MD-simulation of vortex motion in anisotropic superconductors with artificial pinning sites

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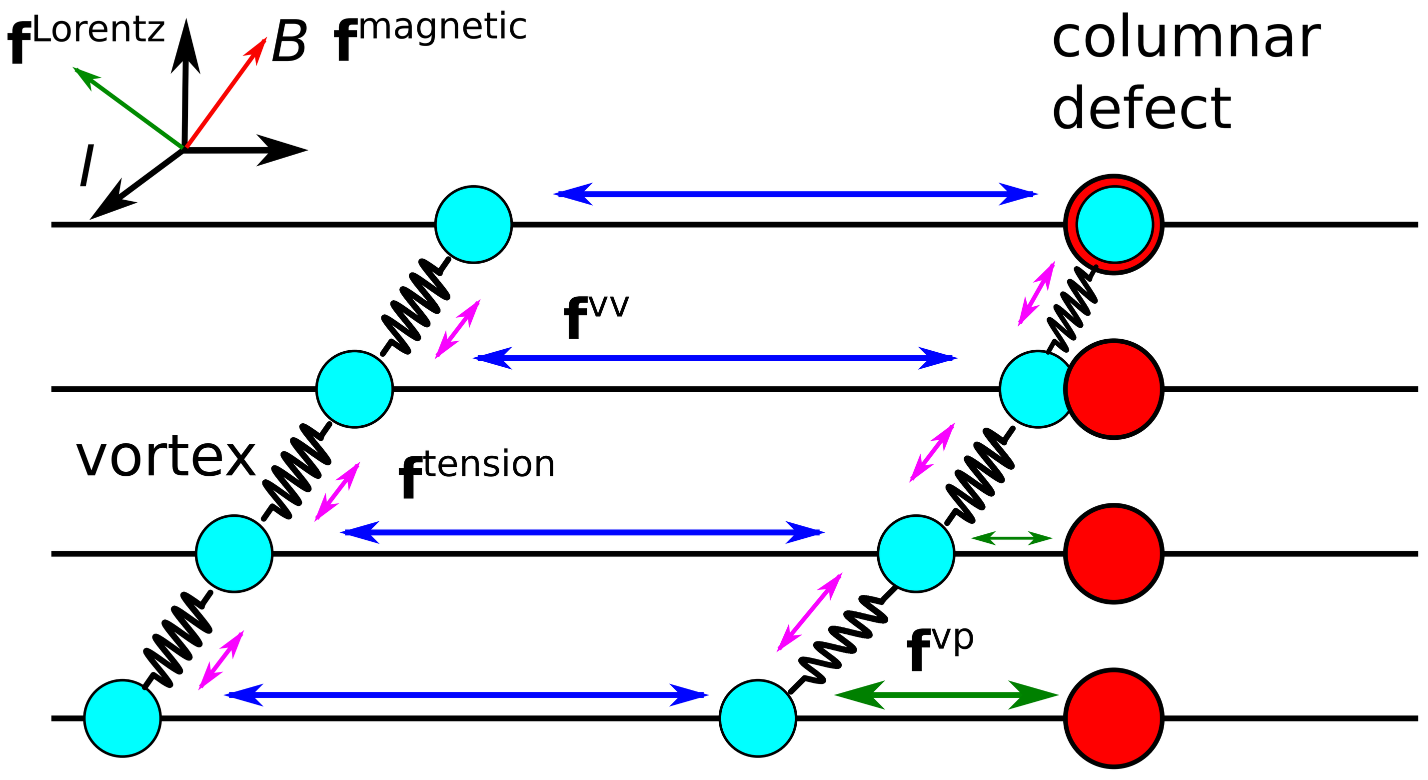
Problem & solution

- Understanding $J_c(\theta)$ and $J_c(B)$ with different pinscapes
- Modelling would enable real design-based pinscapes
- Ginzburg-Landau models require large scale computations
- Forces between different actors (vortices, pinning sites) in a superconductor are known
- The interplay of several pinning sites and vortices cannot be done analytically
- Molecular dynamics simulations require less computational power than GL
- Anisotropy can also be included

