Experimental report

17/02/2020

Proposal: EASY-568 **Council:** 10/2019

Title: The effects of current on the intermediate mixed stat in niobium

Research area: Physics

This proposal is a new proposal

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Samples: Nb

Instrument	Requested days	Allocated days	From	To
D33	48	48	17/01/2020	19/01/2020

Abstract:

The intermediate mixed state (IMS) in a superconductor is found between complete magnetic flux expulsion (the Meissner state) and the penetration of an array of supercurrent vortices (the mixed state). Here we find in Niobium, due to a rare attractive interaction between vortices, a coincidence of these two phases separated on the micron scale. Recent work, with the use of VSANS, going down to a Qmin of 6x10-4 Å-1 followed the temperature dependence of the vortex spacing in the IMS which could be explained by a the standard BCS variation of the London penetration depth. They did not report on any low Q scattering from the mixed state regions which have been shown to exist on the micron scale as shown by the Bitter decoration in figure 1 . They did however see a finite size effect on the Bragg peak corresponding to domains just over a micron at low temperatures. Regions of where the IMS exists within the bulk have been qualitatively imaged using interference techniques but they could not make a quantitative measurement of the IMS structure in the bulk.

Experimental Report: The effects of current on the intermediate mixed state in niobium (EASY-568)

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Applying an external current to the superconductor opens up a new dimension in the two dimensional parameter space of temperature and applied magnetic field. From Amperes law, current can only exist where there is a gradient of vortex density and vice versa, the vortices can only move in the presence of a current. This results in two orthogonal flows, one of electrons and the other of vortices, both confined to the mixed state regions of the material which must themselves move with the vortices.

For our study, we have cut a sample with dimensions of $10 \times 1 \times 0.1$ mm^3 from a pure Nb single crystal previously used for other experiments on the IMS [2, 3]. We determined the I-V-characteristics of our sample in different applied fields to map the 3D-parameter space of current, temperature and applied field for flux flow in the IMS. We confirmed the existence of the IMS in our sample over a range of applied fields and temperatures in agreement with [2].

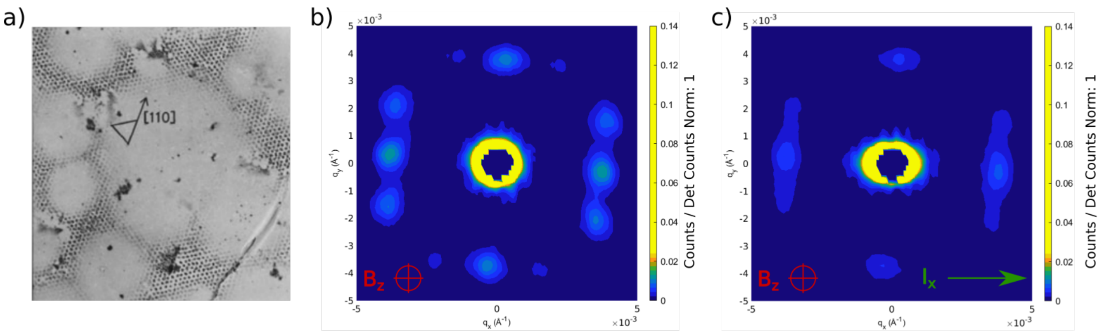

Figure 1: a): A Bitter decoration of the IMS. The dark areas contain vortices [4]. b) and c): Scattering data from Nb in the IMS in $B_{applied}$ = 50 mT and $T_s = 4.2$ K: with no applied current (a) and an applied current I_{Sample} = 42 A (b). We see a clear change in the scattering signal around the masked direct beam.

For the first time, we were able to investigate the IMS in a sample in the state of flux-flow. Typical data obtained at a temperature of T_s =4.2 K and an applied field of $B_{applied}$ = 50 mT are shown in Fig. 1, comparing rocking scans inside the IMS in the flux-low regime (current on) and in the steady state regime (no current). For the current-driven IMS, we observed a broadening in the rocking curves and a slight shift to lower q-values in the position of the Bragg peak. Interestingly, a clear change in the VSANS regime was found, which changes from isotropic scattering around the direct beam to anisotropic in q_x-direction. The anisotropy indicates that the domains rearrange in stripes in y-direction perpendicular to the applied current in x-direction.

References

[1] S. Wolf et al., Phys. Rev. B **96**, 144515 (2017).

[2] A. Backs et al., Phys. Rev. B **100**, 064503 (2019).

[3] T. Reimann et al., Phys. Rev. B **96**, 144506 (2017).

[4] E. H. Brandt et al., J. Supercond. Nov. Magn. **24**, 57–67 (2011).