# Numerical Simulation of Crossed-Field Combined Pulse Magnetization in High-temperature Bulk Superconductor

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## Introduction

High-temperature bulk superconductors exhibit strong flux pinning characteristics and can trap large magnetic fields, thus having the potential to work as low-temperature permanent magnets. The most effective method for trapping flux in high-temperature bulk superconductors is field-cooling magnetization (FCM), which fully utilizes the trap flux properties of the bulk superconductors. However, FCM requires large superconductor coils to provide a static magnetic field, imposing high equipment requirements. Another comparatively simpler magnetization method is pulsed-field magnetization (PFM), which typically uses capacitors to discharge and generate a pulsed magnetic field from an ordinary copper coil to magnetize the sample. In this paper, a novel magnetization method called crossed-field combined pulse magnetization is proposed, which can reduce the magnetic field required for magnetizing the bulk by 9.6%, providing a new approach for combination pulse magnetization.

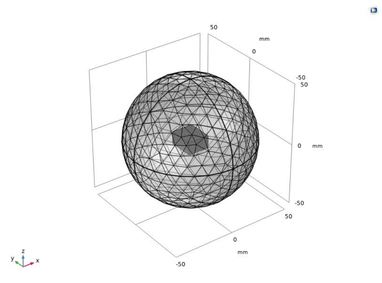
## Numerical Method

Using numerical simulation methods, we study and compare the pulsed-filed magnetization and crossed-field combined pulse magnetization (lateral zero-field cooling magnetization and vertical pulsed-field magnetization) and obtain the optimal magnetic field for each method.

Method：H-ϕformulation

Superconductor： $\nabla \times (\rho \nabla \times \mathrm{H}) = -\mu_0 \frac{\partial \mathrm{H}}{\partial \mathrm{t}}$

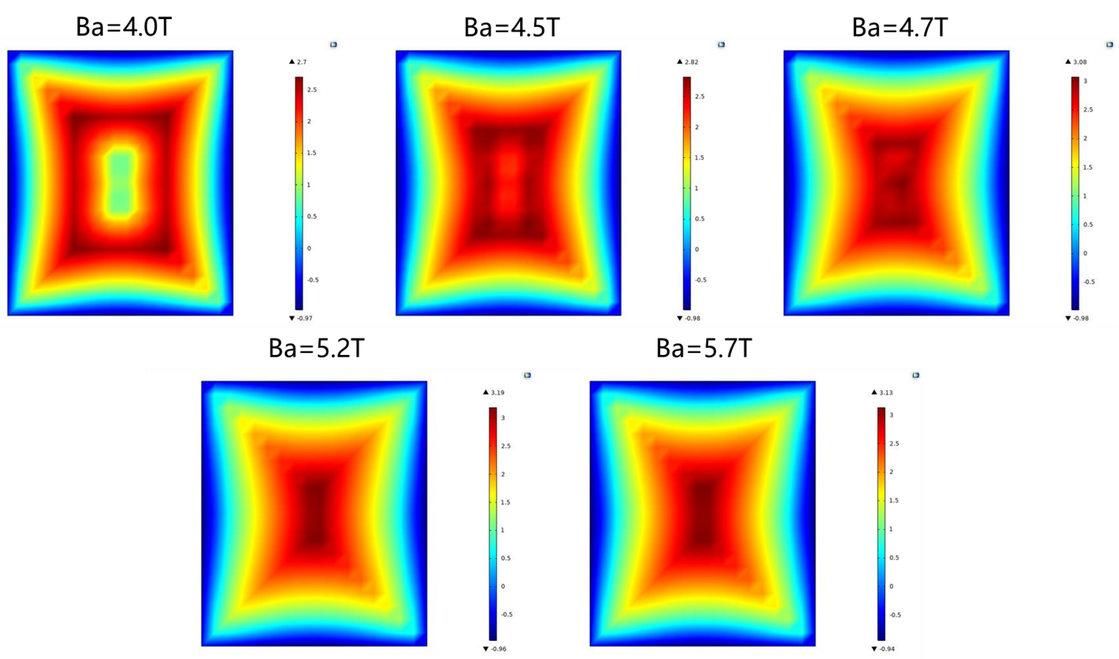
Non-conductor： $\nabla \cdot \nabla \phi = 0$



