Topology and transport in driven vortex lattices

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The dynamics of disordered vortex arrays in type II superconductors is one of the most active fields of investigation in condensed matter physics at present. Recent advances in superconducting technologies constantly require a deeper understaning of the underlying physical mechanisms. At the same time, vortex assemblies have always been regarded as paradigmatic disordered systems, a sort of ideal playground for the most refined theories of driven random media, that appeared equally well accessible on experimental grounds.

Recently, the attention of the scientific community has turned to the topology of vortex arrays[1] and the role of topological defects, such as dislocations, in the emergence of disordered phases and critical current anomalies. Constant improvements in computational performance, together with constant advances in experimental techniques, have somehow broadened the well known phase space, introducing novel metastable states (vortex polycrystals, hexatic phases etc.) which are expected to shed some light on the sometimes counterintuitive electrodynamic behaviour of type II superconductors.

It is well known that magnetic fields penetrate samples of type II superconductors in the form of quantised flux lines, referred to as vortices, which whould arrange themselves into ordered quasi two-dimensional lattices and move under the action of Lortentz-like forces induced by external currents. Disorder and thermal fluctuations tend to break long range order giving rise to disordered phases. The loss of topological order is the main responsible for abrupt variations in the critical current of the driven vortex array.

We propose a numerical study of the interplay of topology and current transport in type II superconductors by tuning certain relevant parameters of these systems, namely the magnetic field, the density of defects and, most importantly, the typical disorder strength, or pinning force. We find that in the case of weak pinning interactions, the dynamics of dislocation assemblies is the relevant mechanisms that accounts for the collective motion of the vortex array. Dislocations rearrange into grain boundaries, accounting for the emergence of polycrystalline order.

A previous analytical study predictied that a crossover between the regimes of individual and collective pinning of grain boundaries should be detected by looking at the critical current as the defect density was increased[2]. Now we find our numerical results in excellent agreement with that model (Figure 1). Simulated critical currents follow the predictions based on grain boundary pinning and collective dislocation dynamics proves essential to explain the electrodynamic behaviour of the superconductor.

In the case of stronger pinning forces, instead, the vortex assembly loses topological order and falls into a completely disordered phase. The consequent increase in the number of degrees of freedom results in a huge increase of the critical current. Depinning is now strongly heterogeneous, accompanied by a sharply discontinous transition and jerky individual vortex dynamics.

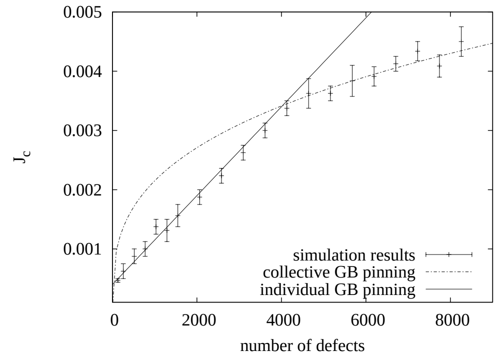

Figura 1. Critical current density J_c as a function of the number of defects. In the case of low defects concentrations, J_c matches the behaviour predicted for individual grain boundary pinning (solid line), while for dense defect configurations grain boundary pinning becomes a collective process, as required by theory (dashed line). Currents are measured in units of Gb^2c/Φ_0, where G is the shear modulus of the vortex lattice, b the lattice spacing, c the speed of light and Φ_0 the magnetic flux quantum.

[1] P. Moretti, M.-C. Miguel, M. Zaiser, and S. Zapperi, Phys. Rev. Lett. **92**, 257004 (2004)

[2] P. Moretti, M.-C. Miguel, and S. Zapperi, Phys. Rev. B **72**, 014505 (2005)

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