Influence of the sample processing method on the roughness of the magnetic flux front in hard type II superconductors

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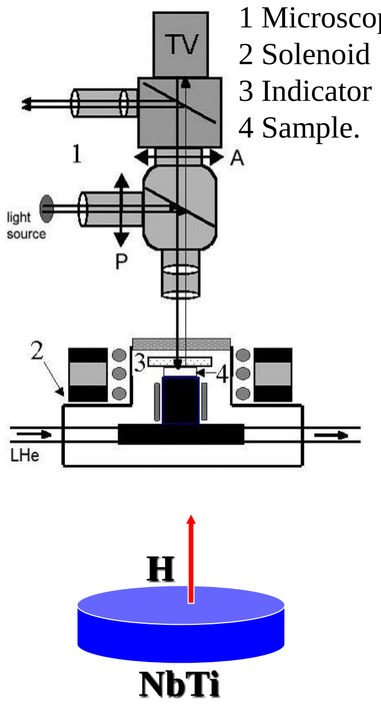
Abstract The influence of the sample processing method and temperature on the roughness of the magnetic induction flux front penetrated into the hard type II superconductor sample was analyzed by means of magneto-optical visualization. In the study NbTi-50% disk having 0.1 mm thickness and 12 mm diameter was investigated. The sample was cut off from the cylindrical hydro extruded rod and subsequently annealed. The structure of the magnetic induction in the sample was examined in both shielding and flux trapping modes. The experiment was done in temperature range T = 4.5 - 8K. The studies were carried out at different external magnetic field values up to 600G both at the boundary between the Meissner and critical states, and at different levels of induction in the sample, at a fixed value of the external magnetic field. The corresponding levels were determined by the degree of grayscale. The roughness exponent was determined by the fast Fourier transform algorithm. The carried-out investigations revealed a very rough magnetic flux front in both described above cases: the boundary of the region of the magnetic field penetration into the sample and the different levels of induction in the region of the mixed state. It was shown that as a result of heat treatment, both the roughness exponent and the critical current density values increase. The experiment temperature has a weak effect on the roughness exponent. The influence of both the sample boundary shape [1] and its prehistory on the roughness of the magnetic flux front was analyzed. It was shown that the roughness exponent is a characteristic of the pinning centers of the sample. The obtained results enable to assert the existence of the fractal nature of the penetrating magnetic flux front structure. The Hausdorff parameter was calculated.

Experimental set-up and sample



1 Microscope
2 Solenoid
3 Indicator
4 Sample.

Magneto-optical method provides a measure of the normal component of the induction B_z. An indicator was used to image the dynamics of magnetic induction pattern at the surface of disc at temperatures 4.5 – 8K. One side of the disk was polished to a mirror to reflect the incident polarized light. The magnetic flux penetration into the 0.1 mm thick superconducting NbTi 50 at % disc with diameter 12 mm at remagnetization in the magnetic field up to 600 G was studied. The magnetic field was applied perpendicular to the surface of disc. A MO-technique allowed observations of the flux dynamics and registration of the field maps. From these maps, we obtained profiles of the constant flux density and analyzed their width, length, correlation functions, and power spectra.

Magnetic flux front dynamics: results of the experiment

SC after the extrusion

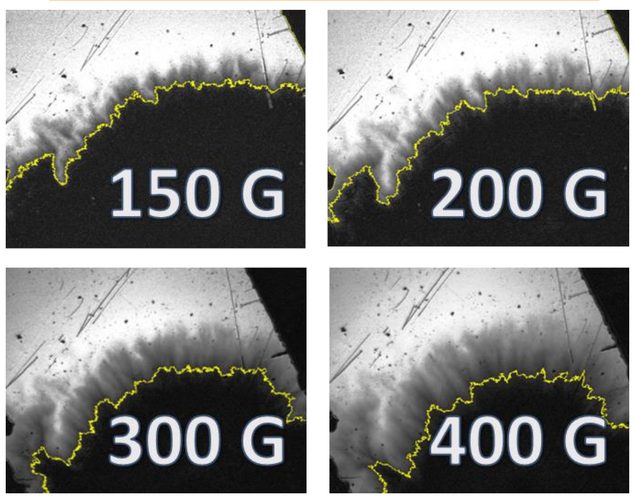
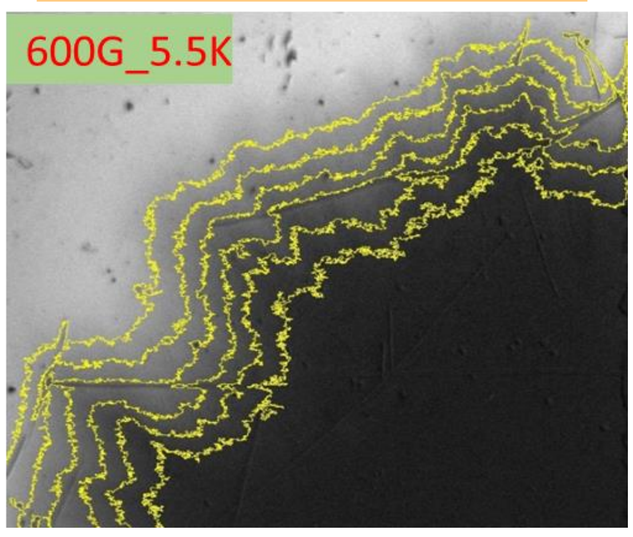