MD-simulation

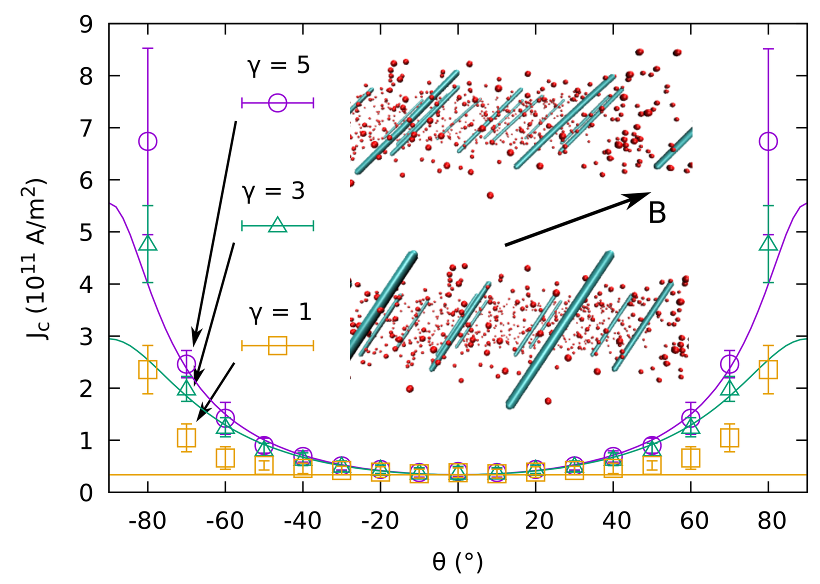
$$\mathbf{F}^{tot}_{(i,n)} = \sum_{m\neq n} \mathbf{f}^{vv}_{(i,n),(i,m)} + \sum_{k} \mathbf{f}^{vp}_{(i,n),(i,k)} + \sum_{j=i\pm1} \mathbf{f}^{tension}_{(i,n),(j,n)} + \sum_{j=i\pm1} \mathbf{f}^{magnetic}_{(i,n),(j,n)} + \mathbf{f}^{Lorentz}_{(i,n)} + \mathbf{f}^{drag}_{(i,n)}$$



$$f^{vv} = \frac{\epsilon_0}{\lambda_{ab}} K_1\left(\frac{r}{\lambda_{ab}}\right)$$
$$f^{vp} = \epsilon_0 \frac{r r_0^2}{(r^2+2\varepsilon_\theta \xi_{ab}^2)^2}$$
$$\varepsilon_\theta^2(\theta) = \frac{\sin^2\theta}{\gamma^2} + \cos^2\theta$$
$$f^{tension} = -\frac{\epsilon_0 r(\gamma^2-1+\ln\kappa)}{d\gamma^2\sqrt{d^2+r^2}}$$
$$f^{magnetic} = \phi_0\mu_0 B_{ext}\sin\varphi \frac{d\varphi}{dr}$$
$$f^{Lorentz} = \phi_0|\hat{\mathbf{B}}_{ext}\times\mathbf{J}_c| = \phi_0 J_c$$
$$f^{drag} = -\eta|\mathbf{v}|$$

Anisotropy

- Anisotropy of the superconductor can be chosen
- 2.5 D structure limits the usable range to $\pm 60°$

