Critical Current in Various Pinning Landscapes
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**Time-dependent Ginzburg-Landau**

TDGL equations:

\[ \frac{\partial \phi}{\partial t} = \mathcal{L}_{\text{GL}}, \]

\[ [-10 -8 -6 -4 -2 0 2 4 6 8 10] \]

\[ [-1 \times 10^{-4} -1 \times 10^{-3} 0.01 0] \]

\[ \text{Modeling of pinning} \]

\[ \text{Simulation results: } \]

\[ B = 0.05 \cdot B_0 \]

\[ V \]

\[ I \]

**Here: Regular simulation grid (on GPUs)**

\[ \text{Critical currents for spherical (metallic) inclusions} \]

\[ \text{Current-voltage characteristics for different inclusion concentrations: Inclusions are randomly distributed in the simulation volume; the critical current is determined by a fraction of the corresponding free-flow flow value} \]

\[ \text{Instead of the concentration, the volume fraction and inclusion diameter are the two parameters characterizing the random spherical pinning landscape} \]

**Optimal critical current**

\[ B = 0.05 \cdot B_0 \]

**Helical motion & Reentrance**

Magnetic field & voltage for one disorder configuration

\[ J_{\text{c}}(\alpha) \]

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\[ \alpha \]

\[ \text{New discovery: a new periodically "rotating" vortex state appears at intermediate field strength having finite resistance} \]

**Simulation**

**Results**

**Competing defects**

\[ \text{The effects from different defects are not additive. Additional defects are simultaneously decreasing the critical current at some directions of the magnetic field and increase it at other directions.} \]

**Parallel fields**

\[ \text{Sample is discretized using a regular mesh of } 512 \times 128 \times 32 \text{ grid points with mesh size of } 0.3 \times 0.3 \text{ nm chosen} \]

\[ \text{Simulation time: } 25 \text{ field steps for } 300 \text{ field values} \]

**Numerical realization**

- Sample is discretized using a regular mesh of $512 \times 128 \times 32$ grid points with mesh size of $0.3 \times 0.3$ nm chosen.
- Sample is periodic in x-direction.
- Inclusions are modeled by a different low-$T_C$ component.
- 0-100 spherical inclusions with diameter $r_{\text{inc}}$ are randomly placed in the volume.
- Average over different disorder realizations.
- A fixed constant current is applied in a direction as well as a variable magnetic field.
- Simulation time: 25 field steps for 300 field values.

**Competing defects**

\[ \text{Commercial superconducting tape with nanorod inclusions is irradiated by heavy ions at } 45^\circ \text{ degrees understanding of the critical current depending on the angle of the external magnetic field} \]

**Random spherical inclusions**

\[ B = 0.05 \cdot B_0 \]

\[ J_{\text{c}}(\alpha) \]

\[ \alpha \]

\[ \text{Critical current also depends on magnetic field:} \]

\[ \text{Experimental result: MoGe slab with parallel current and field} \]

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