Monte Carlo simulations of vortex dynamics in high-temperature superconductors under pulsed-field magnetization

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ABSTRACT

Pulsed-field magnetization of a high-temperature Bi-2221 superconductor with various pinning landscapes has been studied by means of the Monte Carlo method. Computations have been performed for broad ranges of pulse parameters, such as amplitude and shape, and sample parameters, such as temperature and the concentration and type of distribution of defects (pinning centers). The time-dependences and distribution profiles of the average trapped magnetic field have been computed for various conditions. The differences between field-trapping efficiencies of different pinning landscapes have been demonstrated for various temperatures.

COMPUTATIONAL MODEL

$$G=\delta\left(\sum_{i<j}U_{\text{in-plane}}(r_{ij})+\sum_i U_{\text{magn}}(x_i)+\sum_{i,j}U_{\text{bdr}}\left(\left|\mathbf{r}_i-\mathbf{r}_j^{\text{img}}\right|\right)+N\varepsilon+\sum_{i,j}U_{\text{pin}}\left(\left|\mathbf{r}_i-\mathbf{r}_j^{\text{def}}\right|\right)\right)$$

$$U_{\text{in-plane}}(r_{ij})=2U_0\,\mathrm{K}_0(r_{ij}/\lambda)\qquad U_0=\left(\Phi_0/(4\pi\lambda)\right)^2$$

PBCs along the *y*-direction

$$\varepsilon=U_0\left(\log(\lambda/\xi)+0.52\right)$$

$$U_{\text{magn}}(x_i)=\lambda\sqrt{U_0}H\left(\frac{\cosh(x_i/\lambda)}{\cosh(L_x/2\lambda)}-1\right)$$

$Bi_2Sr_2CaCu_2O_{8+x}$

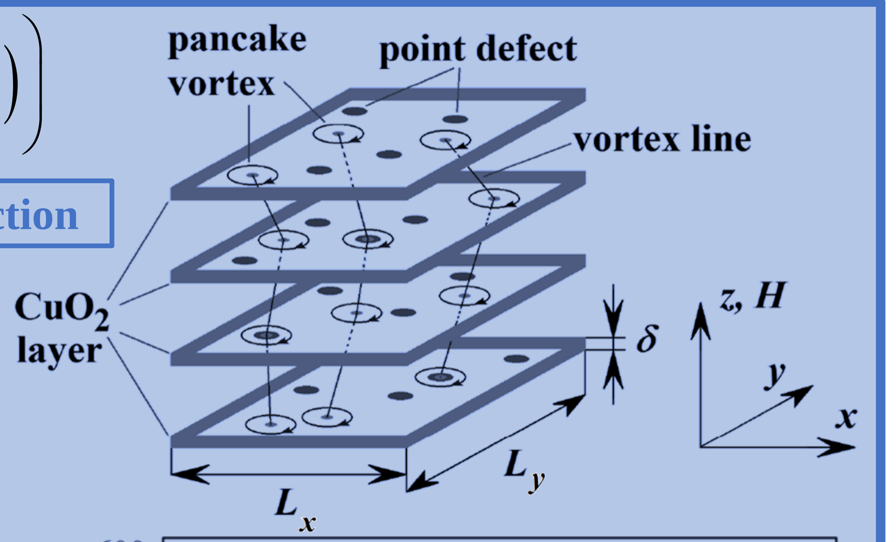
λ = 180 nm, ξ = 2 nm, T_c = 84 K

L_x = 5 µm, L_y = 3 µm, δ = 0.27 nm

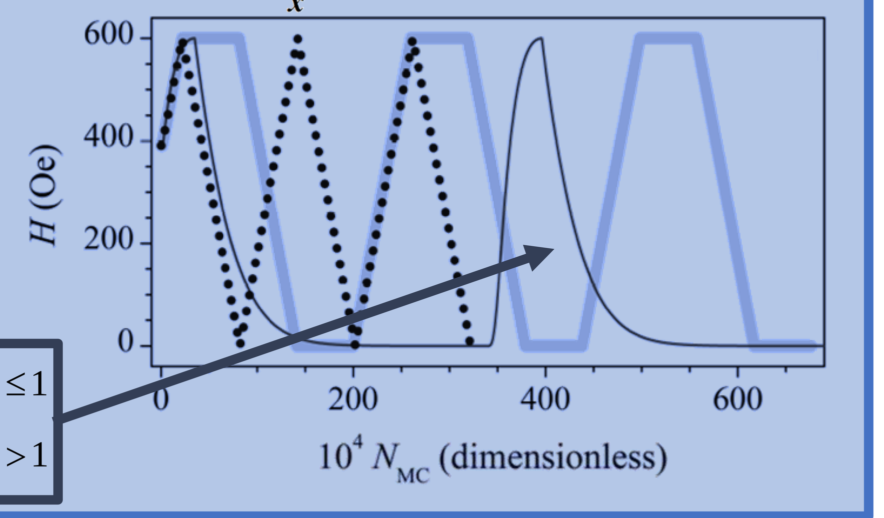
$$U_{\text{bdr}}\left(\left|\mathbf{r}_i-\mathbf{r}_j^{\text{img}}\right|\right)\equiv U_{\text{bdr}}\left(r_{ij}^{\text{img}}\right)=-U_0\,\mathrm{K}_0\left(r_{ij}^{\text{img}}/\lambda\right)$$ ← rigid boundary

