Superconductivity Research in the Czech Republic

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Abstract – **A brief survey is given of superconductivity research in the Czech Republic covering the past and the present. Some remarks on the situation in organization, management, and funding of science are presented, together with ideas on how to facilitate integration of the Czech efforts into the European research systems**.

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I. Research and Education System

After the Second World War, the country started to build up a new research system, which increasingly emulated the Soviet model. Basic research was concentrated in the Czechoslovak Academy of Sciences (CSAS), while investment into research at universities rather stagnated, with teachers and professors being forced towards mainly educational duties. In parallel, research into applications and materials was performed in state industrial, agricultural, military, and other institutes and also company laboratories. Research was supported proportionally to the economical strength of the country, which was one of the best within the Soviet Block, but rather intermediate in the broad European context.

The political change of 1989 resulted in the corresponding transformation of the economical system. Accordingly, the structure of research institutions also changed substantially. Most application institutes lost their rationale and were closed or transformed into small private laboratories. The Academy of Sciences was reduced to about one half in the number of people, with some institutes closed. It survived by being transformed into a modern research institution devoted mainly to basic research. The grant system for research financing has been introduced. Research at universities has been encouraged to grow and gain importance. These changes also influenced the system of education, especially of graduated students.

Until 2001, the Academy of Sciences, as the leading national research institution, had the same right as universities in educating doctoral students and granting the degree of Candidate of Sciences (CSc., an analogue of PhD). After 2001, the role of the Academy of Sciences in education of doctoral students has not changed much in reality, but the students are now enrolled at a university, attend the lectures, and pass the corresponding exams there. Those wishing to work in laboratories of the Academy can perform there the practical part of the doctoral work under supervision of the Academy scientists, who are approved by the university. The university then grants the degree of PhD. Similarly, undergraduate university students can perform their diploma studies in institutes of the Academy.

II. Superconductivity Research

Now, let's turn to the main subject of the paper, to the field of superconductivity. The research into and development of superconducting materials in the Czech part of

Czechoslovakia started, in 1960s, in the National Research Institute for Materials (NRIM). The team led by V. Klabik, responsible for technological part of the research, and by V. Plechacek, in charge of physical investigations, developed and fabricated superconducting NbTi/Cu wires several km long, both single-core and multifilamentary. Later on, towards the end of 70's, Nb_3Sn multifilamentary wires in bronze matrix were also prepared.

In the late 1960s, a research of weak superconductivity and fabrication of Josephson junctions and SQUIDs started at the Institute of Nuclear Physics CSAS in Rez near Prague, in the group of M. Odehnal. The first rf SQUIDs they fabricated [1] were double-bore Zimmerman type, made of bulk Nb with two screw tips properly oxidized and pressed against each other. Both the technology and the associated electronics had to be originally designed, as Western (NATO) embargo was imposed on both SQUIDs and the electronics. The team (V. Petricek, R. Tichy, S. Safrata, M. Kohl, and Z. Janu) constructed several SQUID magnetometers and suitable fiberglass helium cryostats. The first magnetometer, a uniaxial device shielded by an iron shield, detected for the first time (in the Soviet Block) the signals of human brain [2]. The team received a prestigious state award for this achievement. Among others, the group constructed also a three-axial magnetometer for measurement of low-frequency variations of geomagnetic field. This magnetometer succeeded in detecting for the first time the Schumann resonance spectra in all three axes. Weak superconductivity was also studied in Nb_3Ge thin films. In 1979 the group transferred into the Department of Low Temperature Physics of the Institute of Physics CSAS (IP CSAS, after 1994 IP ASCR) in Rez near Prague. After the discovery of superconductivity in cuprates in 1986, the team focused on weak superconductivity in high-T_c compounds with a special attention given to the utilization of these new materials in SQUID detection at high temperatures [3].