Fig 1. Flux pattern and profile near the flux front. For each curve of the flux front spectral function S(k) was obtained.

SC after the extrusion



SC after heat treatment

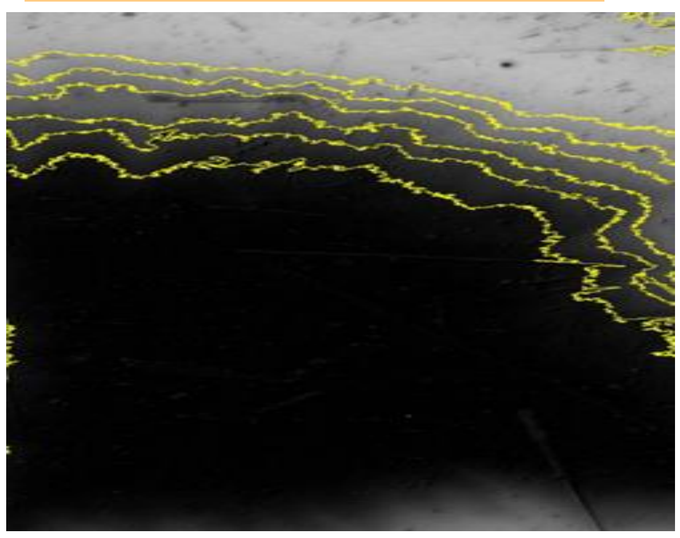


Fig 2 The profiles of induction in NbTi-disk at different B_z levels and processing methods.

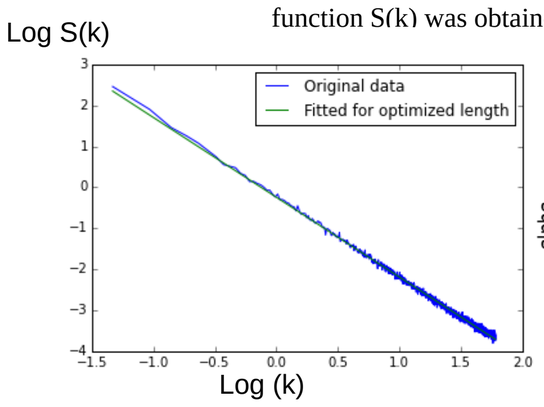


Fig. 4. Spectral function s(k) in double logarithmic scale, from which roughness parameter α and Housdorff dimension D = 2-α were found.

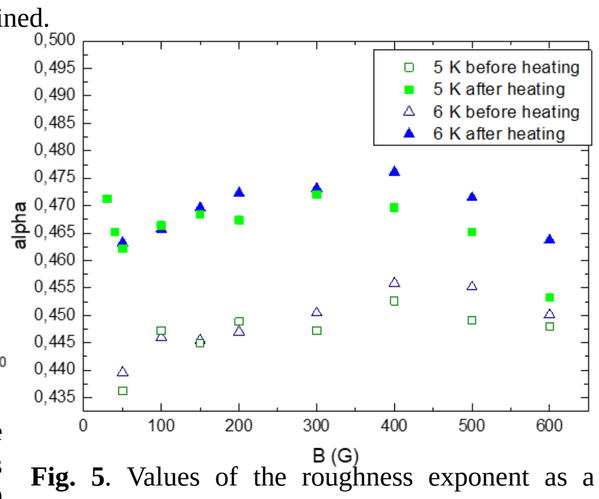
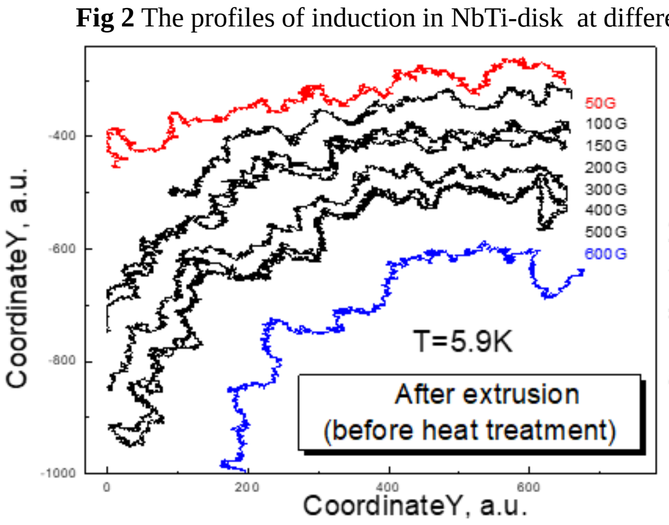


