

Thermal-electrical domain in Y-Ba-Cu-O ceramic and its analogs

Yu. A. Osip'yan, R. K. Nikolaev, N. S. Sidorov, V. S. Bobrov,
and V. S. Tsoï

Institute of Solid State Physics, Academy of Sciences of the USSR

(Submitted 4 January 1988)

Pis'ma Zh. Eksp. Teor. Fiz. **47**, No. 5, 257–260 (10 March 1988)

As a current flows through a sample of a Y-Ba-Cu-O ceramic or one of its analogs, a region with local increases in the temperature and the resistance appears (a thermal-electrical domain). In the direct-current case, this domain is observed to drift. The drift direction depends on the polarity of the current.

As a current is passed through a $Y_1Ba_2Cu_3O_{7-x}$ ceramic, the sample first undergoes a general heating, and then a region with a local temperature increase appears. This region can be distinguished visually by its glow. The boundaries of this localized temperature domain are well-defined, and its length is roughly the same as the transverse dimension of the sample. In the case of a direct current, the domain is observed to drift toward the negative pole of the current source. The drift direction reverses when the current polarity is changed. This reversal of the drift of a domain through the sample can be induced repeatedly.

In the present experiments we focused on samples of a $Y_1Ba_2Cu_3O_{7-x}$ ceramic with characteristic dimensions of $3 \times 3 \times 40$ mm, prepared by the synthesis and compression of powders.¹ Most of the experiments were carried out in air. The initial temperature of the samples was $T_0 \approx 300$ K. We varied T_0 and the composition of the surrounding gaseous medium. We also used ceramic samples of other compositions.

The threshold values of the voltage and the current at which a thermal domain appears depend on the dimensions of the samples and their structure. The values of U_i and J_i increase as the samples are cooled, and they decrease when the samples are heated. The values of U_i and J_i are observed to be influenced by the heat-removal conditions, the composition of the surrounding medium, the state of the contacts, and so forth. All of these factors are related to the conditions under which the samples are heated as the current flows. The typical threshold values for the samples studied were $U_i \approx 3-4$ V and $J_i \approx 8-10$ A. After the formation of a thermal domain begins, the current decreases to a value of 3–5 A, and the value of T decreases in regions of the sample remote from the domain. In some cases we observed the formation of two, and sometimes three, domains, but as one of the domains “flared up” the others “were extinguished.”

The drift of the domains occurs at a velocity ~ 10 cm/h and can be observed visually. Figure 1 shows photographs of one of the samples at various times separated by 5-min intervals. The drift velocity depends on the structure of the sample. It decreases with decreasing T_0 and as the heat-removal conditions are improved. The domains are observed to become “pinned” near the current contacts, in regions of

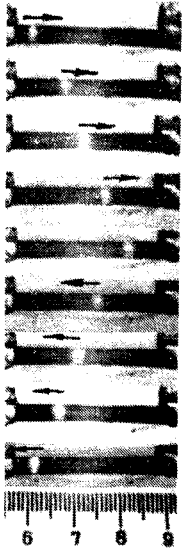


FIG. 1. Photographs of an yttrium ceramic sample during drift of a thermal domain as the current polarity is reversed ($\Delta t \approx 5$ min).

local heat removal, and at irregularities of the samples. Gradients in T influence the kinetics of the motion of the domains. The drift velocity is usually higher as a domain moves into a part of the sample with a higher T . When a domain becomes pinned, its motion can be stimulated by creating an additional gradient of T . An alternating current, in contrast with a direct current, causes no significant drift of the domains.

In zones of the samples separated from a domain by $\Delta l > 1$ cm, the temperature is 450–600 K, depending on the heat-removal conditions and the intensity of the glow of the domain, according to the readings of thermocouples ($d = 0.1$ mm). The corresponding estimate in a domain region is $T \approx 800$ –900 K. It should be kept in mind, however, that the low thermal conductivity of the samples means that the readings of the thermocouples provide only a lower estimate of the actual value of T . We accordingly also carry out some measurements of T in the domain region using an optical pyrometer; we found estimates $T \approx 1000$ –1250 K at various domain glow levels. Most of the measurements were carried out at domain glow levels corresponding to $T \approx 1100$ –1200 K.

