Current-induced self-organisation of mixed superconducting states

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The elemental superconductor niobium features the intermediate mixed state (IMS), the coexistence of flux-free Meissner state and mixed state domains [1]. Besides being a prominent example of superconducting vortex matter, the IMS can also act as a highly tunable model system for universal domain physics [2]. We use a combination of small-angle neutron scattering and transport measurements to study the vortex matter in the IMS with and without applied current [3]. Applying a sufficiently high current induces the flux flow state, where the vortices of the mixed state domains are de-pinned from the pinning centers and start moving orthogonal to the applied current. In contrast to the canonical mixed state, non-trivial ordering phenomena are expected in the vortex movement regime of the IMS due to the highly heterogeneous domain structure. We report the conservation of the IMS in the vortex movement regime. Our main result is an observation of a transition from isotropic to anisotropic IMS scattering, indicating, that the IMS rearranges itself into a stripe superstructure in the vortex movement regime (c.f. figure 1). The stripe pattern is aligned perpendicular to the current direction along the motion of the vortices. Results from numerical simulations obtained using a system of two coupled time-dependent Ginzburg-Landau equations support our experimental findings. They furthermore yield important details of the evolution of the vortex matter under an applied current. This study highlights that the IMS can not only act as a model system for universal domain physics but also demonstrates a mechanism of spontaneous pattern formation that is closely related to the universal physics governing the intermediate mixed state in low-κ superconductors.

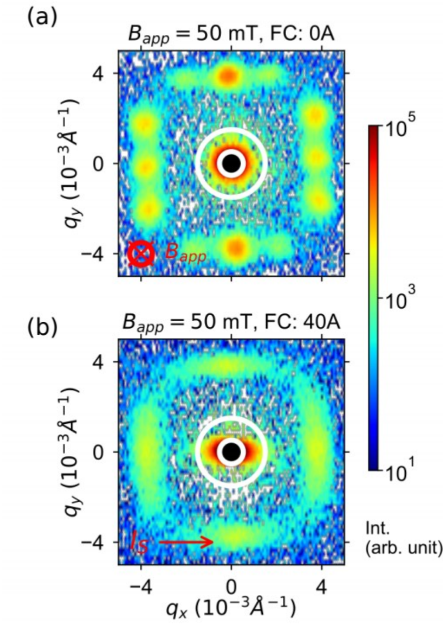

Figure 1: 2D SANS detector images at T = 4K and B = 50 mT without (a) and an applied current of I = 40 A (b). In panel (b) the current-induced anisotropy in vicinity of the blacked-out direct beam within the white circles is clearly visible.

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[3] X. S. Brems, arXiv preprint, 2104.07967 (2021)