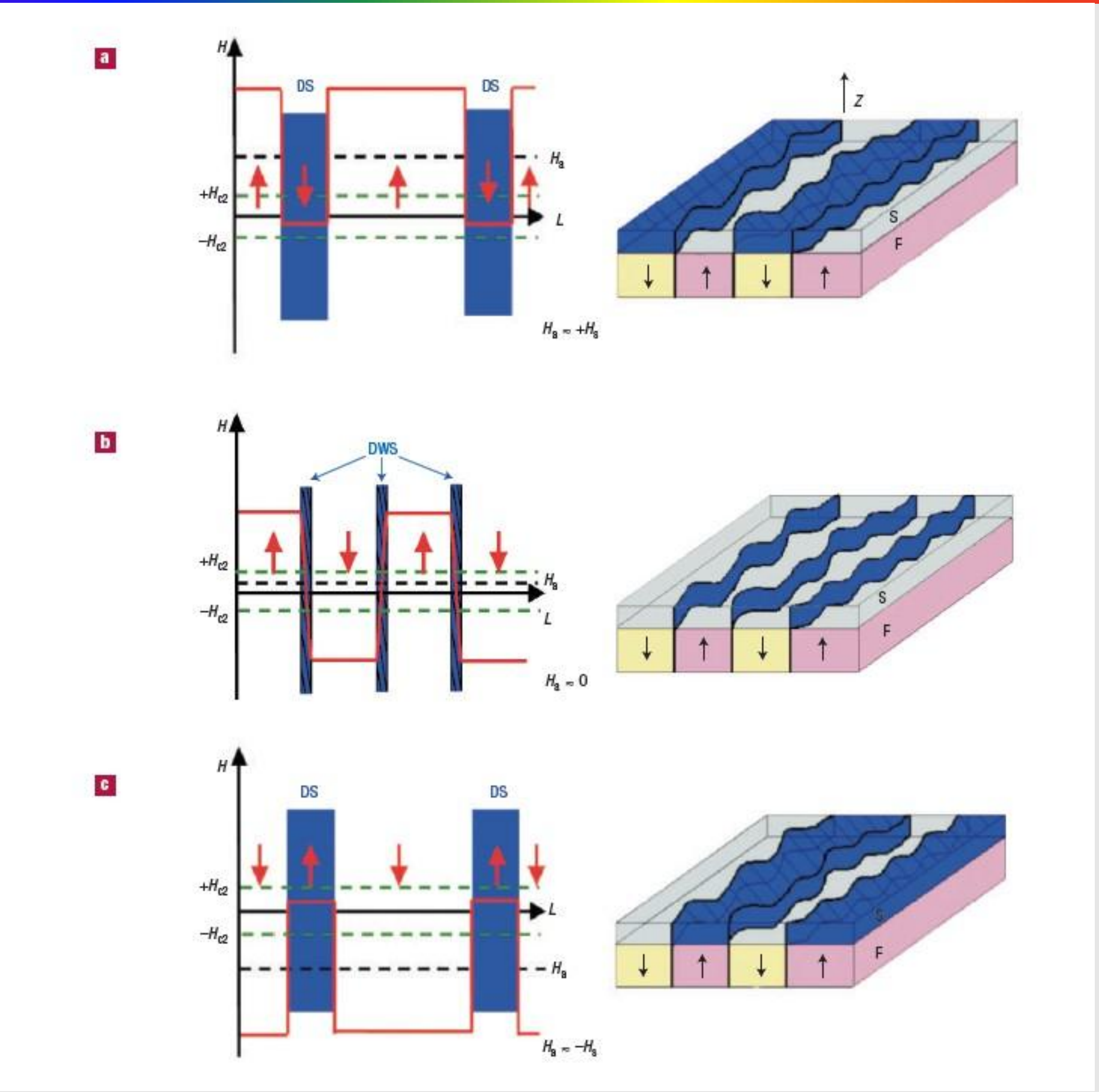


Supercurrent → Andreev bound states (ABS)

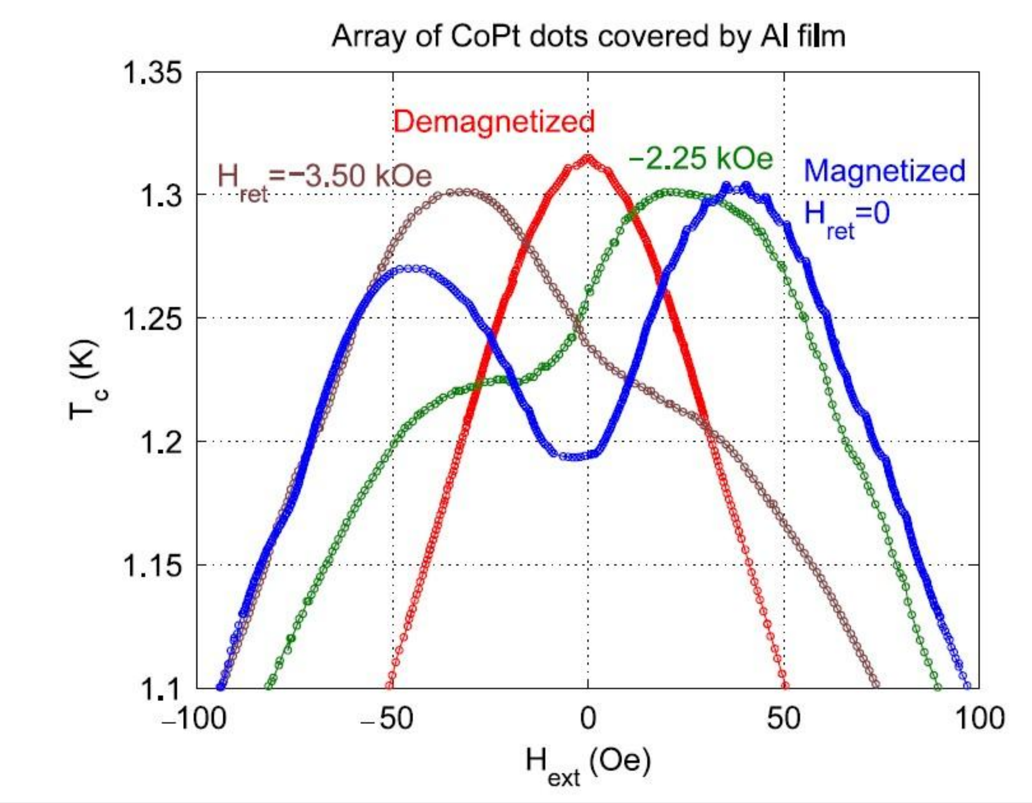
Domain-wall supercondutividade



Domain-wall supercondutividade

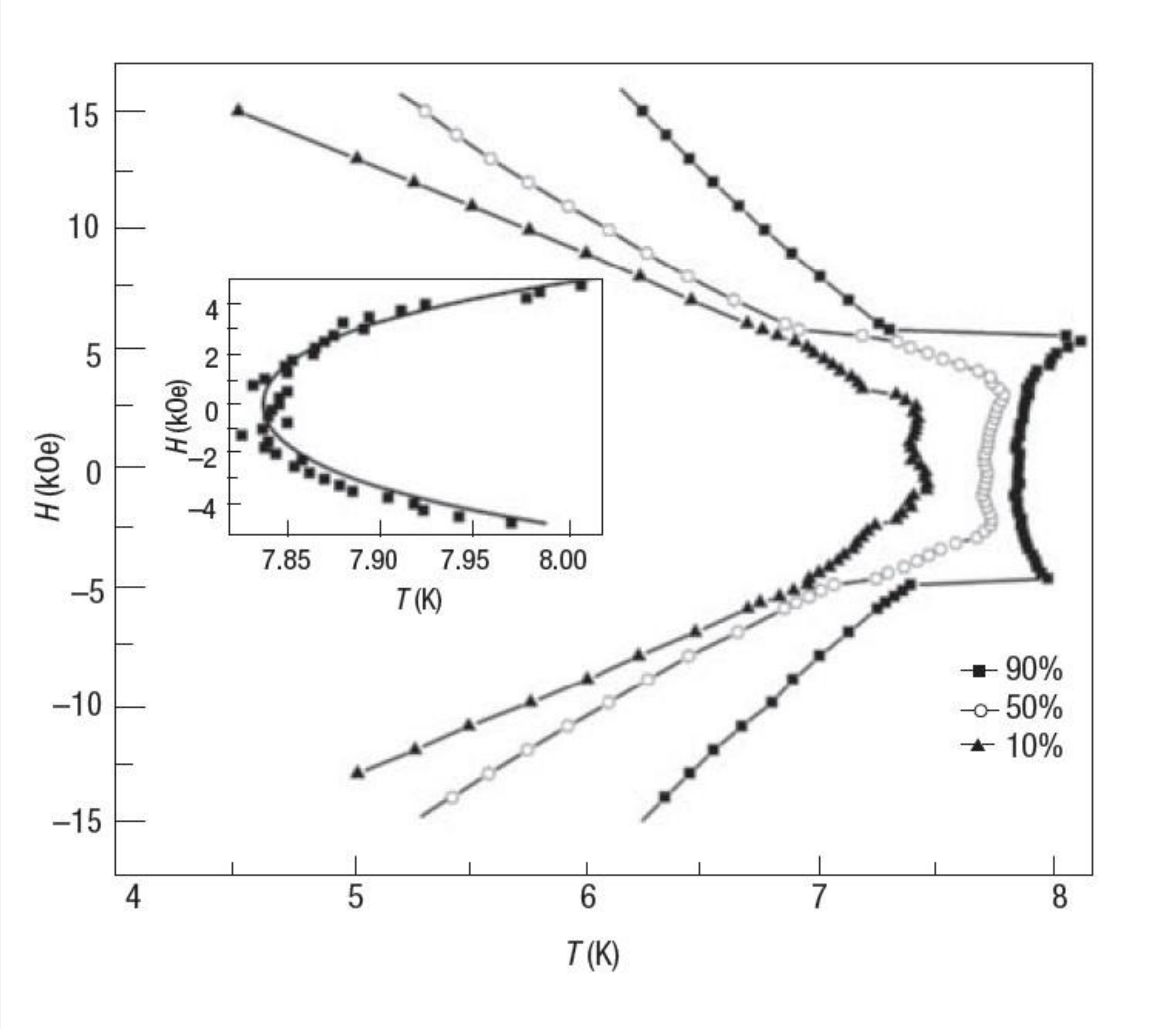


Campo sempre matar SC ?

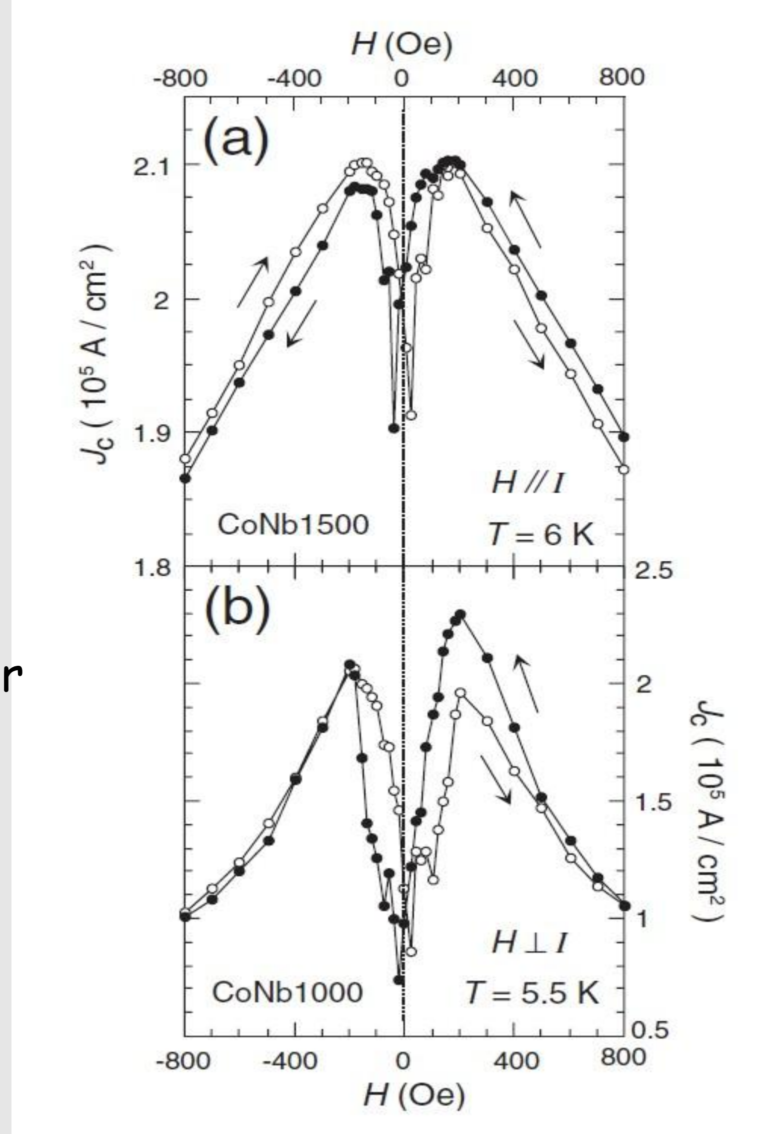


The phase boundaries *Tc(Hext)* for an S/F hybrid, consisting of an Al film and an array of magnetic dots, in the demagnetized state, in the completely magnetized state in positive direction as well as in several intermediate magnetic states

Campo aumenta Tc

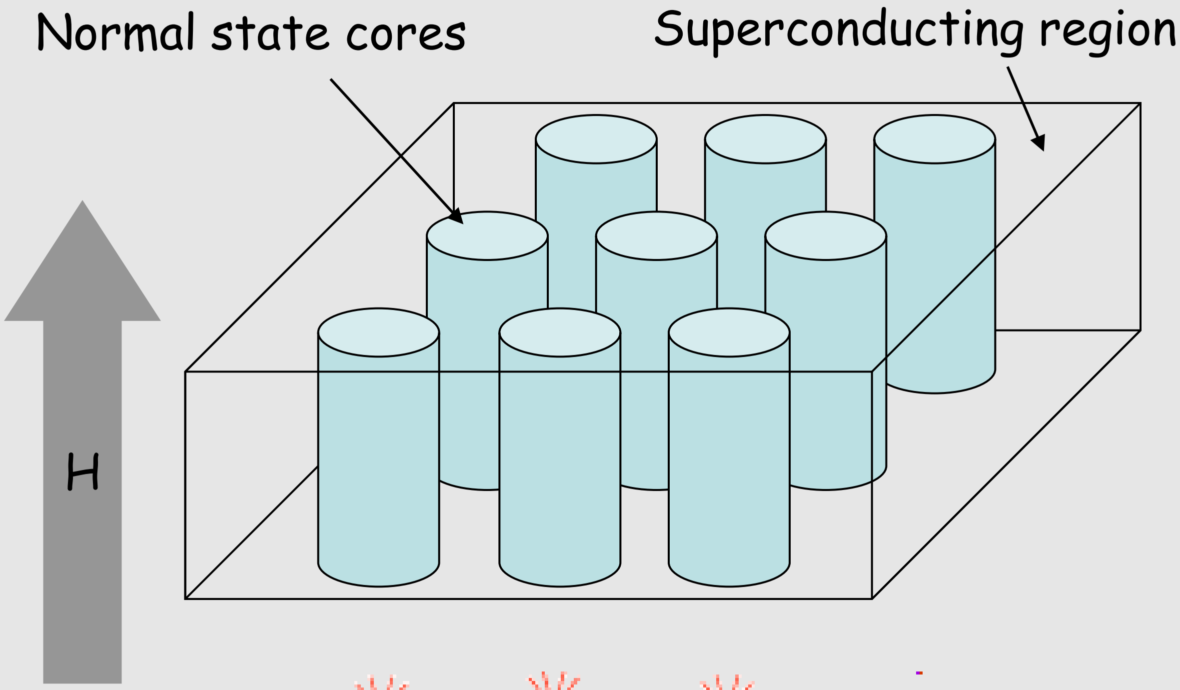


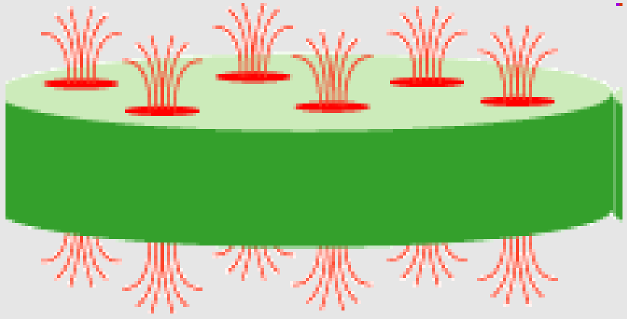
Campo aumenta Jc

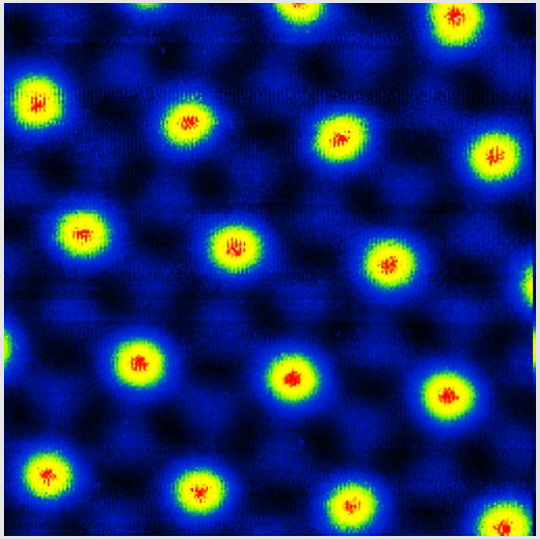


Hysteresis curves of Jc (a) at T = 6K for H k I (CoNb1500) and
(b) at T = 5:5K for (CoNb1000).

Type II Superconductors (ξ < λ)

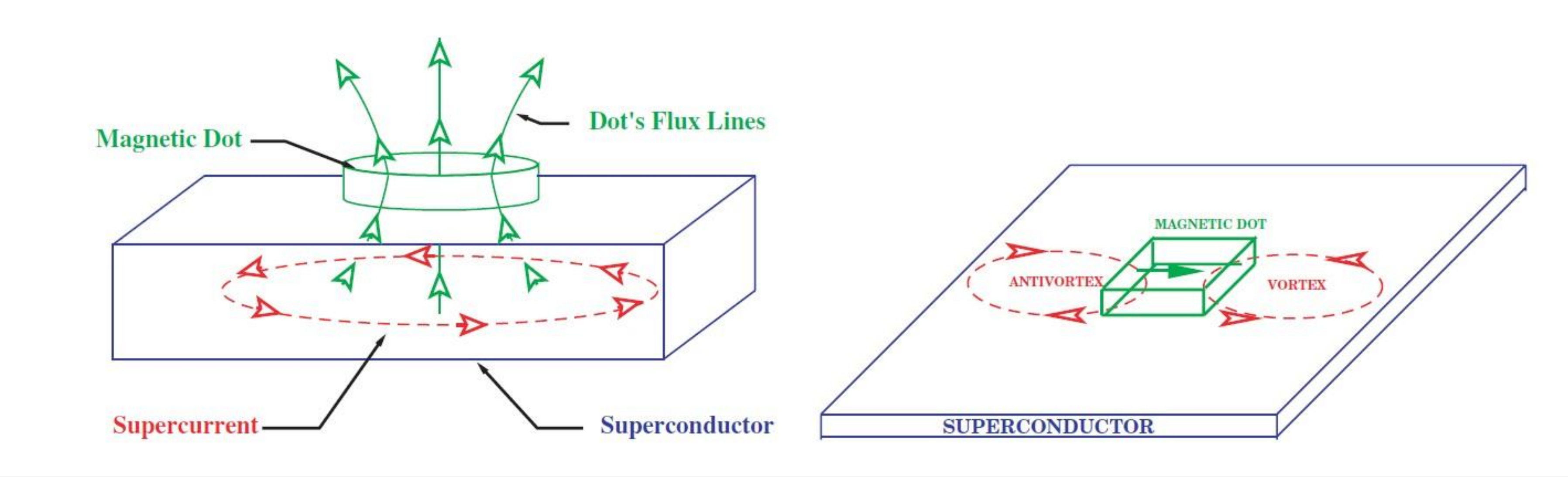




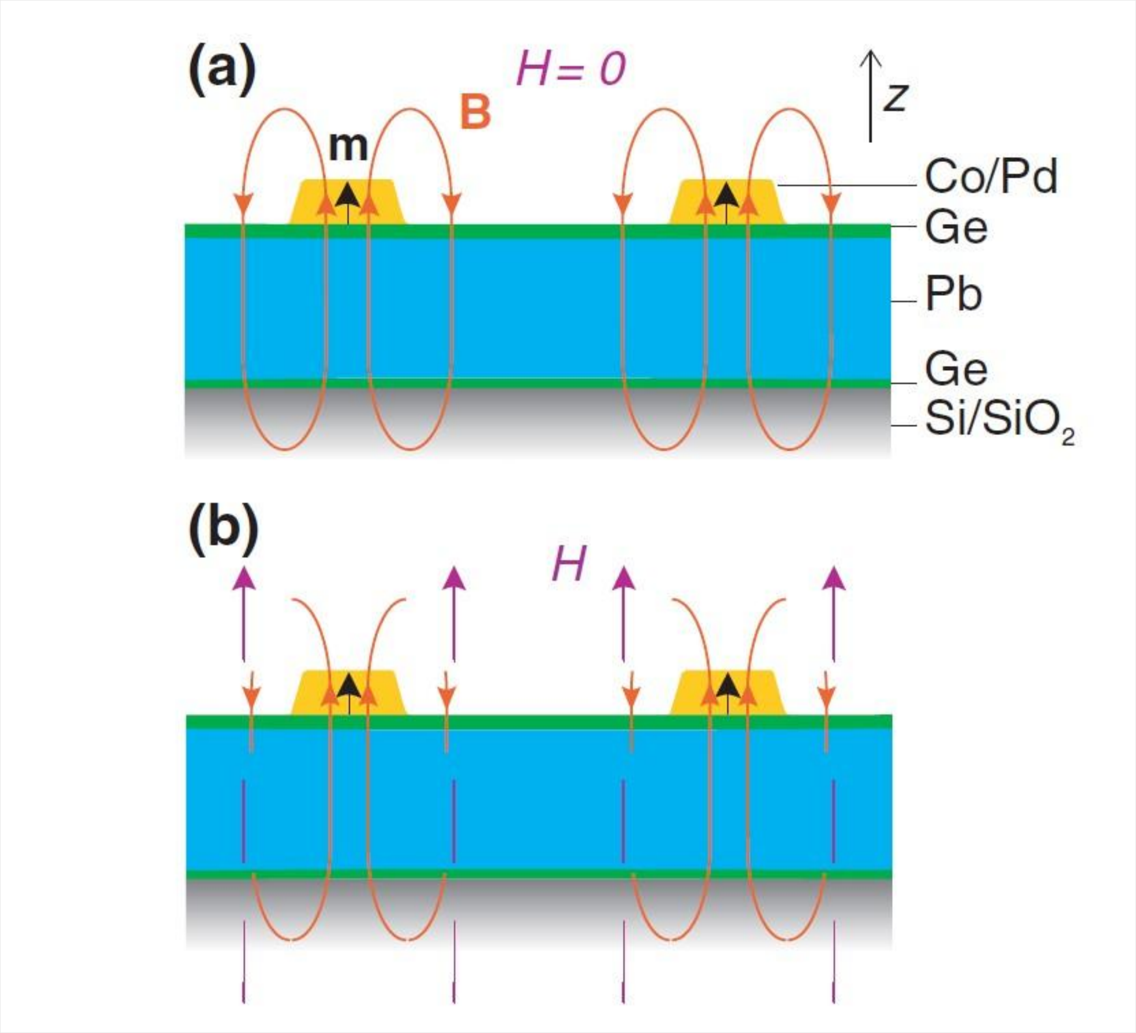


http://www.nd.edu/~vortex/research.html

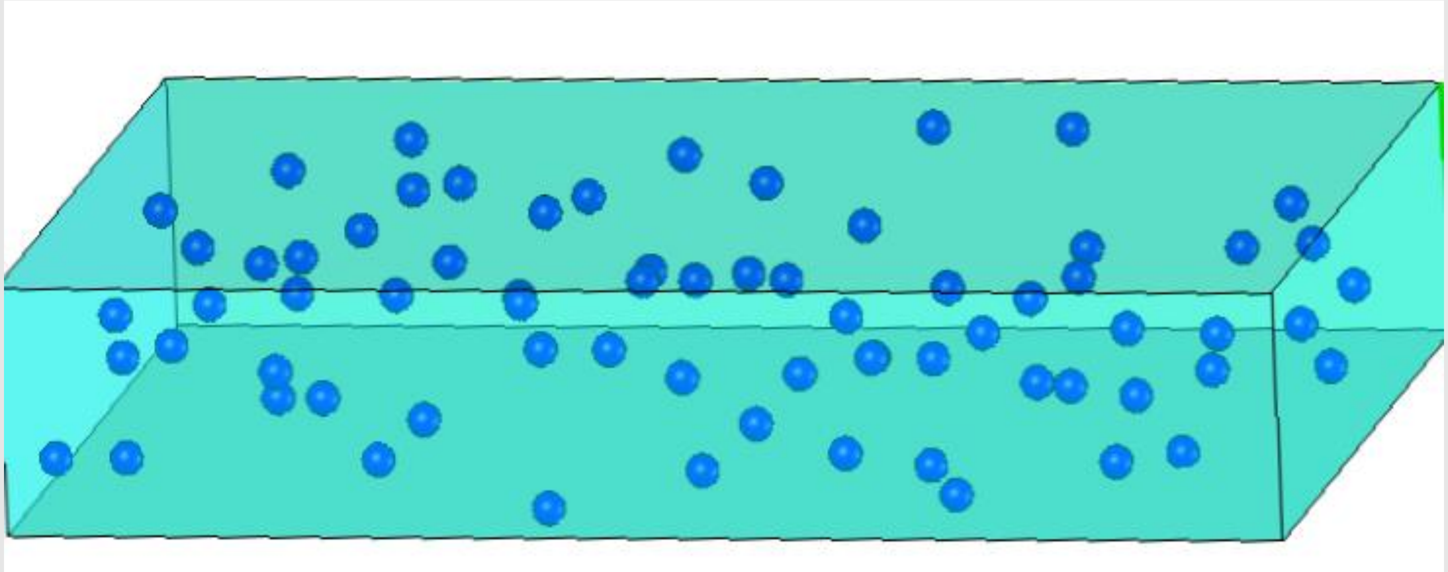
Campo dos dots



Campo sempre matar SC ?