A preliminary study of the domain emission spectrum shows that in the visible region the spectrum is approximately the same as that of an ordinary heated object (a tungsten filament or a Silit rod), but the emission spectrum of the domains also has some structural features, which are presently being studied in more detail.

During the formation of thermal domains, we observe a nonmonotonic dependence of the current on the voltage. At voltages below U_t , the current varies approximately linearly with U , while above U_t the resistance increases sharply, and J decreases. These effects correlate with the results of Ref. 2, where a significant increase in R was observed when an yttrium ceramic was heated above 900 K. During the formation of a thermal domain, most of the increase in the resistance of the sample

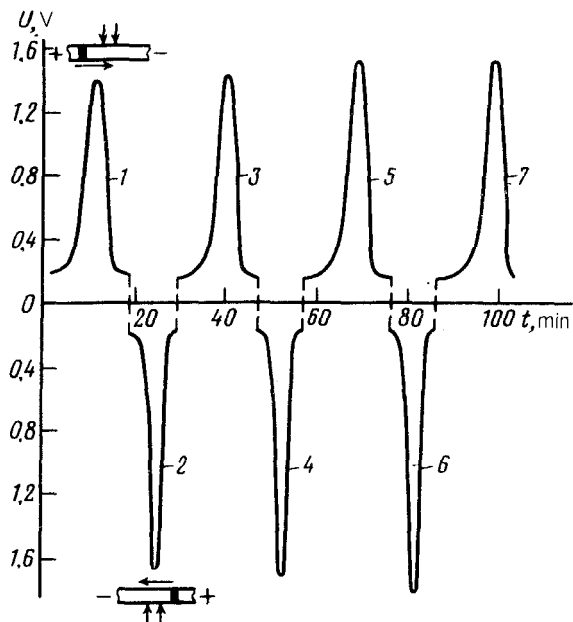


FIG. 2. The voltage U versus the time t during reversals of the drift of a thermal domain upon changes in the polarity of the current ($J \approx 4$ A) (the distance between potential contacts is $\Delta l \approx 7$ mm).

results from the increase in R in the domain region. This conclusion is supported by, for example, the results (Fig. 2) of a measurement of U during repeated reversal of the drift of a domain across a region between potential contacts. From the same results we can see how the drift depends on the temperature gradient in the sample. When there is a gradient due to a difference in the levels of heat evolution near the contacts, $\langle dT/dx \rangle \approx 30$ K/cm, the time required for a domain to traverse the distance between the potential contacts (≈ 7 mm) is shorter by a factor of about 1.6 in the case of motion toward higher T . By measuring the passage of a domain between several successive pairs of potential contacts, one can also draw conclusions about the drift kinetics of the domain.

We carried out experiments in closed volumes, varying the composition of the gases filling the volumes. In oxygen we observed an increase in the domain drift velocity in comparison with that in air, by a factor of 1.2–1.5. In helium we observed a contraction of the domain and a decrease in its drift velocity by a factor of about 10. After several reversals of the domain drift, the samples were fractured. A similar behavior was observed in experiments with nitrogen. In vacuum we again observed the formation of a glowing narrow domain, but we were not able to establish any significant drift of the domain in this case because the sample fractured quite quickly.

We determined the amount of oxygen released when the samples were heated to 1100 K. This analysis showed that after a domain passed repeatedly through one of the samples, the oxygen content in it decreased by 0.12 g-atom, and the value of T_c decreased from 92 K to 71 K.

We carried out observations of the domain motion under a optical microscope.

