Abstract of the habilitation thesis

2.1 First name and family name: Adam Nabiałek

2.2 Diplomas and scientific degrees

Master of Science, Engineer of Fundamental Problems of Technology - specialty Technical Physics, 1990.

Warsaw University of Technology, Faculty of Technical Physics and Applied Mathematics
The Master thesis entitled: *"The study of electric ionic conductivity of solid solutions Li_4SiO_4-Li_3PO_4"* performed at the Solid State Ionics Division under the supervision of Prof. Władysław Bogusz.

Doctor of Physics

Institute of Physics, Polish Academy of Sciences in Warsaw, 1999.
Ph.D. thesis entitled *"Magnetostriction of superconductors in the mixed state"*, performed under supervision of Prof. Henryk Szymczak

2.3 Information of employment in scientific institutions

Since December 1990 until today I am employed in the Institute of Physics, Polish Academy of Sciences at the Division of the Physics of Magnetism

2.4 Indication of the achievement of habilitation procedure

The academic achievement resulting from Article 16 Paragraph 2 of the of Act 14th March, 2003 about the academic degrees and academic title submitted for habilitation procedure is one-subject series of publications consisting of 13 papers. The theme of this series is **"Thermomagnetic avalanches and accompanying phenomena in type II superconductors"**

2.4A. List of works that constitute a basis for habilitation procedure

List in order of publication:

H.1) **A. Nabiałek**, M. Niewczas, H. Dabkowska, A. Dabkowski, J.P. Castellan, B.D. Gaulin, *"Magnetic flux jumps in textured $Bi_2Sr_2CaCu_2O_{8-\delta}$"*, Phys. Rev. B **67** (2003) 024518.

H.2) **A. Nabiałek**, V.V. Chabanenko, V. Rusakov, S. Vasiliev, H. Szymczak, S. Piechota, H. Dabkowska, A. Dabkowski, B. Gaulin, M. Niewczas, O. Mironov, *"The peculiarities of magnetic flux dynamics at magnetothermal instability in textured $Bi_2Sr_2CaCu_2O_{8-\delta}$"*, J. Low Temp. Phys. **130** (2003) 425-433. (Proceedings of the NATO Advanced Research Workshop, „Vortex Dynamics in High Temperature Superconductors", 17-22 maja 2002, Taszkient, Uzbekistan)

H.3) V. Chabanenko, R. Puzniak, **A. Nabiałek**, S. Vasiliev, V. Rusakov, L. Huanqian, R. Szymczak, H. Szymczak, J. Jun, J. Karpinski, V. Finkel, *"Flux Jumps and H-T Diagram of Instability for MgB_2"*, J. Low Temp. Phys., **130** (2003) 175-191. (Proceedings of the NATO Advanced Research Workshop, „Vortex Dynamics in High Temperature Superconductors", 17-22 maja 2002, Taszkient, Uzbekistan).

H.4) **A. Nabiałek**, V.V. Chabanenko, V.F. Rusakov, S. Vasiliev, N.N. Kabdin, H. Szymczak, S. Piechota, B.N. Kodess, S.A. Kononogov, *"Giant magnetostriction and flux jumps in superconducting Nb_3Al slab"*, J. Low Temp. Phys., Vol. **139** (2005) 239-246. (proceedings of NATO Advanced Research Workshop "Vortex dynamics in superconductors and other complex systems", 13-17 September, 2004, Yalta, Crimea, Ukraine).

H.5) **A. Nabiałek**, S. Vasiliev, V. Chabanenko, P. Aleksyeyev, V. Rusakov, S. Piechota, H. Szymczak, „ *Giant magnetostriction jumps in conventional NbTi superconductor"*, Acta Phys. Pol. A **109** (2006) 633-639. (Proceedings of the XI National School "Collective Phenomena and Their Competition", Kazimierz Dolny, September 25-29, 2005).

H.6) **A. Nabiałek**, M. Niewczas, „ *The critical state stability in textured $Bi_2Sr_2CaCu_2O_{8-\delta}$ superconductor"*, Physica C **436** (2006) 43-50.

H.7) **A. Nabiałek**, S. Vasiliev, P. Aleksyeyev, V. Chabanenko, *"Dynamics of thermomagnetic avalanches in melt-textured YBaCuO superconductors"*, Acta Phys. Pol. A **111** (2007) 153-158. (Proceedings of the Symposium K: *"Complex Oxide Materials for New Technologies"* of E-MRS Fall Meeting, Warsaw, September 4-8, 2006)

H.8) **A. Nabiałek**, S. Vasiliev, V. Chabanenko, V. Rusakov, S. Piechota, H. Szymczak, *"The influence of the sample shape on the flux jumps dynamics in conventional NbTi superconductor"*, Acta Phys. Pol. A **114** (2008) 235-241. (Proceedings of the XIII National School of Superconductivity, Lądek Zdrój 2007).

H.9) **A. Nabiałek**, V. Chabanenko, S. Vasiliev, V.F. Rusakov, G. Shushmakova, H. Szymczak, *"The Reversal of the Local Magnetic Field Profile at the Surface of Superconducting Sample Caused by the Thermomagnetic Avalanche"*, J. Low Temp. Phys. **154** (2009) 55–67.

H.10) **A. Nabiałek**, V. Chabanenko, S. Vasiliev, G. Shushmakova, H. Szymczak, B. Kodess, *"Two components of the magnetostriction of the crystalline metallic V_3Si Superconductor"*, J. Appl. Phys. **105** (2009) 063918.

H.11) **A. Nabiałek**, S. Vasiliev, V. Chabanenko, F. Perez-Rodriguez, S. Piechota, H. Szymczak, *"The Influence of Magnetic History on the Stability of Critical State and the Dynamics of Flux Jumps in Conventional NbTi Superconductor"*, Acta Phys. Pol. A **118** (2010) 343-345. (Proceedings of The XIV National School on Superconductivity, Ostrów Wielkopolski, October 13-17, 2009).

H.12) **A. Nabiałek**, A. Wiśniewski, V.V. Chabanenko, S.V. Vasiliev, T.V.Tsvetkov, F. Perez-Rodriguez, *"Influence of crystal anisotropy on the critical state stability and flux jumps dynamics in a single crystal of $La_{1.85}Sr_{0.15}CuO_4$"*, Supercond. Sci. Technol. **25** (2012) 035005.

H.13) **A. Nabiałek**, S.V. Vasiliev, V.V. Chabanenko, X. Yao, Y.Q. Cai, L. Guo, M.V. Kuzovui, „ *Critical state stability and flux jumps' dynamics in a single crystal of $YBa_2Cu_3O_{7-\delta}$"*, Acta Phys. Pol. A **121** (2012) 836-840. (Proceedings of the XV-th National School "Hundred Years of Superconductivity", Kazimierz Dolny, October 9-13, 2011).

