

In-plane anisotropy of the critical current density in detwinned Co-doped Ba122 single crystals

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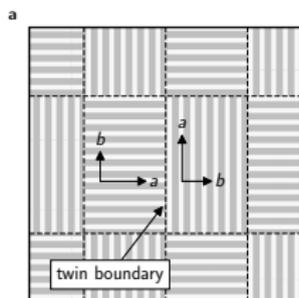
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Focus of this study:

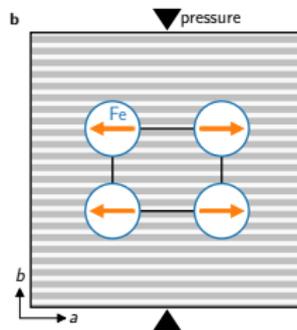
- ▶ Effect(s) of twin boundaries on critical current density (J_c) of $\text{Ba}(\text{Fe}_{1-x}\text{Co}_x)_2\text{As}_2$
 - ▶ Difference between **twinned** and **detwinned** state

What are twin boundaries?

- ▶ Structural transition: tetragonal to orthorhombic
 - ▶ Twin domains with alternating *a* and *b*-axis orientation
- ▶ Detwinning
 - ▶ Applying a small **uniaxial pressure**

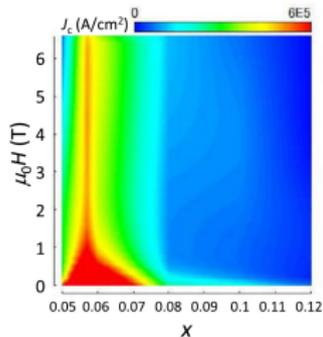


Twinned crystal.



Detwinned crystal.

Effects observed in twinned and detwinned crystals:

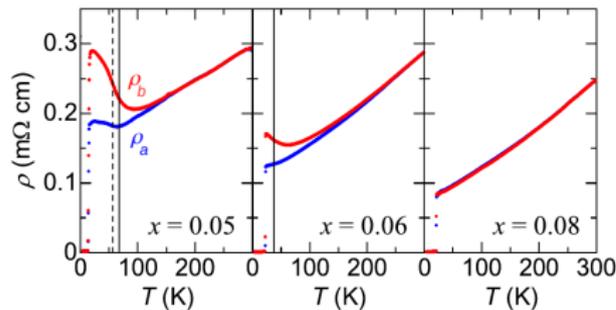


J_c -peak (twinned).

Ishida *et al.* PRB **95**, 014517 (2017).

Resistive anisotropy (detwinned).

Ishida *et al.* PRL **110**, 207001 (2013).



Open questions:

- ▶ What is the origin of the J_c -peak?
- ▶ How does the anisotropy develop into the superconducting phase?

