Nanoscale physics

Penetration of Abrikosov vortices into doubly connected superconductors

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Abstract. The results of the study of spatio-temporal patterns of the penetration of Abrikosov vortex flux into doubly connected bulk superconductors are presented. Comparison of the obtained results with the patterns of penetration into single-connected superconductors (disk) showed significant differences. The limits of stability of the critical state, the magnitude of the magnetic flux entering the sample, and the duration of the vortex avalanches themselves change. We measured the incoming magnetic flux using inductive sensors fixed on the sample, as shown in Fig.1. The outer coil registered the change in the magnetic flux in the entire sample, while the inner coil recorded the change in the ring (cylinder) cavity. The Hall sensor, located above the center of the hole, measured the local magnetic induction.

Introduction In the analysis of dynamic phenomena in doubly connected superconductors, experimental studies play the main role, since the theoretical analysis of these phenomena encounters significant difficulties. Quite a lot of works [see, for example, 1-3 and the literature cited there] are devoted to the analysis of the penetration of the magnetic flux into both single-connected and doubly-connected superconductors. As objects of study of doubly connected superconductors, a hollow cylinder is often used, which screens the magnetic field in the superconducting state (– superconducting screen of the magnetic field) and a ring.

We present the results of a study and comparison of spatio-temporal patterns of magnetic flux penetration into doubly connected (ring and hollow cylinder) and single-connected (disk) bulk superconductors. In the process of increasing the external magnetic field in superconductors of the second kind, flux jumps (thermomagnetic instabilities) can occur, which significantly limit their application. The distribution of the incoming magnetic field is, as a rule, inhomogeneous. The incoming magnetic flux forms a finger-like or more complex structure. The distribution of the magnetic flux in the sample was studied using the method of magneto-optical visualization, which makes it possible to reveal and characterize the features of the behavior of the magnetic flux during and after the development of an avalanche.

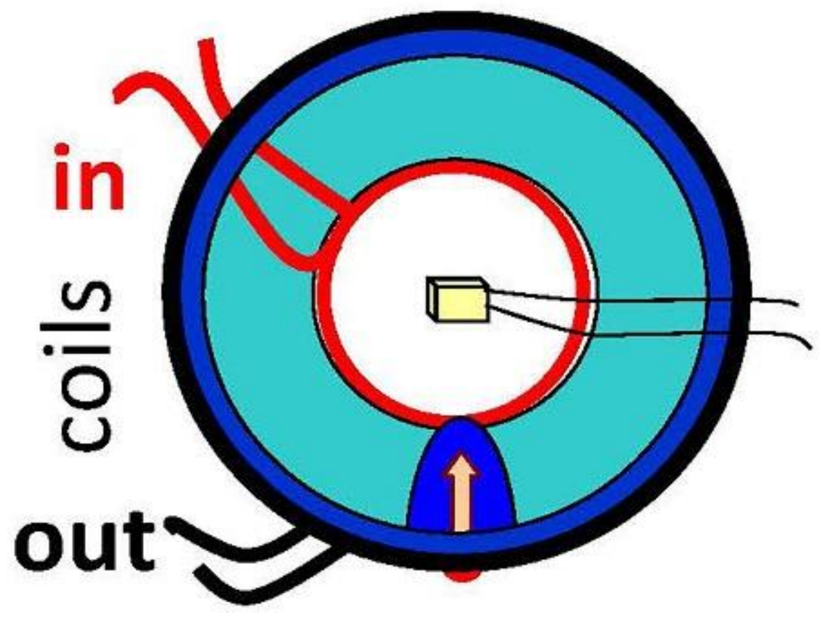

Figure 1. Placement of sensors on the sample.

Aims

The stability of the critical state of doubly connected bulk superconductors of the second kind and the phenomenon of magnetic field penetration both into the bulk of the superconductor and into the shielded hole are studied using both induction and Hall sensors. For a detailed analysis of these phenomena, we used the remagnetization loops of the studied samples obtained at different temperatures. An analysis of the data obtained from inductive sensors made it possible to calculate the magnitude of the magnetic flux entering both the volume of the superconductor and the shielded cavity, as well as the duration of the flux jump. Examples of obtained remagnetization loops with flux jumps and corresponding voltage pulses are shown in Fig. 2. Examples of calculating the value of the incoming flux depending on the external magnetic field and the duration of the flux jumps are shown in Fig.3. Other features of the dynamic response of doubly connected hard superconductors to a changing external field are also discussed.