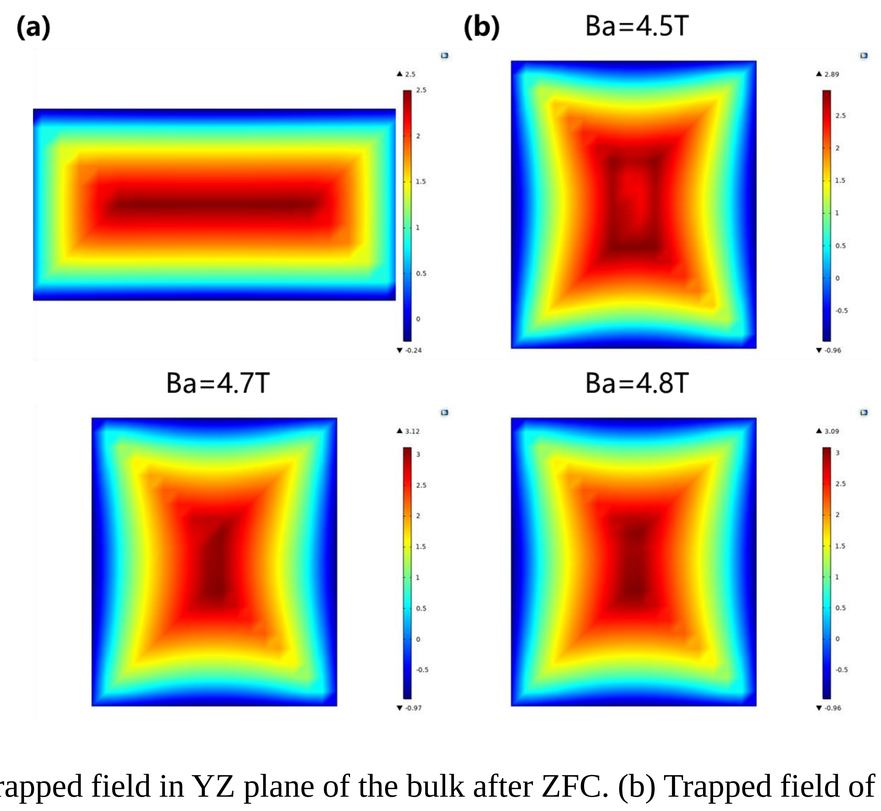
Zero-field cooling magnetization：
$$B_x(t) = \begin{cases} 8*t/45 & (0 \le t < 45) \\ 8*(90-t)/45 & (45 \le t \le 90) \end{cases}$$

Pulsed field magnetization：
$$B_z(t) \begin{cases} B_a \sin\left(\frac{2\pi(t-90)}{0.08}\right) & (90 \le t \le 90.02) \\ B_a e^{\left(\frac{-(t-90)}{0.02}+1\right)} & (t > 90.02) \end{cases}$$