$$U_{\text{pin}}\left(\left|\mathbf{r}_i-\mathbf{r}_j^{\text{def}}\right|\right)\equiv U_{\text{pin}}\left(r_{ij}^{\text{def}}\right)=-\alpha\frac{\exp\left(-r_{ij}^{\text{def}}/2\xi\right)}{1+r_{ij}^{\text{def}}/\xi}$$

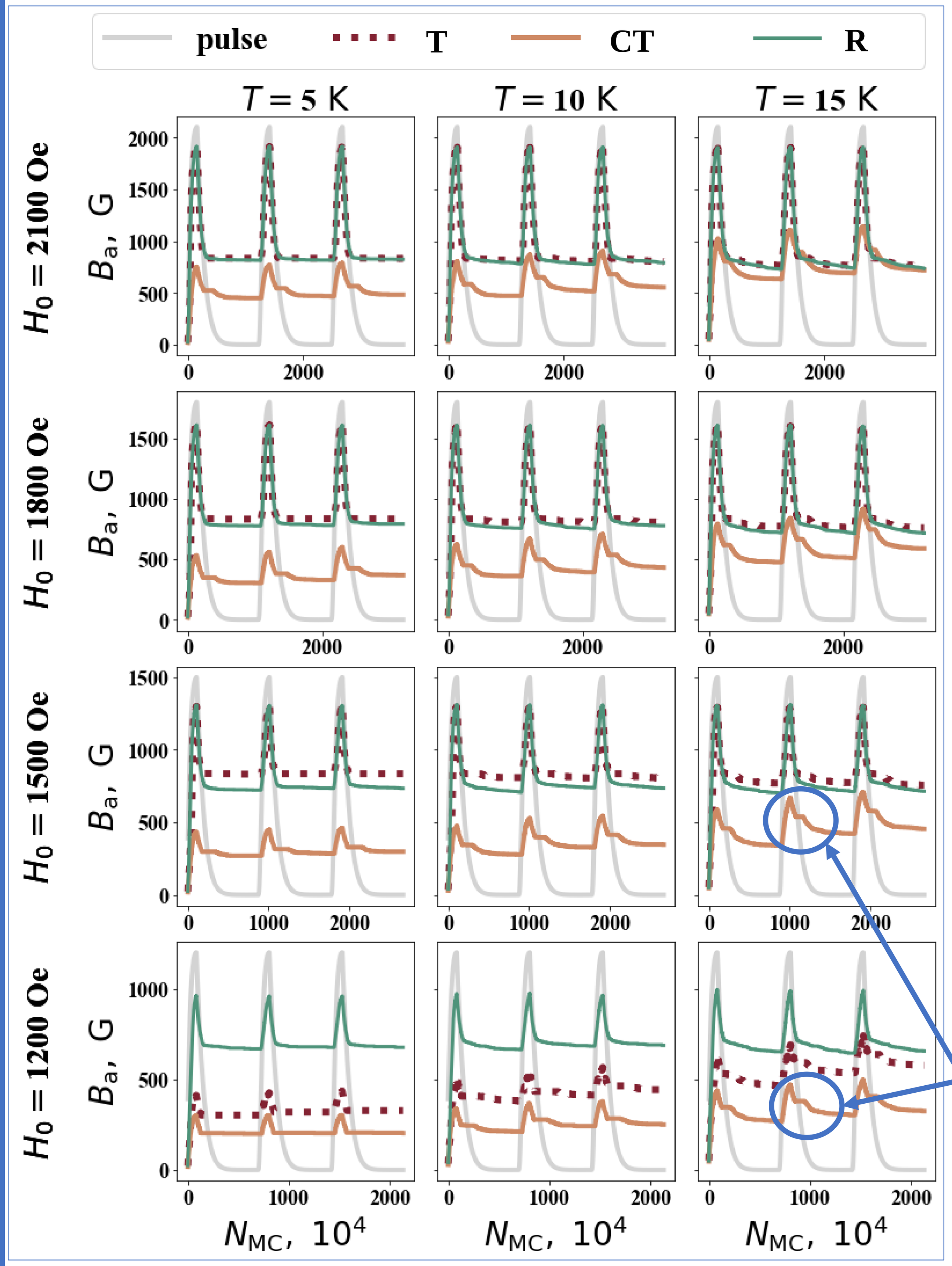
$$\Phi_0=2.07\cdot10^{-7}\text{ G cm}^2$$

