

Enhancement of critical current density by large antidots in inhomogeneous arrays in $\text{YBa}_2\text{Cu}_3\text{O}_7$ thin films

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Abstract

- The current-carrying ability of type II superconductors can be effectively enhanced by introducing certain intelligent defects within the material.
- Antidots are a type of intelligent defect where the superconductor is removed in a controlled manner. Engineering antidots in arrays throughout the superconductor leads to interesting and scientifically appealing effects.
- Various arrays with different shapes of antidots, possessing dimensions larger than magnetic penetration depth, have been created in $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) superconducting thin films.
- Photolithography and ion beam milling were used to produce uniform, graded and spaced arrays.
- Comparing the difference in J_c between the patterned and as deposited films gives an understanding of the effectiveness of the antidots.

Introduction

Extending the operating range in applied magnetic fields (B_a) and controlling the critical current density (J_c) in superconducting thin films is a highly sort after process to increase their novelty.

Magnetic field penetrates type II superconductors in the form of Abrikosov vortices. Under no force these arrange in a triangular array. When subject to a current the vortex will move creating a voltage. Therefore, vortices must be trapped to sustain the superconducting state.

Naturally intrinsic pinning occurs in YBCO through defects. These regions are less favourable for superconductivity making it more energetically viable for a vortex to remain here. However, this may be enhanced by providing extra, controlled defects throughout the material.