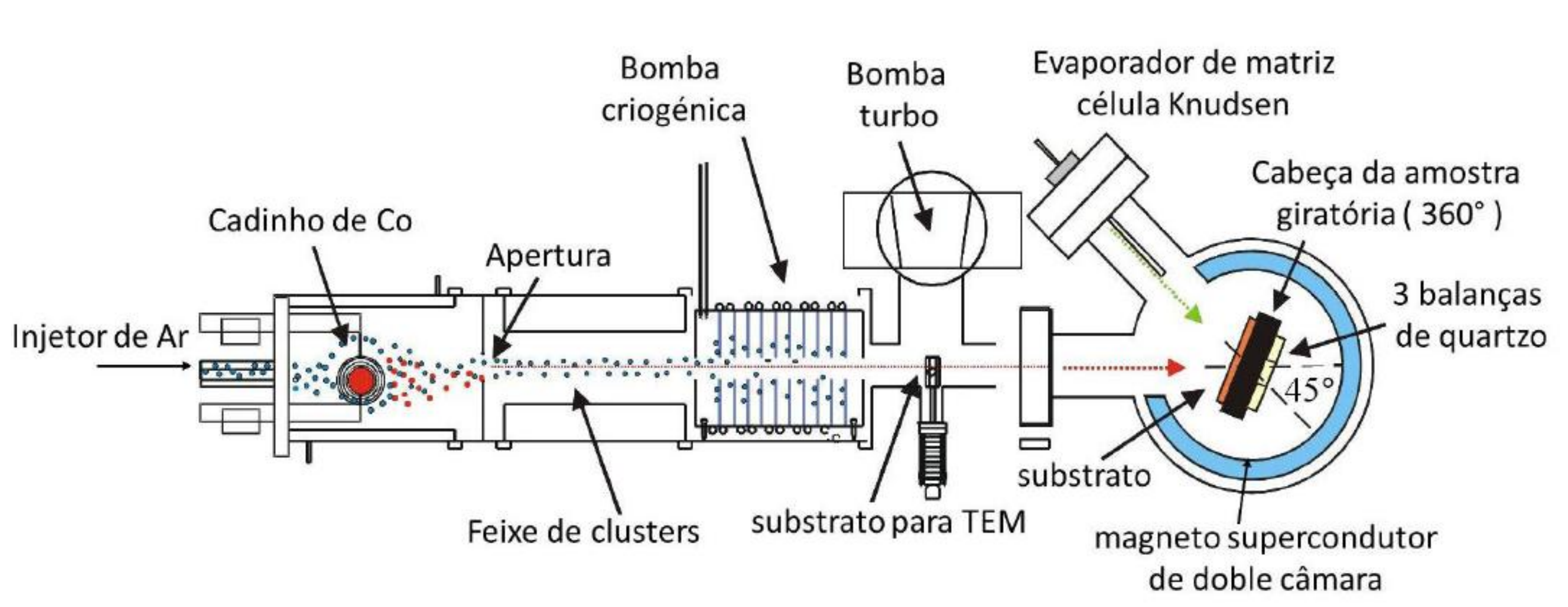


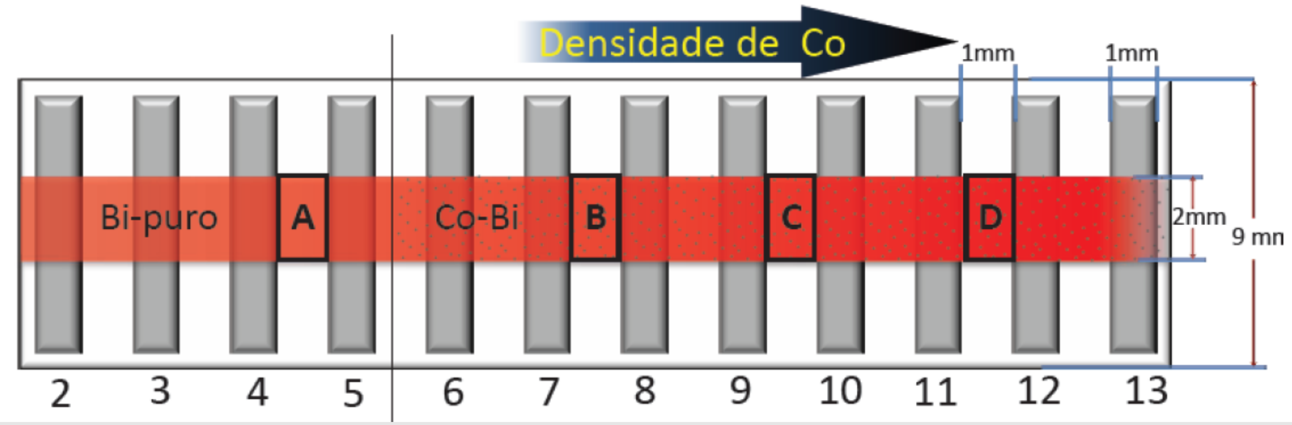
Nossos resultados



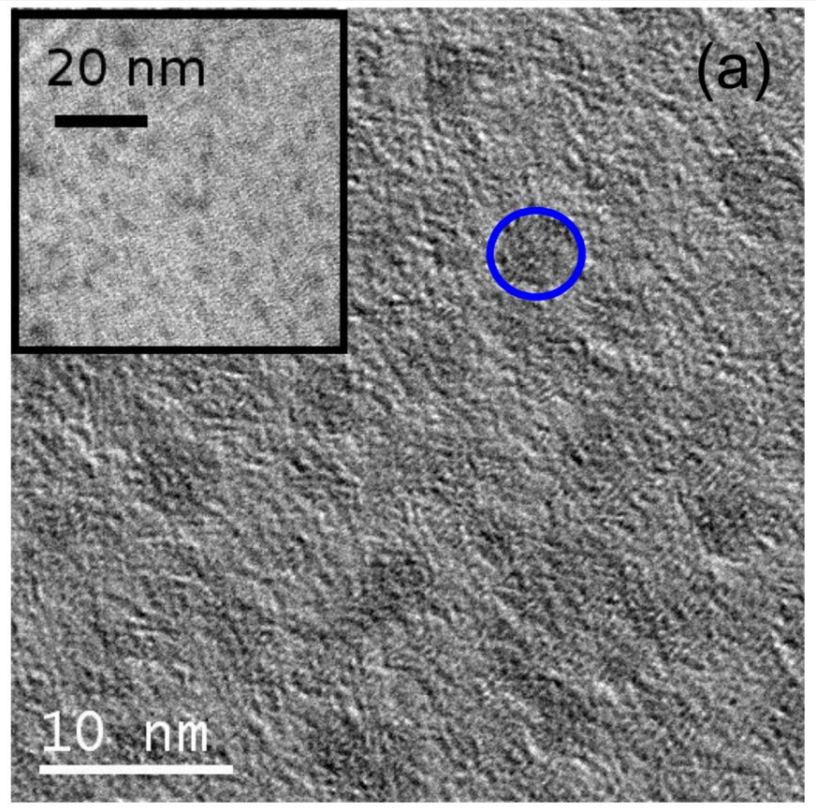
- 100 nm Lead (Pb) film with varying Co particles fraction
- Here we will show results for 4% volume fraction of Co
- Co nanoparticles: ~4.5 nm diameter

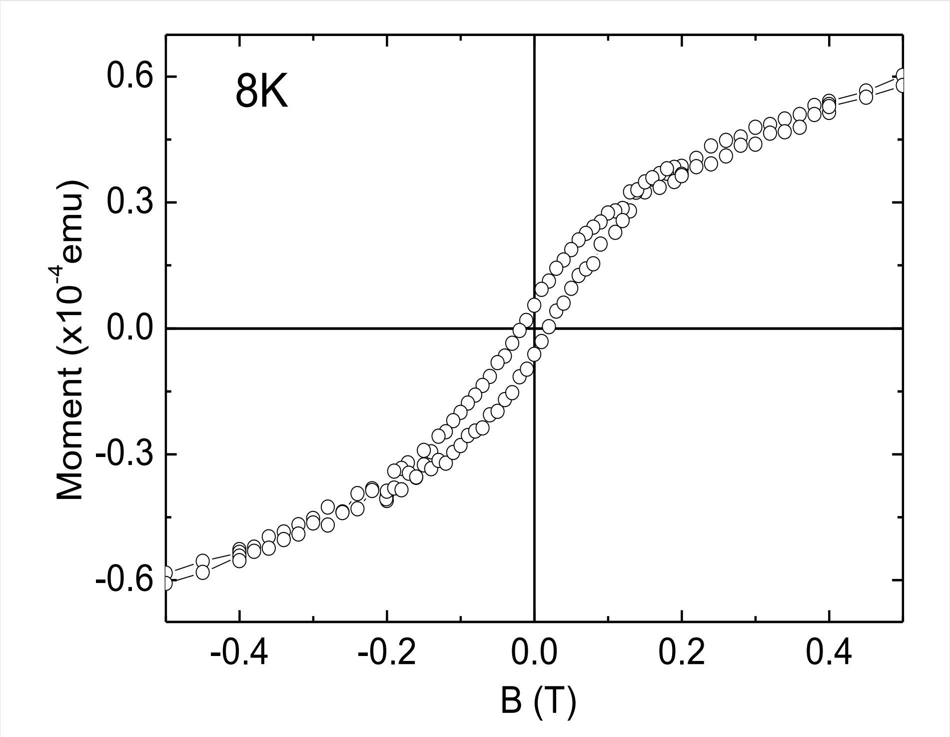
Bi/Co: Sample preparation





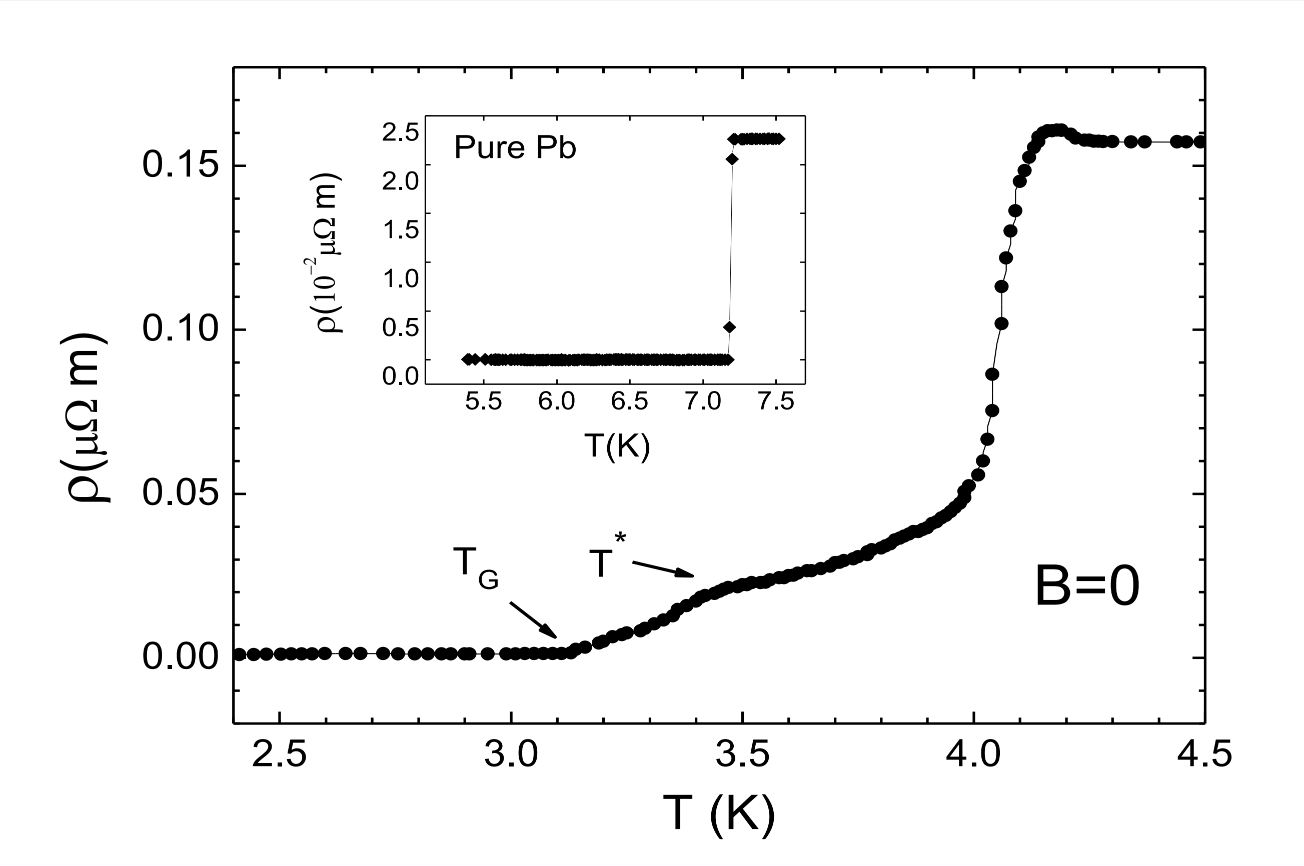
Co nanoparticles





- **Narrow size distribution ~ 4.5 nm diameter**
- **Coercive field = 0.025 T**

Resistivity measurements ($B_{ext}=0$)



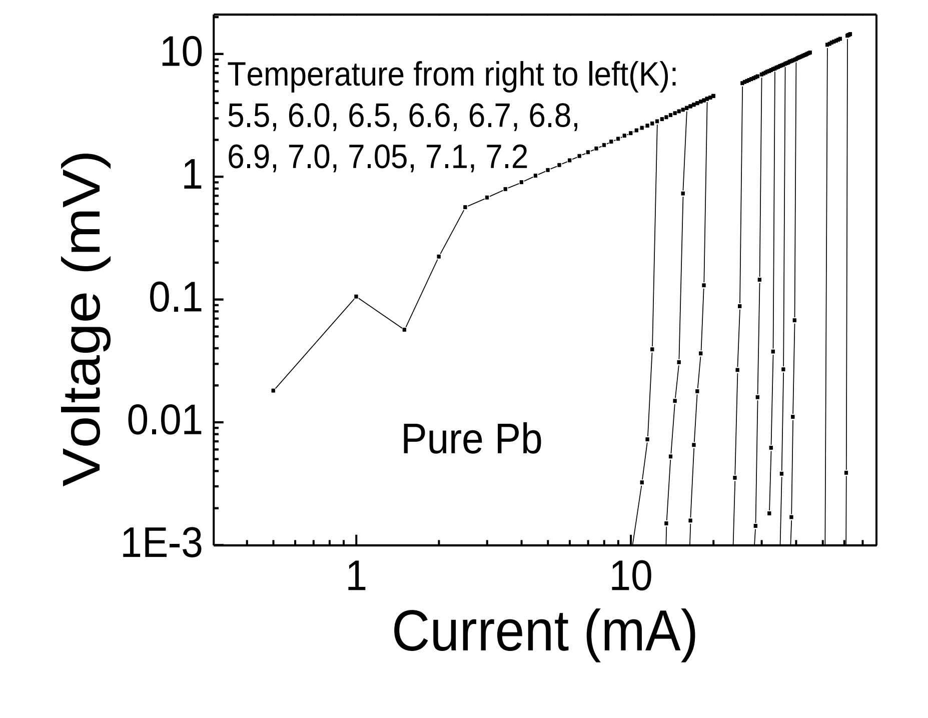
$$l = m^* v_F / ne^2 \rho_0$$

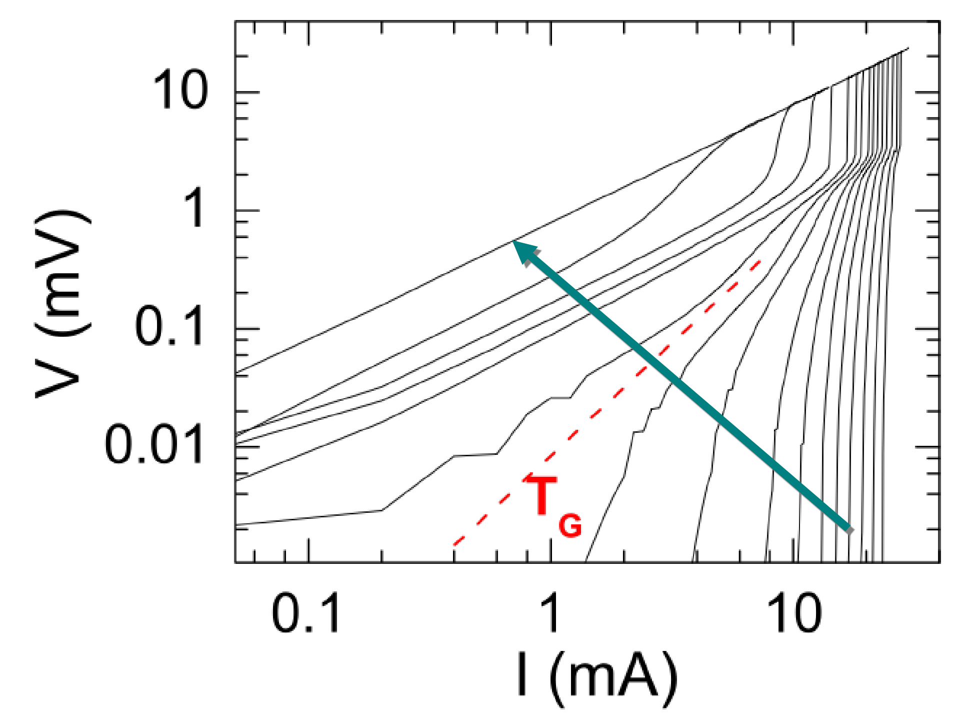
$$\xi = 0.855(\xi_0 l)^{1/2}\sqrt{1-\frac{T}{T_c}}$$

l ~ 3.1 nm

ξ: ~10 nm at 3K

Spontaneous vortices

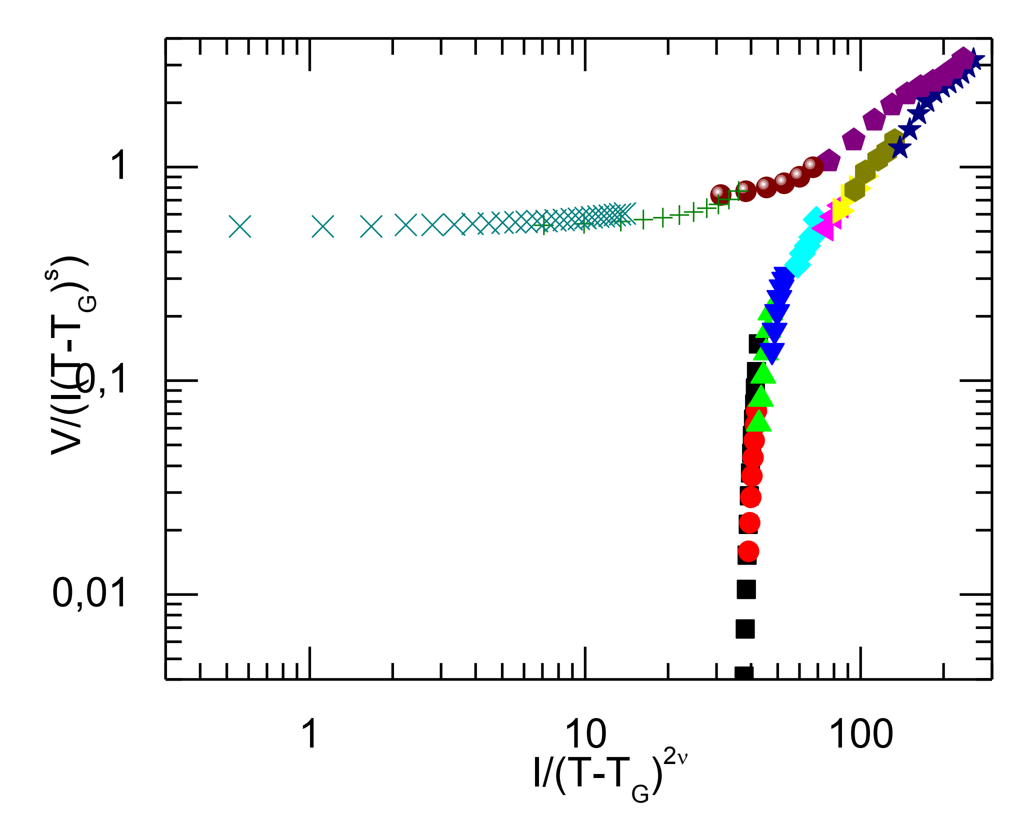




No vortex phase

Vortex phase transition

Scaling analysis



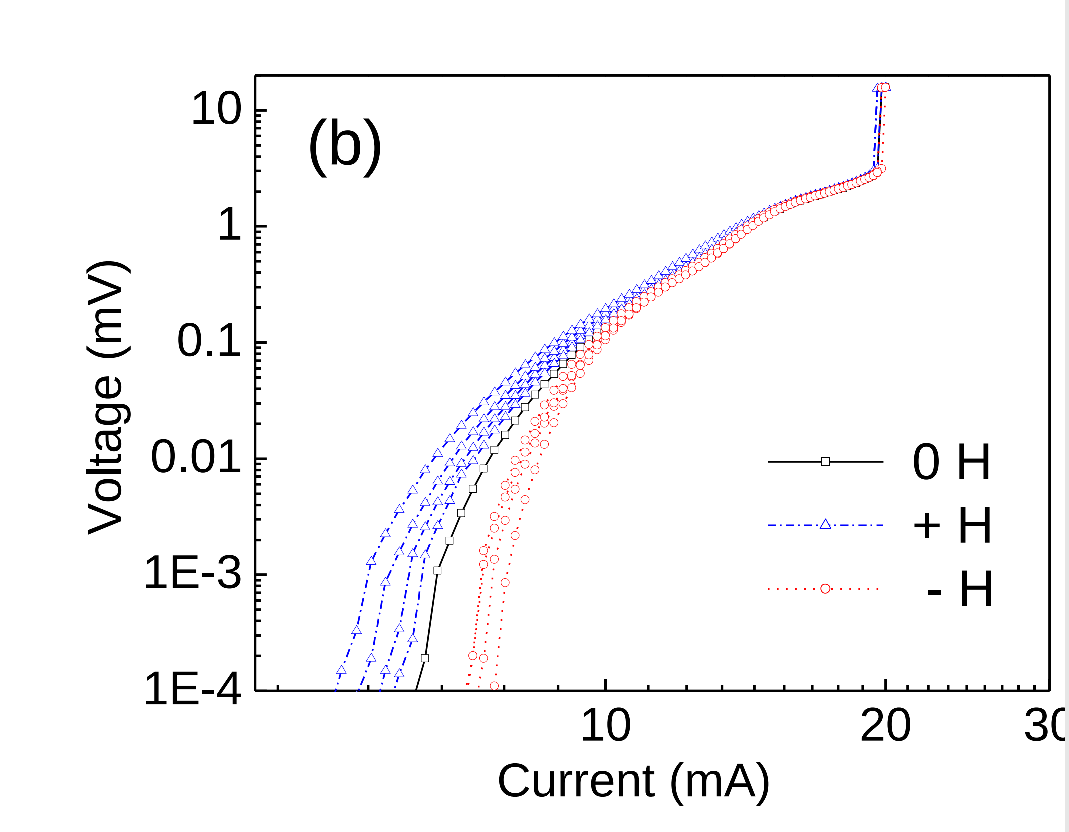
$$E\,|t|^{-\nu(z+1)} = F_{\pm}(|t|^{-3\nu}\,J)$$

$t = (T - T_G)/T_G$,
$T_G = 3.15$ K,

Critical exponents:
$\nu = 0.25$
$z = 4$

Not in the same universality class of the VG transition in high T_c SCs.

