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Normal domain temperature profile in second generation HTS tape wire

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Abstract

Background: Studies of the normal zone in high-temperature superconducting wires are extremely important for power applications, such as fault current limiters, motors, cables etc. We studied the temperature distribution and normal domain propagation in high-temperature superconducting YBCO tape with highly resistive substrate.

Findings: For applied voltages exceeding a certain threshold value the normal domain was found to become unstable and started to propagate along the tape.

Conclusions: The normal domain in superconducting tape with highly resistive substrate appears when voltage is applied to the sample.
At voltages greater than the threshold value, the domain starts to move.
This motion enables us to find the domain temperature and potential profile.

Keywords: High-temperature superconductors; Phase transition; Normal zone propagation

Introduction

Nucleation and propagation of normal zone are of great importance for high-temperature superconductors (HTS) power applications. In previous experimental studies of the normal zone structure in HTS tapes, it was generated e.g. in vacuum by means of an external heater (Daibo et al., 2011, Pelegrin et al., 2011) or by pulsed current (Mader et al., 2011). These conditions are different from those in the HTS power devices where normal zone is generated in liquid N_2 due to overcritical AC current. In the present paper we generate a normal zone by transport current in the sample. The normal zone appears to be restricted in the finite volume, i.e. we deal with normal domain (ND). Using the time resolved thermocouple and potential probe measurements we can explore the ND spatial structure.

Methods and results

The sample of YBCO tape wire SuperPower SF12100 was tested in liquid N_2. The cross-section of the 12 mm width wire has the following structure: 100 μm Hastelloy substrate, 1 μm YBCO, 1.5 μm Ag. Both nominal and measured critical currents of the wire are about 300 A, critical temperature is about 91K. Figure 1 shows the geometry of the sample with the thermocouple (TC) and potential probes.

The procedure of our AC-measurements is described in detail in Ref. (Fleishman et al., 2010). A constant amplitude 50 Hz AC voltage V_0 is applied across the current leads to the HTS sample at the moment t_0.
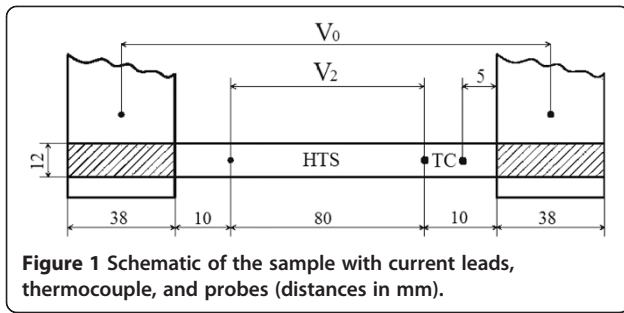
Then, current through the sample I, temperature of the TC T, and voltage in the middle part of the sample V_2 are being measured with 1 ms time resolution within 40 s interval. ND is generated by local overcritical current Joule heating in a specific weak tape segment due to sample inhomogeneity. Location of this weak place (5 mm from the right current lead) was determined by eye from liquid nitrogen boiling in the preliminary experiment. TC was soldered near this point.

Figure 2 shows a typical temperature T versus time plot after an application of $V_0 = 0.76$ V AC voltage. The data indicate that the temperature achieves its maximum in 3 s and almost does not change until switching the voltage off. During this period the voltage V_2 between the potential probes is approximately zero.
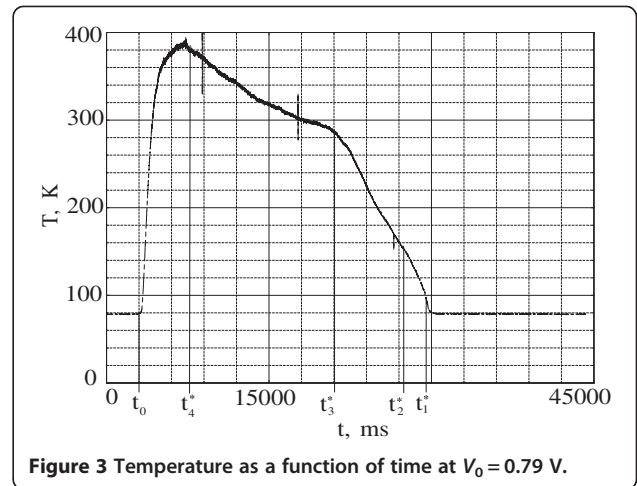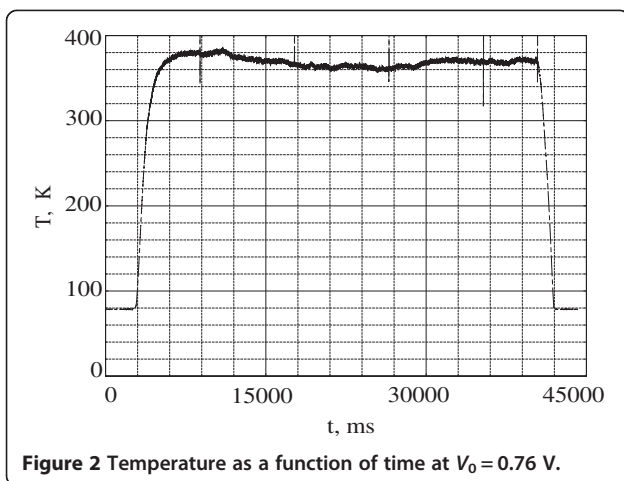
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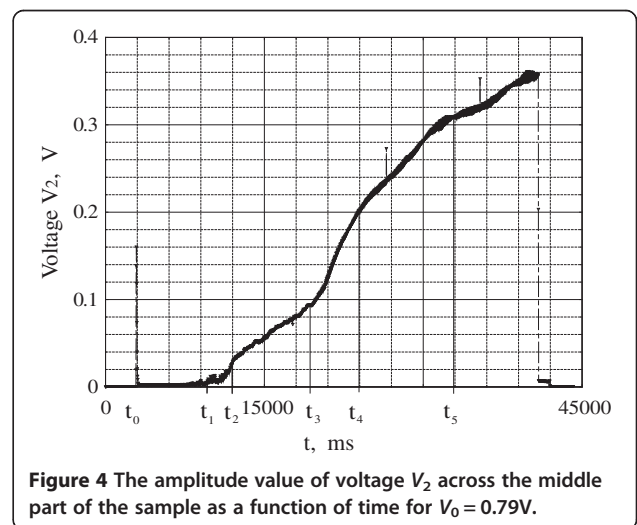Full list of author information is available at the end of the article