2.4B. Presentation of the scientific works and achieved results

Introduction

Most of the currently known superconductors are of the second type. In magnetic fields exceeding the value of the first critical field, H_{c1}, a type II superconductor is in a mixed state. Magnetic and transport properties of superconductors in the mixed state are usually described in the framework of the model of the critical state [1]. The most important parameter in this model is the critical current density, j_c, which determines the maximal density of the current that can be conducted by the superconductor without dissipation, as well as the density of the current screening the superconducting sample in external magnetic field. A critical state of the superconductor, it means a state in which in the whole volume of the superconductor or in a part of the volume of the superconducting sample flows the current of the critical density, j_c, may be, under certain conditions, unstable. In such conditions, small fluctuations of the magnetic field or temperature may cause thermomagnetic avalanches, which are the main subject of the presentation.

The stability of the critical state depends on two correlated processes: 1) the magnetic flux penetration into the superconducting sample – this process results in heat generation; 2) the process of thermal diffusion – i.e. propagation of the heat generated by the magnetic flux penetration. An increase in temperature causes a decrease of the density of the current screening the superconducting sample and, as a result, penetration of some additional magnetic flux into its volume. Under certain conditions, these two processes may have an avalanche-like character. We then say that we are dealing with thermomagnetic avalanche.

A thermomagnetic avalanche is accompanied by a sudden increase in the sample temperature and by a sudden penetration of the magnetic flux into the superconducting sample. This second phenomenon is called in literature "flux jump", and it is often identified with the thermomagnetic avalanche. However, there are also other phenomena that accompany the thermomagnetic avalanche. One is the rapid changes in sample size, called magnetostriction jumps [2].

In some cases, a sample of the superconductor, or a certain part of its volume, may pass during the thermomagnetic avalanche into the normal state. It is obvious that thermomagnetic avalanches are very problematic from the viewpoint of practical applications of the superconductors. Hence, it is very important to understand both the conditions of the thermomagnetic avalanche development and the phenomena which accompany the avalanche. It is also very important to understand the dynamics of this process. Dynamics of magnetic flux jumps determines the power of the energy released during the avalanche. Exceeding a certain value of this power may cause damages of the devices using superconducting elements. The first thermomagnetic avalanches were observed, when researches began to investigate the magnetic and transport properties of conventional type II superconductors characterized by high critical current densities. Relatively early, they also determined the conditions that must be met to avalanche occurred [3,4,5]. In order to determine the conditions of the critical state stability in type II superconductors, it is insufficient to know the temperature and magnetic field dependence of the critical current density, but one must also take into account the shape and size of the investigated sample, as well as its thermal properties. In most cases, one must also consider heat exchange conditions between the sample and its environment. In order to avoid thermomagnetic avalanches, superconducting wires used in technical applications are made in the form of composites consisting of a large number of thin wires made from a type II superconductor embedded in a matrix of normal metal. A theory of the critical state stability in superconducting composites can be found in reviews [6,7]. After discovery of high temperature superconductors, thermomagnetic

avalanches were also observed in these materials [8]. However, due to some specific features of these materials (e.g. anisotropy of the parameters describing the superconducting state, presence of weak links, strong flux creep), many aspects concerning the formation of thermomagnetic avalanches in these materials remain poorly understood. Additionally, some issues connected with the influence of the shape of the superconducting sample on the formation of the thermomagnetic avalanches are not fully clarified yet. Recently, attention of the researches was attracted by the thermomagnetic avalanches in the form of dendrites, which occur in thin superconducting films [9]. Conditions of formation of such avalanches may significantly differ from those observed in macroscopic samples [10]. The dynamics of the thermomagnetic avalanche remains poorly understood.

Objectives

The investigations, whose results are presented in the one-subject series of publications, had the following objectives:

1) Explanation of the influence of specific properties of newly discovered superconducting materials (high temperature superconductors, magnesium diboride) on the formation and structure of thermomagnetic avalanches in this materials.

2) Explanation of mechanisms of some phenomena that accompany thermomagnetic avalanches, including: the reversal of the magnetic field profile at the surface of superconducting sample after the thermomagnetic avalanche, the dynamics of the magnetic flux jumps and giant magnetostriction jumps.

All investigated phenomena strongly depend on both the size and shape of the superconducting sample. For this reason, much attention was devoted to **the influence of the thickness of superconducting sample on thermomagnetic avalanches.**

Specific properties of thermomagnetic avalanches in high temperature superconductors were studied in papers **H.1**, **H.2**, **H.6**, **H.7**, **H.12** and **H.13**. In paper **H.3**, thermomagnetic avalanches in magnesium diboride were investigated.

Many studies of the influence of the sample shape on thermomagnetic avalanches and accompanying phenomena were performed using conventional superconductors NbTi (**H.5**, **H.8**, **H.9**, **H.11**), Nb_3Al (**H.4**) or V_3Si (**H.10**) . Due to differences in properties of high temperature and conventional superconductors, it seemed very interesting to compare the phenomena, which accompany thermomagnetic avalanches, in these two types of materials. Investigations of these phenomena in conventional superconductors are also important from the practical point of view. Because of the well known technology of their preparation, conventional superconductors still play a dominant role in technical applications.

In paper **H.9**, the phenomenon of the reversal of the magnetic field profile at the surface of the superconducting sample after the thermomagnetic avalanche was investigated. This reversal is directly connected with the break of the symmetry of screening currents in superconducting sample caused by the thermomagnetic avalanche. This phenomenon, like most of other phenomena which accompany the thermomagnetic avalanche, depends on the sample shape. The influence of the sample shape on the range of the occurrence of the thermomagnetic avalanches, their magnitude and dynamics in conventional NbTi superconductor was analyzed in paper **H.8**. As it was shown in paper **H.11**, a strong demagnetizing field can change the magnetic field distribution in the superconducting sample after the thermomagnetic avalanche, and thus change the conditions of the formation of the

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succeeding avalanches and their dynamics. The dynamics of the flux jumps was analyzed in papers **H.2**, **H.3**, **H.7**, **H.8**, **H.11**, **H.12** and **H.13**. Giant magnetostriction jumps, which accompany thermomagnetic avalanches, were studied in papers **H.4**, **H.5** and **H.10**.

Experimental technique

Conditions of the formation of thermomagnetic avalanches were investigated using standard magnetometers (vibrating sample magnetometers – VSM, or extraction magnetometers). In these investigations, thermomagnetic avalanches manifested themselves as rapid changes of the magnetic moment. Using standard magnetometers, the influence of different parameters (e.g. temperature or sweep rate) on the field at which the first flux jump occurs were investigated. The changes of the magnetic moment during the following flux jumps were also determined. However, due to the nature of the studied phenomenon, the applied devices must have the capability to control some additional parameters (sweep rate, the condition of the heat exchange between the sample and the environment), which in other types of magnetic measurements are not so important. In some of the presented studies (**H.1**, **H.3**, **H.6**, **H.12**), the Quantum Design PPMS extraction magnetometer was used. This instrument enabled a precise control of the sweep rate. From the viewpoint of the studies of thermomagnetic avalanches, it is also very important that in this extraction magnetometer, the sample is always (both above and below 4.2 K) surrounded by a gas (helium - at the pressure of about 0.5 Torr). For this reason, in this instrument, there is no sudden change of the cooling condition, when the sample passes through the temperature of 4.2 K.