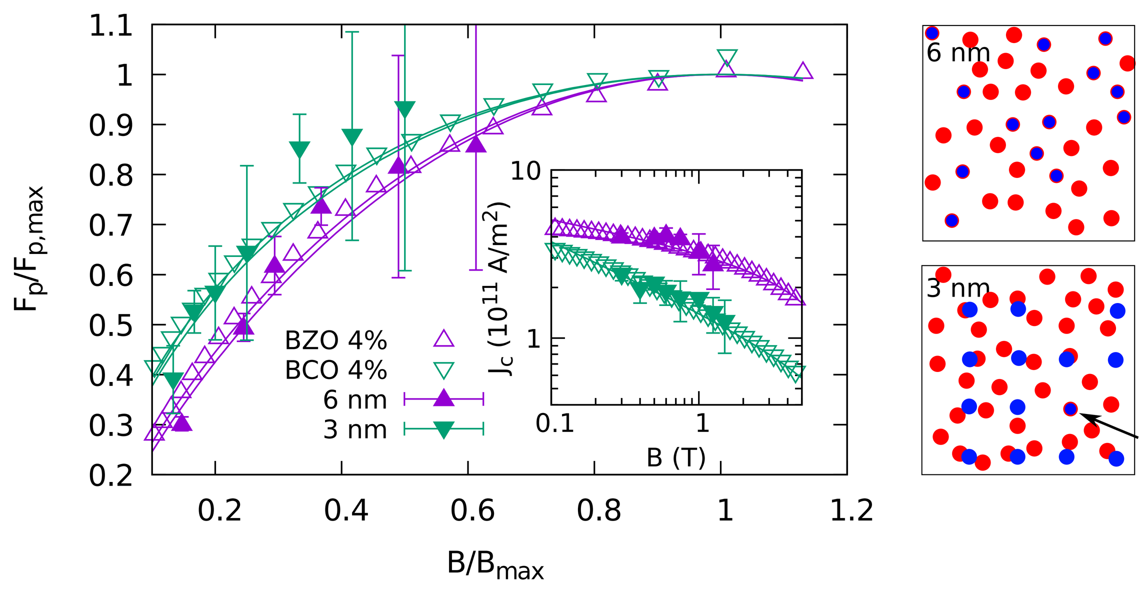


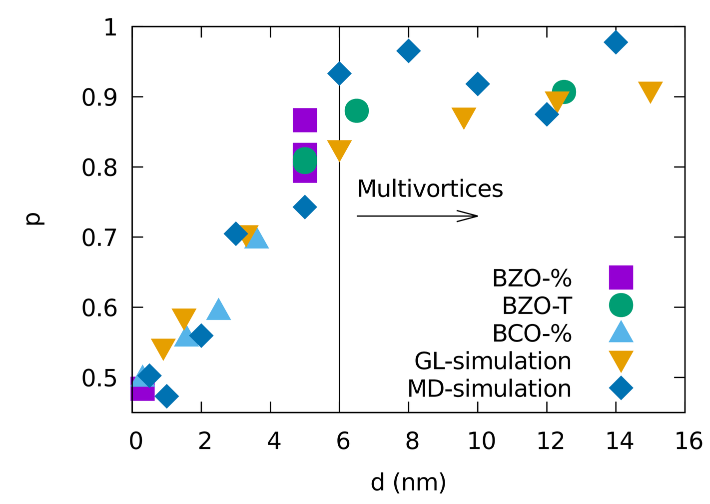
Pinning force vs size

- Pinning force can quite generally be described with

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

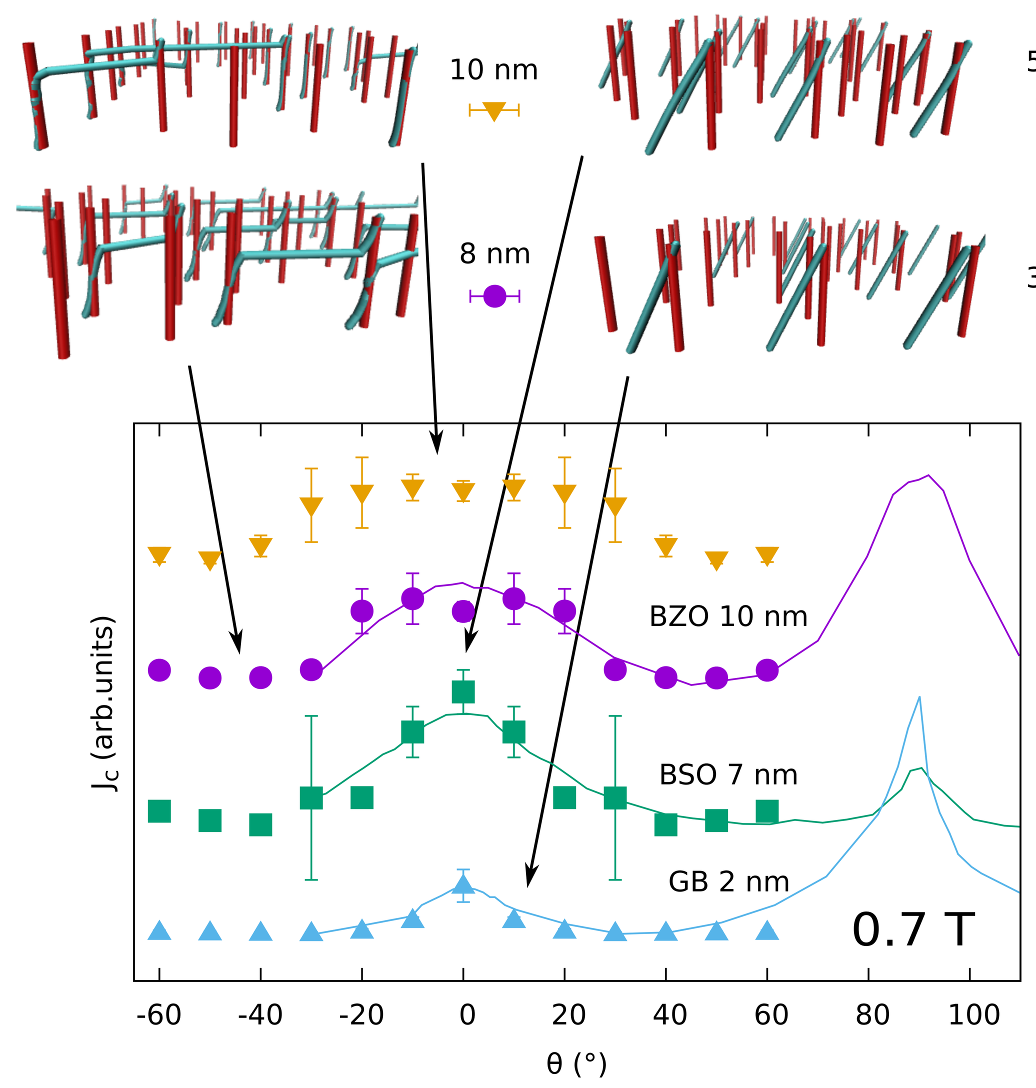
- $p \approx 0.5$ when lattice stays in tact, $p \approx 1$ when the lattice breaks





