# Dopant diameter dependence of $J_c(B)$ in doped YBCO films

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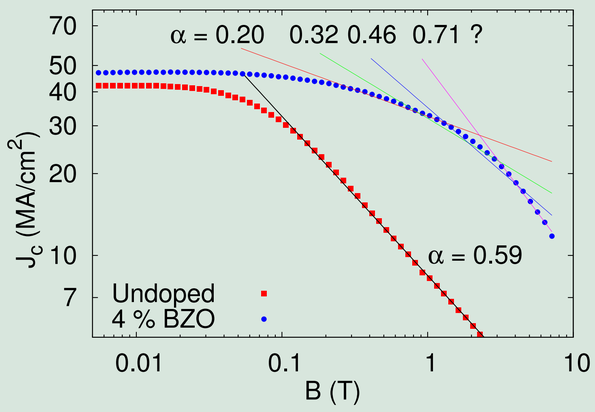
## Problem

- Characterizing $J_c(B)$ with $B^{-\alpha}$ is prone to errors and makes comparison of samples from different groups difficult




- Pinning force is defined as $\mathbf{F_p} = \mathbf{B} \times \mathbf{J_c}$
- Pinning force can quite generally be described with

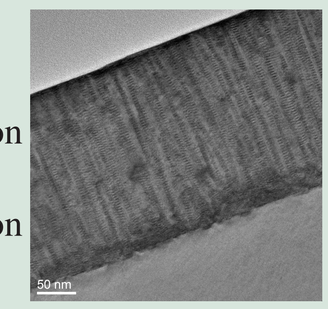
$$F_p(B) = F_{p0}\left(\frac{B}{B_{c2}}\right)^p \left(1 - \frac{B}{B_{c2}}\right)^q, \qquad (1)$$

where $p$ and $q$ are defined by the pinning landscape.

- In high-temperature superconductors $B_{c2}$ is replaced with $B_{irr}$

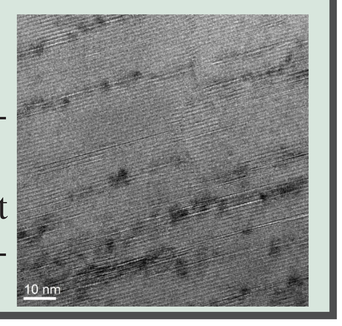
## BZO-doped films

- Nanorods along $c$-axis
- Diameter 5 – 12.5 nm
- Depends on deposition temperature
- Splay at low deposition temperature




## BCO-doped films

- Nanoparticles
- Diameter 1.5 – 3.6 nm
- Size depends on concentration
- Tend to form local, but not global, horizontal agglomerations

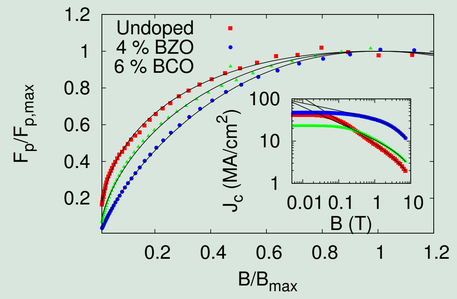


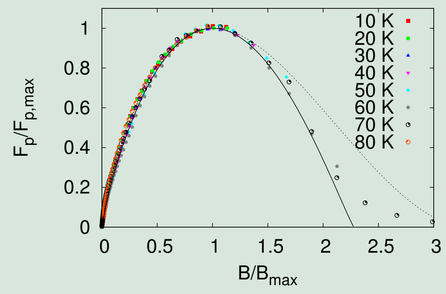

## Experimental results

- Scaled $F_p(B)$ with $F_{p,max}$ and $B_{max}$ to have only two fitting parameters

$$\frac{F_p(B)}{F_{p,max}} = \frac{(p+q)^{p-1}p^q}{q^q}\left(\frac{B}{B_{max}}\right)^p \left(\frac{p+q}{p} - \frac{B}{B_{max}}\right)^q \qquad (2)$$

- Pinning force curve (2) fits data well above the low field plateau
- $p$ is different for films with different kinds of pinning sites
- Curves at different temperatures collapse to a single curve
- $q \approx 1.1$ for all samples at all temperatures
- At high temperatures flux creep has a significant effect, which changes the shape of the curve at high fields