Some of the investigated samples were very large (diameter above 1 cm). Such samples cannot be put into standard magnetometers. In the case of such samples, the magnetic self-field at the sample surface was usually investigated. Thermomagnetic avalanches are accompanied by rapid changes of the self-field. The self-field was measured by the Hall probes. In order to calculate (using the self-field data) the critical current density, an appropriate theoretical model was elaborated (**H.10**). The comparison of the results of the stray field measurements with results of the measurements of the magnetic moment resulted in some conclusions concerning the structure of the thermomagnetic avalanches. These conclusions are discussed in paper **H.8**.

The Hall probes were also very useful in studies of the dynamics of the thermomagnetic avalanches, or (more precisely) of the dynamics of the self-field. The dynamics of the magnetic flux changes in the sample, during thermomagnetic avalanches, was measured using pick-up coils wound around the investigated sample. The pick-up coils were connected to a digital oscilloscope with memory or to a four channel data acquisition board (DAQ), which enabled simultaneous registration of several signals. Such system enabled comparison the dynamics of the magnetic flux changes in the sample with the dynamics of the stray field (see paper **H.8**).

In the investigations presented in paper **H.13**, the technique of the measurements of the magnetic flux dynamics, using pick-up coils, was combined with the technique of the magnetic moment measurements, using VSM.

Giant magnetostriction jumps, which accompany the thermomagnetic avalanches, were investigated using the stain gauge technique. It is important to note that the most commonly used technique of the magnetostriction measurements is the capacitance technique. However, this technique cannot be used when giant magnetostriction jumps occur, because sudden changes of the sample dimension cause the instability of the experimental system.

The studies of the flux jumps' dynamics, VSM or magnetostriction measurements were performed in Cryogenics 12 tesla superconducting magnet system with variable

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temperature insert. In the temperature range 2 K – 4.2 K, the sample was immersed in liquid helium. During experiments at higher temperatures, the sample was surrounded by flowing helium gas with approximately atmospheric pressure.

The influence of specific properties of newly discovered superconducting materials on the formation and structure of thermomagnetic avalanches in these materials.

The following high temperature superconductors were investigated: $Bi_2Sr_2CaCu_2O_{8-\delta}$ (**H.1, H.2, H.6**), $La_{1.85}Sr_{0.15}CuO_4$ (**H.12**) and $YBa_2Cu_3O_{7-\delta}$ (**H.7, H.13**). These high temperature superconductors differ by many parameters – first of all, they have different critical temperatures and different anisotropies. In the case of $YBa_2Cu_3O_{7-\delta}$ superconductor, both single crystalline (**H.13**) and melt-textured (**H.7**) samples were studied. Thermomagnetic avalanches were not observed in common ceramics of high temperature superconductors, because, in these materials, the critical current density is strongly limited by the presence of the weak links. The $Bi_2Sr_2CaCu_2O_{8+\delta}$ and $YBa_2Cu_3O_{7-\delta}$ superconductors play an increasing role in practical applications. Hence, it is very important to understand the conditions of the thermomagnetic avalanches formation in these materials. There are also promising perspectives of applications of the MgB_2 superconductor. However, the properties of this material are very different. It is shown in paper **H.3** that thermomagnetic avalanches in this material reveal a number of specific properties.

The critical state stability in high temperature $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductor

The problem of the critical state stability in the $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductor was studied in papers **H.1** and **H.6**. Among the bismuth high temperature superconductors the highest critical temperature (about 110 K) reveal samples of the composition $Bi_2Ca_2Sr_2Cu_3O_{10}$. In present studies, the samples of the composition $Bi_2Sr_2CaCu_2O_{8-\delta}$ (T_c=85 K) were studied, because for this composition larger single crystals can be obtained. However, the investigated samples were not single crystalline, but they consisted of several flat parallel to each other crystals. The samples were in shapes of relatively thin (thickness 0.1 – 0.2 mm) slabs, and the c-axis of the crystals was perpendicular to their surfaces. Thermomagnetic avalanches were observed only when the external magnetic field was parallel to the c-axis (it means perpendicular to the investigated slabs).

  The main aim of the studies was to compare the conditions of the critical state stability in the investigated material with the conditions of the critical state stability in other superconducting materials (e.g. conventional superconductors), and to determine how the specific properties of the investigated material influence this stability. The bismuth high temperature superconductors are used to produce superconducting composites in the form of tapes. Hence, understanding of the critical state stability in this material is very important from the viewpoint of the application of such composites.

  It was found that with increasing temperature, the value of the field H_{fj1}, in which the first flux jump occur, rapidly increases (**H.1**). Such behavior is similar to that observed in conventional superconductors. The influence of the magnetic history on the following jumps of the magnetic moment was also very similar to that observed in conventional superconductors. However, it was shown that even in the flux flow regime, the locally adiabatic approximation cannot be applied. Such approximation can be applied in the case of conventional superconductors. In the investigated sample, a strong dependence of the field H_{fj1} on the external magnetic field sweep rate was found. A strong magnetic relaxation was also found, which is connected with a strongly nonlinear current-voltage characteristics of the

investigated material. The dependence of H_{fj1} on the sweep rate was analyzed in the framework of the model elaborated by R.G. Mintz for an infinite slab sample [11]. The discrepancies between the theory and the experiment, resulting form the approximations assumed in the theoretical model, were discussed.

It has been hypothesized that in the case thin superconducting samples in the external magnetic field perpendicular to their surfaces the role of the critical, from the viewpoint of thermomagnetic avalanche formation, dimension is played (with better approximation) by the thickness of the sample, measured in the direction parallel to the external magnetic field, rather than by the diameter, measured in the direction perpendicular to the external magnetic field. This hypothesis was argued on the basis of obtained experimental results and theoretical model [12] describing the magnetic field distribution in thin superconducting sample.

More detailed investigations of the effect of sample thickness on the critical state stability were presented in paper **H.6**. In this paper, the critical state stability in samples of different thicknesses was compared. It was shown that the critical state stability increases with a decrease of the sample thickness. To this aim, the original sample was cleaved into two pieces. An inverse operation, it means gluing together the two pieces (by Apiezon), was also applied. It turned out that the stability of the critical state in the bonded sample was practically the same as in the original sample. The result of the experiments shows that the conductivity (both electric and thermal) in the direction perpendicular to the layers of the composite sample does not significantly influence the stability of the critical state, when the external magnetic field is perpendicular to the investigated layers.

It was also shown that the critical state stability of the investigated superconductors increases, when they are in good thermal contact with metallic copper. Such a contact improves the cooling conditions. On the other hand, because of high electric conductivity of metallic copper, it slows down the dynamics of the magnetic flux entering the sample.

