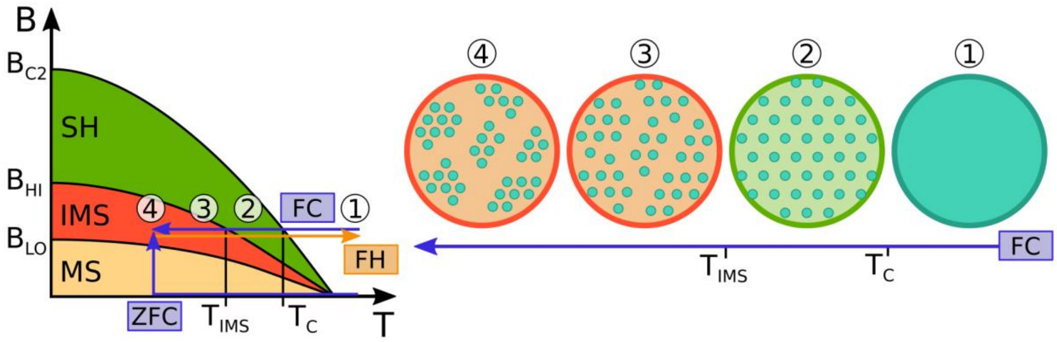
Universal behavior of the transition to the intermediate mixed state in the type-II/1 superconductor niobium

Alexander Backs[1,2], Michael SCHULZ[1,2], Vitaliy PIPICH[3], Markus KLEINHANS[4], Peter BÖNI[2], Sebastian MÜHLBAUER[1]

[1] Heinz Maier-Leibnitz Zentrum, Technische Universität München, Lichtenbergstr. 1, Garching, Germany
[2] Physik Department E21, Technische Universität München, James-Franck-Str. 1, Garching, Germany
[3] Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Garching, Germany
[4] Physik Department E51, Technische Universität München, James-Franck-Str. 1, Garching, Germany

Besides the well-known Abrikosov vortex lattice (VL), superconductors of the type-II/1 exhibit the intermediate mixed state (IMS), where VL domains and Meissner domains coexist, due to an attractive component of the inter-vortex interaction [1]. Despite ongoing work since its discovery in the early 1970s, the IMS bulk properties remain elusive. Especially the interplay with vortex pinning, due to impurities and surface defects, as well as the sample geometry and connected demagnetization effects, play a crucial role. Using a multi scale approach by combining several neutron scattering techniques and bulk measurements, we have readdressed the IMS in a set of bulk niobium samples of varying purity [2,3]. In contrast to many previous studies, we have focused on the field cooled transition from a homogeneous VL in the Shubnikov state into the domain structure of the IMS. In combination with significant pinning, field cooling causes a flux freezing transition above the IMS which effectively suppresses a critical state like behavior. However, the vortex rearrangement in the IMS is not prevented, indicating a breakdown of pinning at the onset of vortex attraction. Independent of the sample quality, and hence pinning strength, we find a universal behavior of the IMS transition, which is, furthermore, unaffected by the measurement history. Especially the vortex spacing shows a distinctive temperature dependence, which is closely related to the superconducting penetration depth.



Schematic phase diagram of a type-II/1 superconductor, subdivided into the Meissner (MS, yellow), intermediate mixed (IMS, red) and Shubnikov (SH, green) state. Arrows depict different measurement protocols: FC, FC/FH and ZFC/FH. For FC measurements, the microscopic magnetic flux redistribution is shown, starting from the normal state (1) with a homogeneous flux distribution, to the regular VL in the SH (2). In the IMS (3, 4) the VL breaks up into small domains containing an increasingly dense VL.

References

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E-mail: alexander.backs@frm2.tum.de