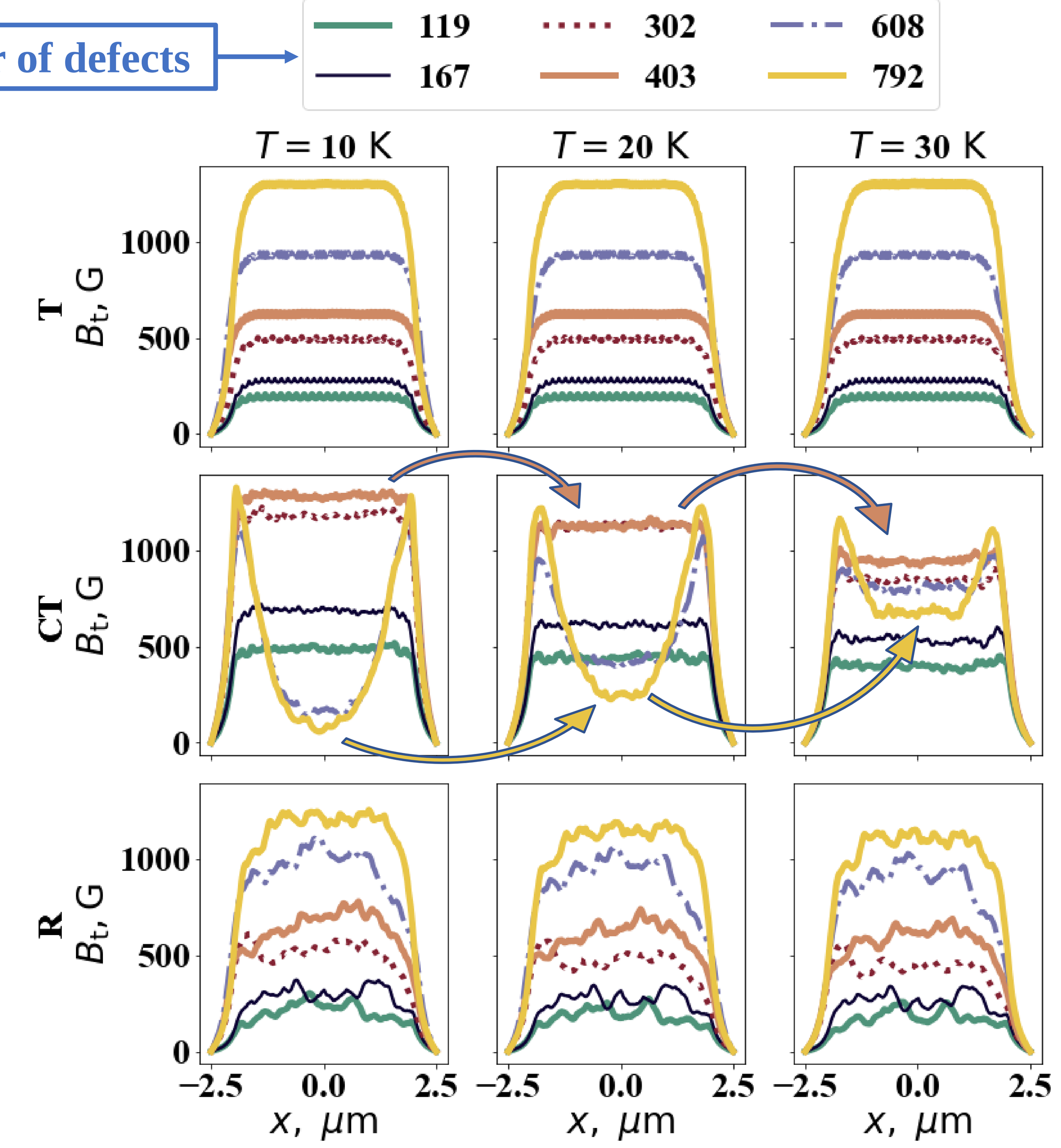


$$H(t)=\begin{cases}H_0t^{-1}\exp(1-t^{-1}), & t\le1\\ H_0\exp(1-t^{1.5}), & t>1\end{cases}$$