Magnetic field polarity



Positive field:

$$B_+ = B_{ext} + B_{Co}$$

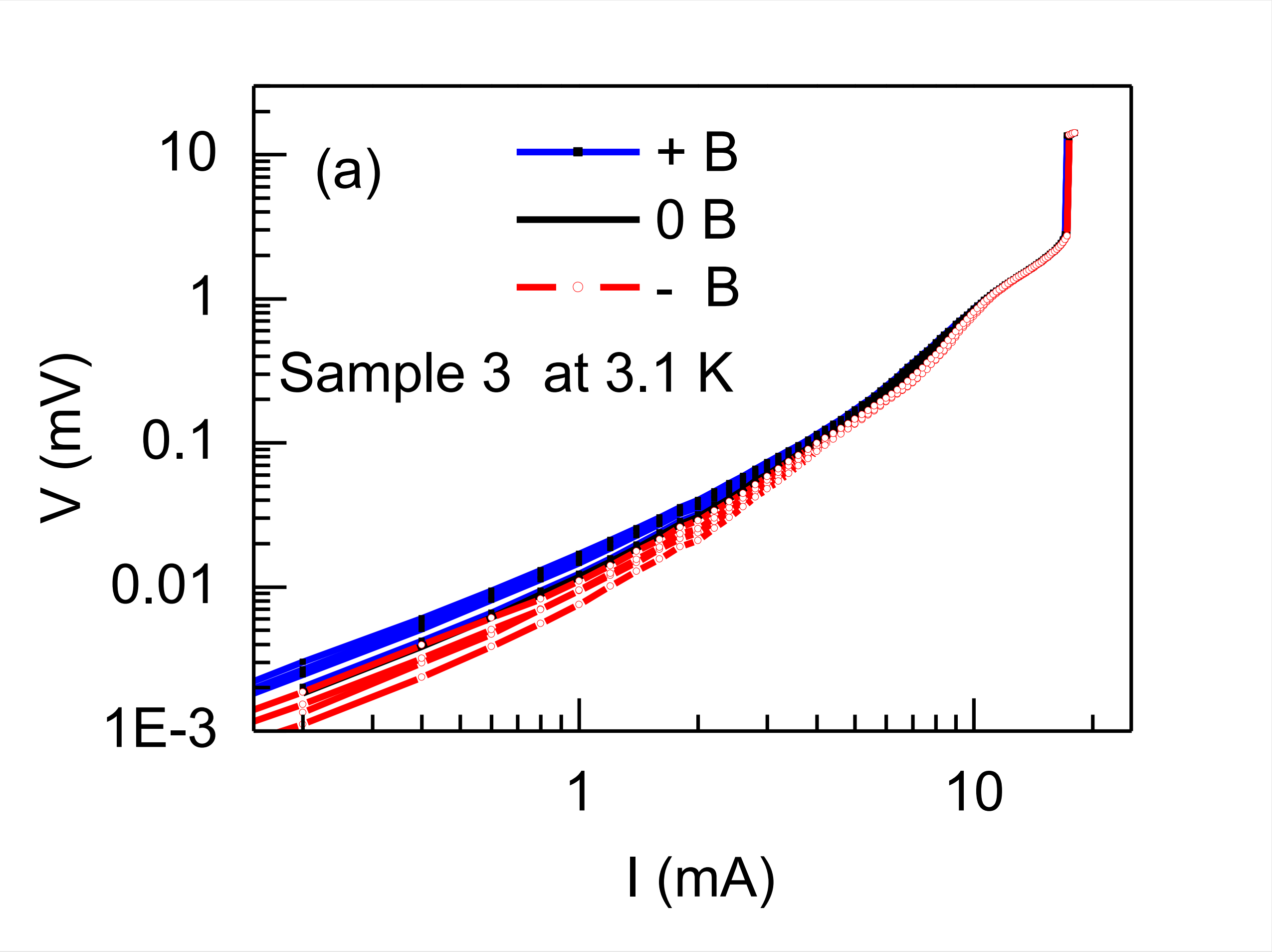
Negative field:

$$|B_-| = || B_{ext} | - B_{Co} |$$

$$B_+ > B_-$$

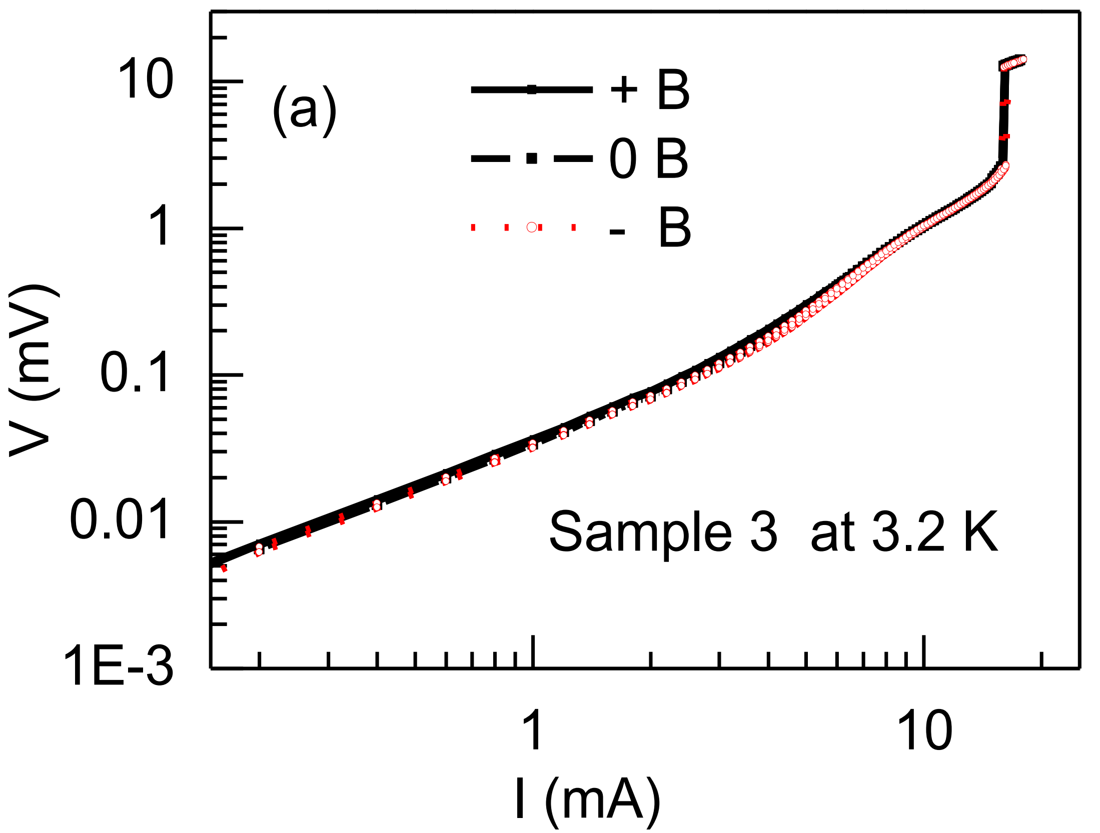
- Particles aligned at $T > T_B$
- Field (<0.01 T) turned on for T=2.9K ($<T_G$)

Magnetic field polarity



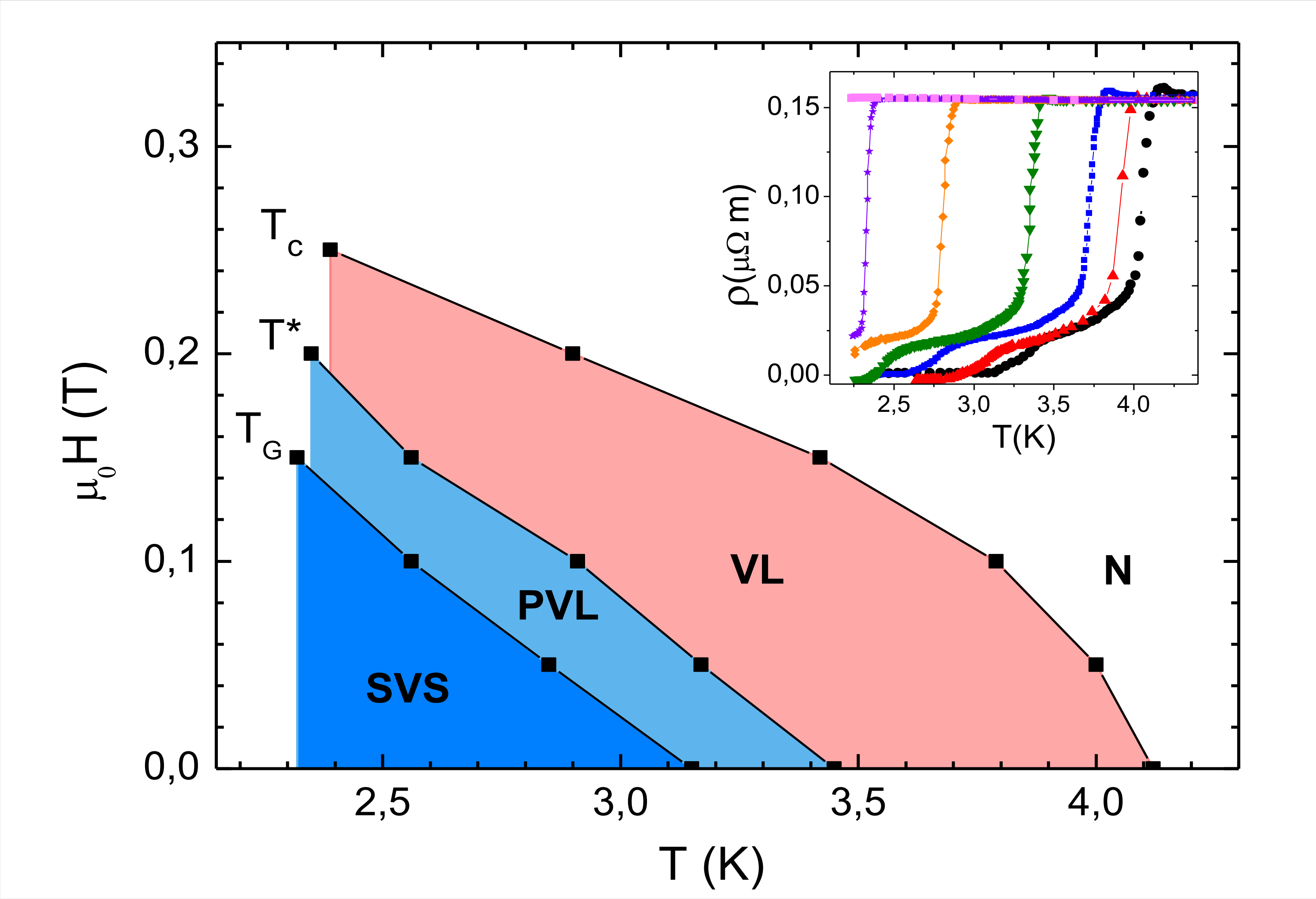
- **Field (<0.01 T) turned on for T=3.1K (~T_G)**

Magnetic field polarity



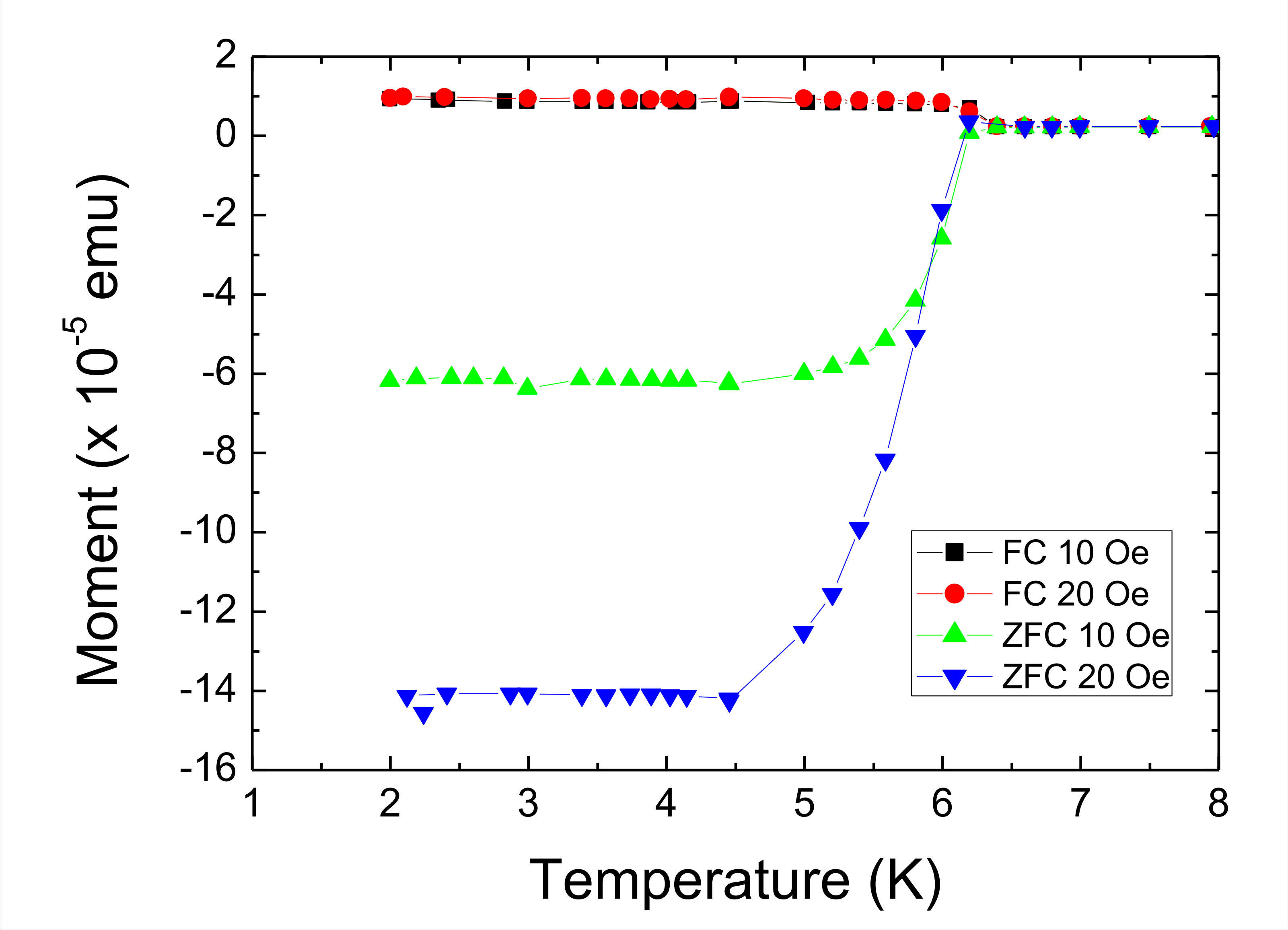
Field (<0.01 T) turned on for T=3.2 K (>T_G)

Phase Diagram for Pb/Co 4 vol%

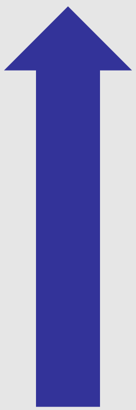


Y. T. Xing et al, PRB 78 224524 (2008)

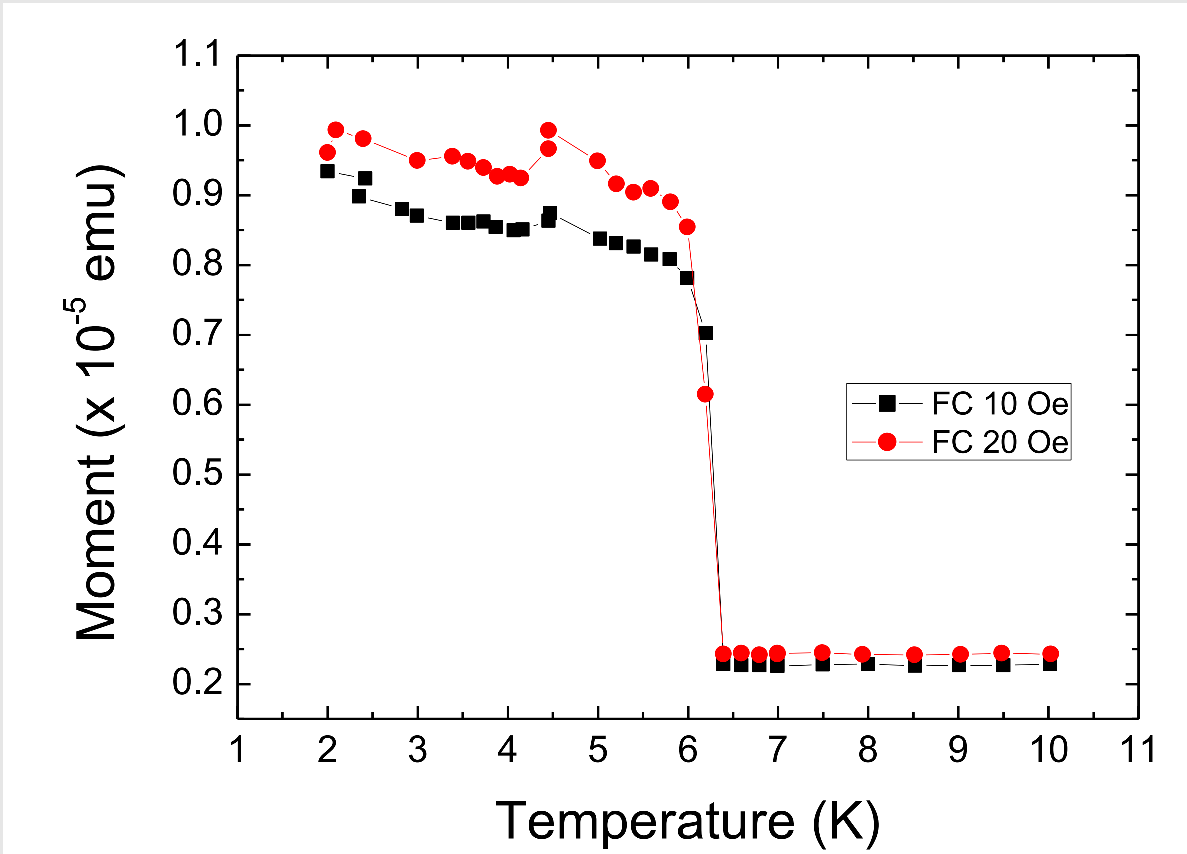
Magnetic properties

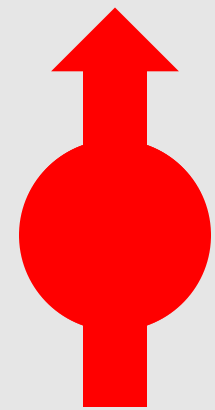


Magnetic properties



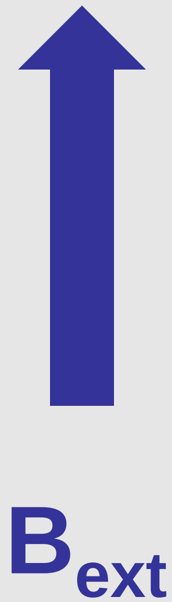
B_{ext}

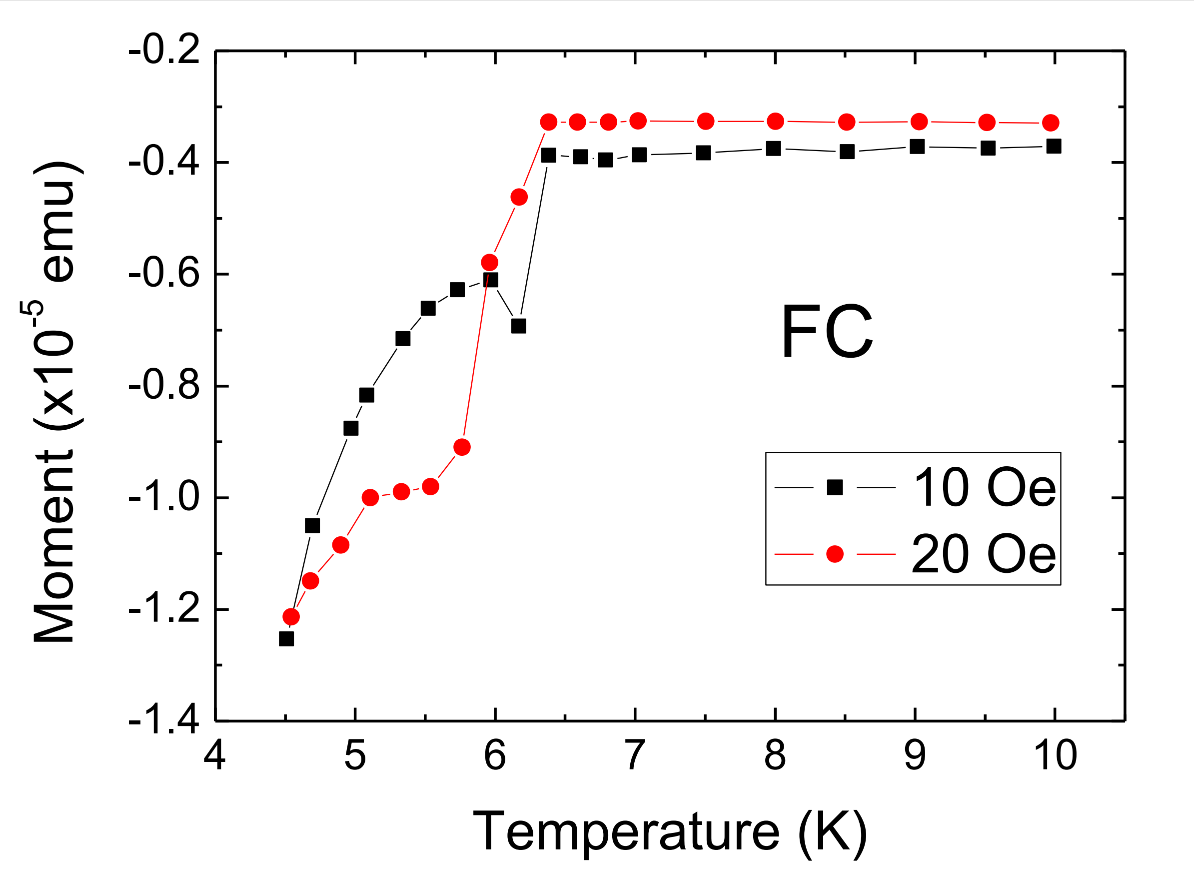




M_{Co} (FC)