The influence of the crystal anisotropy and of the cooling conditions on the critical state stability of a $La_{1.85}Sr_{0.15}CuO_4$ superconductor

Paper **H.12** is completely devoted to the studies of the critical state stability and of the flux jumps dynamics in a crystal of the $La_{1.85}Sr_{0.15}CuO_4$ superconductor. Using the floating zone technique, relatively large single crystals of the compound $La_{2-x}Sr_xCuO_4$ can be obtained. In my investigations, I used a large 3 x 3 x 3 mm^3 single crystal with the strontium doping close to the optimal one. The large crystal in a shape of a cube enabled complex studies of the influence of the temperature, magnetic field sweep rate, cooling conditions as well as of the crystal anisotropy on the conditions of the formation of thermomagnetic avalanches. It is very important that demagnetizing factor of a cubic sample does not change after the change of sample orientation with respect to the external magnetic field (in all investigations the external magnetic field was perpendicular to one of the walls of the cube). Therefore, the influence of the changes of demagnetizing factor after a change of sample orientation on thermomagnetic avalanches could be neglected.

Investigation of this material were performed both in PPMS system and in 12 tesla superconducting magnet. The critical state stability strongly depended on the sample orientation with respect to the external magnetic field. Temperature range in which thermomagnetic avalanches occurred was significantly broader for the external magnetic field parallel to the c-axis than for the external magnetic field parallel to the ab-planes. It was shown that this is mainly connected with the anisotropy of the density of the screening currents. Density of the screening currents flowing in the direction perpendicular to the ab-

planes is, in this material, approximately one order of magnitude lower than of those flowing in the *ab*-plane.

The critical state stability of the investigated sample strongly depended on the cooling conditions. It was also found that the critical state stability strongly depends on the external magnetic field sweep rate. Both these facts clearly suggested that thermomagnetic avalanches in this material are initiated in so-called dynamic conditions, in which the magnetic diffusivity is much smaller than the thermal one. The magnetic diffusivity, D_m, is proportional to the electric resistivity of the investigated material, $D_m = \dfrac{\rho}{\mu_0}$, where μ_0 is the magnetic permeability of vacuum. The thermal diffusivity, D_t, is correlated with the thermal conductivity, κ, and with the specific heat, c_V, of the investigated material by the formula:

$$D_t = \frac{\kappa}{c_V}.$$

In order to perform an analysis in dynamic conditions, it was necessary to determine the current-voltage characteristic of the investigated material. This characteristic was determined on the basis of studies of magnetic moment relaxation. An analysis of the critical state stability was performed in the framework of the model elaborated in Ref. [11], which assumed weak cooling of the sample, as well as in the framework of isothermal model elaborated in paper **H.12**. It was shown that, similarly to the model of the weakly cooled sample, in the case of the isothermal model, the field of the first flux jump, H_{fj1}, also changes with the external magnetic field sweep rate. It was shown that the PPMS results can be better described in the framework of the model which assumed the weak cooling of the sample. However, this model cannot be applied, when the sample is immersed in liquid helium. In this case, a better evaluation of the value of H_{fj1} was given by the isothermal model. According to the calculation performed in paper **H.12**, the thermal boundary conductivity was in the case of experiments performed in PPMS system two or three orders of magnitude lower than in the case of the sample immersed in liquid helium.

Critical state stability in YBa$_2$Cu$_3$O$_{7-\delta}$ crystals

It was shown in paper **H.13** that in the case of the crystals of the YBa$_2$Cu$_3$O$_{7-\delta}$ superconductor, thermomagnetic avalanches are also initiated in dynamic conditions. In the case of large (the size of several millimeters) crystals immersed in liquid helium, in order to determine the conditions of the critical state stability, the isothermal approximation (**H.12**) can be applied. However, this approximation cannot be applied, when the thermal isolation between the sample and the environment will be improved. As it was shown in paper **H.13**, the range of temperatures in which thermomagnetic avalanches occur may be significantly extended in such case.

The specificity of thermomagnetic avalanches in MgB$_2$ superconductor

The discovery of superconductivity in magnesium diboride (MgB$_2$) [13] resulted in the emergence of a large number of works on this material. This new superconducting material is very promising from the viewpoint of practical applications. It has relatively high critical temperature (about 39 K). Moreover, unlike in the case of high temperature superconductors, the intergrain critical current density in this material is not strongly limited by the presence of the weak links. Hence, one can use in practice polycrystalline samples. From this point of view, magnesium diboride is more similar to conventional superconductors. In order to apply the MgB$_2$ superconductor in practice, one must take into account the possibility of the

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occurrence of the thermomagnetic avalanches. Paper **H.3** was the first work in the literature concerning this problem.

In this paper, a polycrystalline MgB_2 sample with the dimensions 1.8 x 2 x 2 mm³ was investigated. Thermomagnetic avalanches were observed in a very wide range of temperatures, below 10 K. The structure of the observed flux jumps was very interesting. After cooling in zero magnetic field, in increasing external magnetic field, a series of the successive jumps of the magnetic moment with increasing amplitude were observed. Because of a small amplitude and limited sensitivity of the extraction magnetometer, precise determination of the field of the first flux jump was impossible. It was very interesting that the first complete jump, it means a jump after which the magnetic moment drops almost to zero, occurred in a the external magnetic field of about 0,75 T, and the value of this field did not depend on the initial temperature (in the range from 2 K to 7 K).

An analysis of the critical state stability required, at the first stage, determination of the relation between thermal and magnetic diffusivity of the investigated material. According to this relation, the conditions of the thermomagnetic avalanche formation in this material are locally adiabatic. It was also shown that in calculations of the field of the first flux jump, the magnetic field dependence of the heat capacity must be taken into account. Theoretical calculations of the field of the first flux jump at 2 K gave the value $\mu_0 H_{fj1} \approx 0.06$ T. This value was significantly lower than the value of the field of the first complete jump (about 0.75 T). In order to explain this fact, one must calculate the temperature, to which the sample can be heated by the stored during the magnetization process energy. It turns out that the magnetic energy stored in the external magnetic field with the induction of 0.06 T is definitely to low to cause a significant decrease of the critical current density in this materials. The magnetic energy that can heat the sample above T_c, the sample could reach in the external magnetic field with the induction of about 1 T. This analysis allows to understand why in the investigated sample of MgB_2, we observe a series of the jumps with increasing amplitude, and why the almost complete jumps occur only in the external magnetic field with the induction of about 0.75 T.

The experimentally determined duration times of the following flux jumps were used to calculate the magnetic diffusivity. The calculated values of the magnetic diffusivity corresponded, approximately, to the values characteristic of the magnetic flux flow in this material.