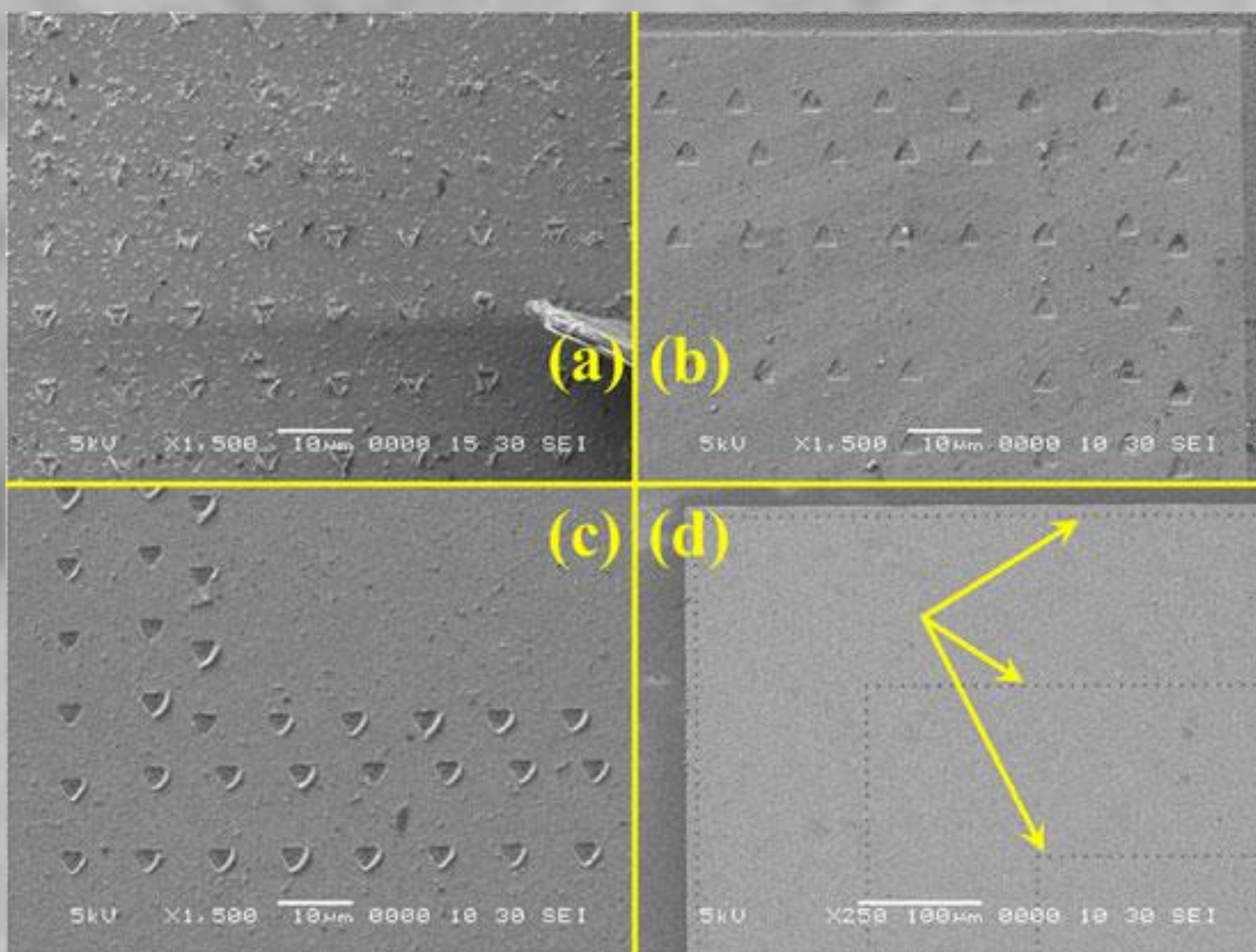


Figure 1: Examples of uniform and graded triangular arrays of triangle antidots

One such defect is the absence of the superconductor, namely an antidot. Antidots are created through a process of optical lithography and ion beam etching to engineer user defined arrays of holes. Generally antidots are created in triangular arrays to match that of the vortex lattice.

When the amount of vortices is a multiple of the number of antidots strong vortex pinning occurs. However, these types of artificial arrays were also found to be susceptible to flux-jump instabilities and flux channelling [1, 2, 3]. One such type was a linearly graded array that demonstrated the resistance to flux-jumps and also flux channelling, hence the effective enhancement of current carrying ability. [4]

Experimental details

Superconducting YBCO thin films of 200nm thickness are created through pulsed laser deposition. High quality films of $T_c=90\text{K}$ and $J_c \approx 3.5 \times 10^{10} \text{ Am}^{-2}$ at 77K are produced. The films are patterned through optical lithography, then bombarded with argon ions to produce arrays of micron sized antidots, for example in Figures 1 and 2. The films were measured before and after etching using a Quantum Design MPMS system to determine enhancement or degradation of J_c .

As shown on right, graded and inverse graded arrays of antidots were created to match flux penetration/retraction according to the Kim model. [5]

