Verifying theoretical models of flux pinning using heavy ion irradiated in YBCO thin films

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Introduction

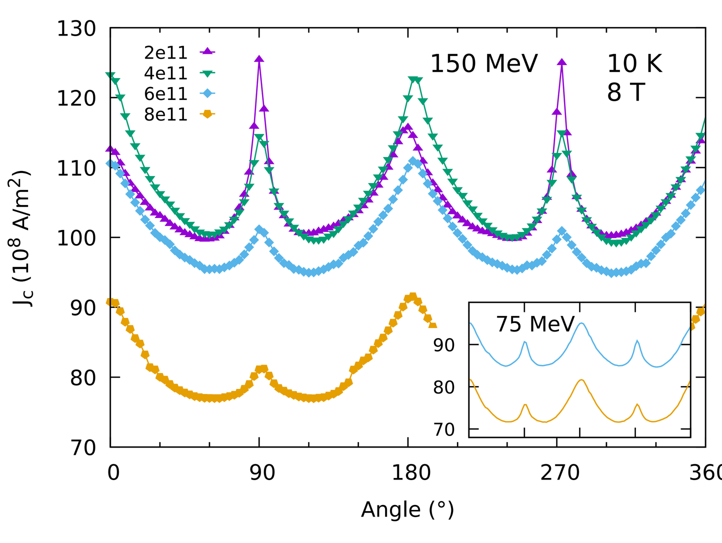
- HTS wires are made in km length, but how can we still increase their in-field properties?
- Increasing $J_{c,0}$ requires better YBCO crystal quality
- Optimizing $J_c(B)$ requires effective pinning sites, most effectively tailored artificial pinning centers (APC)
- Theoretically, at low T, the APC-free distance between APCs is about the same as the diameter of the APCs.
- The optimal APC diameter is 8–10 nm, strong enough to break the vortex lattice, but small enough to accommodate only one vortex.
- Typical APCs are BaMO$_3$ nanorods, which cause strain in the YBCO matrix and reduce $J_{c,0}$.
- Here, we use heavy ion irradiation to introduce APCs that the YBCO matrix is not affected.

Experimental

- PLD: λ=308 nm, E = 1.5 J/cm^2 & f = 5 Hz, $T_{substrate} = 725 - 800$ °C and p = 175 mTorr.
- APC-free micrograined YBCO target
- XRD: 10–130° 2θ-ω and 2θ from (005) peaks and $2\theta - \phi$ of (122)/(212) peak sets, texture (102)/(012)
  → Lattice parameters, Williamson-Hall analysis (WH) oxygenation level, texturing, twins
- Magnetic PPMS at 10 K and in -8 – 8 T
  → T_c from $M_{ac}(T)$ and $J_c(B)$ from $J_c = \frac{3\Delta M}{a^3 d}$
- Irradiation with Ag$^+$ ions at 75 and 150 MeV with fluence 2–8·10^{11}cm^{-2}
- XRD and magnetic measurements repeated
- Patterning and transport measurement with PPMS ACT option for $J_c(\theta)$
- HRTEM with a JEOL JEM-2200FS (200 kV) and STEM with Titan 80–300 at 200 kV.

$J_c(\theta)$

- Irradiation causes very sharp c-peaks in $J_c(\theta)$.
- c-peaks are wider with high fluence