The influence of the thickness of superconducting samples on thermomagnetic avalanches

In my experiments, I often used superconducting samples in shapes of relatively thin (thickness above 0.1 mm) slabs or disks. According to the critical state stability criteria derived for the samples with zero demagnetizing factor [6,7], one can expect that the critical state stability of the sample should decrease with the increase of the sample diameter, it means that for the sample with larger diameter thermomagnetic avalanches should be observed in wider range of magnetic fields and temperatures. In the case of the investigated thin samples, the critical state stability was always lower when the external magnetic field was perpendicular to the surface of the sample, whose diameter was at least several times larger than thickness. For example, in the case of a disk of V_3Si superconductor (diameter 8.4 mm, thickness 0.85 mm), thermomagnetic avalanches occurred only in the external magnetic field perpendicular to the disk surface (**H.10**). In the case of a 11 x 7 x 2 mm³ slab of the Nb_3Al superconductor, thermomagnetic avalanches were observed both for the external magnetic field perpendicular and parallel to the surface of the investigated slab. However, the range in which thermomagnetic avalanches were observed was significantly broader for the

field perpendicular to the surface of the slab (**H.4**) These results seemed to confirm, at least qualitatively, the above discussed theory, according to which the critical state stability of the superconducting sample should decrease with the increase of its dimension measured in the direction perpendicular to the external magnetic field.

In order to explain the influence of demagnetizing factor on the critical state stability, it was necessary to compare the critical state stability in samples of the same diameter but of different thicknesses. The answer to the question how the thickness of the investigated sample affects the critical state stability was partially found in the above discussed studies of the $Bi_2Sr_2CaCu_2O_{8-\delta}$ superconductor (**H.1, H.6**). However, due to fragility, anisotropy and polycrystalline nature of the samples of the $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductor, more detailed studies were performed for a conventional NbTi superconductor (**H.8**).

The samples investigated in paper **H.8** had cylindrical shapes with a diameter of 14 mm and thicknesses of 4 mm and 20 mm, respectively. Both investigated samples were cut from one large cylinder. Hence, the superconducting properties of both samples were assumed to be the same. Hall probes, placed on the surface of the samples, were used to measure the changes of the magnetic field induction during a sweep of the external magnetic field. Pick-up coils wound around the investigated samples were used to measure the magnetic flux changes during the subsequent avalanches. In the case of the sample with thickness 20 mm at the temperature of 4.2 K, the range of the magnetic fields in which thermomagnetic avalanches were observed was approximately twice broader than in the case of the sample with thickness 4 mm. Hence, the results of the investigations of the conventional NbTi superconductor have confirmed that, similarly to the case of the high temperature $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductor, the critical state stability of superconducting samples in the external magnetic field perpendicular to their surfaces decreases with the increase of their thicknesses. In paper **H.8**, a simple theoretical model was presented, which enabled to correlate the amount of the magnetic flux entering the sample during thermomagnetic avalanches with its thickness. An influence of the sample thickness on magnetic flux dynamics was also studied.

Phenomena that accompany thermomagnetic avalanches

Breaking the symmetry of the screening currents by thermomagnetic avalanches

A comparison of changes of the magnetic moment during thermomagnetic avalanches with the changes of the local magnetic field induction at the surface of investigated samples has led to the discovery of a phenomenon of breaking the symmetry of screening currents by thermomagnetic avalanches. On of the consequences of breaking this symmetry may be, described in details in paper **H.9**, phenomenon of reversal of the magnetic field profile at the surface of superconducting sample after the thermomagnetic avalanche.

Performed on a superconducting cylinder of conventional NbTi superconductor magnetic moment measurements show that the observed jumps of magnetic moment are only partial, i.e. the magnetic moment of the sample during each jumping never drops to zero. Measurements of a local magnetic self-field were also performed on the same sample of superconductor. The local magnetic self-field is a difference between the magnetic field measured locally on the sample surface by the Hall probe and the external magnetic field. It turned out that the local self-field during some the jumps, not only drops to zero, but may even change its sign. After changing the sign, absolute values of the local self-field reached several percent of the absolute value of the local self-field observed before the jump. In the above described experiments, macroscopic samples with sizes ranging from a few to over a dozen of millimeters were investigated. Investigations of the local magnetic field distribution, using a system of several Hall probes, were also performed. These studies have shown that, in

some cases, the thermomagnetic avalanche may lead to a reversal of the magnetic field profile at the surface of the sample. This phenomenon is connected with the fact that that breaking the symmetry of the screening currents leads, locally, to the reversal of their directions.

In order to explain this phenomenon, a theoretical model was elaborated (**H.9**). Assuming certain approximations and considering the simplest geometries of the sample (plates and cylinders), and of the propagating avalanche, the phenomenon of the reversal of the magnetic field profile was described by analytical formulas. The ratio of the absolute value of the local self-field after thermomagnetic avalanche to the value before the avalanche was calculated. It was shown that the value of this ratio depends both on the sample shape (the ratio of the sample thickness to the sample diameter) and on the width of the propagating avalanche. Calculations have shown that in the case of macroscopic sample whose diameter is comparable with the thickness, this ratio may reach a few percent, which agreed very well with experimental results. It was also shown that particularly strong effects can be expected in the case of thin layers.

As an extreme phenomenon of breaking the symmetry of the screening currents, one can consider propagation thermomagnetic avalanches in the form of dendrites. This phenomenon occurs in superconducting thin films [9,10].

An occurrence of thermomagnetic avalanches may lead to a very complex distribution of the screening currents in a superconducting sample. To determine this distribution, measurement of the magnetic moment is insufficient, since the same magnetic moment of the sample can be induced by different distributions of the screening currents. These distributions in turn influence the conditions of the formation of the successive avalanches. As an example of the fact that knowledge of the magnetic moment is insufficient to determine the critical state stability conditions, one can use the results presented in paper **H.11**.

In paper **H.11**, an influence of the magnetic history on thermomagnetic avalanches in conventional NbTi superconductor was investigated. A jump of the magnetic moment caused by the thermomagnetic avalanche was found in the investigated sample in decreasing external magnetic. This jump occurred in the external magnetic field close to zero, and during the jump the magnetic moment of the sample dropped almost to zero. Hence, one could expect that the structure of the following jumps should be very similar to that which was observed in increasing magnetic field after zero field cooling (in this case the initial magnetic moment was also zero). However, it turned out that the structure of the subsequent jumps was absolutely different. As discussed in work **H.11**, the formation of a complex distribution of screening currents can also be associated with non-zero demagnetizing factor of the investigated sample. As shown in this work, a complex distribution of the currents in superconducting sample influences both the conditions of the formation of the subsequent flux jumps and their dynamics.

Dynamics of the magnetic flux jumps

Dynamics of a thermomagnetic avalanche depends on correlated processes of thermal and magnetic diffusion. Analytical description of this dynamics, one can only obtain at the initial stage of the avalanche, in means at the stage at which fluctuations of temperature and magnetic field are relatively small, and therefore the equations of thermal conductivity and the Maxwell equations can be linearized (these equations are nonlinear because of the nonlinearity of the parameters appearing in them) [6].