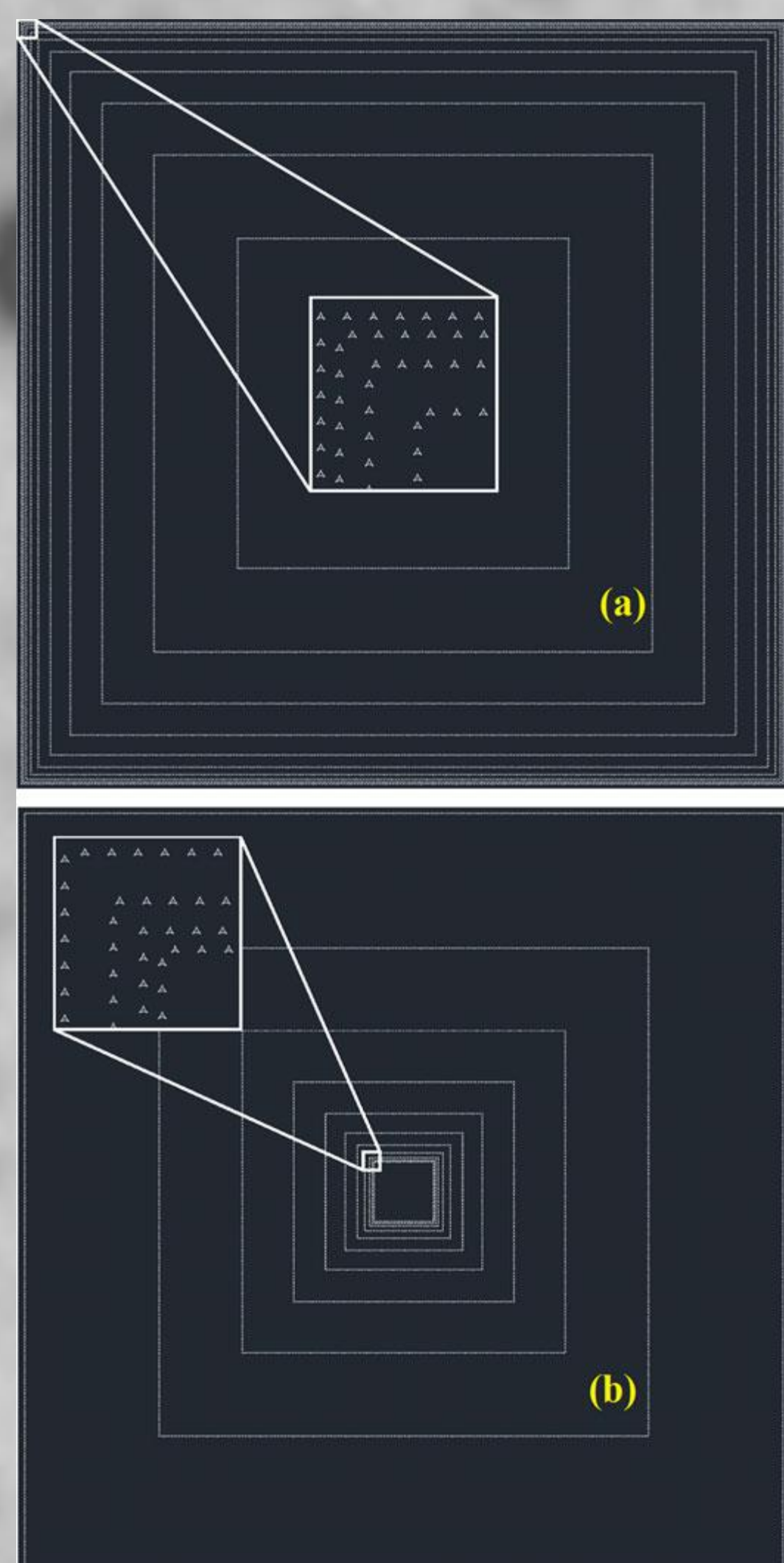


Figure 2: Difference between the graded and inverse graded arrays

Results