Introduction

Twin Domains

Co-Ba122

Scanning
Hall-probe
Microscopy

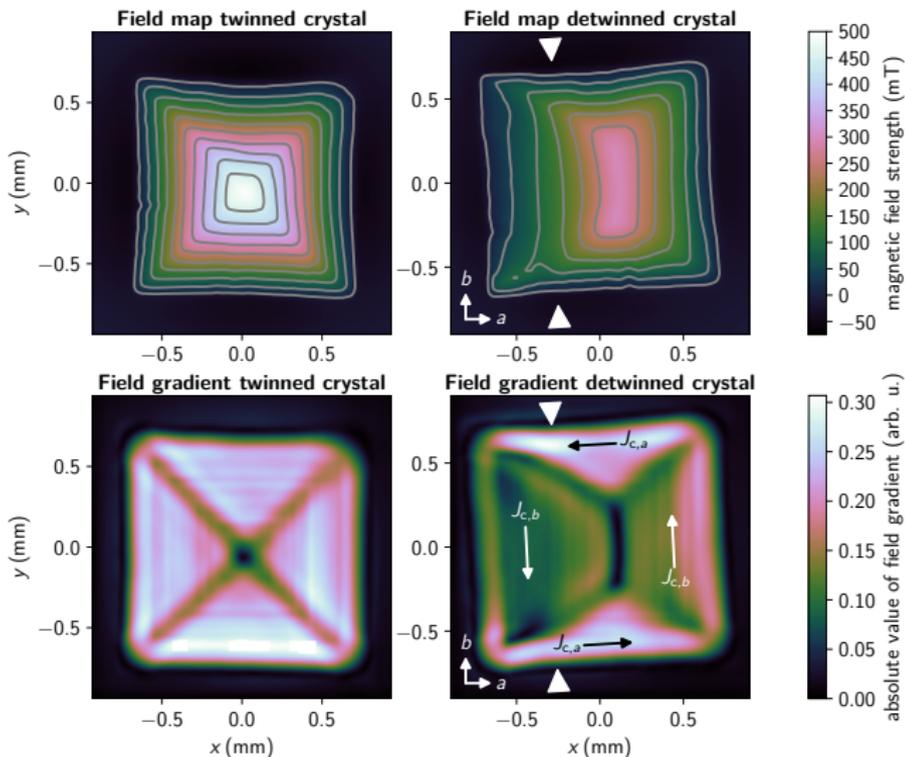
Field Maps
Evaluation

Discussion

J_c -Peak

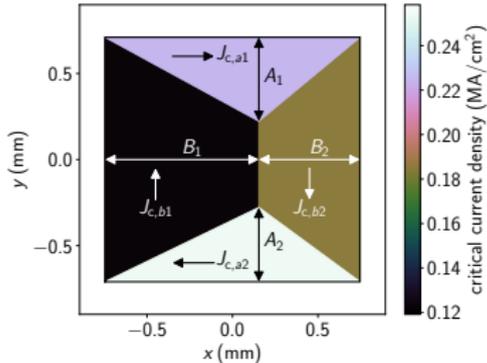
J_c -Anisotropy

Summary

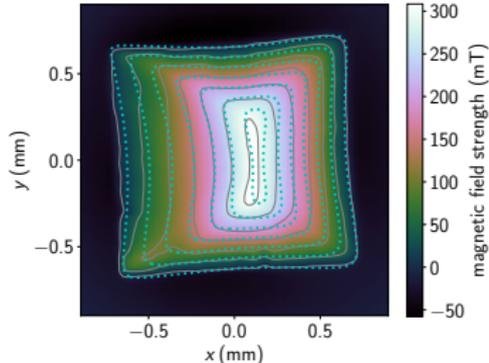


Remanent field profile of single crystalline $\text{Ba}(\text{Fe}_{0.95}\text{Co}_{0.05})_2\text{As}_2$ at 5 K.

Detwinned $\text{Ba}(\text{Fe}_{0.95}\text{Co}_{0.05})_2\text{As}_2$ crystal at 5 K.



Simplified J_c distribution.



Comparison fit \leftrightarrow field profile.

- ▶ 4 parts with invariant J_c
 - $J_{c,a}$: J_c parallel a -axis (top and bottom)
 - $J_{c,b}$: J_c parallel b -axis (left and right)

J_c -anisotropy:

$$\frac{J_{c,b}}{J_{c,a}} = \frac{(J_{c,b1} + J_{c,b2})/2}{(J_{c,a1} + J_{c,a2})/2}$$

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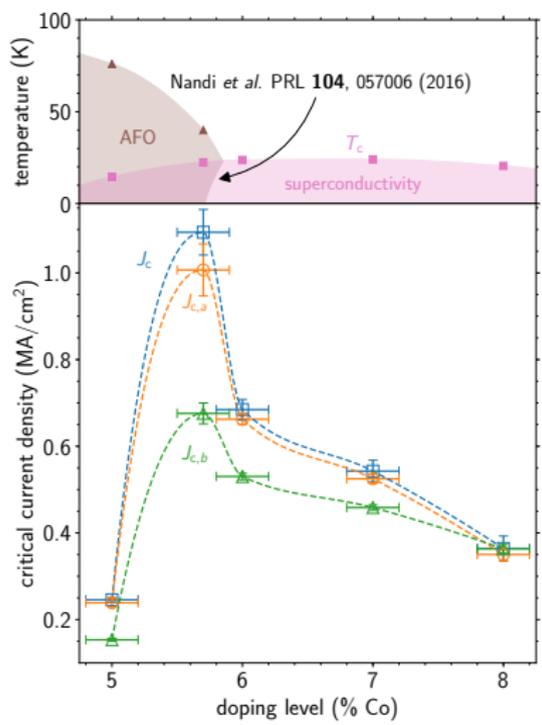
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J_c -Anisotropy

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Ba(Fe_{1-x}Co_x)₂As₂ at 5 K.