In preformed investigation, I concentrated on the analysis of the dynamics of the changes of the magnetic flux in superconducting samples and of the magnetic induction on the surface of the investigated samples during thermomagnetic avalanches. In most cases (see e.g. **H.3**, **H.12**, **H.13**), two characteristic stages of the magnetic flux jump can be recognized,

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i.e. 1) the stage of the thermomagnetic avalanche development, at which the rate of the changes of the magnetic flux increases and 2) the stage of the thermomagnetic avalanche disappearance, at which the rate of the changes of the magnetic flux decreases. In some cases, this final stage of the thermomagnetic avalanche can be described in the framework of the model of the magnetic diffusion (**H.12, H.13**).

In the case of some of the investigated samples, the dynamics of the magnetic flux jump had a more complex character. In the case of $Bi_2Sr_2CaCu_2O_{8-\delta}$ superconductor, two processes of two different time scales were observed (**H.2**). The time of the fist process was comparable to the characteristic time of magnetic diffusion in the studied material. The time of the second process was comparable to the time of the thermal diffusion.

In large textured samples of YBCO superconductor, giant oscillations of the magnetic induction at the surface of the investigated sample were observed (**H.7**). The amplitude of the observed oscillations was larger than the difference between the surface magnetic induction measured before and after the flux jump. Oscillations of the surface induction, but with much smaller amplitude, were also observed in samples of conventional NbTi superconductor (**H.7**).

It was shown in paper **H.11** that dynamics of magnetic flux jumps may strongly depend on the magnetic history. The most complex structures of the jumps were observed in the region of sample remagnetization. It is connected with the fact that in this region during the thermomagnetic avalanche due to changes of demagnetizing field of the sample, a complex distribution of the screening currents may appear. This distribution influences both the conditions of the formation of the following jumps and their dynamics.

In most cases, the observed durations of the flux jumps can be explained in the framework of the model of magnetic diffusion. The experimentally estimated magnetic diffusivities corresponded, approximately, to the calculated diffusivities, assuming the resistivity of the of the investigated material is equal to the resistivity in the flux flow regime. However, a precise determination of this resistivity was very difficult, because temperature and hence resistivity changes during the thermomagnetic avalanche in a very wide range. In some cases (**H.3, H.12, H.13**), a significant reduction of duration of the jumps with an increase of the external magnetic field was observed. This dependence can be understood assuming that the electric resistivity in the flux flow regime increases with the increase of the magnetic field.

The results of papers **H.12** and **H.13** show that during a thermomagnetic avalanche, the resistivity and the magnetic diffusivity varies in very wide ranges. These studies have shown that in the crystals of high temperature $La_{1.85}Sr_{0.15}CuO_4$ and $YBa_2Cu_3O_{7-\delta}$ superconductors, thermomagnetic avalanches are initiated in dynamic conditions characterized by low resistivity and low magnetic diffusivity. However, in a short time after initiation, the rate of change of the magnetic flux rapidly increases, and the experimentally determined magnetic diffusivities correspond to the resistivities characteristic for the magnetic flux flow in this material.

The influence of demagnetizing factor on the dynamics of the magnetic flux jumps was studied in paper **H.8**. In this paper, two cylindrical samples of conventional NbTi superconductor with the same diameter but different thicknesses were investigated. The external magnetic field was parallel to the axis of the cylinder. It was shown that the duration of the observed jumps increases with increasing thickness of the cylinder.

In paper **H.8**, the dynamics of the magnetic flux in superconducting sample was also compared with the dynamics of the stray field, which was measured by a specially designed pick-up coil. Durations of the changes of the stray field were significantly longer than durations of the changes of the magnetic flux in the sample. This phenomenon can be explained, assuming that after the penetration of the magnetic flux into the sample of the

superconductor is finished, a process of the magnetic flux redistribution in the sample occurs. During this process, the total magnetic flux in the sample is not changing, but there is still a change of the of the screening current distribution in the sample, and, as a result, the change of the magnetic stray field around the sample.

Giant magnetostriction jumps that accompany thermomagnetic avalanches

The phenomenon of giant magnetostriction jumps was first observed by me in high temperature $La_{1.85}Sr_{0.15}CuO_4$ superconductor, and presented in paper [2]. However, thorough understanding of this phenomenon required additional investigations. First of all, it was necessary to prove a close relationship between the giant magnetostriction jumps and the thermomagnetic avalanches. It also seemed very interesting to compare this phenomenon in high temperature and conventional superconductors. Investigations were performed in conventional superconductors: Nb_3Al (**H.4**), NbTi (**H.5**) and V_3Si (**H.10**).

The phenomenon of giant magnetostriction jumps turned out to be as common as the phenomenon of the thermomagnetic avalanches, and closely associated with it. Field and temperature ranges in which this phenomenon was observed always coincided with the corresponding ranges in which the magnetic flux jumps were observed using other experimental techniques. The jumps of both transverse (**H.4, H.5, H.6**) and longitudinal (**H.4**) magnetostriction were observed.

The phenomenon of giant magnetostriction jumps can be explained in the framework of the model of the magnetostriction induced by the pinning forces [14]. During the thermomagnetic avalanche, sudden decrease of the current screening the superconducting sample occurs. This decrease causes both rapid penetration of the magnetic flux into the sample (flux jump) and, according to the model of the pinning induced magnetostriction, rapid changes in sample sizes (magnetostriction jump). In the above works, examples of modeling of this phenomenon were presented. In some cases, modeling of the magnetostriction induced by pinning forces required to take into account the occurrence of the second maximum of the critical current density, so-called "peak effect" (**H.4, H.10**).

It turned out, however, that the mechanism of the magnetostriction induced by pinning forces may be insufficient to describe the experimentally observed magnetostriction hysteresis loops, although in most samples this mechanism played a dominant role. The study of crystalline V_3Si superconductor (**H.10**) revealed the presence of a strong component of the reversible magnetostriction, which could not be described in the framework of the model of the pinning induced magnetostriction. This component of the magnetostriction can be described by means of the mechanism that take into account the changes of the free enthalpy of the superconducting sample in external magnetic field [15]. In paper **H.10**, a model was elaborated that take into account the coexistence of both mechanisms, i.e. the mechanism connected with occurrence of the pinning forces and the mechanism connected with the change of the free enthalpy of the superconducting sample in magnetic field.

Conclusions

In the presented series of publications, the results of investigations of thermomagnetic avalanches and of the accompanying phenomena in a number of superconducting materials, which differ by many parameters, were presented. The results have shown that the specific properties of the investigated materials strongly influence of the formation of thermomagnetic avalanches.

It was shown that in contrast to conventional superconductors in high temperature superconductors, the critical state stability conditions cannot be analyzed within the

approximation assuming the occurrence of the locally adiabatic conditions. An analysis of the critical state stability in these materials requires a knowledge of their current-voltage characteristics. Due to the strong nonlinearity of these characteristics, the stability of the critical state depends on the external magnetic sweep rate. The critical state stability conditions in high temperature superconductors also strongly depend on the cooling conditions of the investigated samples. Improving the cooling conditions can limit the range of fields and temperatures at which the thermomagnetic avalanches occur. The conditions of the formation of the thermomagnetic avalanches in high temperature superconductors are also strongly influenced by their anisotropy – in particular by the anisotropy of the critical current density.