Acknowledgements

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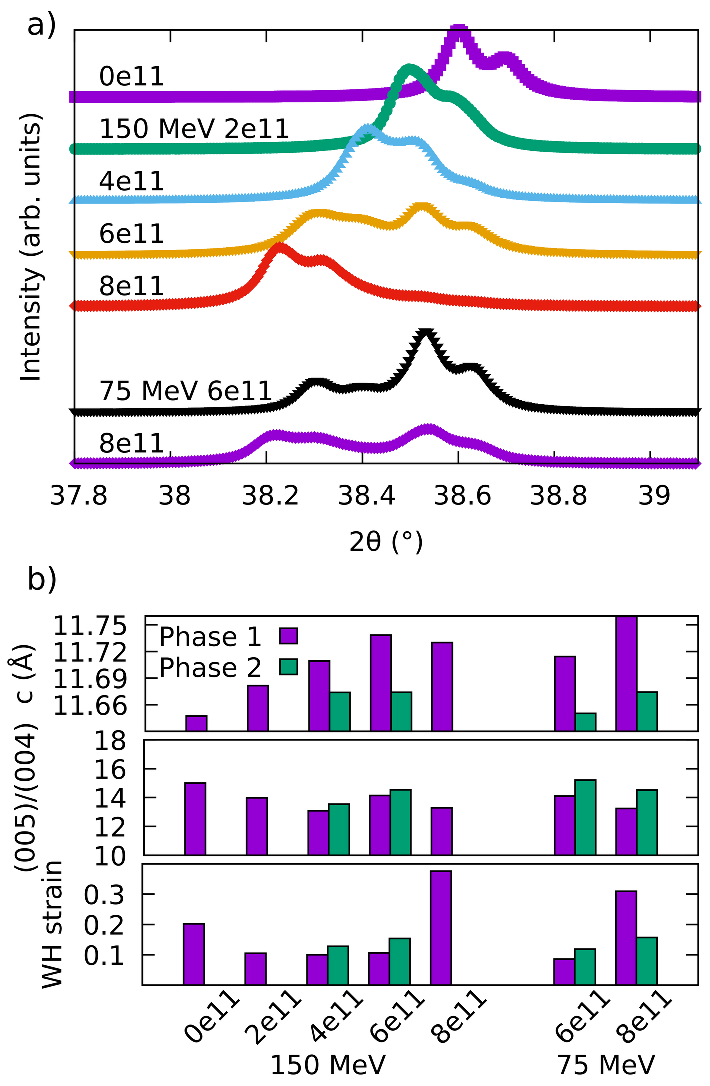
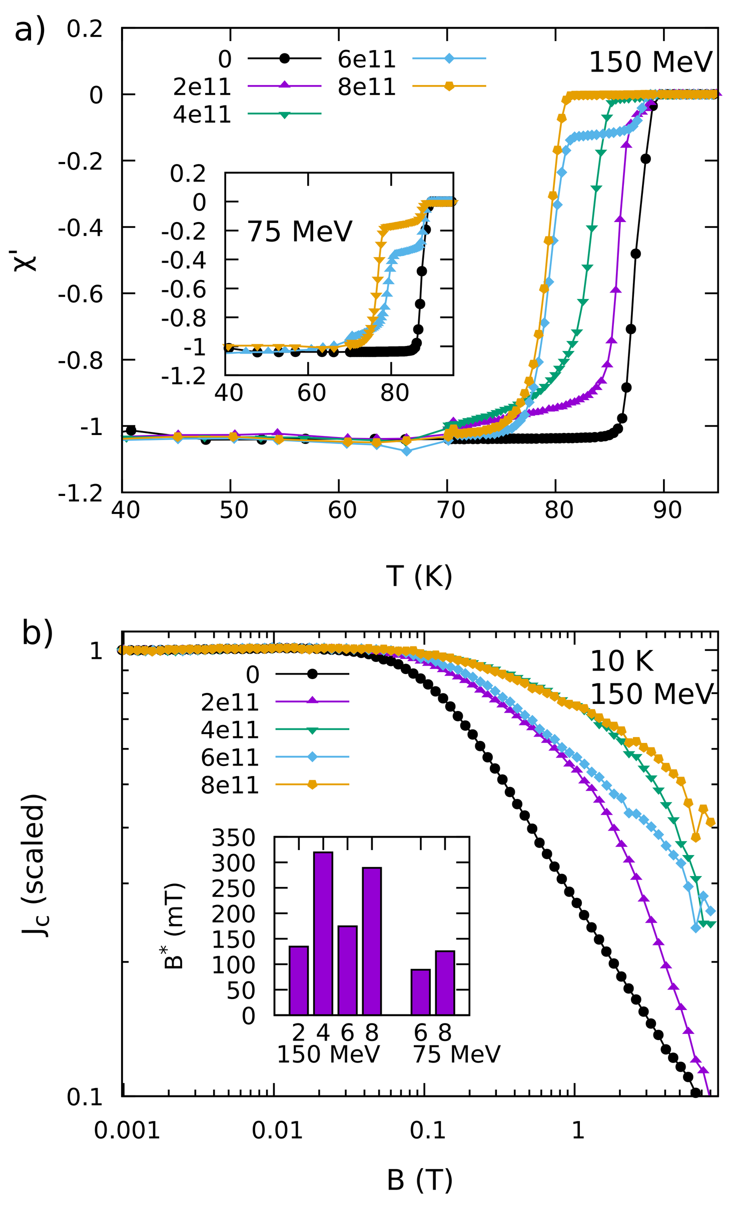
XRD