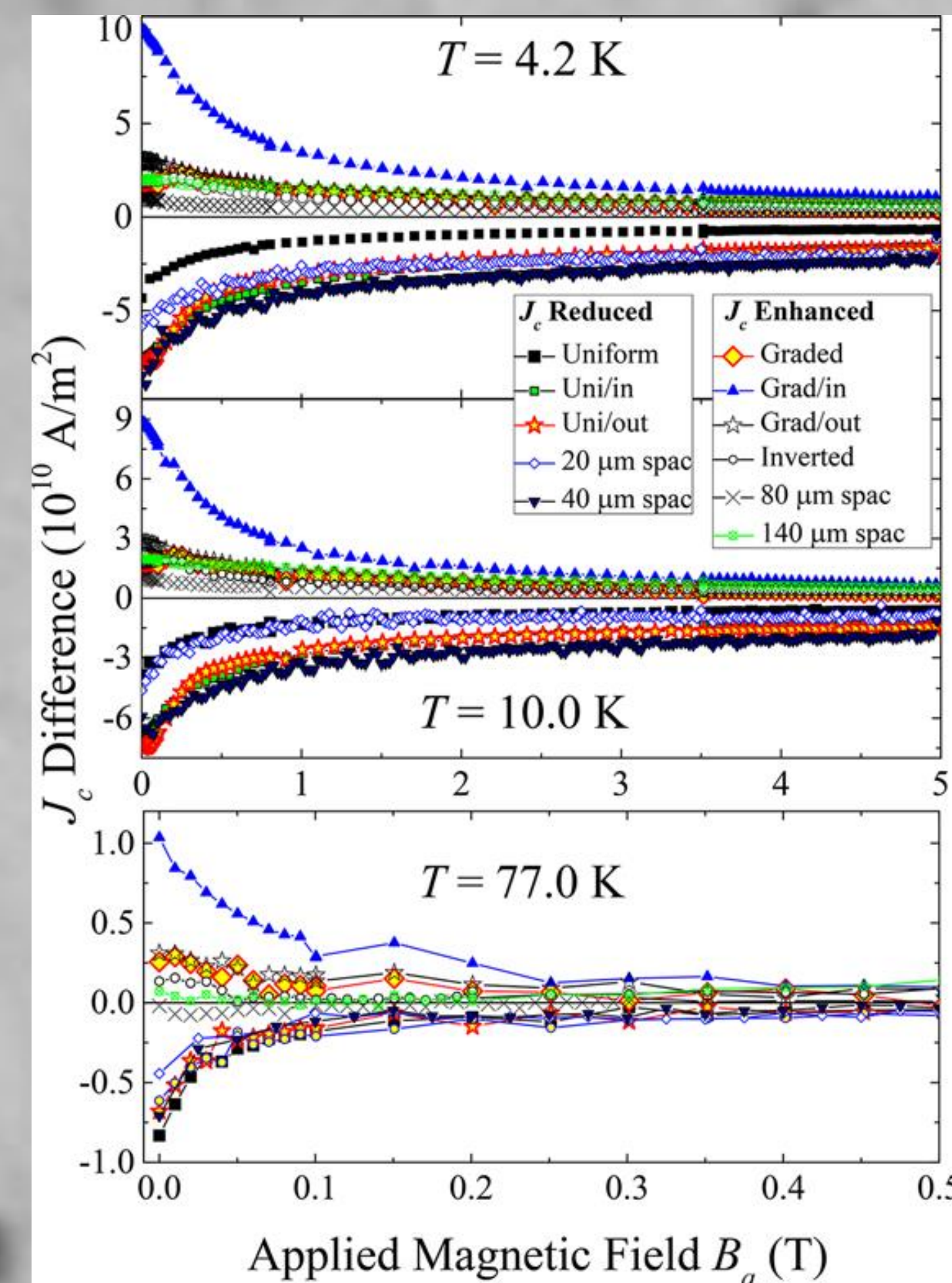


Figure 3: Critical current density difference (magnetisation measurements) for 4.2K, 10K and 77K