RESULTS



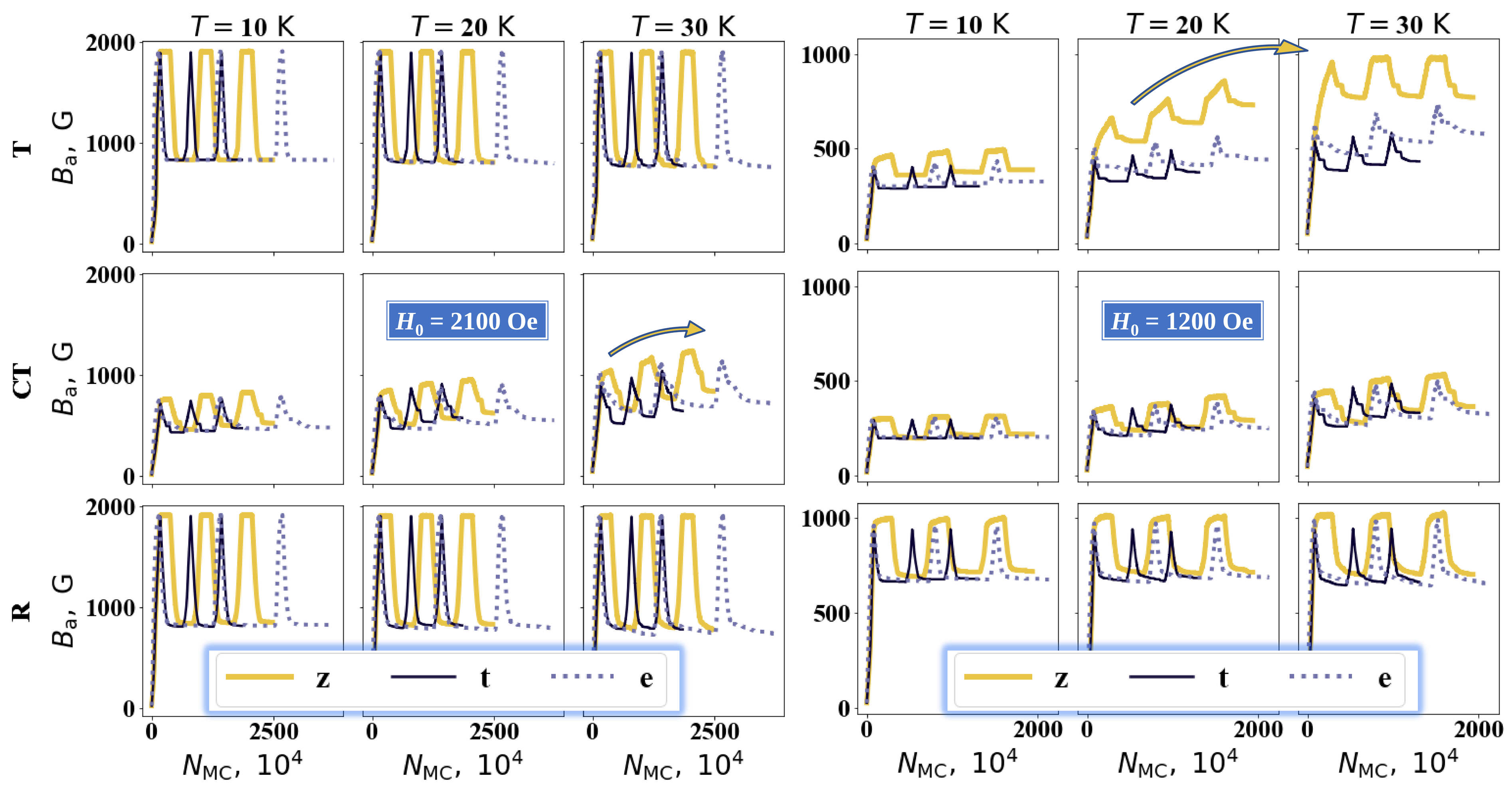


H_0 is the pulse amplitude,
N_{MC} is the number of Monte Carlo steps
B_a has the meaning of the magnetic flux density
B_t is calculated on a 2 nm mesh using the expression below ($\mathbf{h}_{\text{vort}}(r)$) with consecutive averaging along the sample's *y*-axis