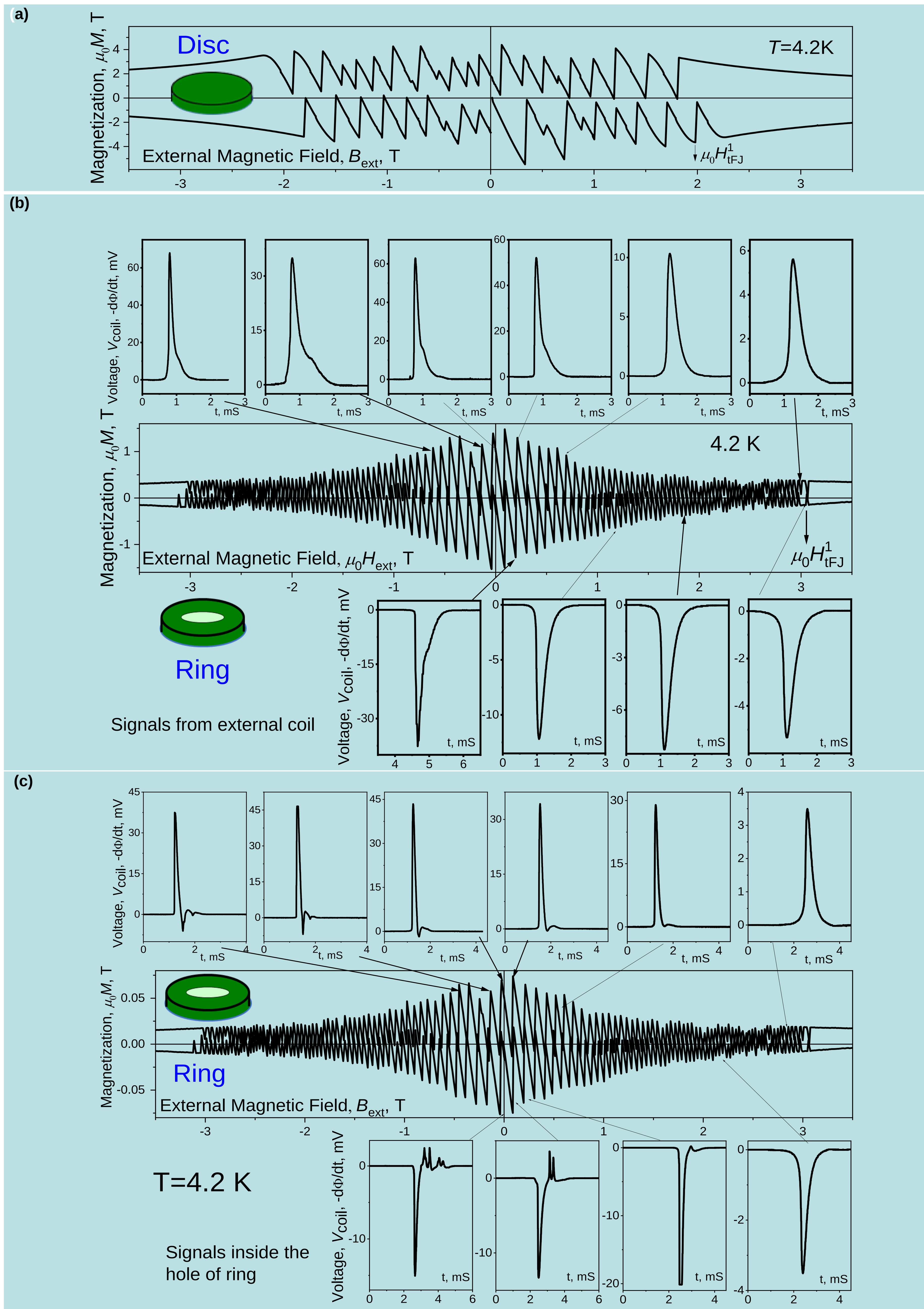

Figure 2. Remagnetization loops $M(B_{ext})$ for a disk (a), for a ring at (b), and for a inner cavity of the ring (c) at 4.2 K; voltage signals $U_{coil}(t)$ from the respective sensors for flux jumps for chosen magnetic fields are presented around hysteresis loops.