III. High-T_c Superconductor Research and Development

The discovery of high-T_c superconductors caused an enormous excitement in the scientific community and everyone wanted to contribute to this field by own abilities, equipment, and experience.

In early 1987, chemists in the Department of Magnetism of IP CSAS, led by E. Pollert, prepared first ceramic samples [4] and later single crystals of YBaCuO, exploiting their previous experience with fabrication of perovskite-like compounds, including YBaCuO, to that time not recognized as a superconductor. In the same year they patented their own method of preparing superconducting materials [5]. In 1988, probably as the first, they reported on differential thermal analysis (DTA) of ceramic $YBa_2Cu_3O_X$ [6]. This group then conducted study of the $REBa_2Cu_3O_y$ family (where RE is a rare-earth element) with respect to phase stability [7], phase diagrams, synthesis of bulk materials, single crystal growth, and influence of chemical composition, including oxygen stoichiometry, on structural properties. Furthermore, they investigated modulated structures in the bismuth system, fundamental electric and magnetic properties, spectroscopy of chemical bonds, *etc*. In 1989-1990 M. Nevriva from this group joined the international team at ICTP Trieste, Italy, that organized courses of high-T_c superconductivity for students. During this period, he prepared and studied single crystals of Y(Gd)-Ba(Sr)-Cu(Al)-O, Bi-Sr-Ca-Cu-O, and Nd-Ce-Cu-O. Later, this group in collaboration with the Institute of Chemical Technology (D. Sedmidubsky, J. Leitner, and M. Nevriva, who moved there), extended their interest to HgBa(Sr)CaCuO [8], the effect of solid solution of LRE/Ba in the compounds with light rare earth elements (LRE=Nd, Sm, Eu, Gd), Tl- and Tl/Hg-based cuprate single crystals, and the influence of mechanical and thermal treatment on the critical parameters of superconducting tubes and composite Ag/Bi(Pb) tapes.

The team of Dr. Plechacek in NRIM developed applicable $YBa_2Cu_3O_{7-x}$ products, both pure and containing Ag - for mechanical strengthening. These were soon followed by

BiPbSrCaCuO (Bi-2223 phase) polycrystalline blocks of various shapes for use as magnetic shielding, superconducting leads, *etc*.

In the Department of Low Temperature Physics of IP CSAS, V. Gregor produced YBCO thin films by evaporation in an ultra-high vacuum system. Superconducting BiSrCaCuO polycrystalline thin films were sputtered there under UHV conditions. REBaCuO thin films were also fabricated by means of laser ablation using an excimer laser (M. Jelinek).

Scientists in the Department of Surfaces and Interfaces of IP CSAS (J. Dominec, L. Smrcka, P. Vasek, P. Svoboda *et al.*), collaborating with the chemists from the Institute of Chemical Technology, Prague, O. Smrckova and D. Sykorova, published in 1988 a widely recognized paper on stability of YBCO in water [9]. Later on, they studied the effects of annealing, irradiation, and atmosphere on properties and structure of superconductors, especially BiSrCaCuO [10], prepared by means of solid-state reaction. Furthermore, their interest was oriented towards the influence of various dopands, *e.g.*, Pb, Ag, V, Nb, B, on the growth of different phases of the BiSrCaCuO family. In collaboration with the Demokritos Institute in Athens, Greece, they investigated the effect of the rare earth ionic radius on superconducting properties in the REBaCuO system [11]. In the BiSrCaCuO compounds they studied intrinsic pinning, the anomalous Hall effect [12], transport properties, guided vortex motion, and more recently the transverse electric field, which, in contrast to the Hall voltage, is an even function of the applied magnetic field [13].