Magnetic properties

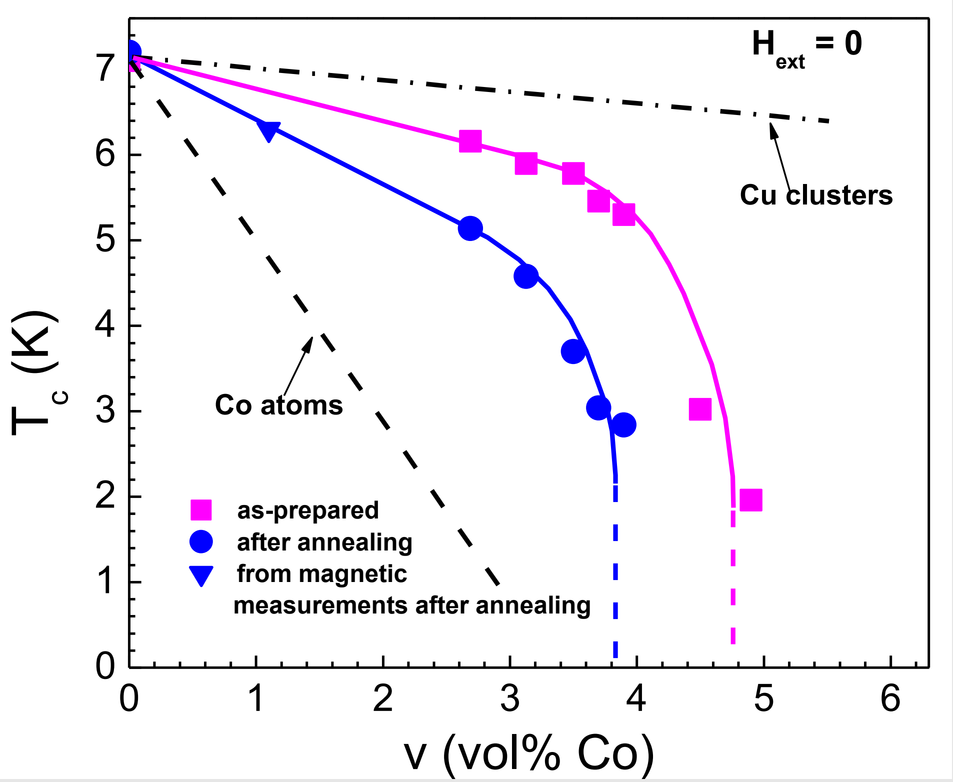




Origin of PME: Interaction between Co and Pb

<u>*Y. T. Xing et al, PRB*</u> 80, 224505 (2009)

T_c as function of Co-volume fraction



1. Low critical Co-volume fraction due to the formation of spontaneous vortices.
2. Annealing leads to a decrease of critical Co-volume fraction

__Explanation__:

$$\xi = 0.855(\xi_0 \ell)^{1/2}$$

$$d = 2\xi \quad ; \quad \xi_0 = 83nm$$

Increase of mean free path ℓ , gives increase in ξ :

ξ(as prepared) = 10 nm

ξ(annealed) = 25 nm

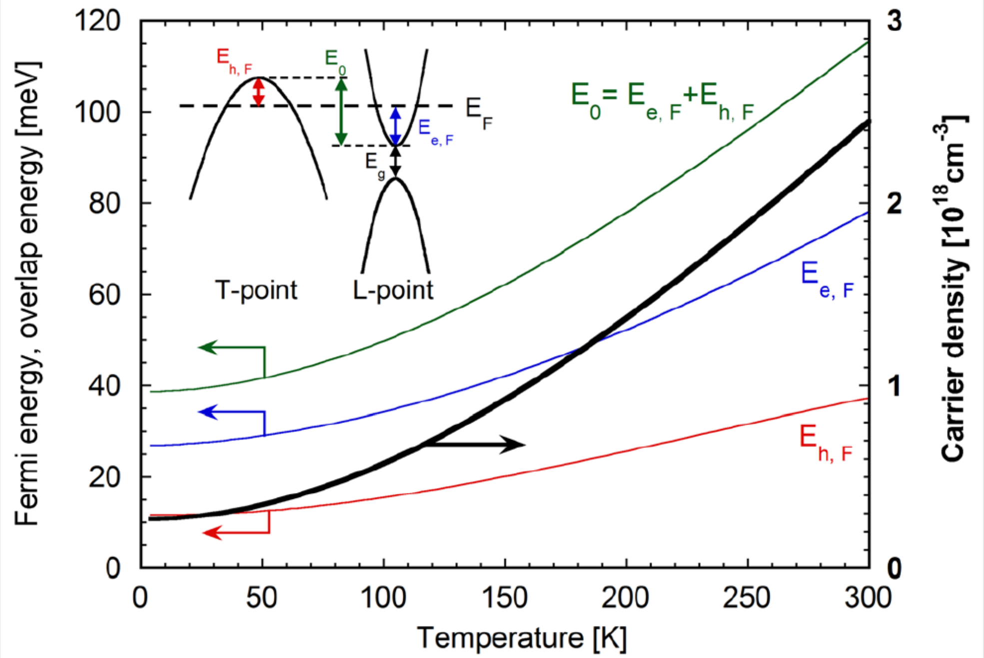
Y.T. Xing et al, Eur. Phys. J. B **76**, 353 (2010).

Shorter coherence length? -Bi film

Bi: $\xi \approx 7$ nm Much shorter than ξ_{Pb}

Bulk Bi:

Rhomboedral structure, semimetal with very small $E_F \sim 27.2$ meV and Fermi surface (10^{-5} times Brilloin zone)



Problem:

Bulk Bi: **not superconducting**!

High pressure phases of Bi: superconducting

$$\text{Different structure}\begin{cases} 25 \quad kbar \quad ; \quad Bi - II \quad ; \quad Tc = 3.9K \\ 27 \quad kbar \quad ; \quad Bi - III \quad ; \quad Tc = 7.2K \\ 88 \quad kbar \quad ; \quad Bi - IV \quad ; \quad Tc = 8.5K \end{cases}$$

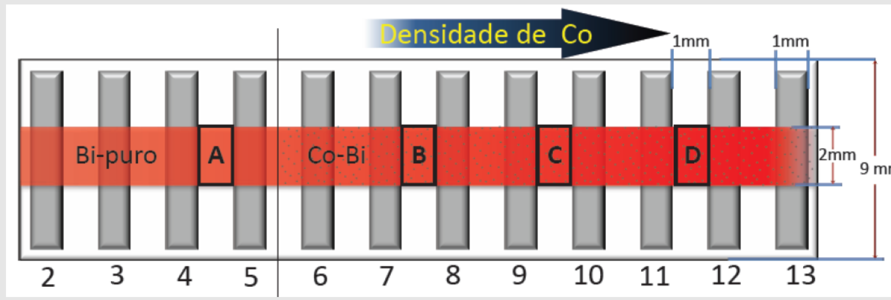
Amorphous Bi (a-Bi): superconducting $T_c = 6$ K

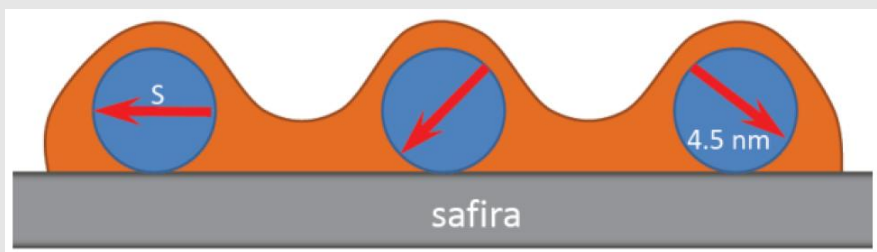
Bi-clusters: superconducting

Superconductivity in granular systems built from well-defined rhombohedral Bi-clusters: Evidence for Bi-surface superconductivity.

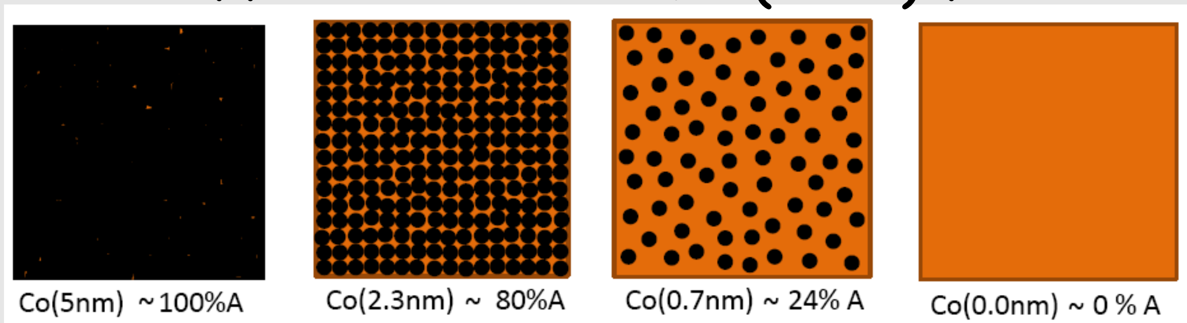
B. Weitzel and H. Micklitz, Phys. Rev. Lett. **66**, 389 (1991)

Bi films covering Co clusters

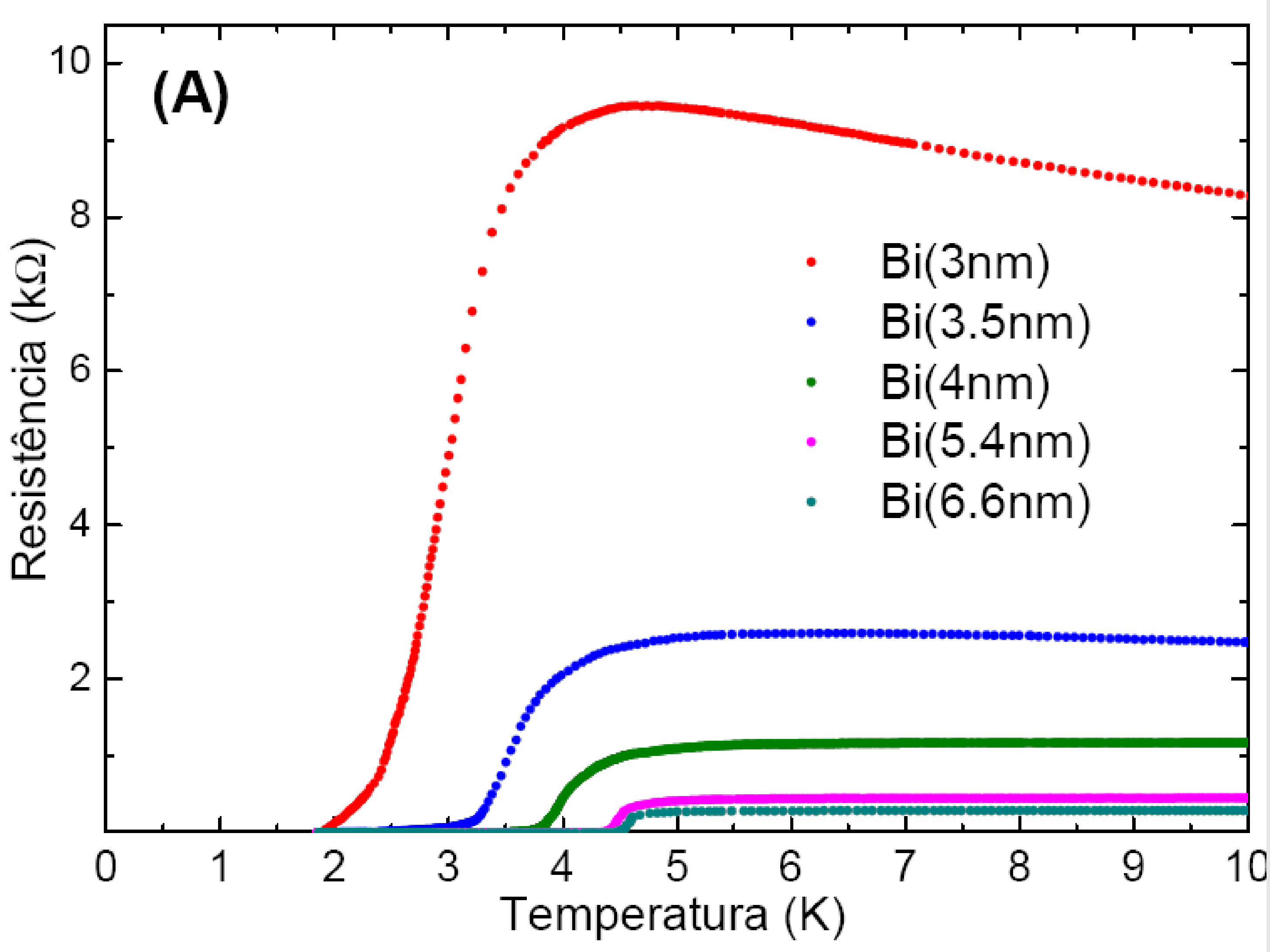




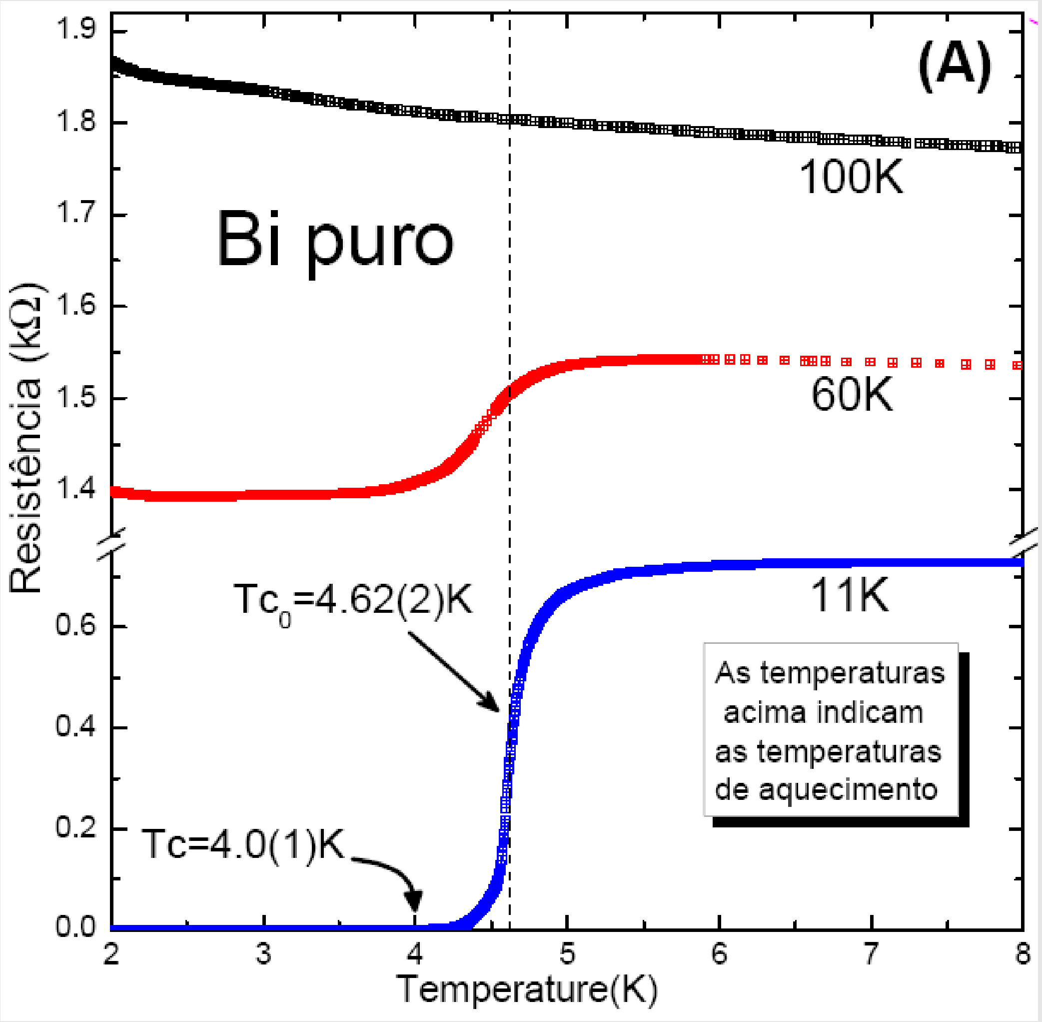
Different Co-volume (area) fractions



Pure Bi-films (as-prepared)



Annealed pure Bi-film:



After annealing at 100 K:

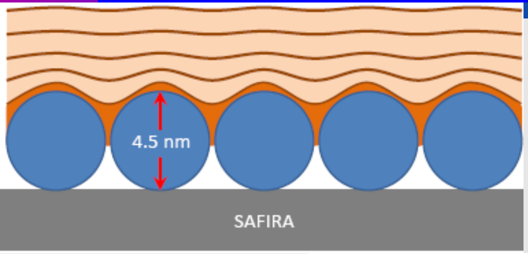
Metallic behavior with
2D - weak localization

no indication for
superconductivity

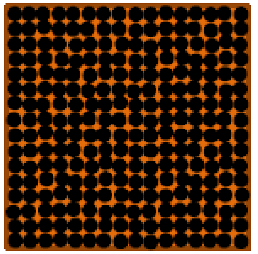
$$\rho = \rho_0 + \Delta\rho$$

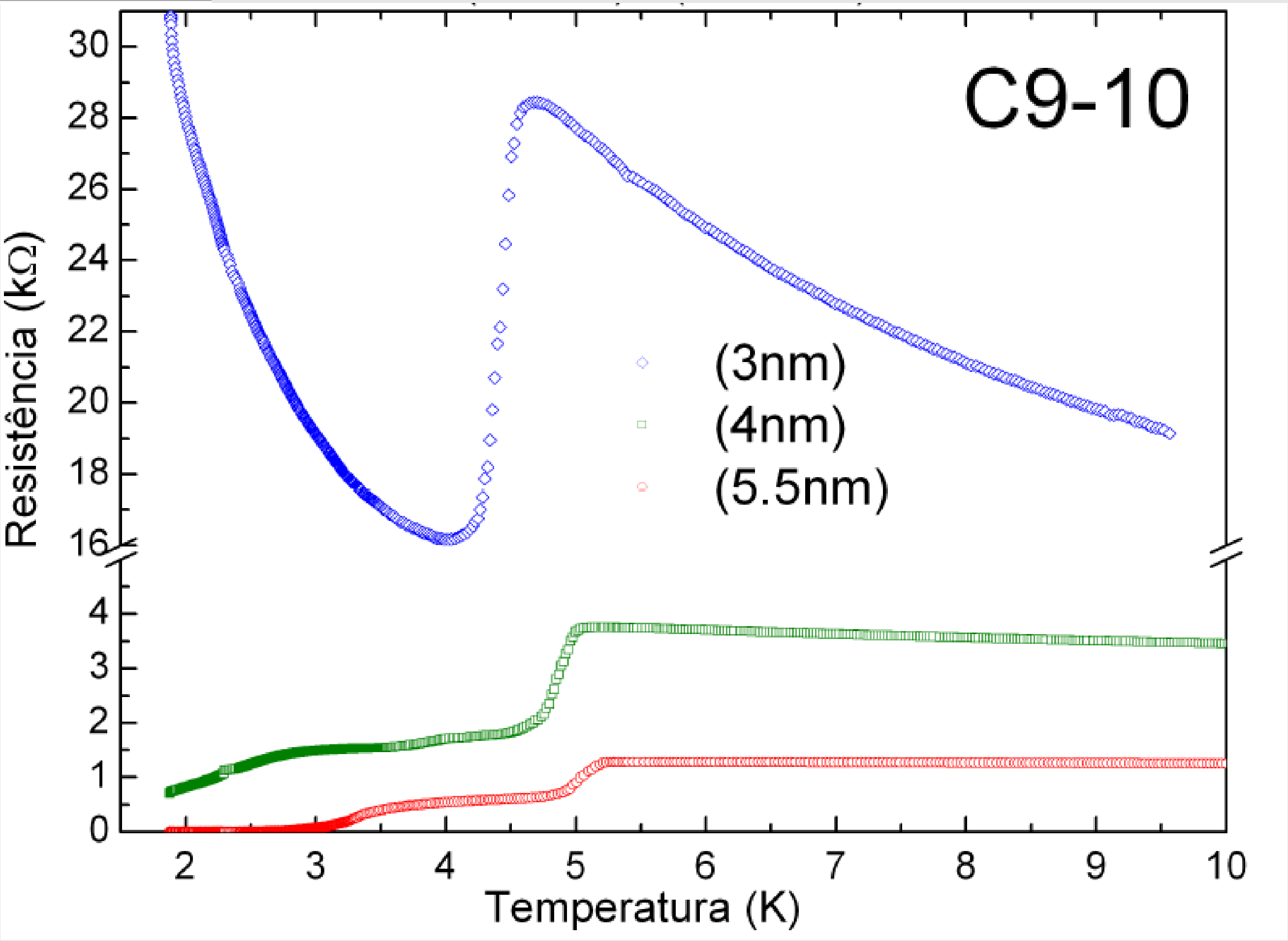
$$\Delta\rho \propto -\ln T$$

Bi-film with Co clusters



Co(80% A)Bi(3-5.5nm)

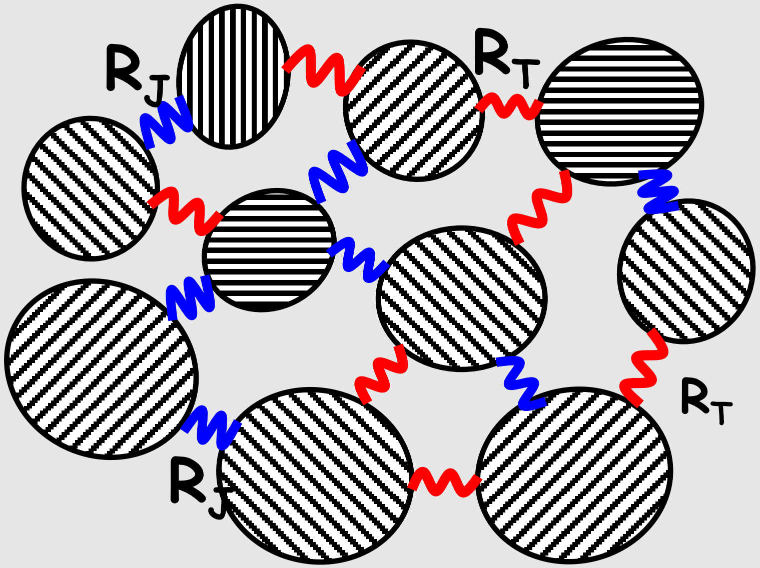


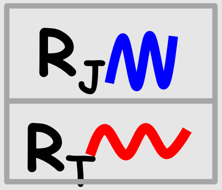


Explanation

Thermal activated **tunneling** between islands (or grains)