Fig. 5. Values of the roughness exponent as a function of the external magnetic field at the front of the magnetic flux in the samples before and after heat treatment at two temperatures.



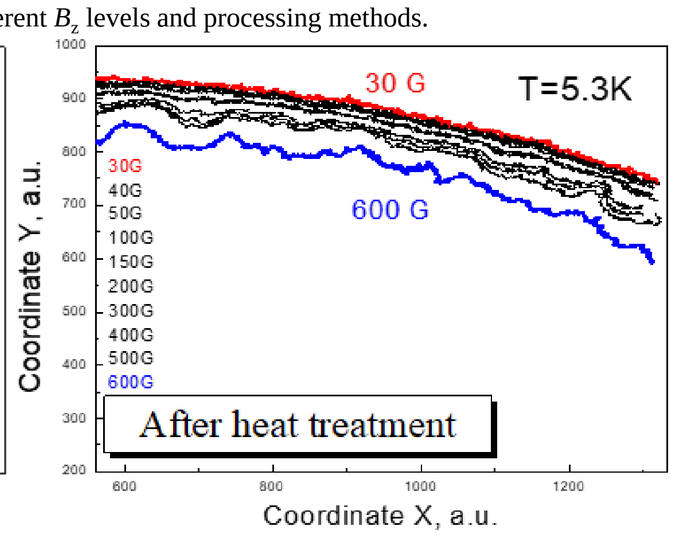


Fig. 3. a) - The structure of the boundary between the Meissner and critical states for different values of external magnetic fields after extrusion and after heat treatment.

Conclusion.

1.To analyze the shape of the curves representing the flux front, the spectral function S (k) was constructed, which for the case under consideration has a power-law character. This behavior of the front of the penetrating flux was observed in many works (see, for example [1, 2]. The analysis showed that the behavior of the front of the magnetic flux penetrating into the superconductor has a fractal nature. Using the standard technique, we determined the roughness exponent of the curve defining the flux front – α. We have obtained the values of the roughness exponent for different levels of magnetic field induction in the sample, at a given value of the external magnetic field, and for the flux front at different values of the external magnetic field, different temperatures and material processing methods, used a single criterion – the minimum of its standard error.

2.The heat treatment process has a more significant effect on the value of the roughness exponent than temperature. The penetration depth of the flux into the sample after annealing decreased significantly (~ 4 times), which indicates an increase in the critical current density and a change in the pinning structure, which leads to a change in the roughness exponent.

3.The dependence of α on the magnitude of the magnetic field induction has a non-monotonic character: the roughness index first increases and then slightly decreases. A similar behavior was observed in [1]. It is assumed that the decrease in roughness is associated with the alignment of the flux along the edge of the sample. We also believe that a redistribution of the flux occurs here due to relaxation processes, which leads to a more uniform distribution of the magnetic field induction.

4.The obtained values of the roughness index are in the range of 0.435–0.480. If we accept, as stated by many authors [1,2,], the fractal (self-affine) nature of the flux front, it should be recognized that in the case under consideration the system obeys the model of dynamic stochastic disorder, for which, as Kardar-Parisi-Zhang [3] pointed out, the roughness index should satisfy the condition α<0.5 (the so-called KPZ model).

References

1. V. K. Vlasko-Vlasov et. al. Phys. Rev. B **69**, 2004, 140504(R). 2. R. Surdeanu, et.al. Phys. Rev. Let**.** (1999), **83**, 2054. 3. M. Kardar, G. Parisi, Y.-C. Zhang. Phys. Rev. Let. (1986), **56**, 889.