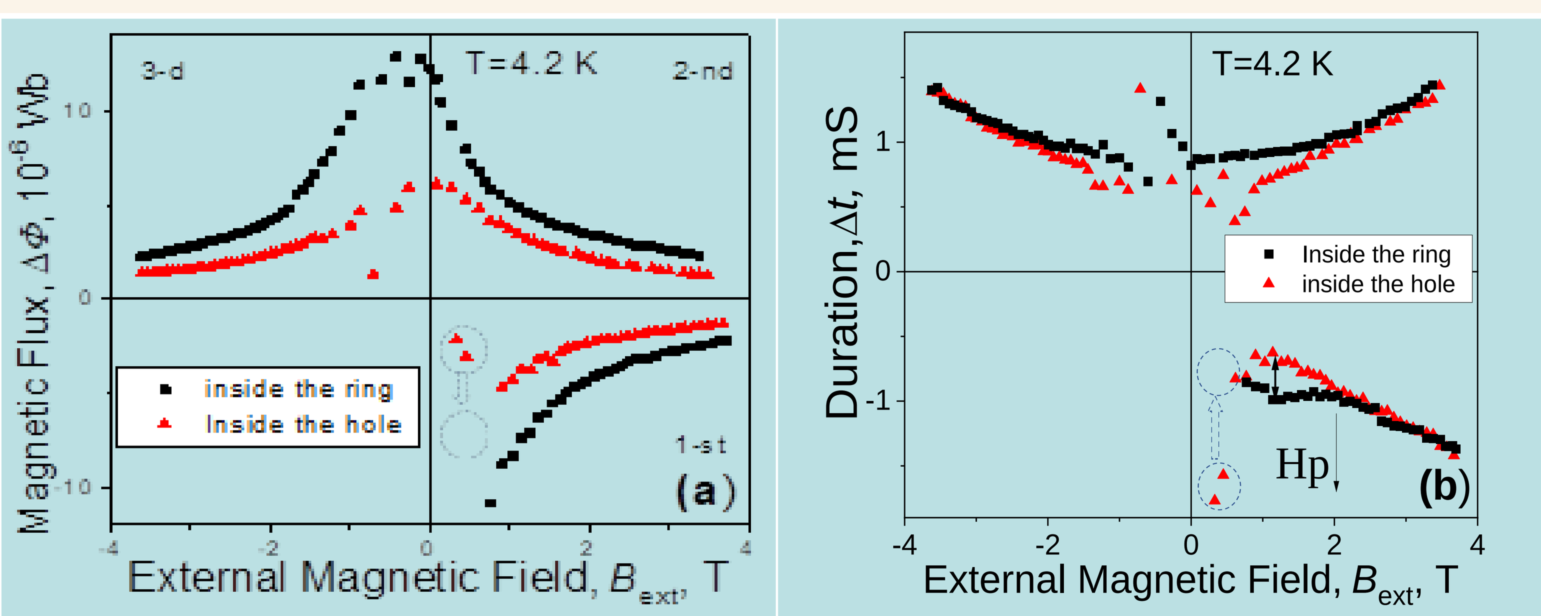

Figure 3. Field dependence of the magnitude of the magnetic flux $\Delta\Phi$ that entered the sample during the avalanche (a), and the duration of the avalanche Δt (b) for a complete remagnetization loop for the ring and hole at a temperature of 4.2 K.

CONCLUSIONS

It has been established that the stability limits of the critical state in the disk and the ring, which have the same external dimensions, differ significantly:
– the interval of instability of the critical state in a magnetic field in the ring almost doubles, compared with the disk, from 2 T to 3.7 T;
– in the specified range of magnetic fields, 9 avalanches occur in the disk, while more than 60 in the ring.
When the magnetic flux entered the internal cavity (screen flow), the rate of flux entry increased throughout the sample during the avalanche.
As the temperature increases, the value of the magnetic flux entering the sample decreases for the ring and increases for the disk.

References

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