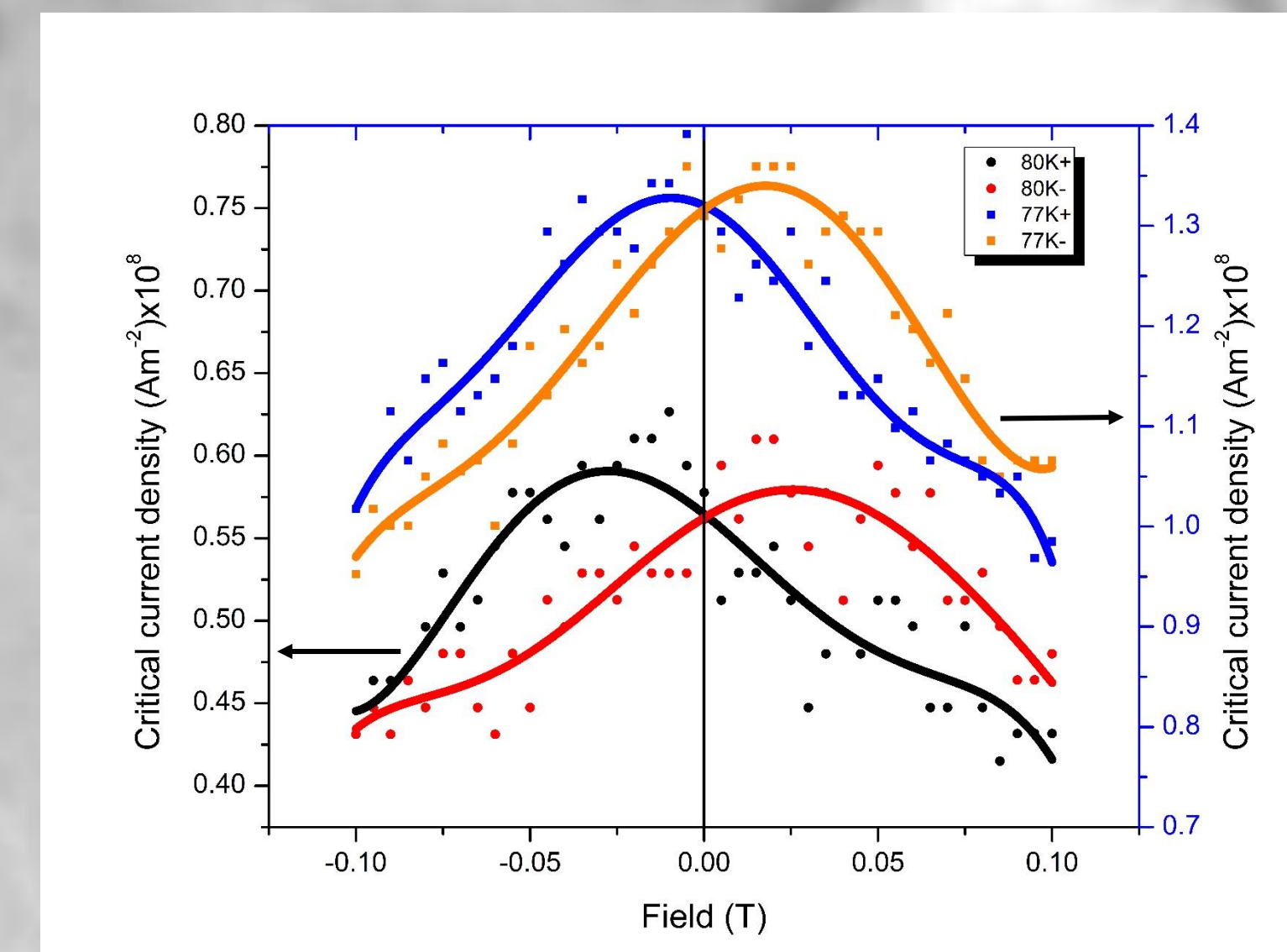


Figure 4: Critical current density (transport) dependent on direction of applied current for 77K and 80K

Rectified motion of the vortices leads to a ratchet effect. In this case the base of the triangle serves as a stronger pinning centre than the apex. Sine wave added for guide to the eye.