## Experimental details

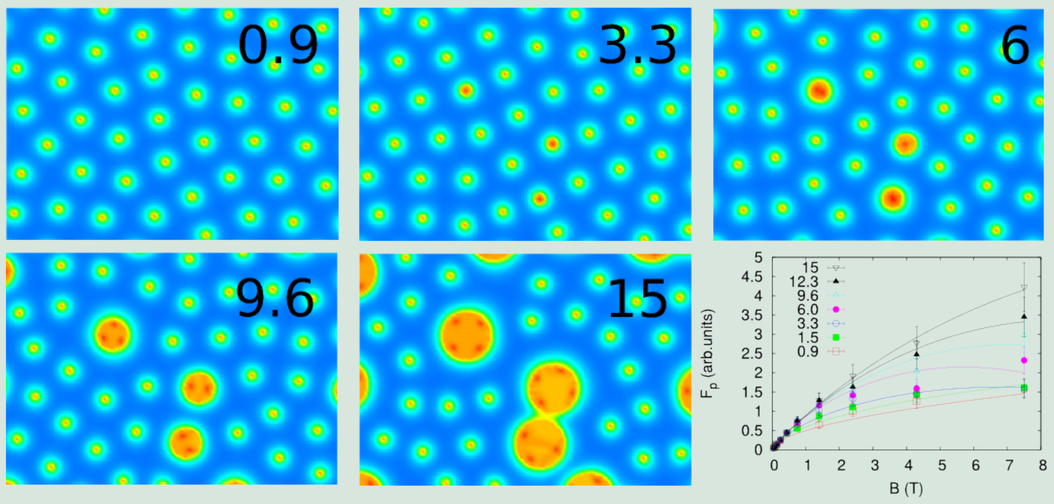
- PLD of YBCO films with 0–10 wt-% $BaZrO_3$ and $BaCeO_3$ dopants on $SrTiO_3$ single crystals [1]
- $T_s$= 750 – 850 °C
- $J_c$ defined from magnetization loops at 0 – 80 K and 0 – 9 T with a PPMS
- Pinning site sizes with TEM [4, 3]

## Simulation details

- Large scale Ginzburg-Landau simulations [2]
- Pinning as local restrictions of the order parameter
- $J_c$ was determined from the proportion of pinned vortices to all vortices

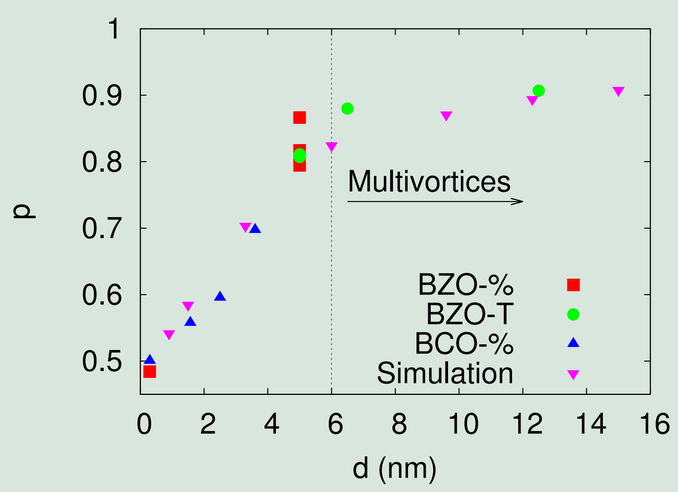
## Simulation results

- Vortex lattice distorts more when rods are large
- Hardly any trace of triangular lattice when rods are large
- Several vortices per pinning site when $r \geq 2\xi$
- $p$ = 0.5 – 0.9




## Discussion

- All $p$ values fall into same dependece
- No dependence on concetration of pinning sites
- At pinning site size $d \ll \xi$, $p \approx 0.5$
- When $d \gg \xi$, $p \approx 0.9$
- Smooth change in between
- Levelling to 0.9 above the multivortex size
- Simulation results fall onto the same dependence




**Ginzburg-Landau theory**

- When a vortex sits on a pinning site the energy recovered is

$$U_0 = \frac{3}{2}\mu_0 H_c^2 V \frac{\delta H_{c2}}{H_{c2}} \langle |\frac{\psi}{\psi_0}|^2 \rangle, \qquad (3)$$

where $|\psi/\psi_0|^2 = 1 - B/B_{c2} = 1 - b$

- When the lattice stays intact $F_p = \pi U_0/a_0$, where $a_0 \propto \sqrt{\phi_0/B}$ is the average distance between the vortices. Therefore

$$F_p \propto b^{1/2}(1-b) \qquad d \ll \xi \qquad (4)$$

- When $d \gg \xi$ the total pinning force is

$$F_p \approx f_p N \propto b(1-b) \qquad d \gg \xi, \qquad (5)$$

because $N \propto b$ is the number of vortices

## Conclusions

$p$ is defined by the size of the pinning sites
Using $F_p(B)$ enables better description of $J_c$ than $J_c \propto B^{-\alpha}$

## References

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Materials are also available at
`users.utu.fi/peetu/papers/`

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