In the case of magnesium diboride, the critical state stability conditions are more similar to those found in conventional superconductors. However, explanation of the characteristic structure of the magnetic flux jumps in this material requires taking into account its specific thermal and magnetic properties.

Both in the case of high temperature superconductors and in the case of conventional superconductors, the critical state stability strongly depends on the shape of the investigated samples. Comparative studies of superconducting samples of the same diameter but different thicknesses have shown that the range of the magnetic fields and temperatures at which thermomagnetic avalanches occur becomes narrower with decreasing thickness of the sample. Demagnetizing field of the sample may lead to a complex distribution of the screening currents in the superconducting sample after the thermomagnetic avalanche. This distribution affects the conditions of formation and the dynamics of successive thermomagnetic avalanches.

After the thermomagnetic avalanche, the symmetry of the screening currents distribution may be broken. One of the manifestations of this phenomenon may be a reversal of the magnetic field profile at the surface of the sample.

The dynamics of thermomagnetic avalanches is determined by the thermal and magnetic diffusion. The parameters that influence the dynamics of the thermomagnetic avalanche strongly change during the development of the avalanche. An analysis of the dynamics of the magnetic flux jumps in the framework of the magnetic diffusion model has shown its strong correlation with the resistivity of the investigated materials in the flux flow regime.

It was shown that the observed in many different superconducting materials giant magnetostriction jumps are caused by thermomagnetic avalanches. This phenomenon can be described in the framework of the pinning induced magnetostriction model. However, a full description of the magnetostriction in type II superconductors requires, additionally, consideration of the magnetostriction component associated with the change of the free enthalpy of the investigated material in the magnetic field.

All the above results may be important in the design of technical devices using superconducting elements.

References

[1] C.P. Bean, Phys. Rev. Lett. 8, 250 (1962).
[2] A. Nabialek, P. Komorowski, M.U. Gutowska, M.A. Balbashov, J.N. Gorecka, H. Szymczak, O.A. Mironov. Supercond. Sci. Technol. 10, 786 (1997).
[3] S.L. Wipf and M.S. Lubell, Phys. Lett. 16, 103 (1965).
[4] S.L. Wipf, Phys. Rev. 161, 404 (1967).
[5] P.S. Swartz and C.P. Bean, J. Appl. Phys. 39, 4991 (1968).
[6] R.G. Mints and A.L. Rakhmanov, Rev. Mod. Phys. 53, 551 (1981).

[7] A.V. Gurevich, A.L. Rakhmanov, R.G. Mints, The Physics of Composite Superconductors, Begell House, New York, USA, 1997.
[8] L.S. Wipf, Cryogenics 31, 936 (1992).
[9] T.J. Johansen, M. Baziljevich, D.V. Shantsev, P.E. Goa, Y.M. Galperin, W.N. Kang, H.J. Kim, E.M. Choi, M.S. Kim, S.I. Lee, Europhys. Lett. 59, 559 (2002).
[10] D.V. Denisov, A.L. Rakhmanov, D.V. Shantsev, Y.M. Galperin, T.H. Johansen, Phys. Rev. B 73, 014512 (2006).
[11] R.G. Mints, Phys. Rev. B, 53 (1996) 12311.
[12] E.H. Brandt, M. Indenbom, and A. Forkl, Europhys. Lett. 22, 735 (1993).
[13] J. Nagamatsu., N. Nakagawa, T. Muranaka, Y. Zenit, J. Akimitsu, Nature 410 (2001) 63.
[14] H. Ikuta, N. Hirota, Y. Nakayama, K. Kishio, K. Kitazawa, Phys. Rev. Lett. 70 (1993) 2166.
[15]] H. Kronmüller, Phys. Stat. Sol. 40 (1970) 295.

2.5 Presentation of other scientific research achievements

Note: The articles cited in this section are separately listed in the attached list of my publications (works [1-108] see Appendix 3), and conference presentations (presentations [K1-K73] see Appendix 4).

Achievements in research before Ph.D.

My scientific activity at the Institute of Physics PAS, I began shortly after graduating from the Warsaw University of Technology, i.e. in 1990. From the beginning, the main direction of my research was connected with superconductivity, in particular with the newly discovered high temperature superconductors.

At the begin, I focused on the research of the modulated microwave absorption in ceramic high temperature superconductors. The experimentally observed microwave absorption was mainly connected with the system of the weak links, which are present in these materials. In paper [1], I presented an influence of the fast neutron irradiation and of the subsequent annealing of ceramic YBCO samples on the modulated microwave absorption.

Several works from this period are devoted to the investigations of high temperature superconductors of the group 123, in particular to the influence of defects or doping by different rare earth ions on magnetic properties and on the critical current density [1,2,7,42,45], as well as to the electromagnetic field absorption at radio frequency [4]. I also participated in the study of newly discovered mercury superconductors [3,40].

I spent a particularly long time studying the magnetostriction of superconductors [26,32,35,36,40,43]. As a result of my research, I was able to determine the influence of the sample shape on the pinning induced magnetostriction [32], as well as the influence of the weak links on the observed phenomena [40]. For the first time in the literature, I have observed giant jumps of the magnetostriction of the superconductors. I have investigated the magnetostriction in a number of different superconducting materials, both single crystalline and ceramics, as well as in textured materials. As a result of these investigations, my Ph.D. thesis entitled "Magnetostriction of superconductors in mixed state" was elaborated, under supervision of professor Henryk Szymczak. The Ph.D. thesis defense took place in the Institute of Physics PAS in the year 1999.

In the years 1996-1999, I participated in, led by prof. Igor Troyanchuk from Belarus, studies of the magnetic and transport properties, as well as magnetostriction studies, of manganites [10-12, 14-22, 27-31, 44, 48] and molybdates [38.39]. In the studied materials, different dopants were used. A large number of metamagnetic transitions and giant

magnetoresistance have been observed. The influence of the ion size of the dopant on the properties of the investigated compounds were analyzed.

I also participated in the search for organic materials exhibiting ferromagnetic ordering. My research concerned the atactic polypropylene [5,8] and the doped with sodium cobalt phthalocyanine [13].

In collaboration with dr. Przemysław Byszewski, I performed EPR studies of carbon nanotubes. The observed EPR signal was associated with structural defects in the investigated materials [8].

I participated in the studies of magnetic [25] and magnetoelastic [6] properties of Co/Cu and Fe/Gd multilayers. For the MBE grown Co/Cu multilayers, on the basis of changes in the shape of the hysteresis loop, the change of the character of interactions between the magnetic cobalt layers depending on the thickness of the copper layers was determined [25]. It was shown that magnetostriction of the Fe/Gd layers depends on the preparation technique [6].