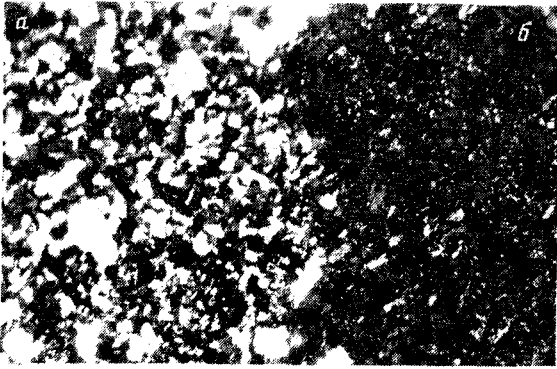


FIG. 3. Surface of an yttrium ceramic sample (300 \times). a—Region of initial sample; b—domain passage zone.

During the passage of the domain, there was an obvious change in the surface morphology. Figure 3 shows a photograph of the boundary between the domain passage zone and the original surface of one of the samples. An x-ray structural analysis showed that the initial samples and also samples which had been subjected to repeated reversal of the domain drift consisted primarily of the orthorhombic phase, but the relative amount of tetragonal phase increased slightly after the passage of a domain. Making use of data on phase transitions in an yttrium ceramic during heating and during oxygen depletion (Ref. 3, for example), we might suggest that reversible phase transitions occur in the domain region. Further studies will make it possible to say something more definite in this regard.

In addition to the yttrium ceramic, we used samples of other compositions: $\text{Ho}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x}$, $\text{Er}_1\text{Ba}_2\text{Cu}_3\text{O}_{7-x}$, and $\text{La}_{1.6}\text{Sr}_{0.4}\text{CuO}_4$, with respective values $T_c \approx 96, 66,$ and 37 K. The behavior of the holmium and erbium samples was similar to that of the yttrium ceramic. In the lanthanum ceramic, the region in which the heating was localized was noticeably more diffuse, and we did not observe a drift of this region. The explanation may lie in the particular features of the state of oxygen in this ceramic. We also carried out some experiments with the ceramic⁴ La_2CuO_4 , whose structure contains no distinct oxygen vacancies. When a current was passed through this ceramic, the sample was heated over its entire length. We did not observe the appearance of a thermal domain.

The phenomenon observed here may be associated with a nonlinear temperature dependence of the resistance and a sharp increase in R during the intense evolution of oxygen during Joule heating. This effect could lead to the appearance of a thermal domain, according to a theoretical analysis and also according to data on metals (see Ref. 5, for example). The formation of a domain would apparently proceed in an autocatalytic fashion, accompanied by the formation of a high concentration of positively charged oxygen vacancies. At a high mobility of these vacancies, these events may determine the observed drift of a domain in an electric field. An exchange of gas with the surrounding medium would apparently also play an important role here. Other effects (e.g., a diode effect and a pyroelectric effect) could apparently also play a certain role in the formation and motion of domains.

We wish to thank G. K. Baranova, O. V. Zharikov, M. V. Indenbom, B. G. Karepov, N. V. Klassen, V. V. Korshunov, V. Sh. Shekhtman, and I. M. Shmyt'ko for cooperation in the course of the study and for discussions. We also thank V. S. Lunev, B. A. Skakun, and S. S. Shevag for assistance.

¹M. K. Wu, J. R. Asburn, C. J. Torny *et al.*, *Phys. Rev. Lett.* **58**, 908 (1987).

²M. Gurvetch and A. T. Fiory, *Phys. Rev. Lett.* **59**, 1337 (1987).

³J. K. Schuller, D. G. Hinks, J. D. Jorgensen *et al.*, in: *Novel Superconductivity* (ed. S. A. Wolf and V. Z. Kresin), Plenum, New York, 1987, p. 647.

⁴K. I. Portnoi and N. I. Timofeeva, *Oxygen Compounds of Rare-Earth Elements (Handbook)* [in Russian], Metallurgiya, Moscow, 1987, p. 41.

⁵G. I. Abramov, A. Vl. Gurevich, S. I. Zakharchenko *et al.*, *Fiz. Tverd. Tela. (Leningrad)* **27**, 2250 (1985) [*Sov. Phys. Solid State* **27**, 1350 (1985)].

Translated by Dave Parsons