- Some samples had an unirradiated part
- c increases with irradiation
- Oxygenation stays the same
- Microstrain is minimal with low doses

T_c and J_c



- Irradiation reduces T_c
- Some samples have non-irradiated areas
- Irradiation reduces $J_{c,0}$, but improves $J_c(B)$
- B^* increases with fluence and is higher with 150 MeV than 75 MeV irradiation

References

[1] P. Paturi and H. Huhtinen, Supercond. Sci. Tech. **35**, 065007 (2022)

[2] E. Rivasto, M. Todorovic, H. Huhtinen, and P. Paturi, New J. Phys., **25**, 113046:1–15 (2023).

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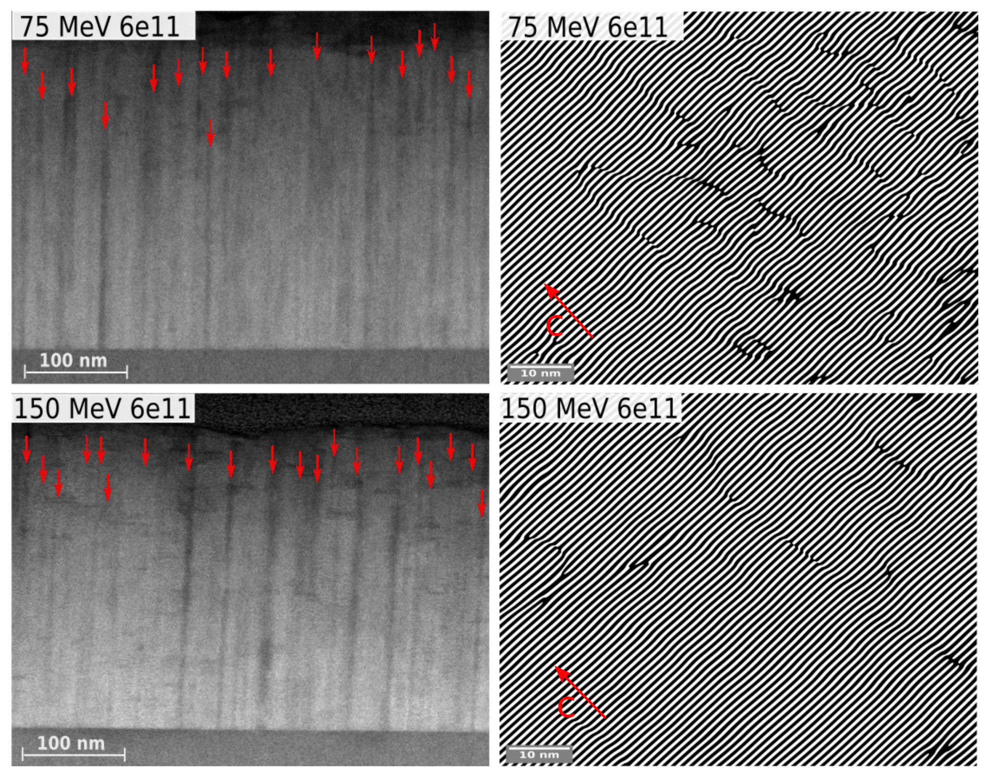
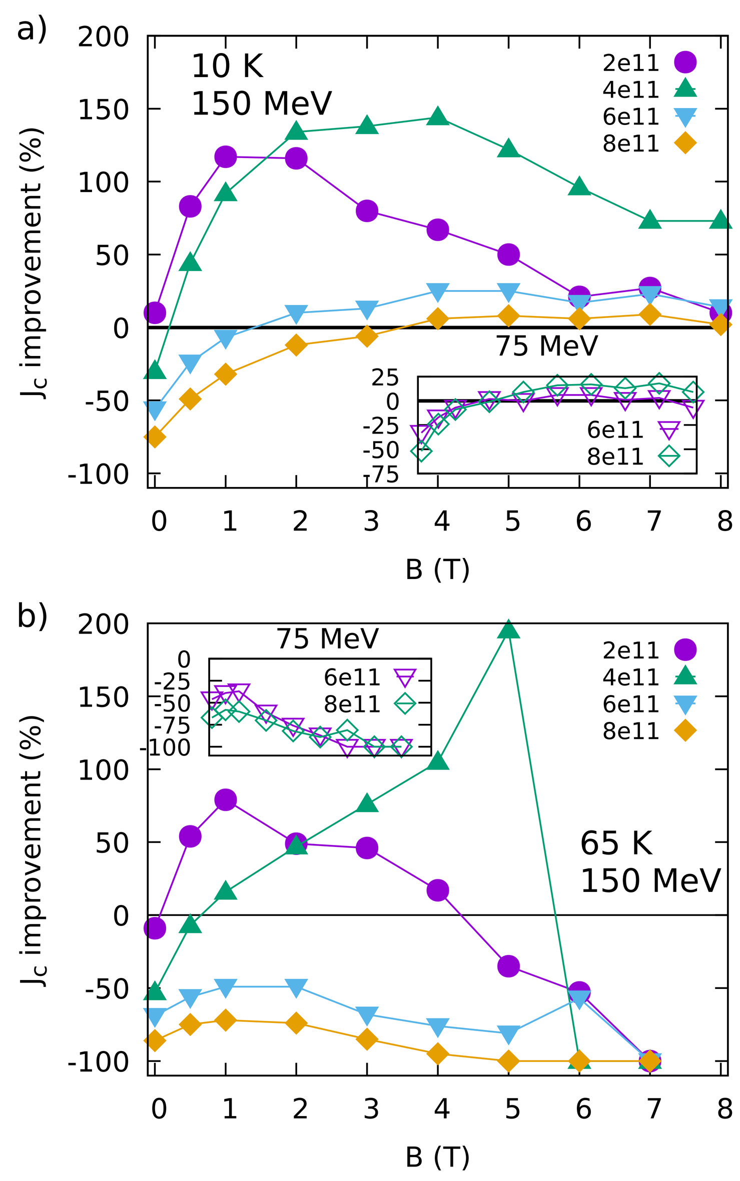
TEM



- Both energies form straight amorphous tracks
- 150 MeV tracks are all through the sample
- 75 MeV track only partly, causing more distortion in the lattice
- Track diameter is about 5 nm
- Same amount of tracks in samples with the same fluence

J_c improvement



- Highest improvement of J_c is obtained with 4e11 fluence at both 10 K and 65 K
- Reduction of $J_{c,0}$ increases with fluence
- One can calculate the effective diameter of the rods from reduction of $J_{c,0}$ as $\frac{J_c(0)'}{J_c(0)} \propto 1 - F\pi r_{eff}^2$ and get

F (10^{11})	J_c'(0)/J_c(0)	$2r_{eff}$ (nm)	D_r (nm)	D_{free} (nm)	B_ϕ (T)
2	0.89	8.18	22	14.2	4.1
4	0.77	**8.47**	**16**	**7.3**	8.3
6	0.72	7.7	13	5.2	12.4
8	0.65	7.45	11	3.7	16.6

Conclusions

- Irradiation reduces T_c
- Irradiation reduces $J_{c,0}$, but improves $J_c(B)$
- Best improvement when distance between rods roughly equals effective rod diameter
- This concurs with models [1] and [2]