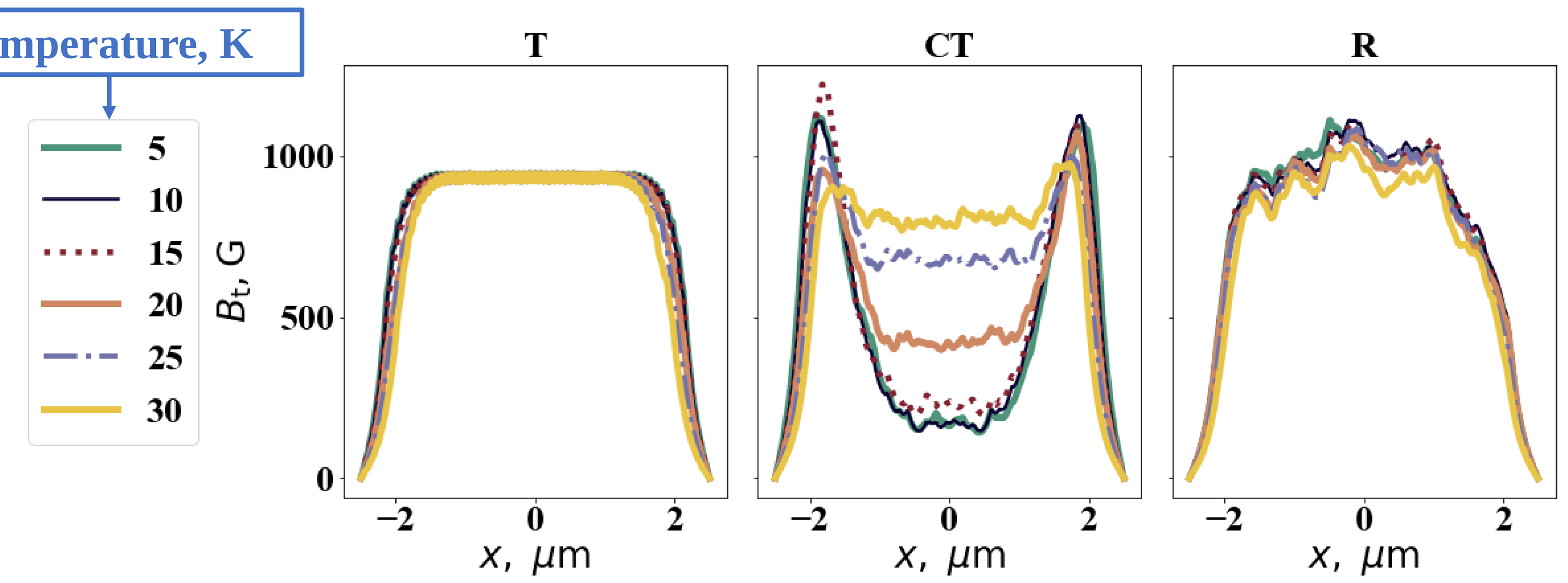
$$B_a=N\Phi_0/(L_xL_y)$$

$$\mathbf{h}_{\text{vort}}(r)=\frac{\Phi_0}{2\pi\lambda^2}\times\begin{cases}\log(\kappa)-0.28, & r\le\xi\\ \mathrm{K}_0(r/\lambda), & r>\xi\end{cases}$$

(on the left) The time-dependences of the averaged magnetic field induction B_a inside three samples with different pinning landscapes: a triangular lattice (T), a conformal triangular array (CT), and a random distribution (R); All samples contain approximately the same number of defects (608) corresponding to a density of $4\cdot10^9$ cm^{-2};
(on the right) The distribution profiles of the trapped magnetic field B_t (after the external field has been switched off) for samples with different numbers of defects (provided in the legend above) distributed in 3 different ways (T, CT and R as denoted on the left of the images); Here, H_0 = 2100 Oe.



(on the right) The time-dependences of B_a inside samples with different pinning landscapes (T (top row), CT (central row), and R (bottom row)) for three different pulse-shapes (trapezoidal (z), triangular (t) and exponential (e)). The image on the left and right correspond to different pulse amplitudes H_0; The samples contain 608 defects;
(below) The distribution profiles of the trapped field inside samples with different pinning landscapes at various temperatures (from 5 to 30 K). H_0 = 2100 Oe



CONCLUSION

1) The CT array requires much higher pulse amplitudes for full magnetization but allows for more trapped flux at lesser defect densities;
2) The increasing temperature causes thermoactivated flux creep which leads to successive magnetization upon repetitive application of pulses but also to step-like flux relaxation from CT arrays.

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