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Macroturbulence in Superconductors*

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Macroturbulence in Superconductors

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Direct magneto-optic observation of coupling of the Abrikosov vortices into macroscopic drops of increased flux density at remagnetization of the YBCO single crystals is presented. Appearance of these flux structures correspond to strong perturbations of the current trajectories and transition from laminar to turbulent current flow.

1. INTRODUCTION

Processes of remagnetization of the type-II superconductors are usually described in the frames of the critical state model [1]. This model supposes that during increasing field H_{ext} magnetic flux enters samples with the induction gradient perpendicular to the sample boundaries, so that the penetration front is parallel to the boundaries and the critical current J , determining the flux gradients dB/dr , is also flowing parallel to the boundaries. At decreasing field the flux starts escaping the sample and the induction gradient and the critical current change sign in a layer near the sample boundaries. Finally a roof-like induction pattern is formed with the "roof edges" touching sample boundaries at $H_{ext}=0$. At application of the negative field the "roof" keeps its shape and moves below zero field level. During this the critical current distribution is not changing and the line where the "roof" slope crosses zero level (corresponding to the remagnetization front) is moving inside the sample keeping parallel to its boundaries.

Above behavior can be considered as a mixed state with the laminar current flow. In the present work we report direct observation of the loss of stability of the of the laminar flow and appearance of essentially turbulent current trajectories under conditions of a strong enough flux creep. Recently such a transition was predicted for anisotropic superconductors with nonlinear I-V curves [2].

2. EXPERIMENT

Observations were conducted in high-quality mainly untwinned YBCO single crystal plates with $T_c=93K$ and transition width $\Delta T=0.2K$ using advanced real time magneto-optic technique [3]. External field was normal to the (001) sample plane and distribution of the normal component of induction was revealed as a color pattern with changing intensity, corresponding to the flux density.

3. RESULTS AND DISCUSSION

At small temperatures the front of the initial flux penetration and the remagnetization front are parallel to the sample edges in accordance with the critical state model. However due to the shape effect [4,5] the normal induction gradients are increased near the edges and in the middle of plates. With increasing temperature penetration and remagnetization fronts start bending and at $T>45K$ qualitatively new features appear at the latter. Bright spots corresponding to local concentration of vortices are nucleating at the remagnetization front (Fig.1) which are then moving along it, merging and growing. Some of them detach from the front and move as bubbles across the sample, some annihilate. Often coupling of such spots of opposite polarity, placed at opposite sides of the remagnetization front, is observed.

Fig.1 Nucleation of the "flux drops" at the remagnetization front (indicated by arrow). Saw tooth pattern is due to in-plane domains in the magnetooptic film. $T=63K$, $H_{ext}=35$ Oe.

"Flux drops" are nucleated at different point from cycle to cycle of changing field. However in some places, especially at some twin lamellae, the process is reproducible.

With increasing temperature the number of nucleating spots increases and the time of their evolution decreases. Similar changes take place at increasing the field sweep rate dH/dt . Fig.2 shows remagnetization of a YBCO sample with crack (broken line) at 63K. Due to concentration of the

Fig.2 Appearance of the turbulence near the crack (dashed line) is more pronounced than that at the edge due to higher dH/dt at the scratch. $T=63K$ and $H_{ext}=28$ Oe.

field in the crack about two times larger than at the sample edge dH/dt here is also twice that at the edge and it can be easily seen that here much more spots are nucleated.

Observed flux drops can be described in terms of essential perturbation of the current trajectories and formation of shock-like patterns and closed current loops at the remagnetization front [6]. Inside these loops the field is naturally concentrated. Similar transition from laminar to turbulent current flow in anisotropic superconductors with substantially nonlinear differential resistivity due to the flux creep was predicted in [2]. The nature of the instability, which should occur in some current range (determined by the interplay of nonlinearity and anisotropy), is declination of the current towards the direction of minimum resistivity. In our case the instability is essentially supported by magnetostatic interactions of oppositely magnetized regions through demagnetizing fields. This is suggested because flux drops are not observed during initial magnetization but only at the remagnetization of the samples. Also flux drops are usually nucleating in the ambient of concentration of the flux of opposite polarity and are coupling with oppositely magnetized spots.

In [2] appearance of macroturbulence is supposed to result in specific domain structure, whereas observed flux spots behave more like hydrodynamical vortices. We should emphasize that revealed turbulent structures should be taken into account for explanation of the ac response of superconductors, especially in the case of high- T_c materials.

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