The performed in collaboration with me EPR studies of the crystals of double tungstates $KDy(WO_4)_2$ [23,24,94] and $RbDy(WO_4)_2$ [37] have revealed the occurrence of a structural phase transition at the temperature of 6.38 K and 9 K, respectively. These studies in combination with the investigations of specific heat [23,94] and of the magnetization [41,101] allowed to determine the structure of the magnetic ground state of the tested materials.

Achievements in scientific work after Ph.D.

In 2000, after finishing my Ph.D, I went for one year on the post-doctoral NATO Science Fellowship to Canada. I was on the fellowship at McMaster University in Hamilton, under supervision of prof. Bruce Gaulin and prof. Marek Niewczas. My job was mainly to grow the crystals of BSCCO superconductors using the floating zone technique and to study their magnetic properties. The obtained crystals were then used in studies of thermomagnetic avalanches (**H.1, H.2, H.6**). These crystals were also used in x-ray studies. These studies revealed the presence of three distinct incommensurate charge modulations [69]. I also participated in the works, whose aim was to improve the technology of preparation of powdered BSCCO superconductor in order to produce superconducting composites [64].

After returning to Poland, in 2001, the main subject of my scientific research was the thermomagnetic avalanches in type II superconductors. The first studies on this subject, I performed before receiving a doctoral degree [26,33,34,96]. The main results on this subject after obtaining a doctoral degree (**H.1-H.13**) were indicated by me as the academic achievement, and discussed in detail in the previous section. However, I wish to emphasize that into the one-subject series of publications, I have only included those publications that were created on my initiative, have been written by me, and in which, because of the significant contribution of my work, I can be regarded as the main author. Except the thirteen indicated works, I am also a co-author of a dozen of other works on this subject [46,47,50,51,54,57,62,74,81,82,90,100,102,104,107]. These works were created in cooperation with Donetsk Physico-Technical Institute in Ukraine, with a team led by dr. Victor Chabanenko.

Among the important results presented in these works, I wish to draw attention to the numerical modeling of the magnetization hysteresis loops of the superconductors to determine the range of temperatures and of magnetic fields in which magnetic flux jumps occur [33,34], and explanation of the phenomenon of so-called "island jumps" [46,47], which have been shown to be closely associated with the second maximum of the critical current density. In papers [50,51,54], a complex dynamics of the magnetic flux jumps in samples of niobium was analyzed. The influence of the normal metal screens on the dynamics of thermomagnetic

avalanches was also investigated [62]. Numerical simulations of the avalanche dynamics, which took into account the influence of the magnetic field, were presented in paper [90]. Dynamics of thermomagnetic avalanches is also related to the problem of the dynamics of a single vortex line. This problem was analyzed in papers [75,83].

The investigations of the thermomagnetic avalanches are continued by me until today. At present, I focus on determination of the critical state stability conditions in pnictides [K73], investigations of the fine structure of magnetic flux jumps in conventional V_3Si superconductor [K71], explanation of the flux jump occurrence in the external magnetic field higher than the field of full penetration [K70] and explanation of the influence of frozen, in the direction perpendicular to the external magnetic field, magnetic flux on the formation and dynamics of the magnetic flux jumps [K69]. Basic issues related to the formation of thermomagnetic avalanches in type II superconductors, I have presented in popularizing article (in Polish) in the journal "Nowa Elektrotechnika" ("New Electrotechnics") [105].

In cooperation with Donetsk Physico-Technical Institute, I also conducted research of the impedance of type II superconductors at the frequencies up to 1 MHz [73,84]. These results were used to determine the resistance in the magnetic flux flow regime [84]. In the framework of this cooperation, I also continued the study of organic materials doped with magnetic ions. EPR studies of bromocresol green ($C_{21}H_{14}Br_5O_5S$) doped with Fe^{3+} ions and of crystal violet ($C_{25}H_{30}ClN_3$) showed similar, unusual temperature changes in microwave absorption [53,63]. The results were used to determine the dynamics of molecules surrounding the magnetic ion.

After obtaining a Ph.D., I continued to study magnetostriction of superconductors. In papers [49,56,60], I analyzed the magnetostriction of the newly discovered magnesium diboride. I described transverse and longitudinal magnetostriction of magnesium diboride in the framework of the pinning induced magnetostriction model. In paper [62], I presented the results of the investigations of the influence of fast neutron irradiation on the magnetostriction of ceramic YBCO samples. I have observed an increase of the magnetostriction after irradiation. Magnetostriction of superconductors was also the subject of the invited lecture, which was presented by me in 2004 on the NATO Advanced Research Workshop "Vortex dynamics in superconductors and other complex systems" [K36], as well as of a review paper [65].

I also studied the magnetostriction of other materials including CuB_2O_4 [67,76,77,103], $Fe_{0.27}Mn_{0.73}S$ [88], composite $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ / polyurethane [106,108] and containing rare earth ions double tungstates [70,78]. In CuB_2O_4 crystals, magnetostriction jumps in the range of the induced by the magnetic field phase transition to the phase of weak magnetic ordering were observed [77]. These results, together with the results of magnetization measurements and EPR studies, were used to construct the magnetic phase diagram of the investigated material [67,76,103]. In the material $Fe_{0.27}Mn_{0.73}S$, a change of the sign of the longitudinal magnetostriction after a change of temperature or of the external magnetic was observed [88]. In composites $Tb_{0.3}Dy_{0.7}Fe_{1.9}$ / polyurethane, the influence of the magnetic phase content and of the technology on the magnetostriction was analyzed [106,108].

The performed in collaboration with me investigations of double tungstates $KDy(WO_4)_2$, $KHo(WO_4)_2$ and $RbNd(WO_4)_2$ revealed in strong magnetic field anomalies associated with structural phase transition [70,78]. EPR studies of $KYb(WO_4)_2$ crystal showed the existence of only one type of paramagnetic centers Yb^{3+}. The components of the g tensor, which in this material is characterized by strong anisotropy, were determined [79].

I continued, in collaboration with Professor Vladimir Dyakonov, studies of selected compositions of manganites in systems $(La_{0.7}Ca_{0.3})_{1-x}Mn_{1+x}O_3$ [52] and $La_{1-x}Pr_xMnO_{3-\delta}$ [71].

For both investigated systems, the phase diagrams were constructed, and the occurrence of non-collinear magnetic structures was observed.

In my opinion, the conducted by me research of thermomagnetic avalanches in type II superconductors can be certainly regarded as unique in Poland, and in many cases also in the world. Discovery of new superconducting material, as well as increasing technical applications of superconductors will certainly create opportunities for the continuation of these studies. In the future, I also plan to use my experience in magnetostriction studies to determine magnetoelastic interactions in the newly discovered materials. Over the next few years, I plan to improve experimental techniques to study the magnetostriction of thin films using the capacitance technique and the strain-modulated ferromagnetic resonance.

Adam Nabrałek

Warsaw, August 20, 2012