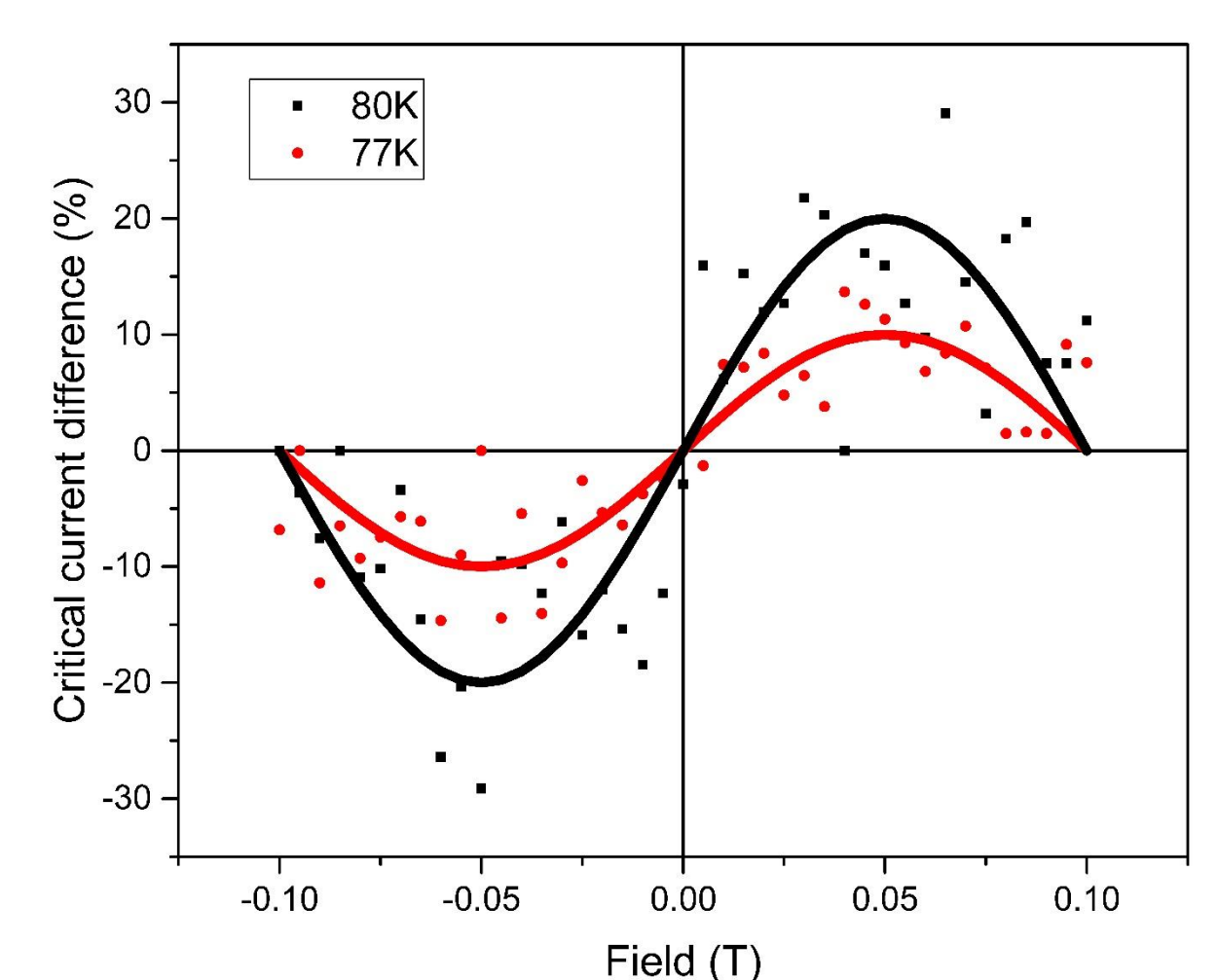


Figure 5: Evidence of a ratchet effect

Conclusion

Different arrays with large antidot dimensions ($\gg \xi(T)$ and $> \lambda(T)$) have been manufactured and investigated in high quality YBCO thin films. Non uniform arrays all enhanced critical current density due to a matching between the Kim model and antidot locations. The strongest effect of up to 20% J_c enhancement in graded and inverted arrays over the entire applied field range. Anisotropic antidots were employed to successfully create rectified motion of vortices. Optimisation of the pinning array is predicted to create further enhancements to J_c . It should also be noted that the ratchet effect was measured with a uniform pinning of triangular antidots. Therefore, this is another area which may be investigated to enhance rectification.

References

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