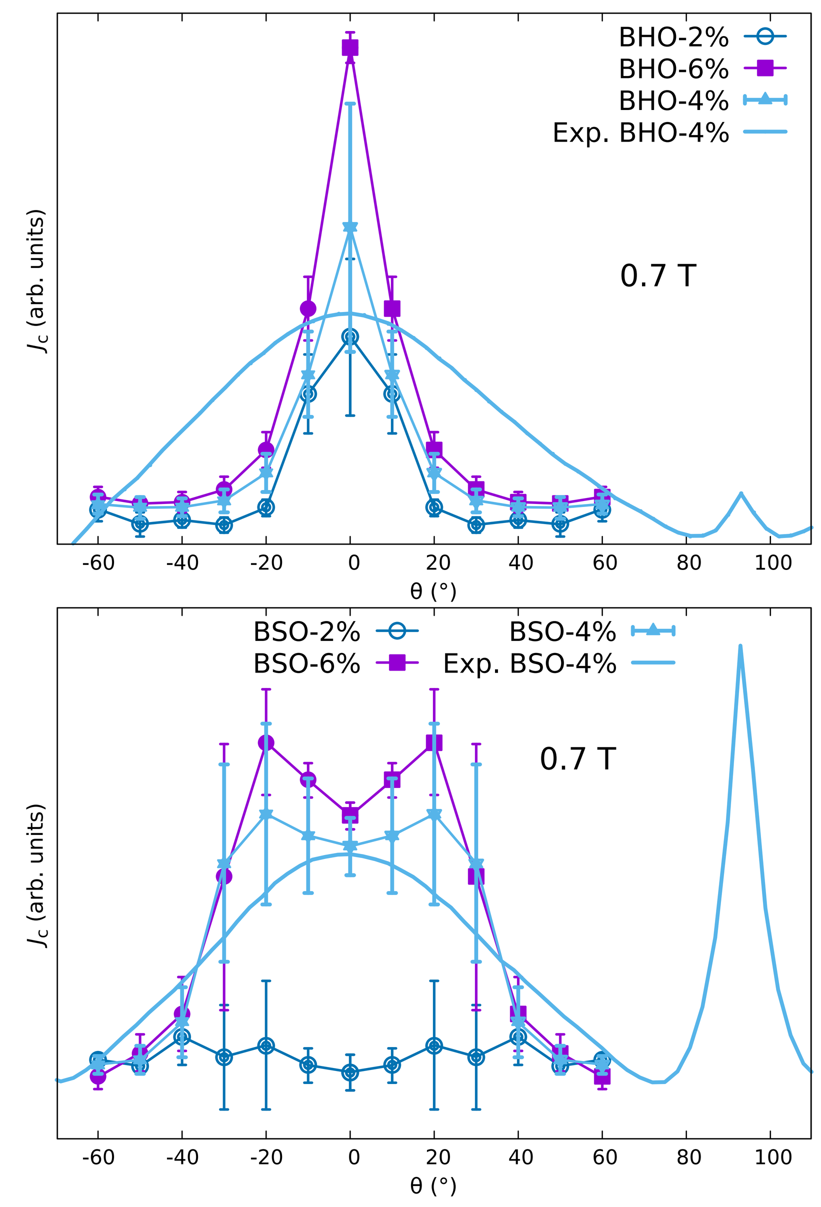
$J_c(\theta)$ vs size

- Width of c-axis peak depends on the size of the pinning site
- At peak the vortices are deformed by the pinning sites
- Outside the peaks the vortices pin as with spherical pinning sites
- The peak widths correspond well with experimental data



$J_c(\theta)$ vs density

- Rod density does not affect the c-peak width
- It affects the J_c of the sample
- Experimentally BSO rods are straight and correspond well to the simulated data
- BHO doped films have much wider peak → more splay in the rods



Discussion & conclusions

- A simple MD-simulation can replicate essential features of $J_c(\theta)$ close to $B \| c$
- This enables true understanding of pinning and designing effective pinscapes for applications
- Large pinning sites lead to $p \approx 1$ due to breaking of the vortex lattice
- Small pinning sites cannot break the lattice
- Width of c-axis peak is defined by pinning site size
- Pinning site density does not affect the width of the peak
- In future:
  - True 3D implementation will enable modelling around $B \perp c$
  - Implementation of temperature

Videos at:

Materials at:

References

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