Electron tunneling (R_T) and Cooper pair tunneling (R_J)





$$R = \sum_i R_T^i + R_J^i$$

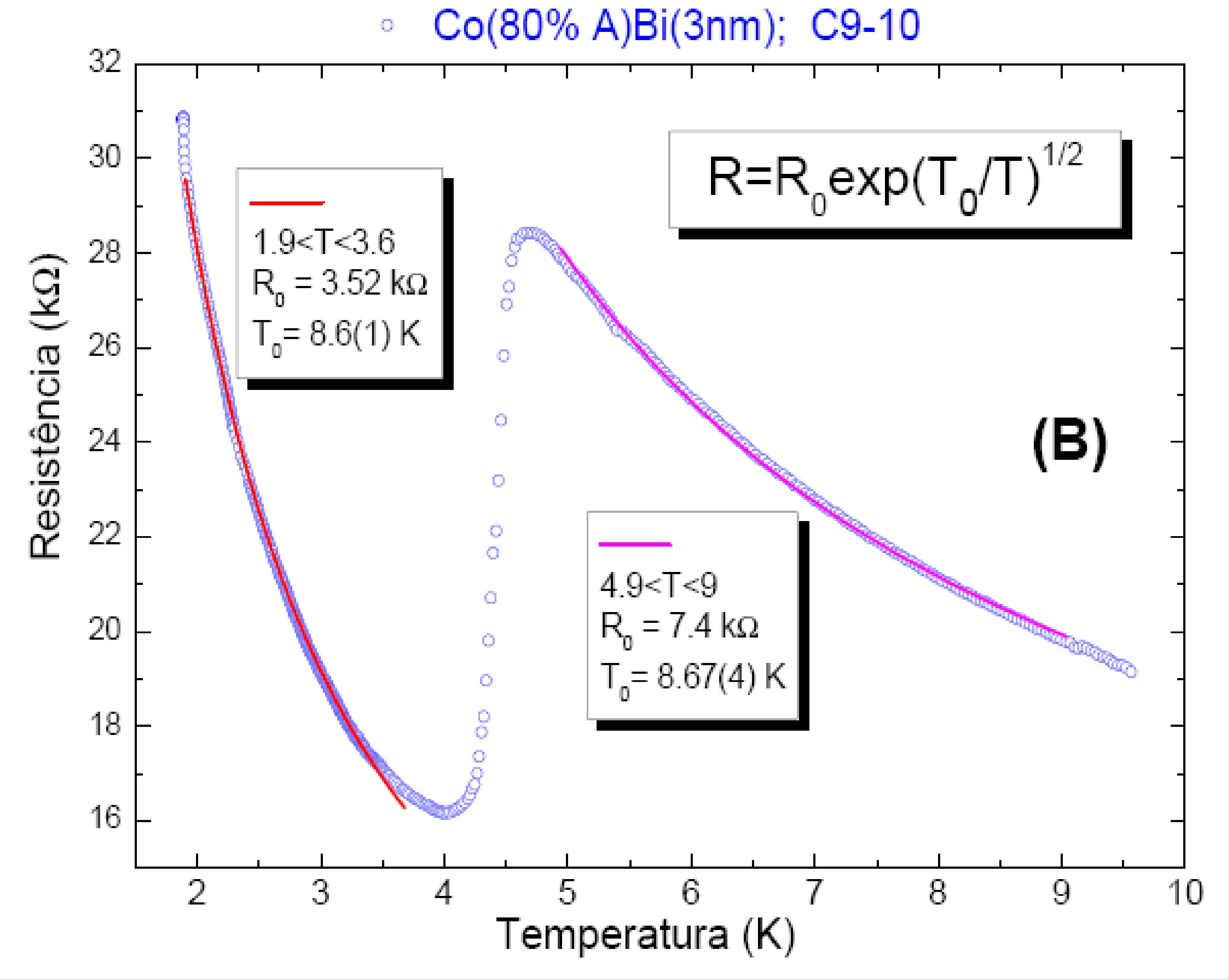
$$R_J = \begin{cases} R_T & \text{for} \quad T > T_c \\ 0 & \text{for} \quad T < T_c \end{cases}$$

$$R = R_0 \exp(T_0 / T)^{1/2}$$

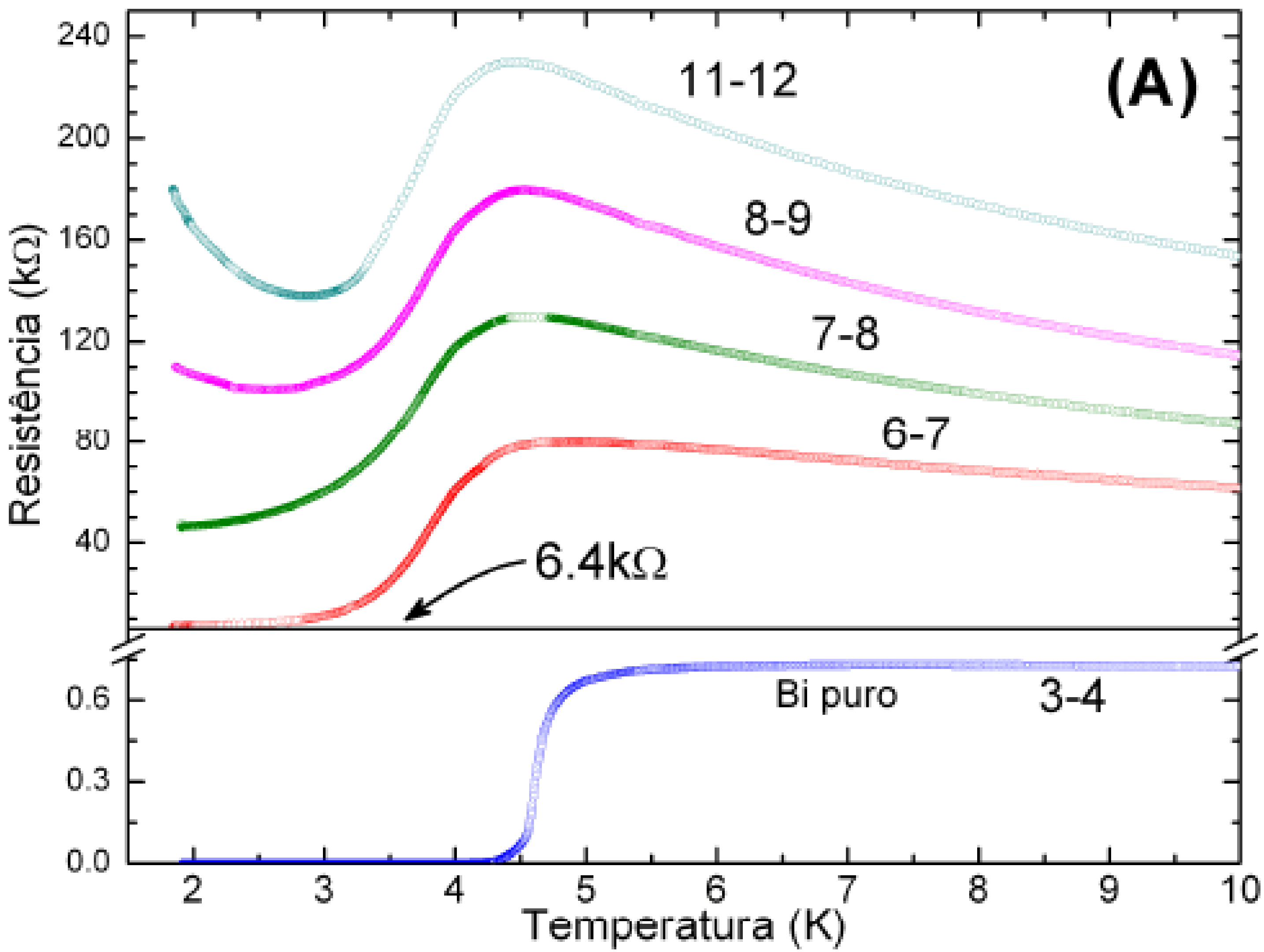
Tunneling resistance with Coulomb barrier

…

Explanation

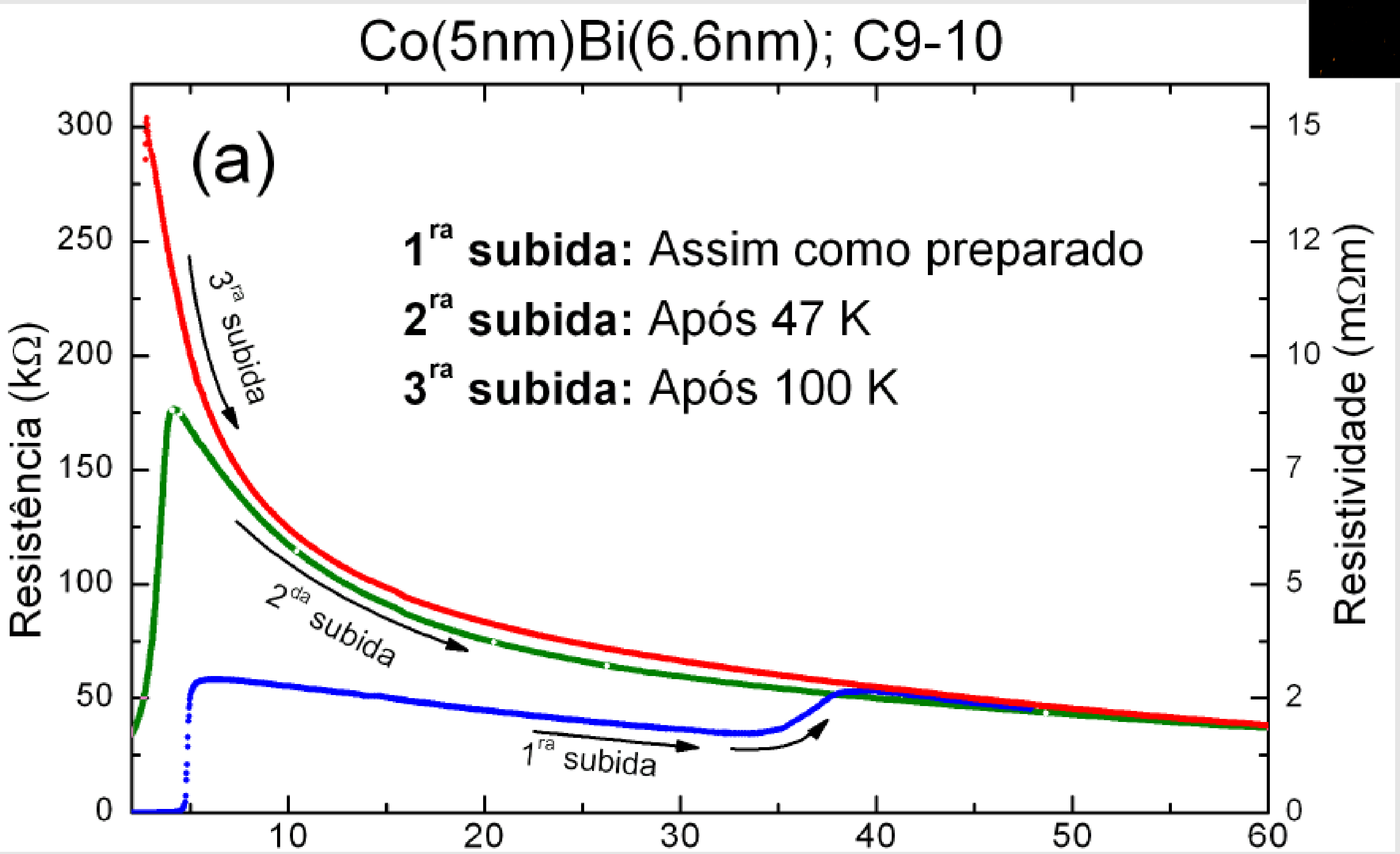


Co(24 A%)/Bi(5nm)

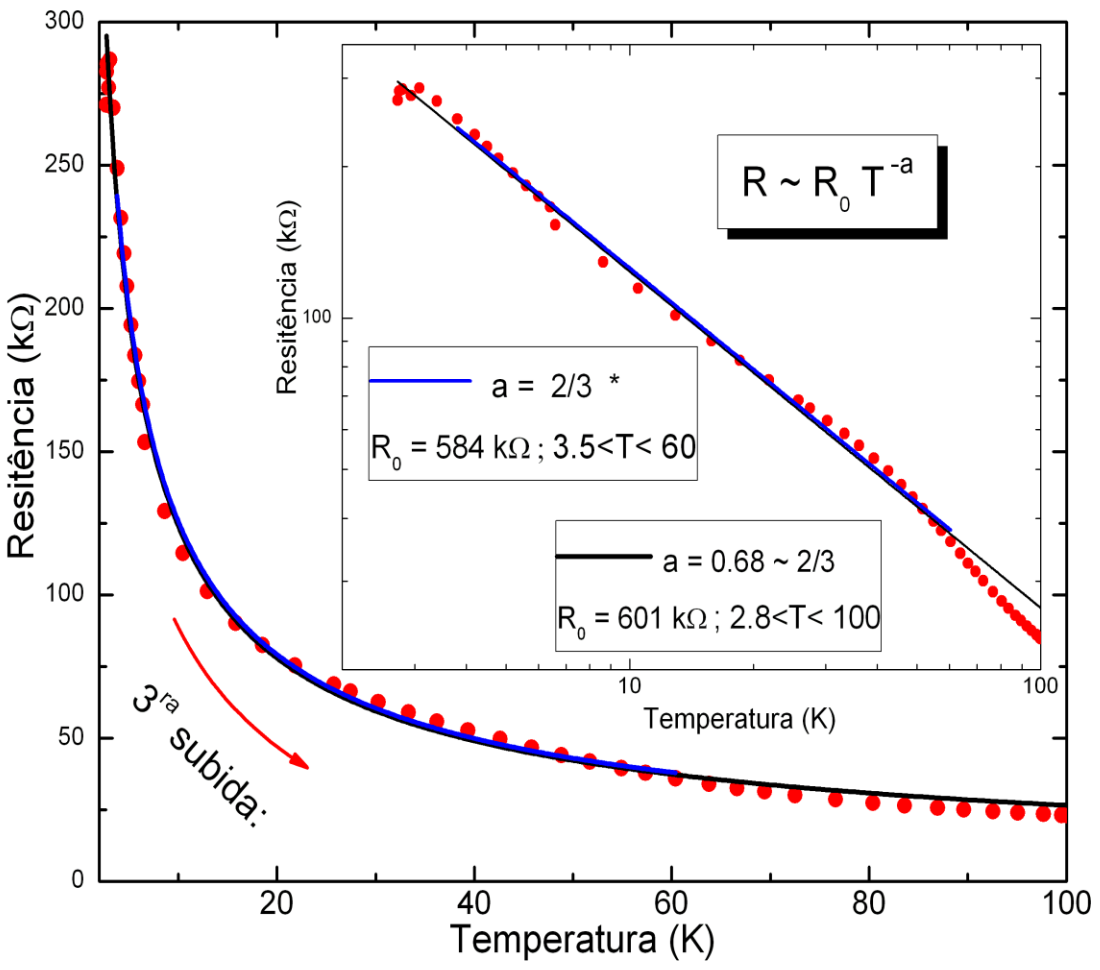


(A)
11-12
8-9
7-8
6-7
6.4kΩ
Bi puro
3-4
Resistência (kΩ)
Temperatura (K)
240
200
160
120
80
40
0.6
0.3
0.0
2
3
4
5
6
7
8
9
10

Annealed Bi-Layer



Interpretation of result



- Due to annealing opening of gap in DOS of 2D crystalline Bi-layer

This is caused by (?):

(i) Magnetic impurities at surface of Bi

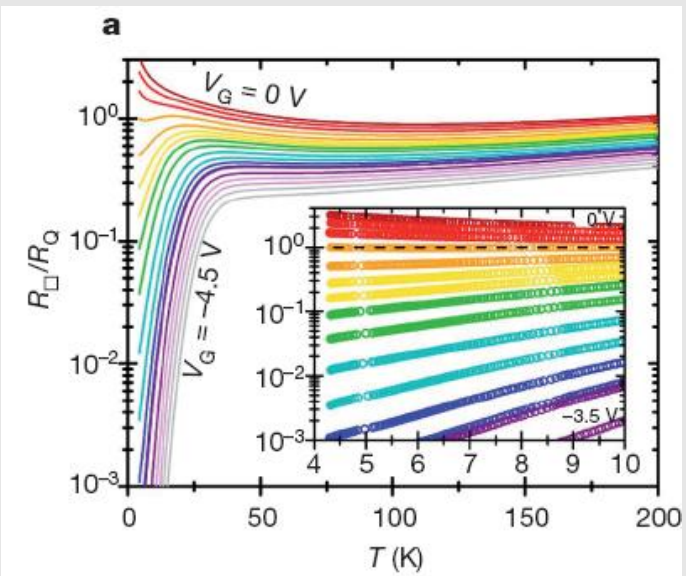
(ii) Stress at the interface between crystalline Bi and Co-clusters.

(iii) Disorder

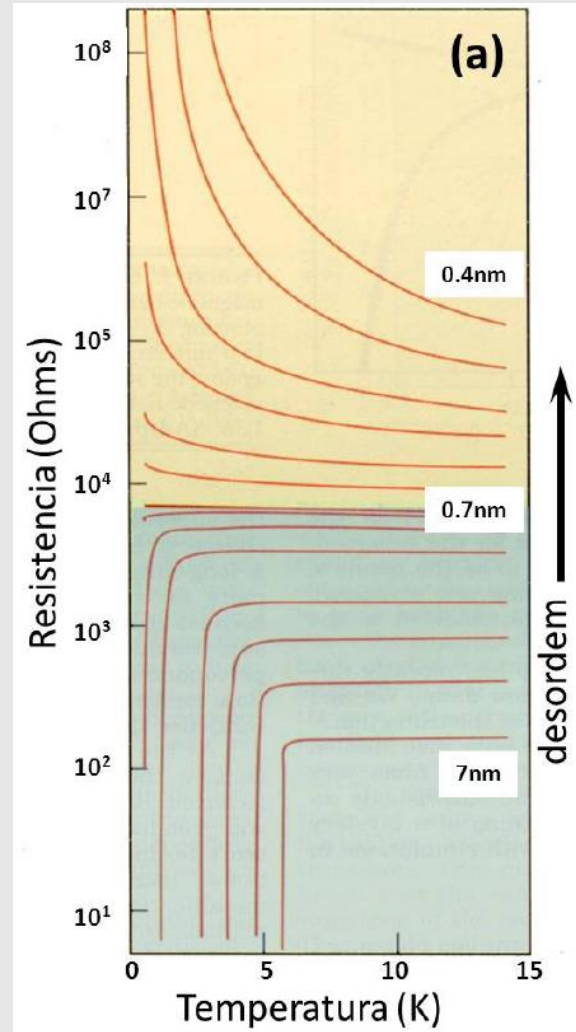
SC-I transition in 2D systems

$$R_{\square} = R_c \cdot F(|x - x_c| T^{-1/z\nu})$$

$$z\nu = 1.5$$



$T^{-2/3}$. For $4.3\,\mathrm{K} < T < 10\,\mathrm{K}$



A. T. Bollinger et al., Nature, **472**, 458 (2011),

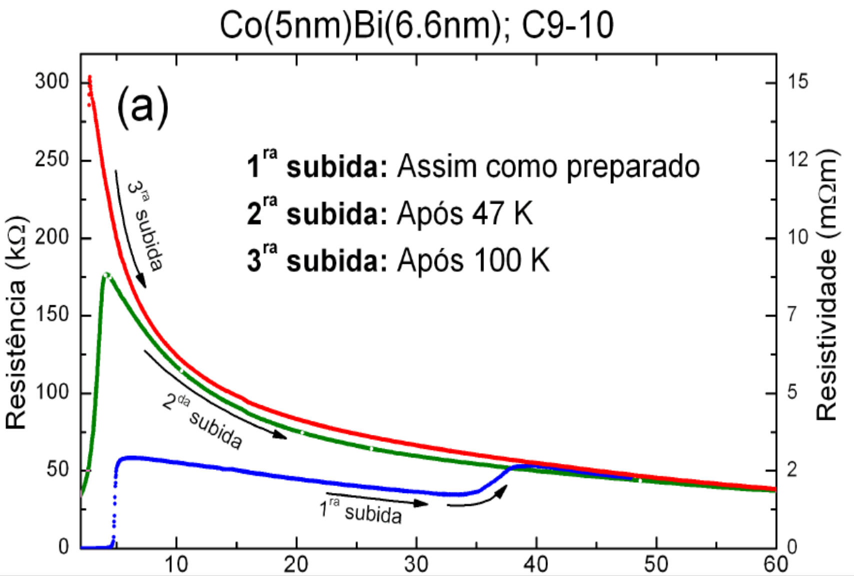
D. V. Haviland et. al., Phys. Rev. Lett. **62**, 2180 (1989)

Near QCP

$$R_\square = R_C \cdot F(|x - x_c| T^{-1/z\nu})$$

with $f(u) = 1$; $z\nu = 1.5$

for $u \to 0$; $T \to \infty$

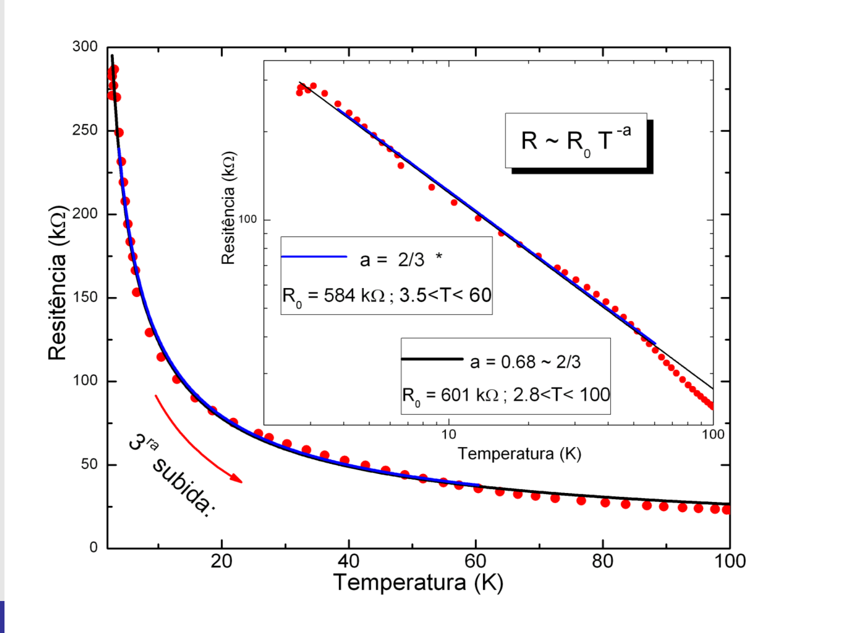


We have:

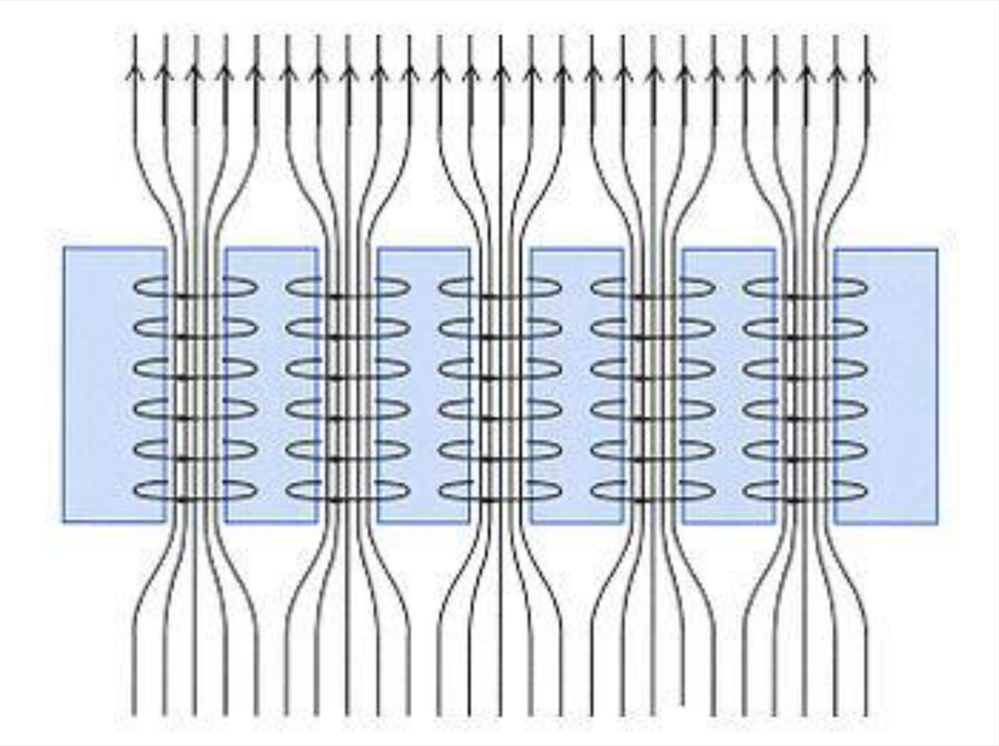
$$R_\square = R_C \cdot F(|x - x_c| T^{-2/3})$$

$$R_\square = R_0 \cdot T^{-2/3}$$??

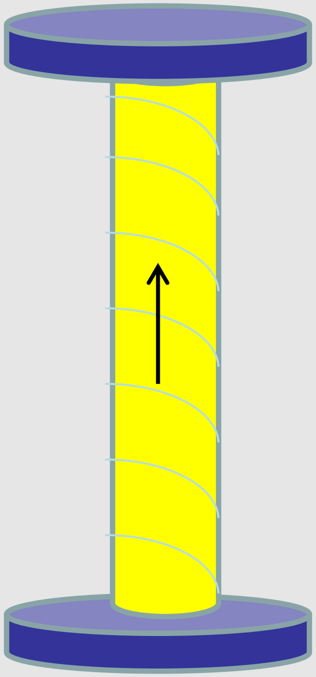
$$R_\square \to 0 \quad \text{for} \quad T \to \infty$$



Vórtices em supercondutores



Simplificação da Formação de Vórtice



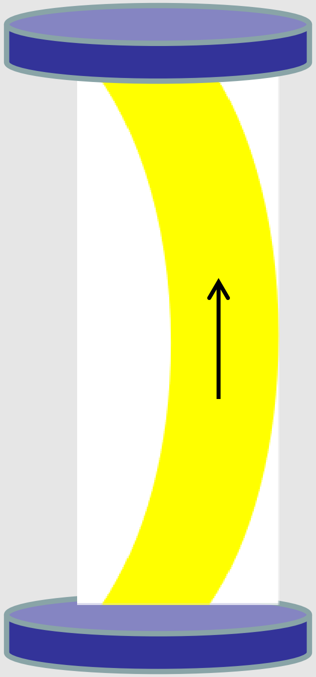
Fluxo Magnético - Φ

A nucleação de um vórtice é possível próximo a uma região magnética com momento magnético suficientemente forte.