J_c depends on Co concentration

Distinct peak

Higher J_c :

- ▶ **Number:** more pinning centers (twin boundaries?)
- ▶ **Efficiency:** pinning energy/force

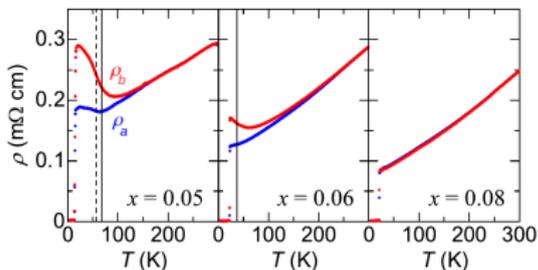
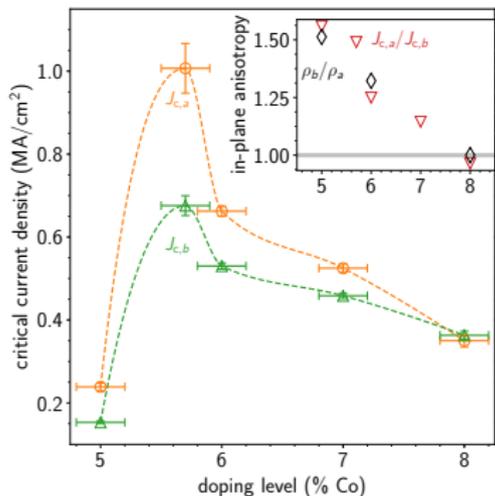
Detwinning:

- remove pinning sites
- ⇒ J_c should decrease

We find:

- ▶ J_c still enhanced in detwinned state
- ⇒ other mechanism

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J_c and ρ -anisotropy:

Experimental:

$$\frac{J_{c,a}}{J_{c,b}} \approx \frac{\rho_b}{\rho_a}$$

Theoretical (dirty limit):

$$\frac{\lambda_b}{\lambda_a} = \frac{J_{c,a}}{J_{c,b}} \sim \left(\frac{\rho_b}{\rho_a} \right)^{1/2}$$

Superconducting state:

Ginzburg-Landau theory

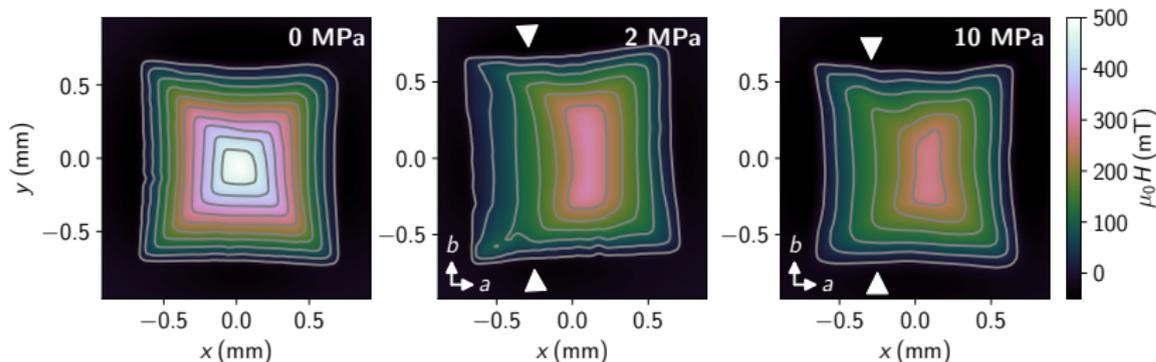
$$J_d \sim H_c/\lambda \text{ and } J_c = \eta J_d$$

$$J_{c,a}/J_{c,b} = \lambda_b/\lambda_a$$

Correlation to normal state:

$$1/\lambda^2 \sim 2\Delta/\rho \quad (\text{dirty limit})$$

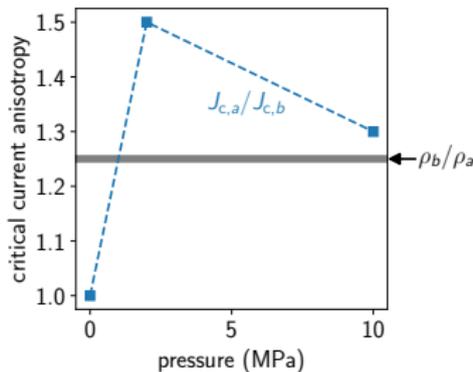
Anisotropy depends strongly on the applied pressure.