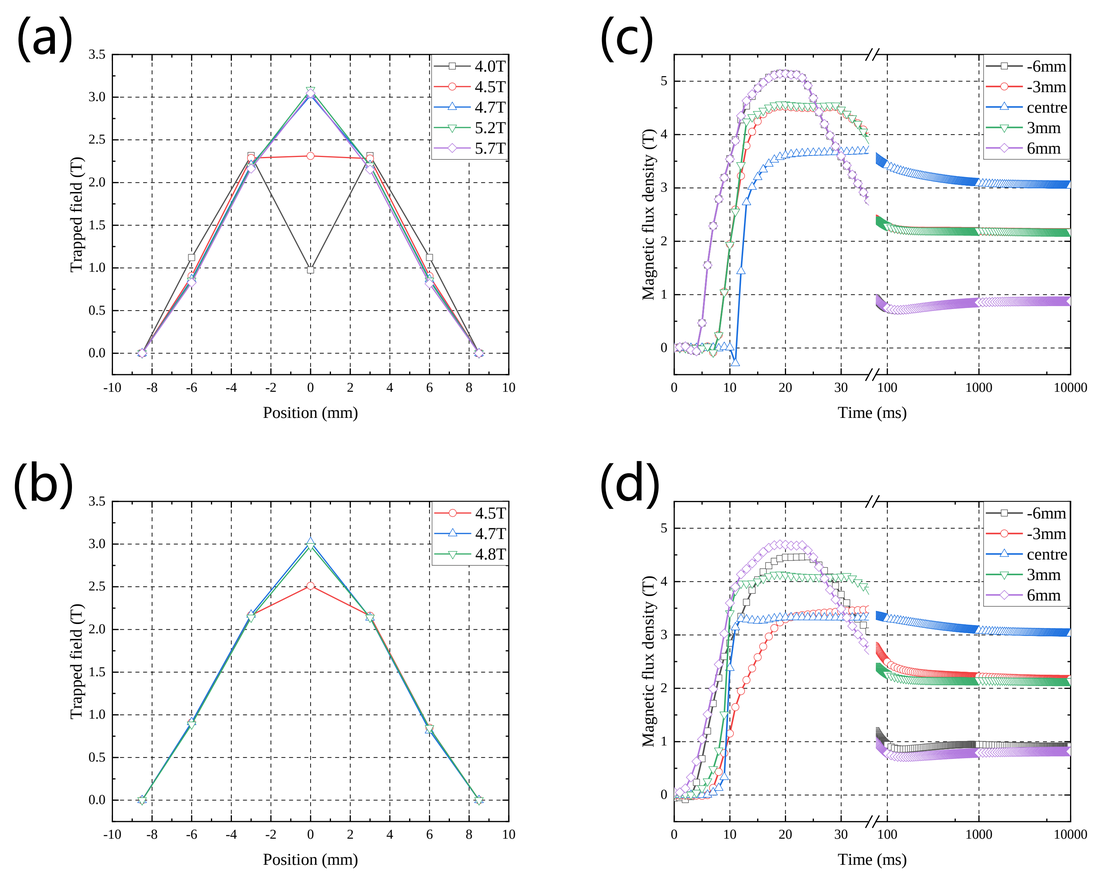
## Results and discussion




Trapped field of the bulk after different magnetic fields PFM.




(a) Trapped field in YZ plane of the bulk after ZFC. (b) Trapped field of the bulk after different crossed-field combined pulsed-field magnetization.




(a) Trapped field distribution of the bulk under different magnetic fields for PFM. (b) Trapped field distribution of the bulk under different magnetic fields for crossed-field combined pulsed-field magnetization. (c) Magnetic flux density at different positions of the bulk after 5.2T PFM. (d) Magnetic flux density at different positions of the bulk after 4.8T crossed-field combination pulse magnetization.

## Conclusions

1. Figure (a), the peak trapped field increases with the increasing applied field, and the field distribution gradually changes from an “M” shape to a cone shape. When the magnetic field reaches 5.2T, the trapped field of the bulk reaches its maximum value, indicating that 5.2T is the optimal field for PFM. Figure (c), the flux jump first occurs at -6mm and 6mm, and then at -3mm and 3mm, finally, the flux penetrates to the center of the sample.

2. Figure (b), the peak trapped field increases with the increasing applied field. When the magnetic field reaches 4.7T, the trapped field of the bulk reaches its maximum value, indicating that 4.7T is the optimal field for crossed-field combined pulsed-field magnetization. Figure (d), the flux jumps occur at 6mm and 3mm before -6mm and -3mm, indicating that the flux is more easily penetrated in the x-direction.

3. By applying ZFC in the positive x-direction, the penetration of flux can be promoted, reducing the magnetic field required for magnetization of the bulk material by 9.6% (0.5T), providing a new idea for combination pulse magnetization.

## References

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[4] Yuchen Wang et al 2023 Supercond. Sci. Technol. 36 075006.