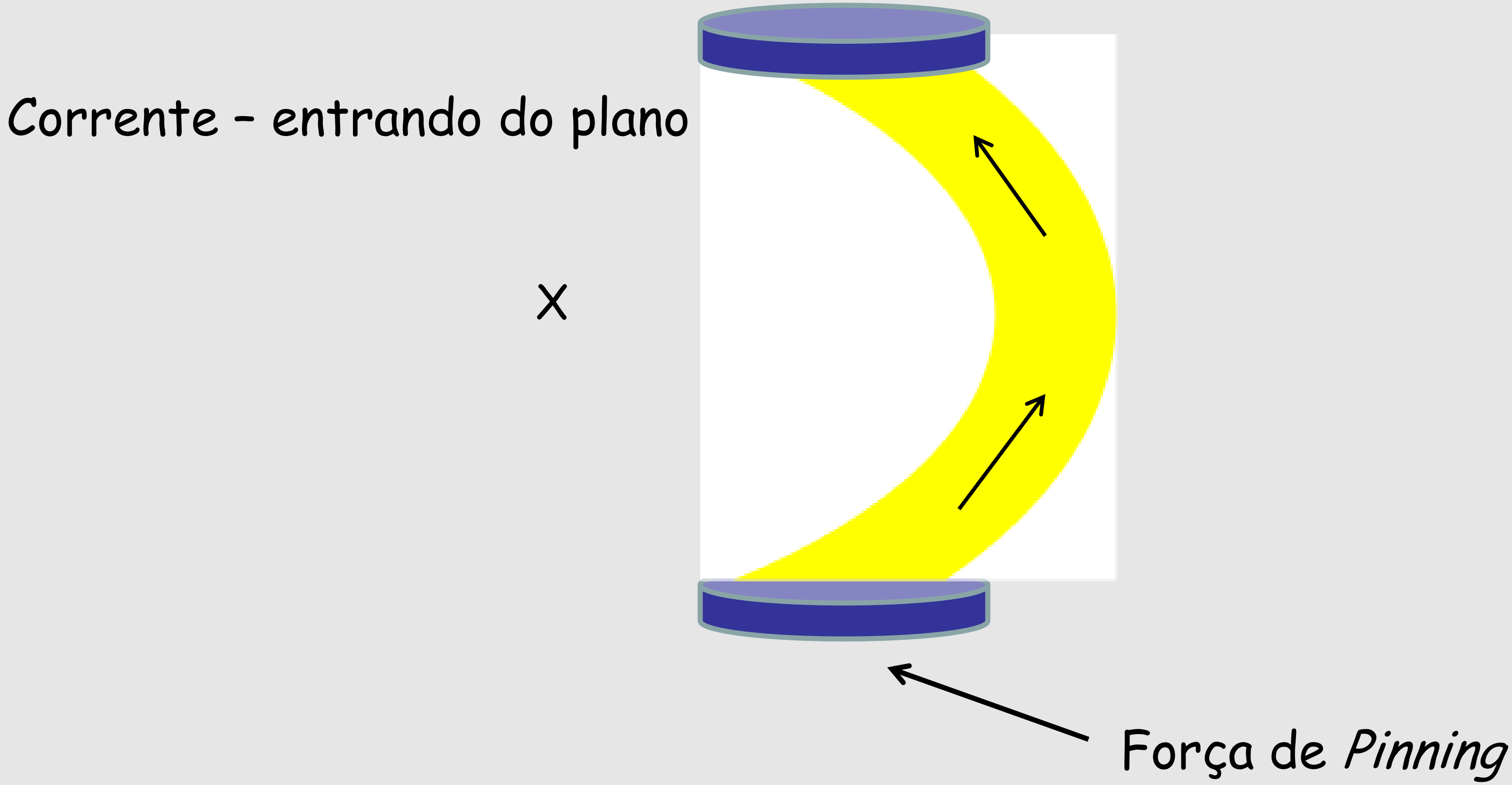
Dinâmica de Vórtice

Corrente – entrando do plano

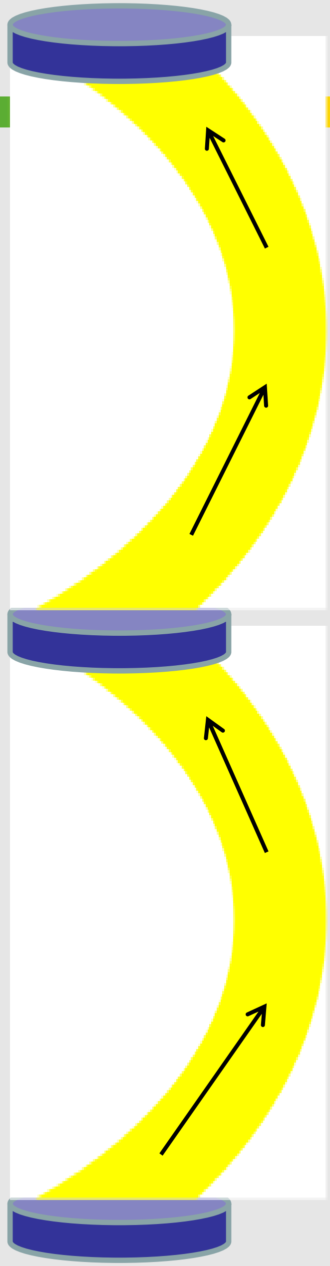
X



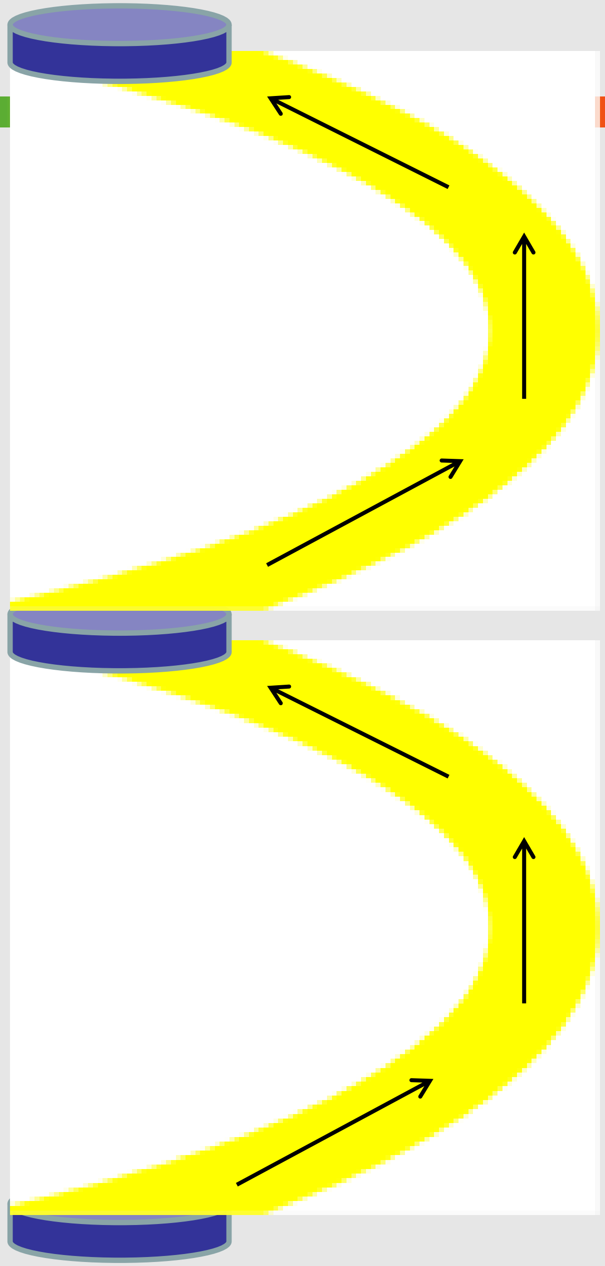
Dinâmica de Vórtice



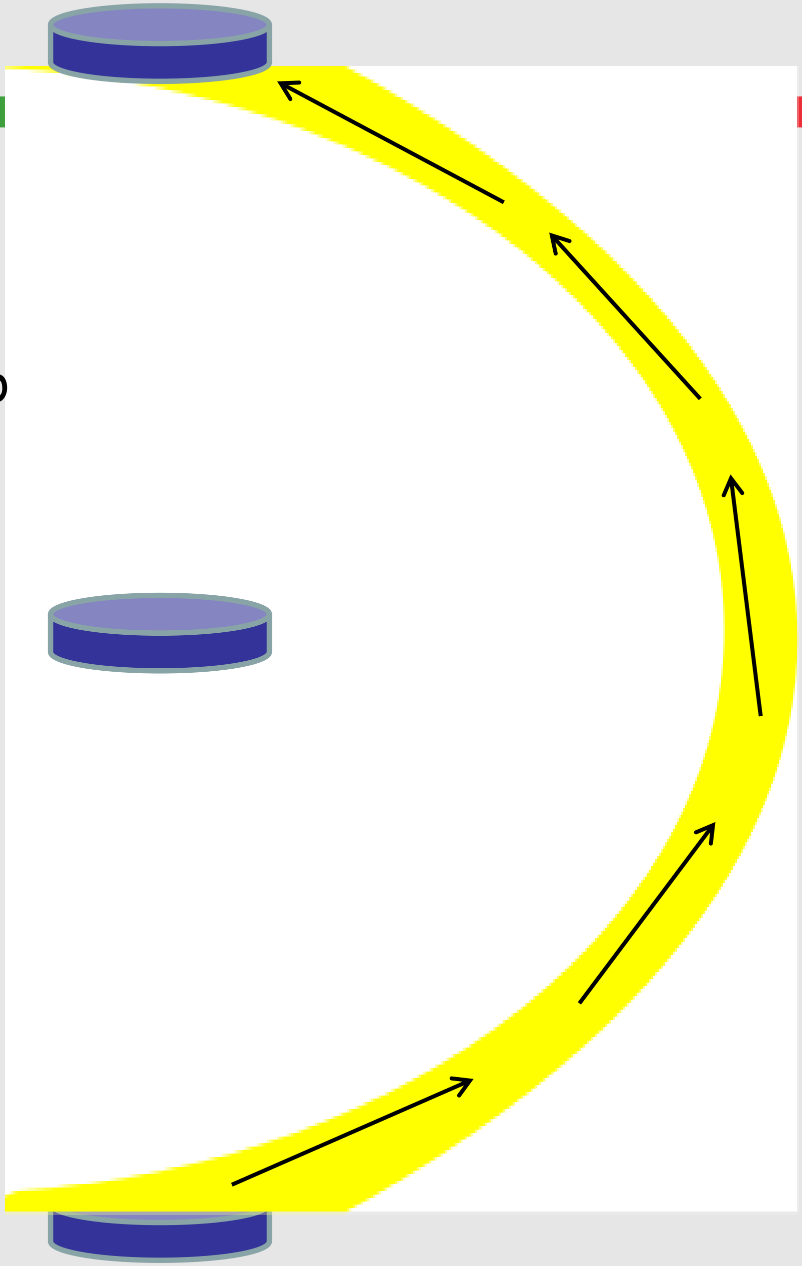
Corrente – entrando do plano

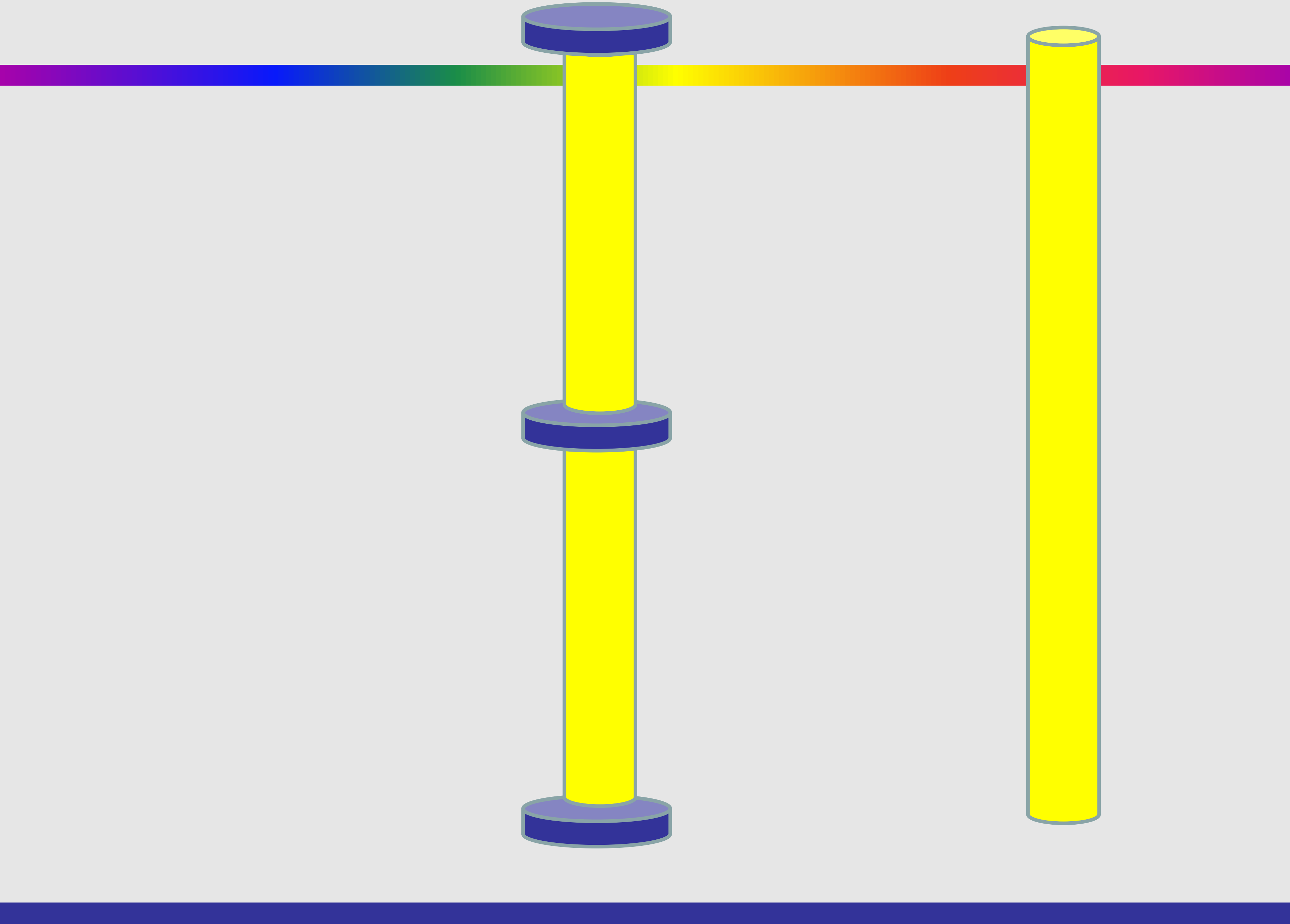


Corrente – entrando do plano

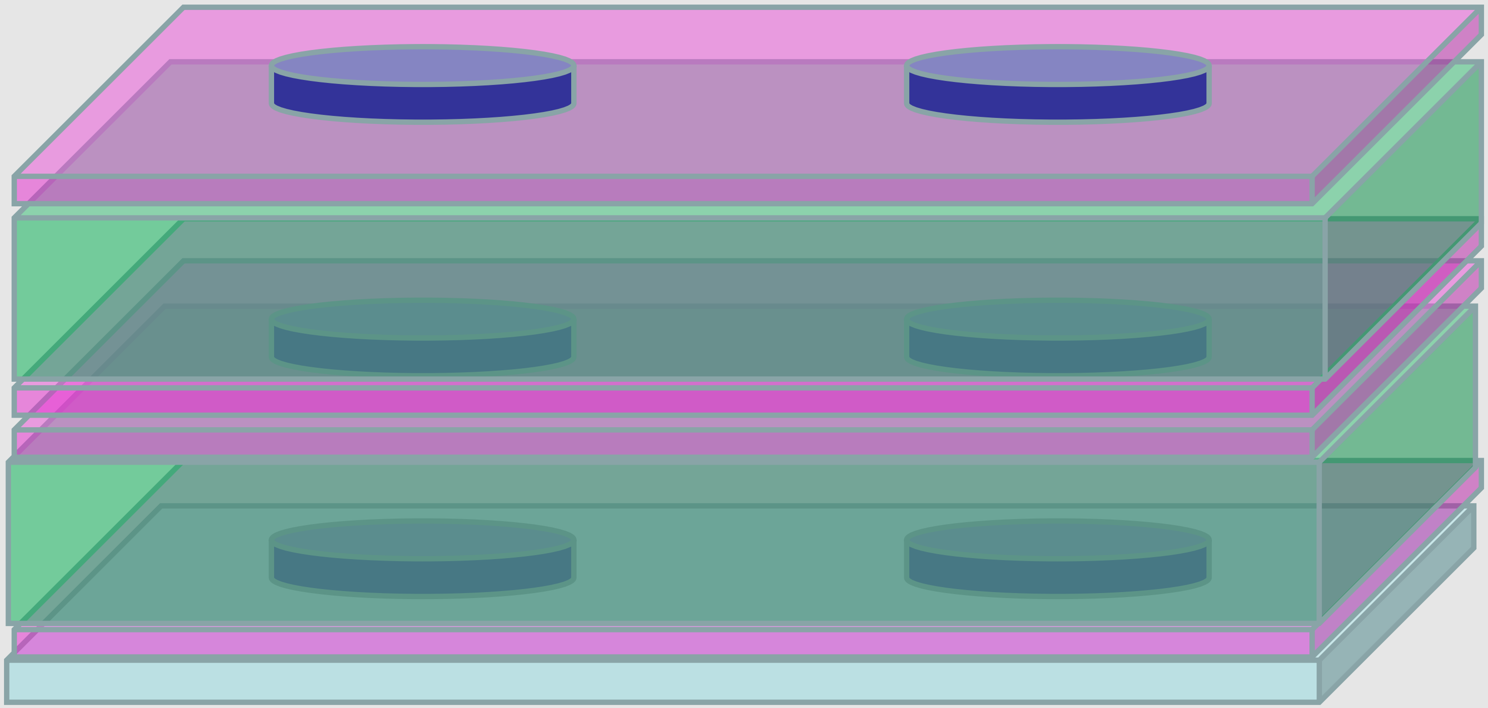


Corrente – entrando do plano

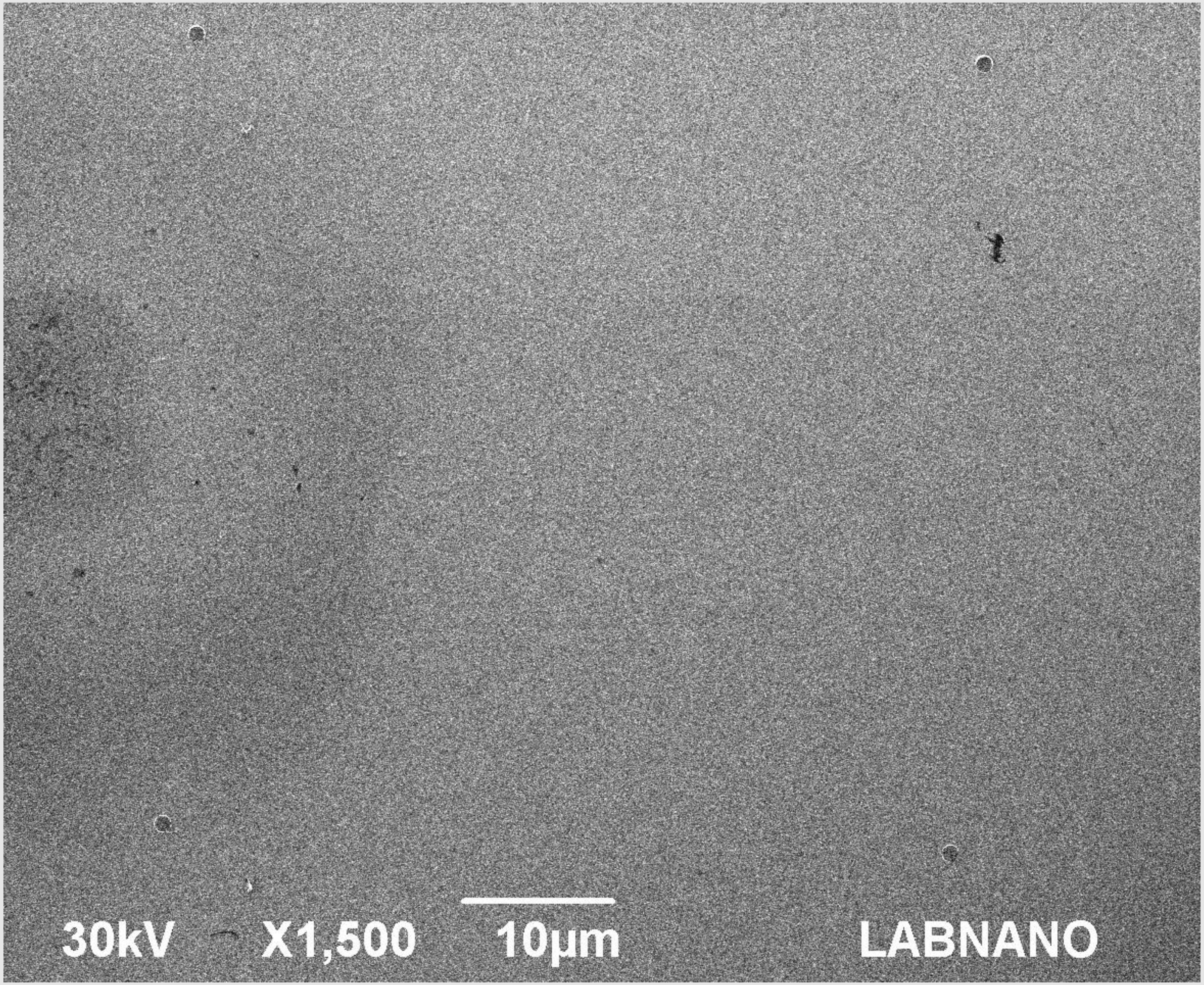




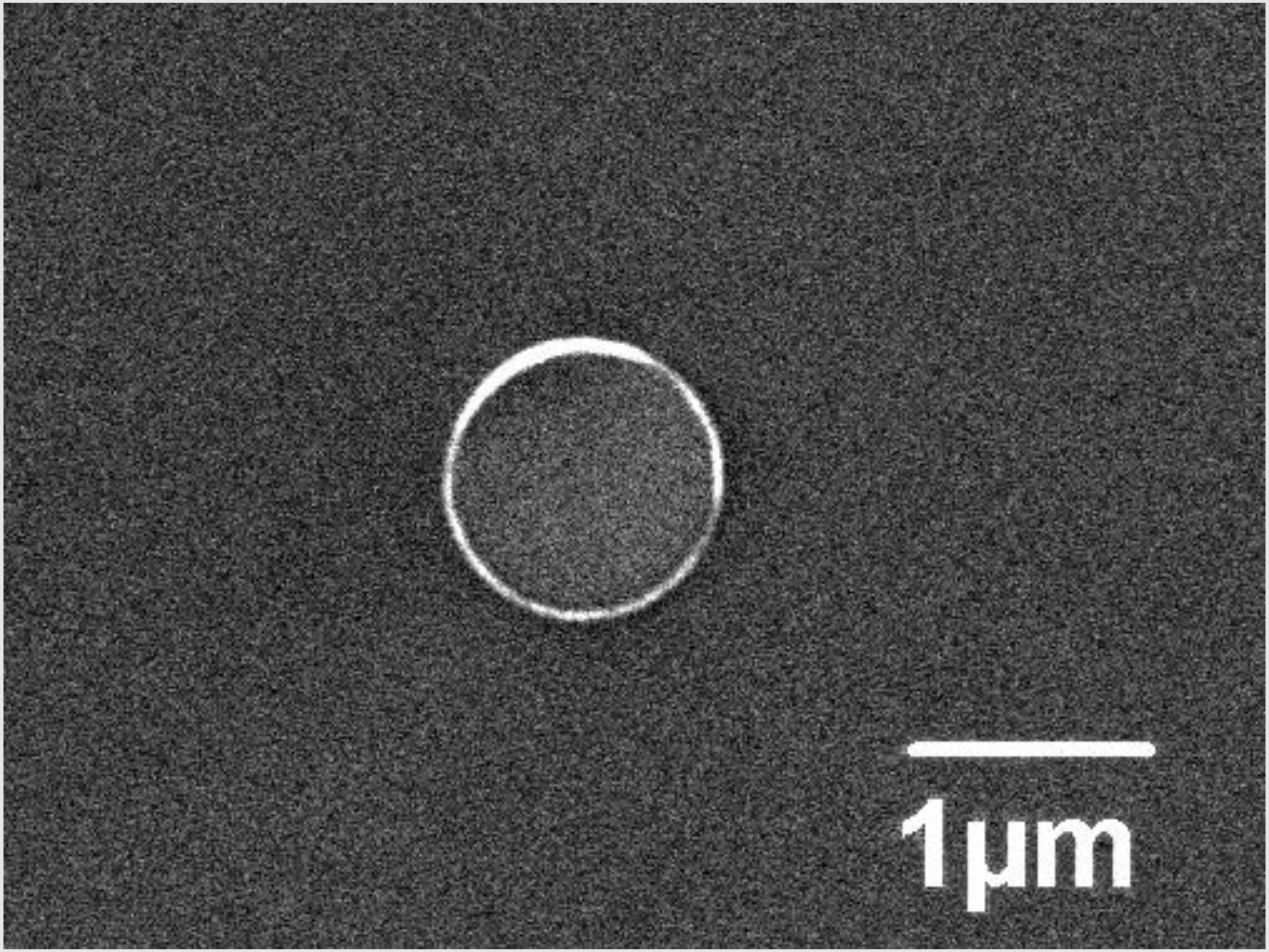
Sample structure



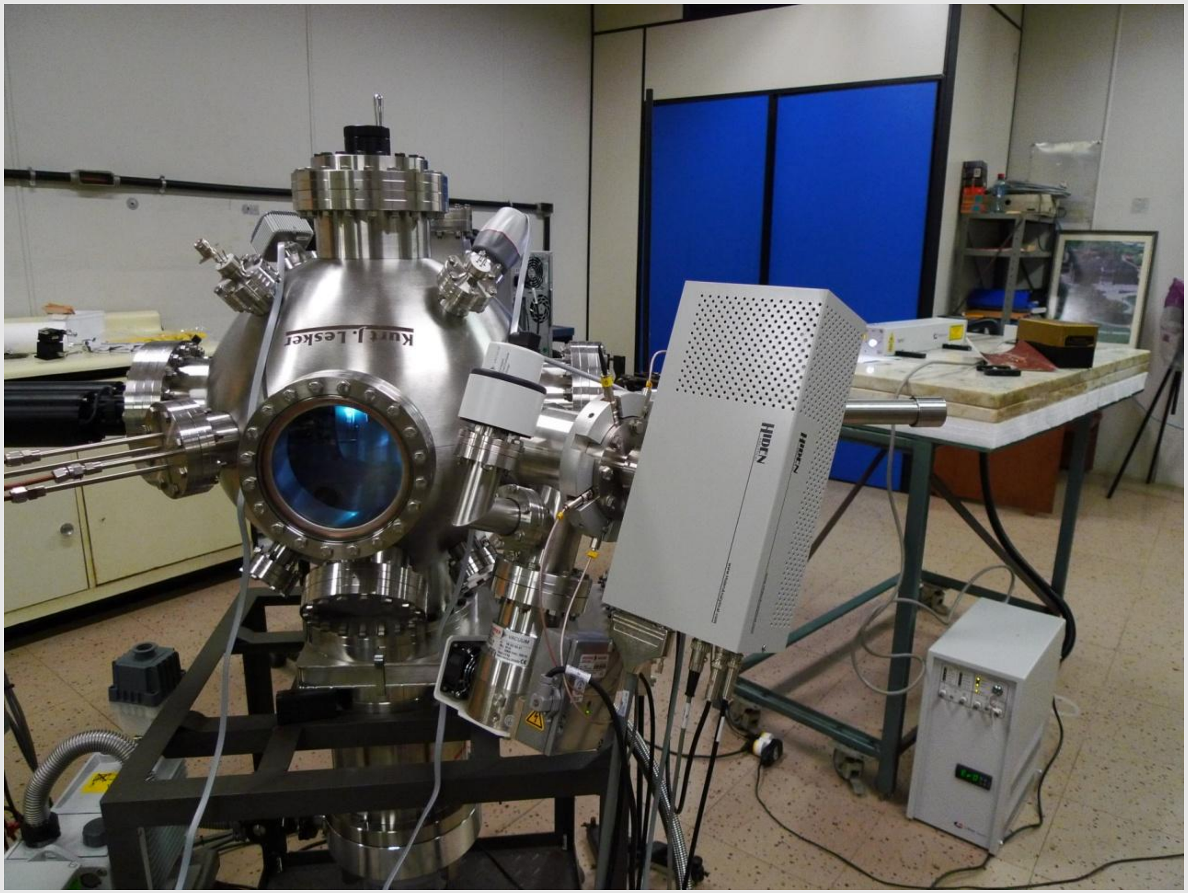
Nanodisk of NiFe



Nanodisk of NiFe



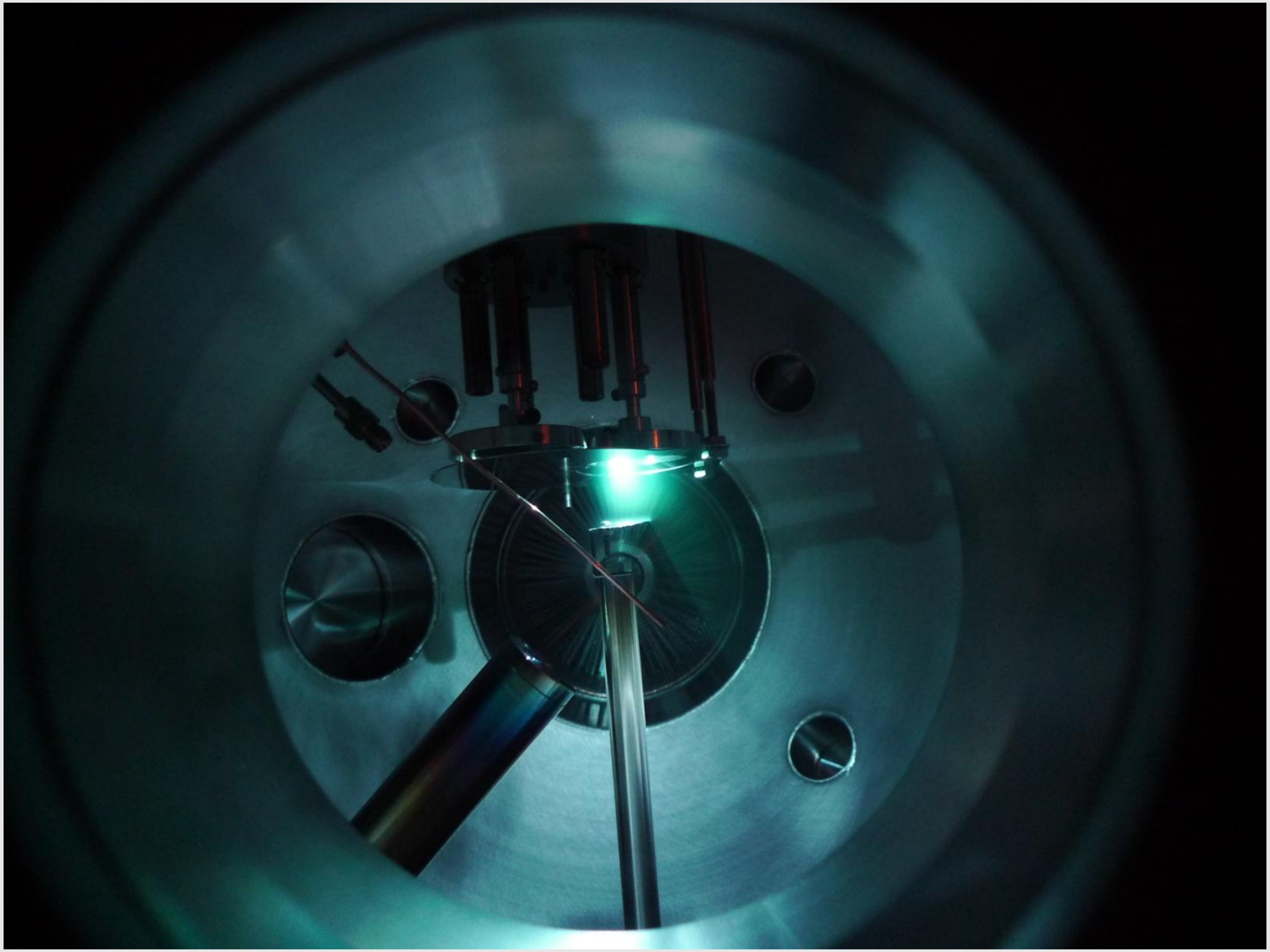
Laser ablation system