We could explain our data if the crystal experienced

- ▶ slightly smaller OR
- ▶ significantly larger pressure

during the resistivity measurement.



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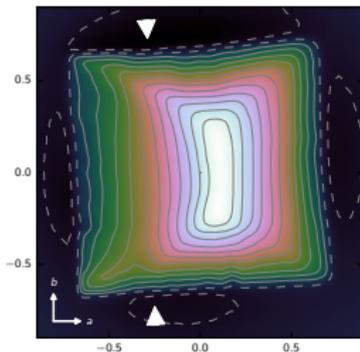
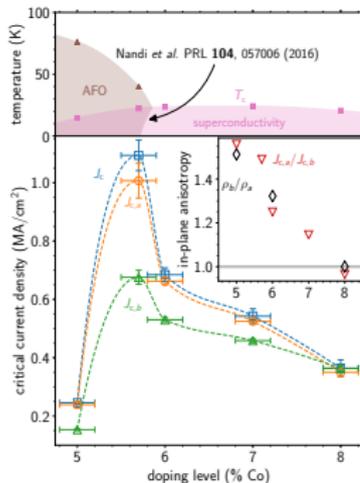
Summary

Peak of J_c :

- ▶ Twin domains
 - ▶ Not the reason
- ▶ Other pinning mechanism
 - ▶ AFO phase boundary?
 - ▶ Relevant for applications?

In-plane anisotropy:

- ▶ $J_{c,a}/J_{c,b} \leftrightarrow \rho_b/\rho_a$
 - ▶ Qualitative agreement
 - ▶ $J_{c,a}/J_{c,b} \sim \sqrt{\rho_b/\rho_a}$ (basic model)
 - ▶ $J_{c,a}/J_{c,b} \approx \rho_b/\rho_a$ (experiment)
- ↪ J_c -anisotropy is larger than expected
- ▶ very sensitive to pressure



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Superconducting state:

$$J_c = \eta J_0 \text{ with } J_0 \sim H_c / \lambda$$

$$J_{c,a} / J_{c,b} = \lambda_b / \lambda_a$$

$H_c \sim 1 / (\lambda \xi)$ is isotropic, thus:

$$J_{c,a} / J_{c,b} = \xi_a / \xi_b$$

Normal state:

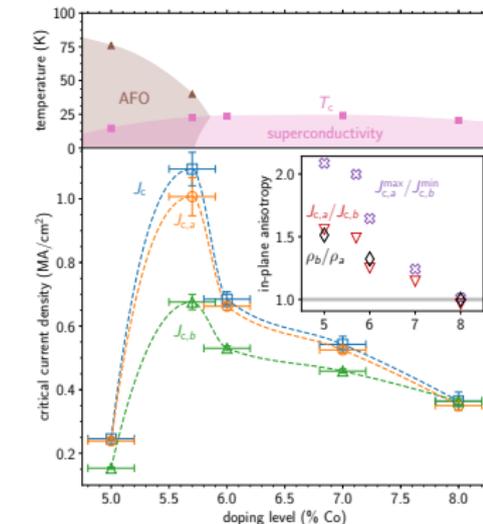
$$\rho_s \sim 1 / \lambda^2$$

$$\rho_s \approx \sigma_{dc} 2\Delta \text{ (dirty limit)}$$

$$\sigma_{dc} \sim 1 / \rho$$

$$\frac{J_{c,a}}{J_{c,b}} \sim \left(\frac{\rho_b}{\rho_a} \right)^{1/2} \text{ (dirty limit)}$$

- η pinning efficiency
- J_0 depairing current density
- λ penetration depth
- ξ coherence length



- Δ energy gap
- H_c thermodynamic critical field
- ρ_s superfluid density
- σ_{dc} ... conductivity

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