Figure 1 Schematic of the sample with current leads, thermocouple, and probes (distances in mm).

Figure 3 Temperature as a function of time at $V_0 = 0.79$ V.

The data in the range 0.3 V < V_0 < 0.76 V demonstrate qualitatively similar behavior: once normal domain is formed it stays in the same place and its parameters remain unchanged. It means that for V_0 < 0.76 V the normal zone is located between the potential probe and the right current lead, and TC measures the ND temperature.
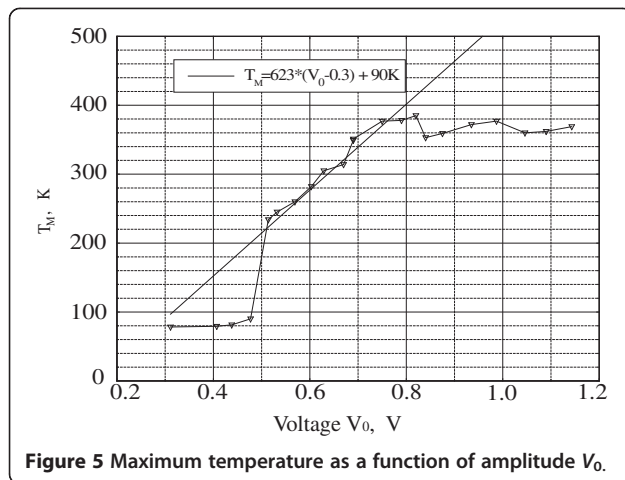
The temperature versus time dependence changes drastically when the voltage step V_0 is increased to 0.79 V (Figure 3). The temperature reaches almost the same maximum value as for lower V_0 value but instead of being constant decreases afterwards. The rate of temperature drop changes at points t_4^*, t_3^*, t_2^*, t_1^*. At the same time the voltage $V_2 \neq 0$ appears between the potential probes (Figure 4) exhibiting irregularities at points t_1, t_2, t_3, t_4. The data in Figures 3 and 4 suggest that ND begins to move as a whole from the sample end towards its center. The irregularities in the $T(t)$ and $V_2(t)$ dependences correspond to the motion of specific ND regions across the TC and voltage probe respectively. TC traces the outgoing right edge of the domain. Passing of the left edge is traced by V_2, e.g. from t_1 to t_2 a foremost portion crosses a probe. This portion is cooled by film boiling and has temperature slightly above 77K. From t_2 to t_3 the left edge moves into the segment between the potential probes. From t_3 to t_5 the ND top part passes the probe and the temperature is maximal at t_4. The interval from t_4 to t_5 corresponds to the TC measurement interval from t_4^* to t_3^*. At the period from t_3^* to t_2^* the right edge passes TC and after t_2^* the outermost portion crosses TC position. All the processes occur at the voltage of $V_0 = 0.79$ V. Current achieves a stable $I = 50$ A level in 3 s after t_0. The ND velocity estimated from the rate of the resistance change is about 1 mm/s. To obtain temperature and potential profiles of the ND as function of distance one should multiply t-axis in Figures 3 and 4 by scale factor 1 mm/s. For higher V_0 values ND also drifts towards sample center and both $T(t)$ and $V_2(t)$ dependencies demonstrate the similar behavior.

Figure 5 shows the maximum temperature measured by TC as a function of V_0 value. When V_0 < 0.3 V the

Figure 2 Temperature as a function of time at $V_0 = 0.76$ V.

Figure 4 The amplitude value of voltage V_2 across the middle part of the sample as a function of time for $V_0 = 0.79$V.

Figure 5 Maximum temperature as a function of amplitude V_0.

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ND is so small that TC is out of it and does not respond to heating.

We have shown that for voltages greater than 0.79 V the domain moves and the TC measures its temperature profile. In the interval 0.3 V < V_0 < 0.79 V the domain stays within the weak place and TC measures the temperature near its top. In this case the ND maximum temperature T_M (in K) as a function of applied voltage V_0 (in V) is approximated by: $T_M = 623 \ (V_0\text{-}0.3) + 90$. This fit allows one to estimate the upper boundary of the voltage ($V \sim 1$ V), for which the tape survives ($T \sim 500$ K).

Conclusions

To summarize, the above experimental data indicate that the normal domain in superconducting tape with highly resistive substrate appears when voltage is applied to the sample. At voltages greater than 0.79 V the domain starts to move. This motion enables us to find the domain temperature and potential profile from the simultaneous measurements with a thermocouple and potential probes.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors planned and designed the experiment, read and approved the final manuscript.

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