Presure:
$3x10^{-7}$ torr in one hour

Laser system:
600 mJ

Ni Plasma

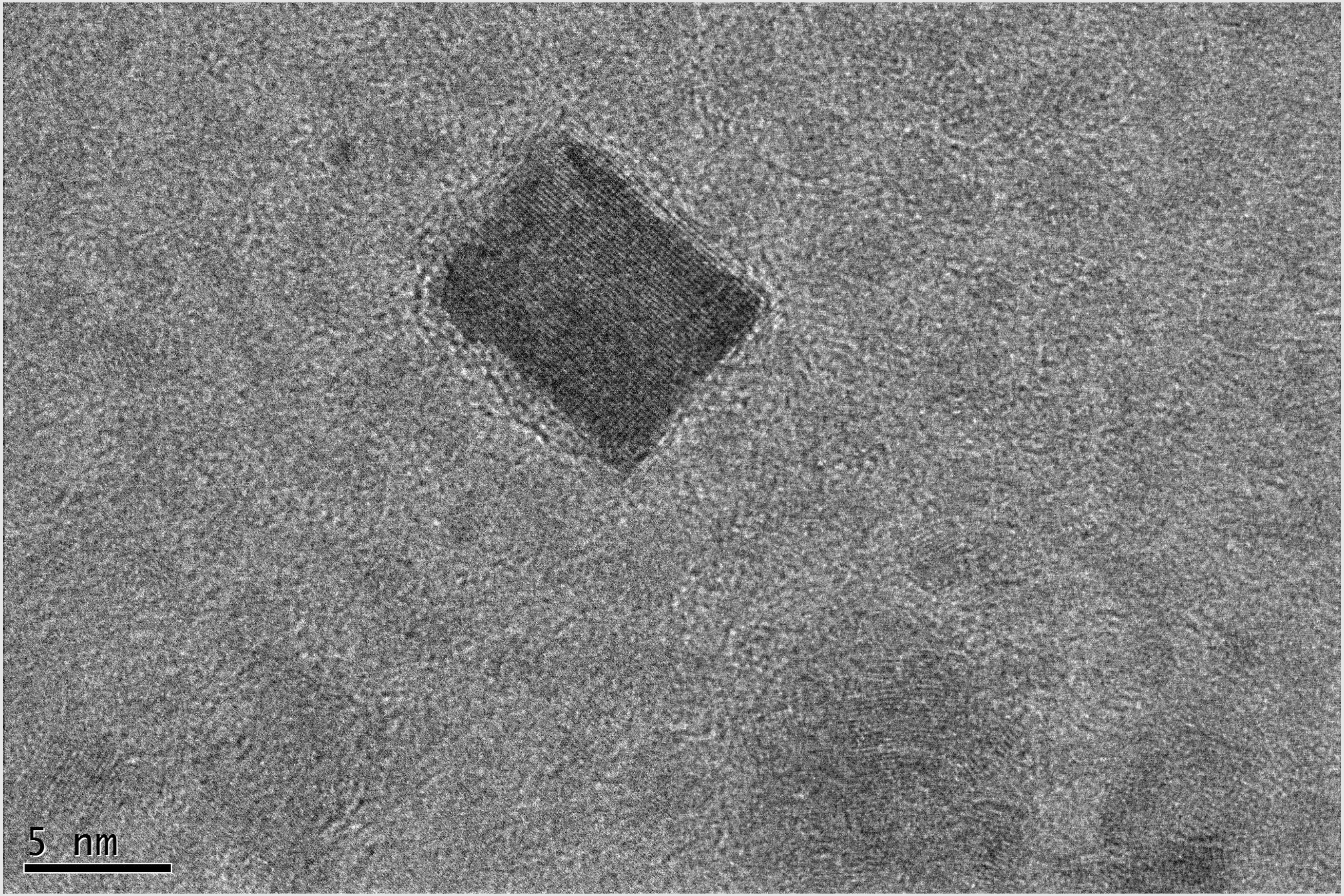


Sample preparation

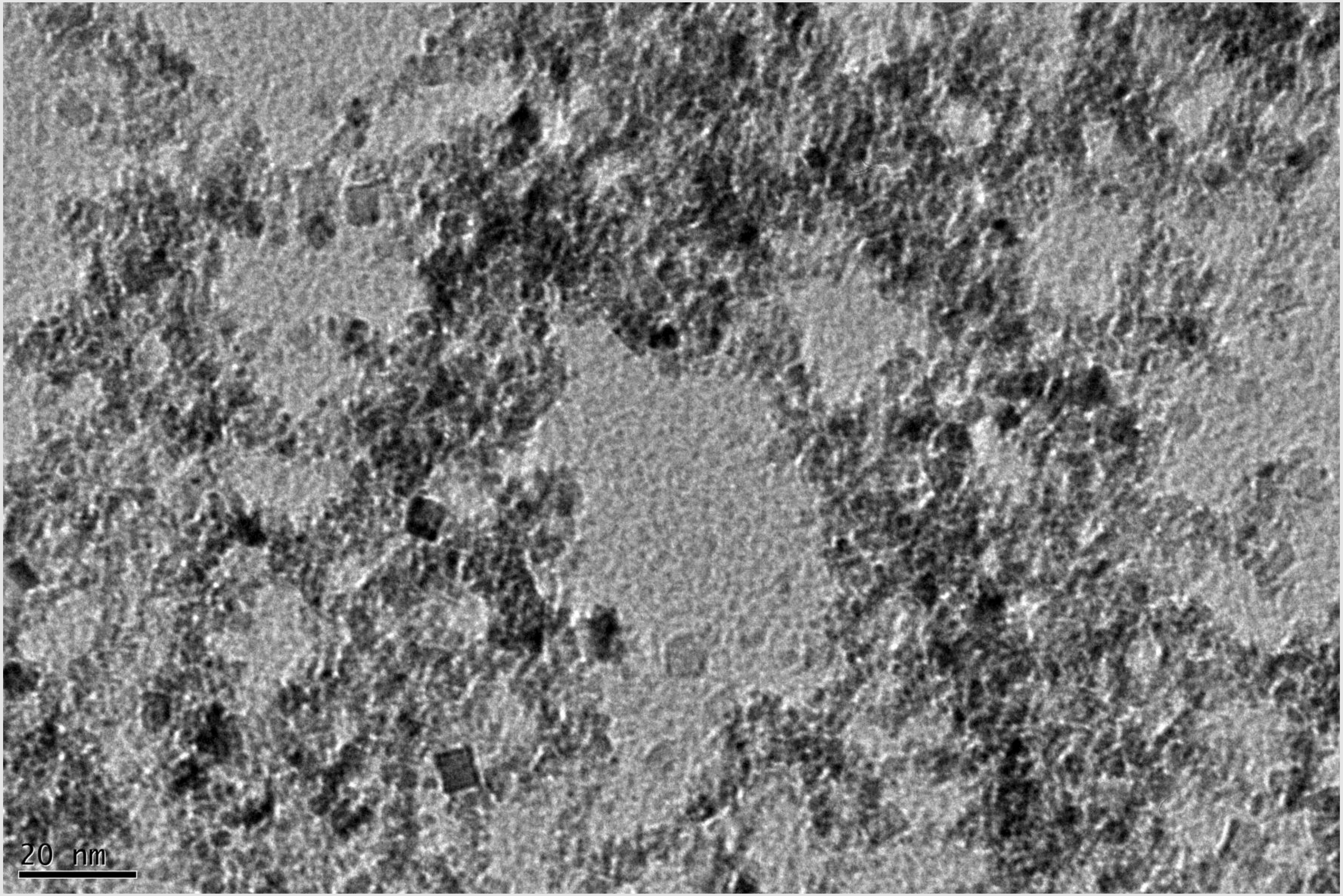
Thin films: in vacuum

Nanoparticles: in Ar with a pressure of 1 torr

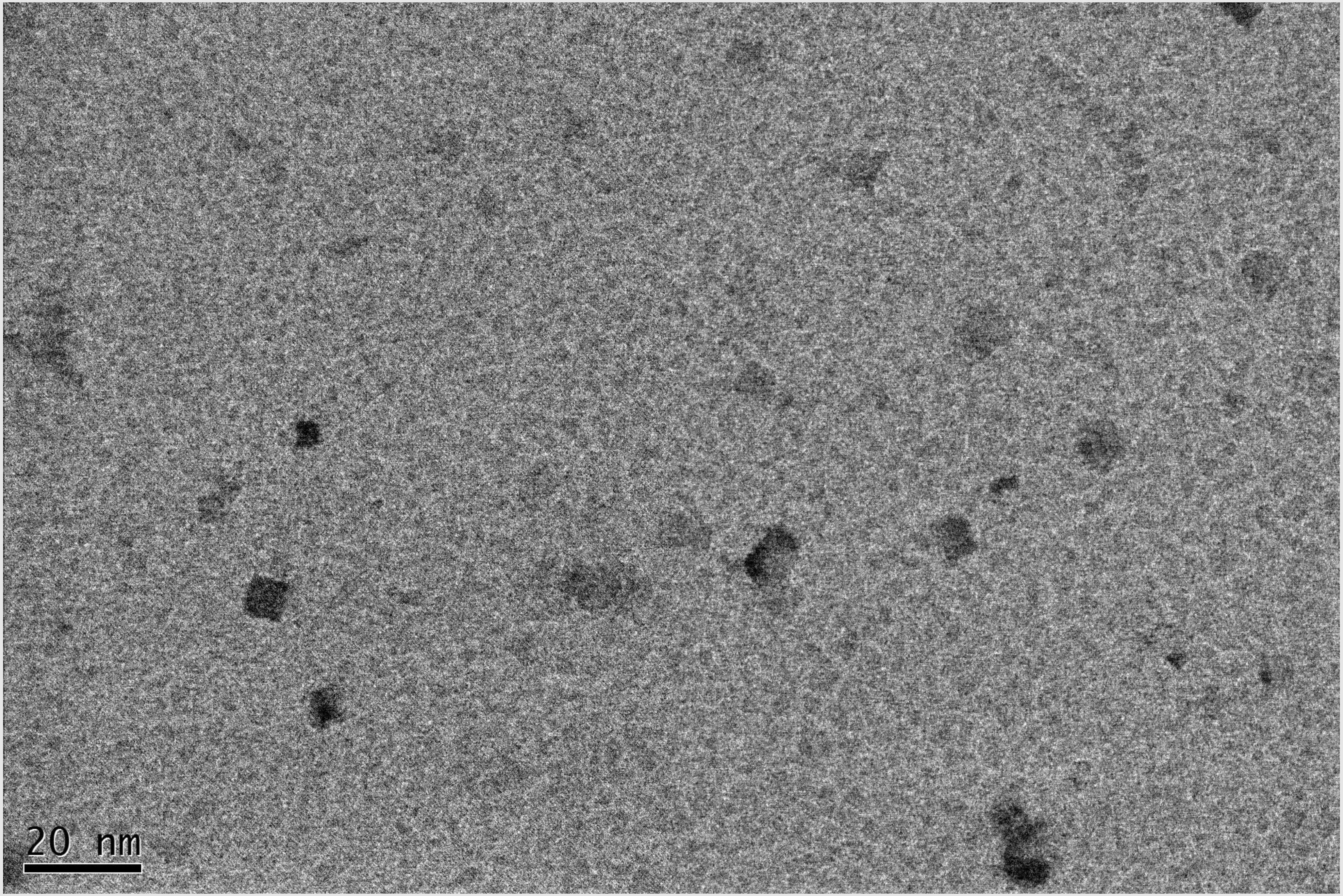
Ni nanoparticles prepared in Ar



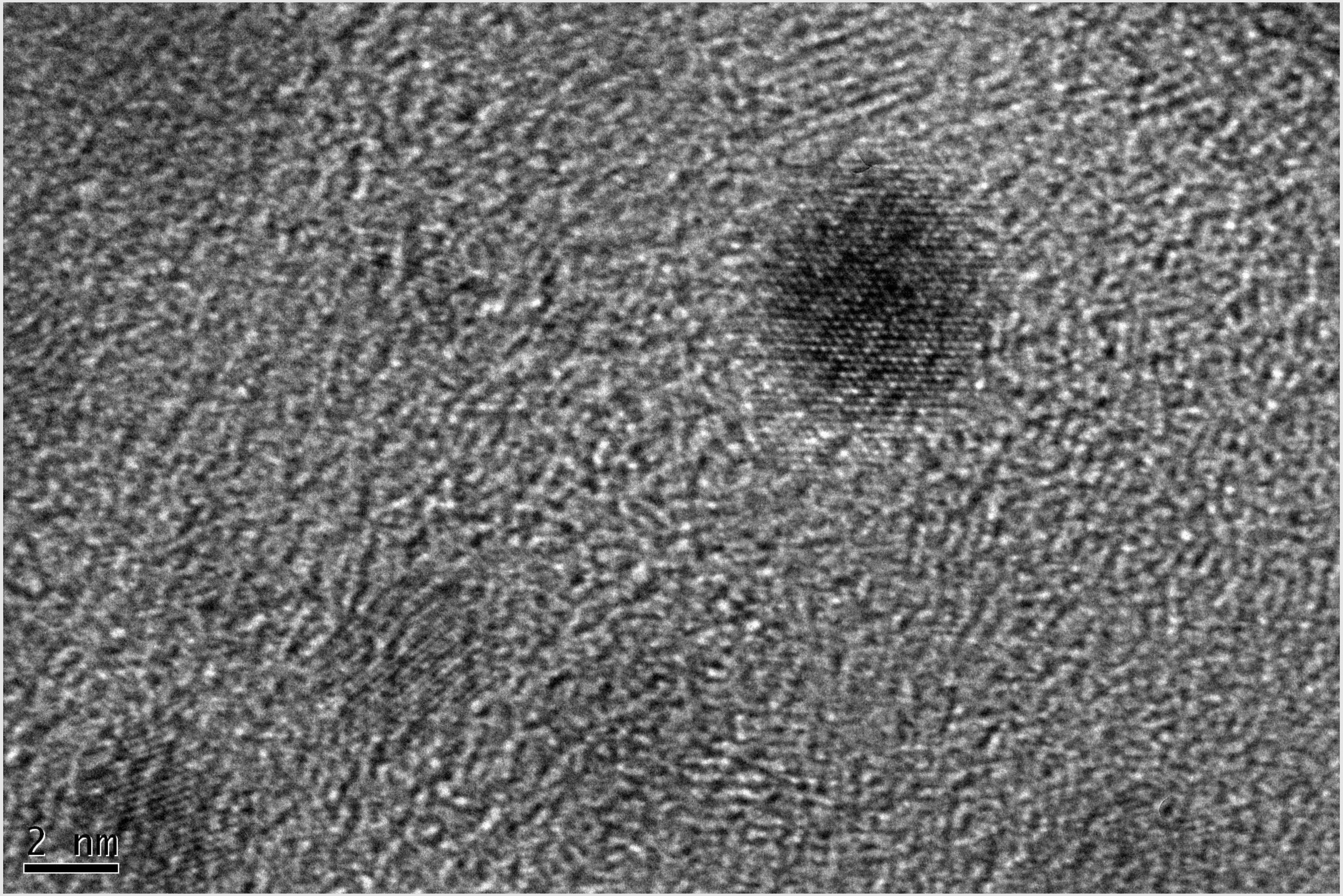
Ni nanoparticles prepared in Ar



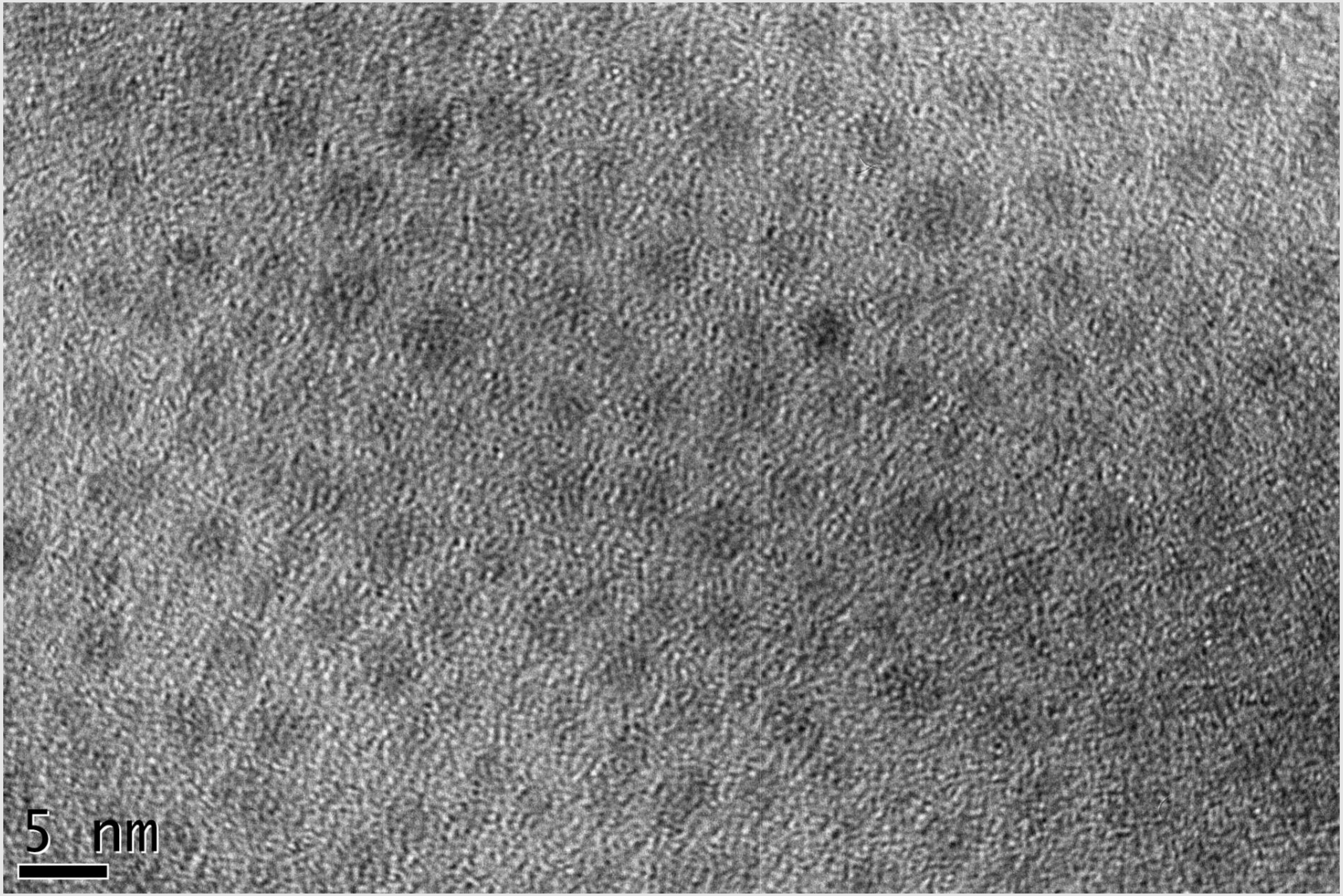
Ni nanoparticles prepared in Ar



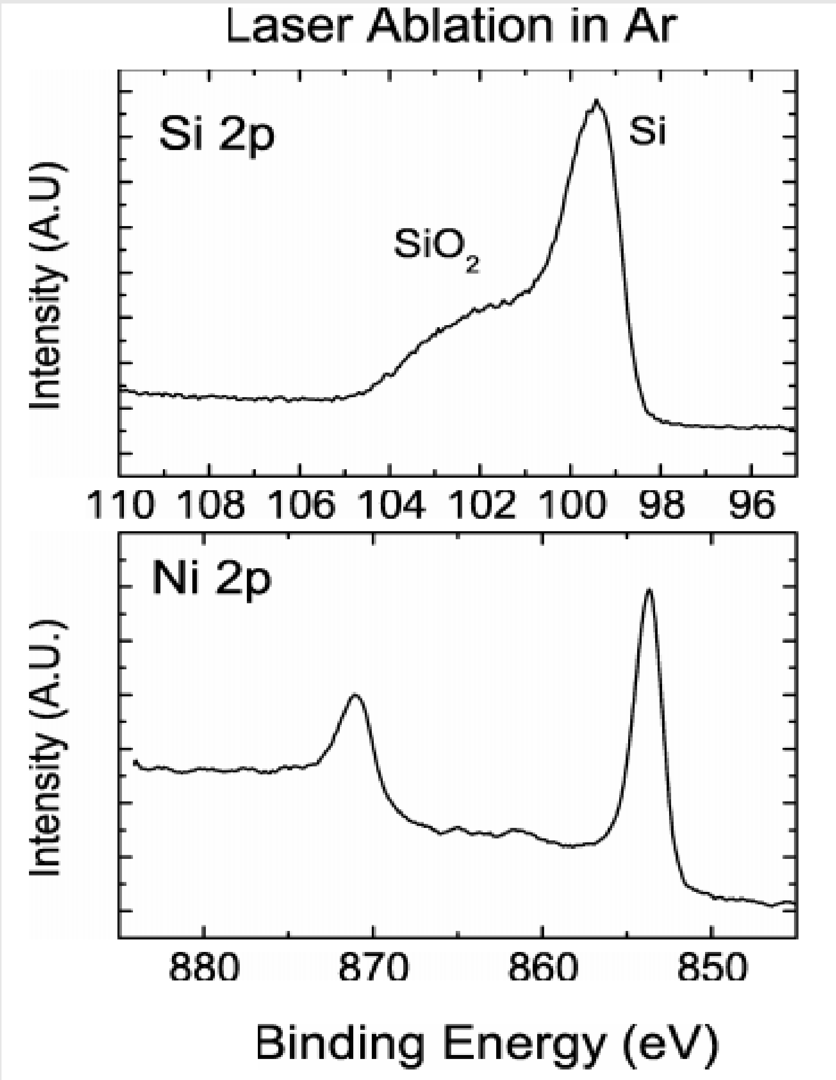
Ni nanoparticles prepared in O_2

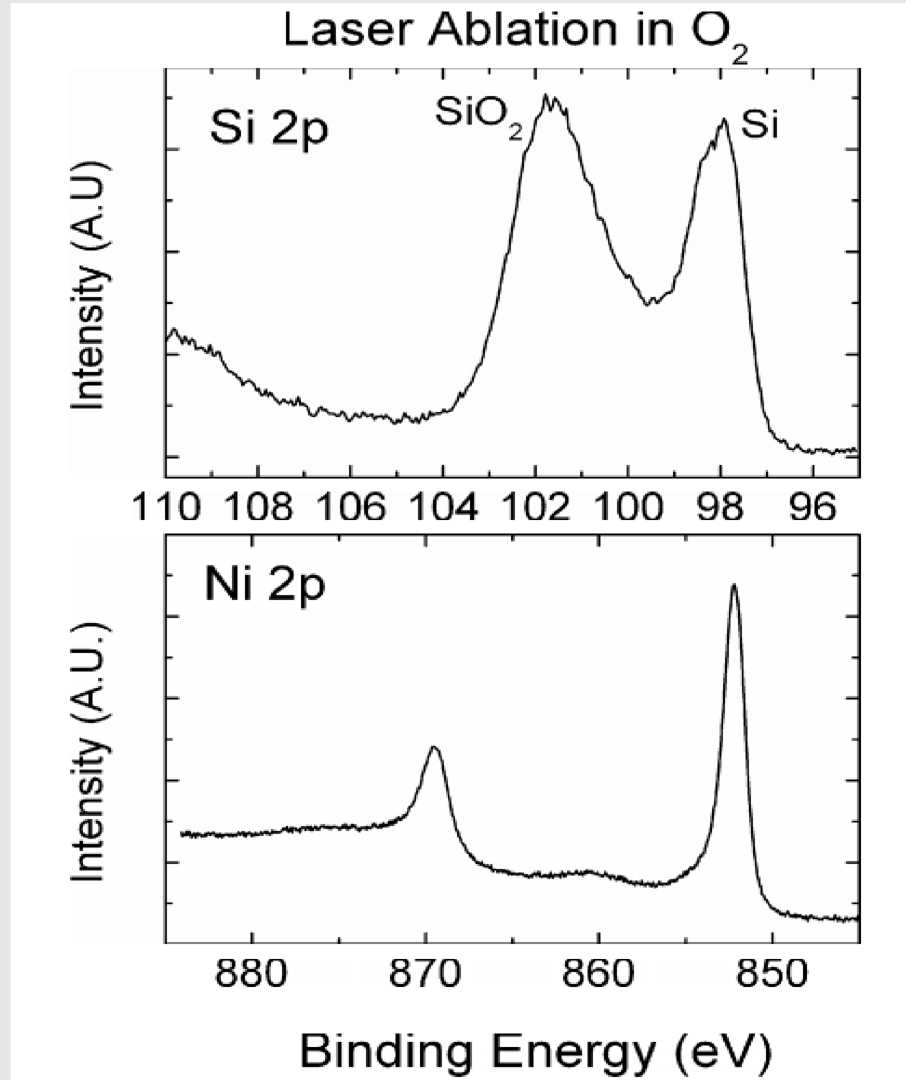


Ni nanoparticles prepared in O_2

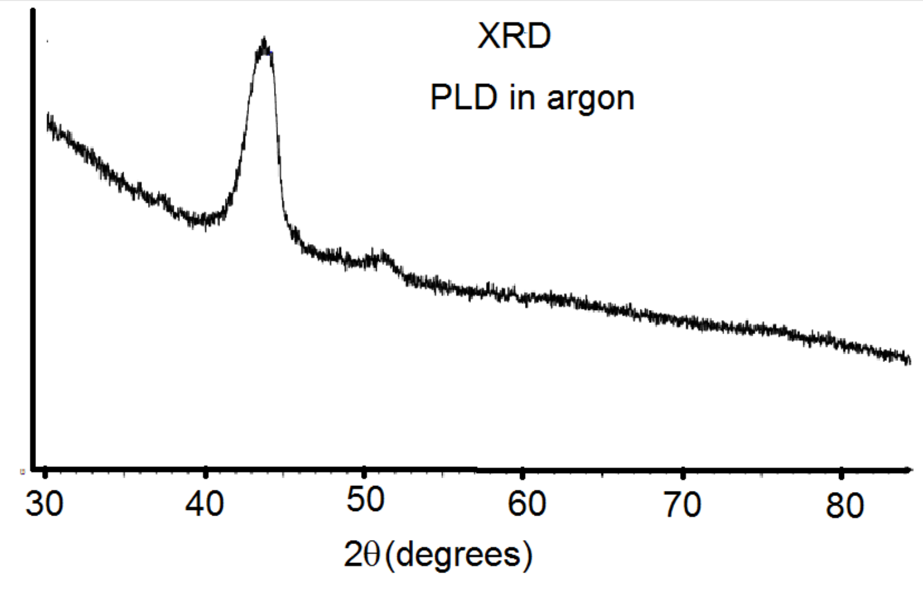


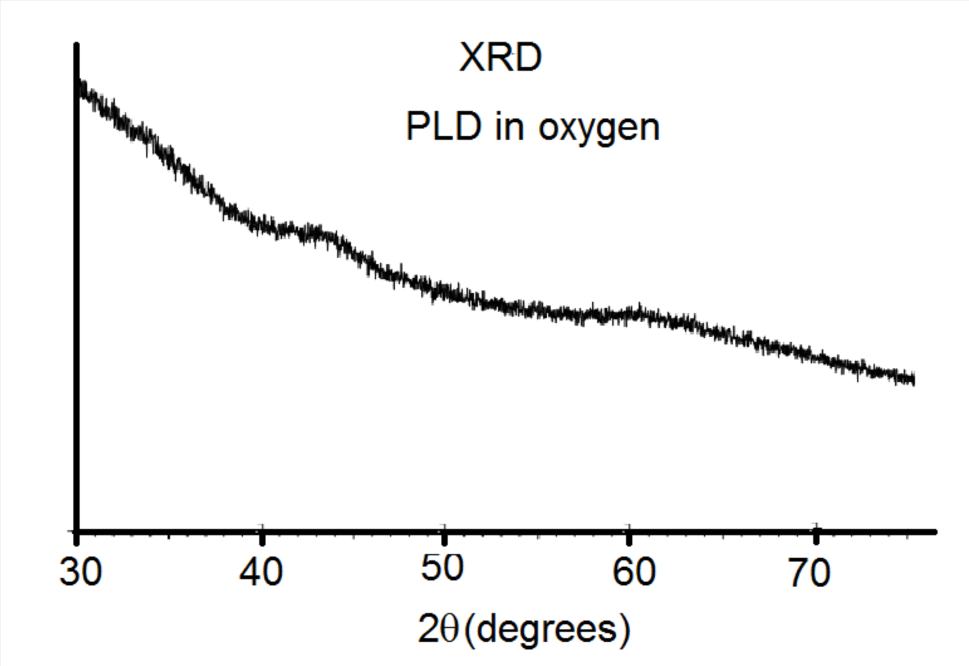
XPS spectra of Ni nanoparticles



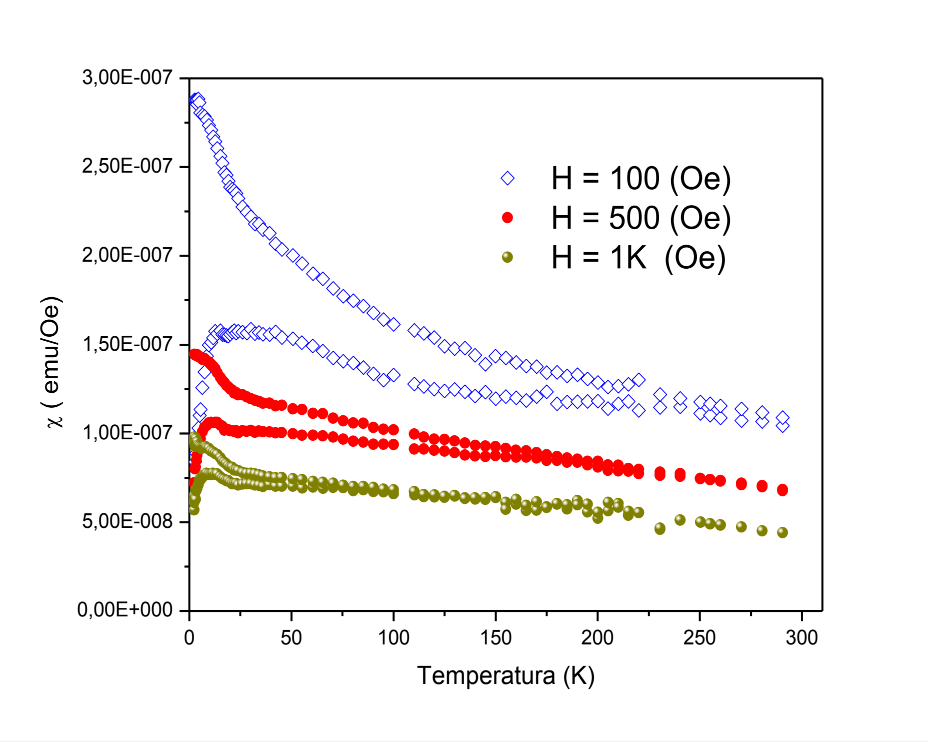


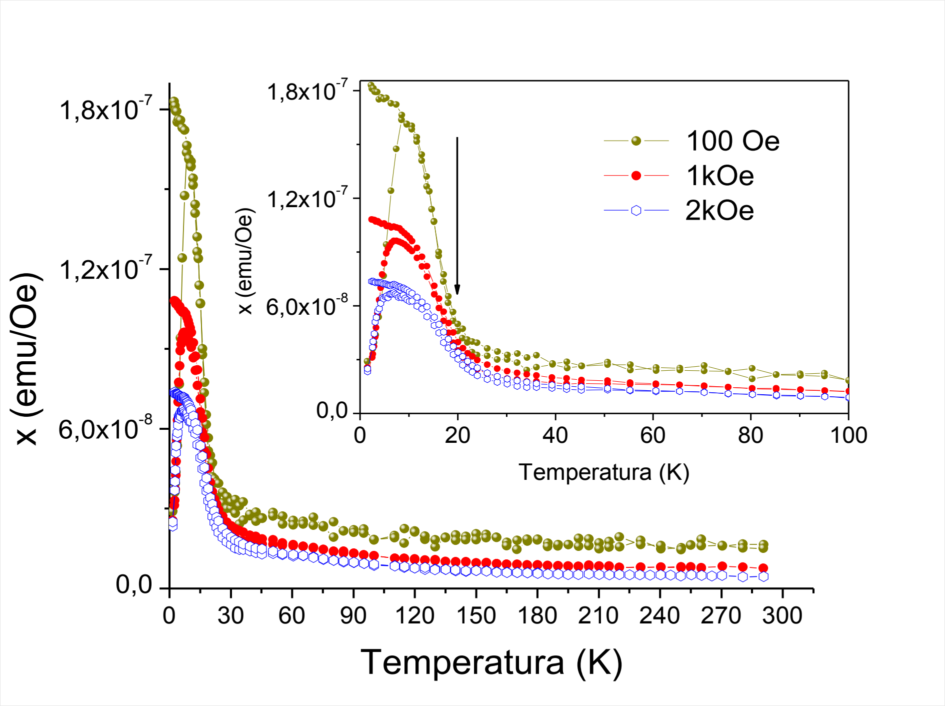
XRD of Ni nanoparticles



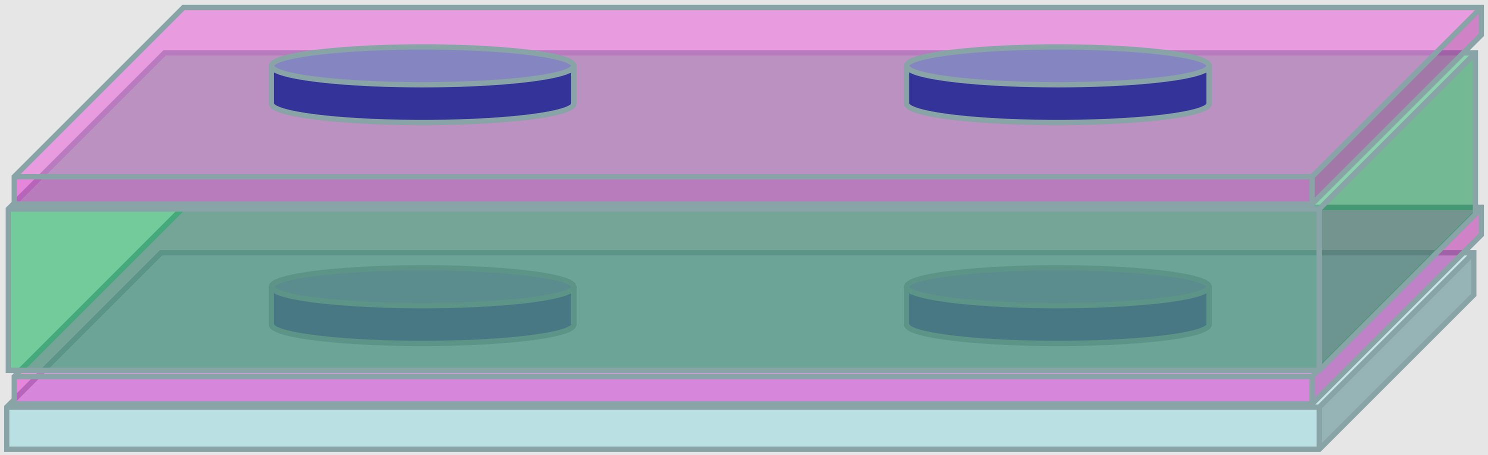


Magnetic susceptibility

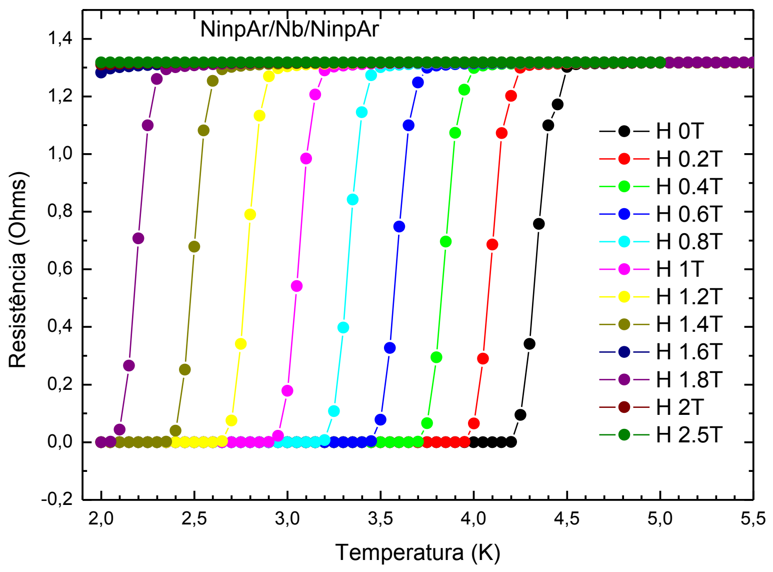


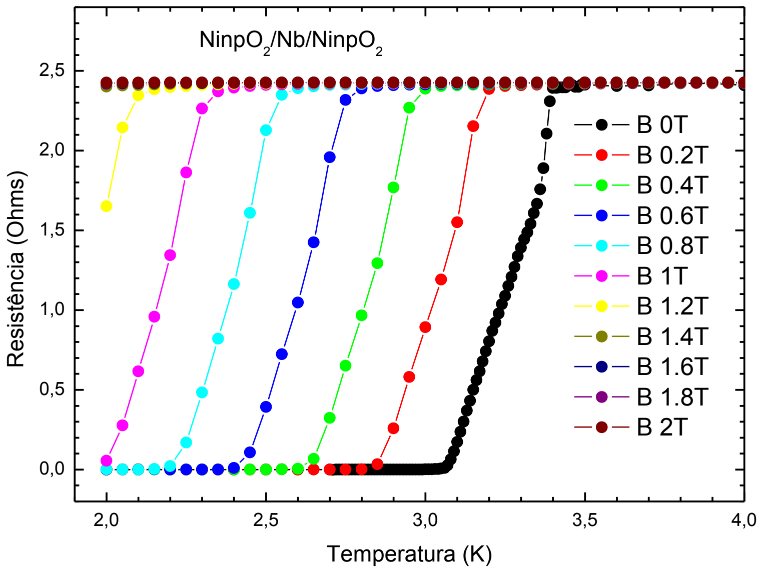


Sample prepared

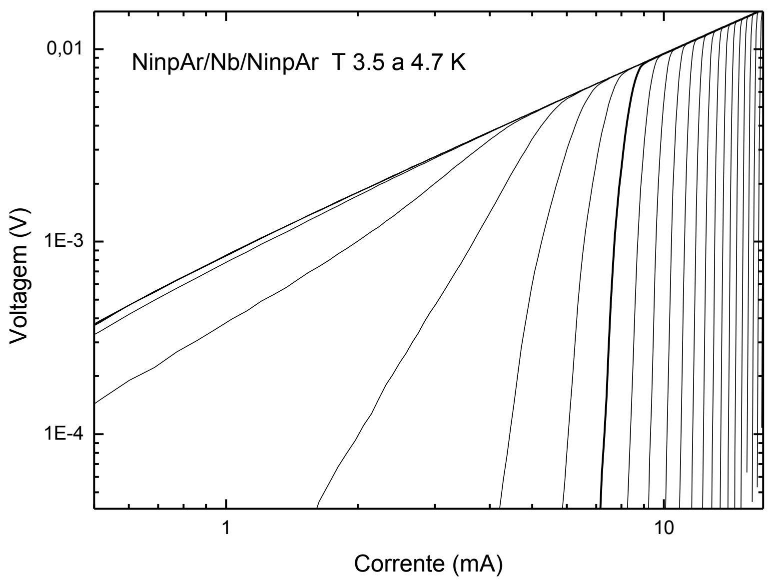


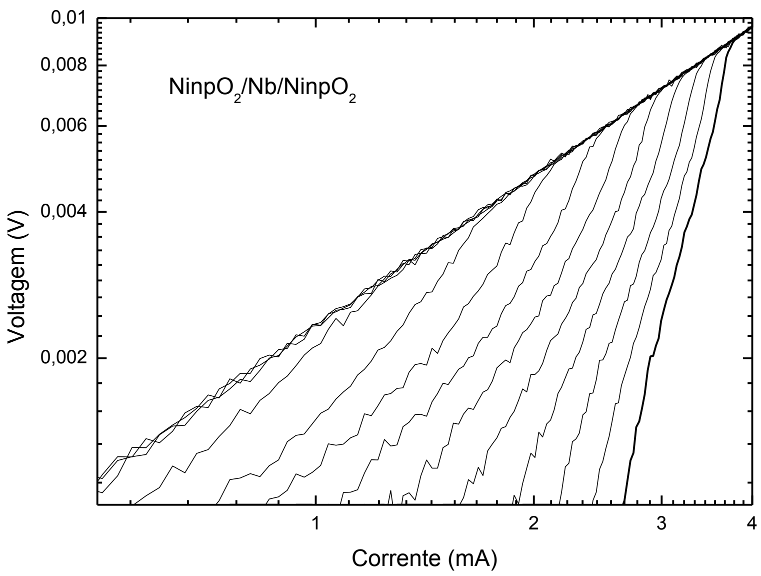
Transporte meausrements





Transporte meausrements





Magnetic measurements

SQUID

From Google Image:

Magnetic measurements

SQUID em Português:

Lula

Na google Imagem:


Obrigado!

Work at IF-UFF