In 1987, Z. Frait and L. Pust from the Department of Magnetism of IP CSAS started to investigate ferromagnetic (FMR) and electron paramagnetic (EPR) resonances in YBCO samples [14]. The team headed by L. Pust (M. Jirsa, J. Kadlecova) utilized the vibrating sample magnetometer equipped with a precise custom-made analogue field-sweep and field-stabilization unit, which enabled them to observe the sensitivity of the magnetization loop on the field sweep rate [15] and to introduce the new method of dynamic relaxation [16]. Later on, this group investigated magnetic properties and the associated vortex physics in YBCO thin films, the magnetic anomaly in single-core and multifilamentary BiSrCaCuO tapes [17] of various origins (NKT Denmark, Geneva University, Switzerland, the Institute of Electrical Engineering, Bratislava, Slovakia, *etc.*). The team designed YBCO thin-film structures for modeling properties of the tightly-packed granular cores of BiSrCaCuO tapes [18]. These thin film structures, fabricated at Chalmers University of Technology, Gothenburg, Sweden, and at the ISG, Research Center Julich, Germany, finally helped to confirm that the magnetic anomaly observed in the granular BiSrCaCuO tapes was due to demagnetizing effects. In collaboration with Aristotle University in Thessaloniki, Greece, the group measured and analyzed properties of YBCO ceramics doped by Ca and Mg [19]. The shape of the magnetic hysteresis loop (MHL) of bulk REBaCuO samples exhibiting fishtail peak was analytically expressed starting from the Perkins' model of vortex dynamics [20]. In 1998 L. Pust left IP ASCR and M. Jirsa took over the group. Simultaneously, they started a close collaboration with the Superconductivity Research Laboratory of the International Superconductivity Technology Center (ISTEC), Tokyo, Japan. During the first stay in ISTEC in 1998, M. Jirsa and M. R. Koblischka (now Saarland University in Saarbruecken, Germany) measured the angular dependence of the mysterious "third peak" on MHL of a twinned Nd-123 single crystal. The angular experiment showed that the peak was a rest of the regular fishtail peak deformed by the vortex channeling effect of the twin plane structure [21]. This structure introduces an additional in-plane anisotropy into the system so that the magnetic data cannot be interpreted in terms of a simple Bean model. Further, magnetic studies of various ternary melt-textured compounds were conducted, together with M. Muralidhar and M. Murakami, including those with a nanoscale lamellar substructure filling the channels between regular twin planes (responsible for significant increase of pinning at high magnetic fields and thus enhancement of the irreversibility field by a factor of nearly two) [22]. Refinement of secondary phase particles by ZrO ball milling to a nanoscale size led to an exceptionally high pinning at high temperatures, which made possible levitation even in liquid oxygen, 90.2 K [23]. This collaboration, still continuing, has resulted in more than 50 common publications. The vortex interaction with large particles of secondary phases in melt-textured compounds motivated theorists in the group (V. Zablotskii, P. Petrenko) to develop a theoretical model of this interaction [24], giving the exponential $J(B)$ decay at low magnetic fields (the central peak of MHL), in agreement with experiment [20].

In connection with ISTEC, one should also mention the work of V. Zelezny from the Department of Dielectrics of IP CSAS (IP ASCR after the separation of the Czech Republic and Slovakia in 1994), who spent two years in ISTEC Tokyo studying the infrared and Raman spectroscopy on high-T_c superconductors [25]. In a similar direction J. Humlicek from the Institute of Condensed Matter Physics, Faculty of Natural Sciences, Masaryk University, Brno, has been also active since 1987, investigating the optical response of high-T_c materials in the infrared range, adaptation of elipsometry technique, data analysis and interpretation concerning condensate, phonons, electron background, and energy gap. Later, D. Munzar, A. Dubroka, and J. Chaloupka joined this effort and in a close collaboration with Max Planck Institute in Stuttgart, Germany, have developed a theory of the optical response in the infrared range and of the Raman response. On the phenomenological level, they explained frequency shifts and optical phonon weights below critical temperature in optical spectra when E//c-axis [26] and the absorption onset above energy gap in optical spectra when E//a-axis [27]. At present, the group is dealing with theory of optically and Raman active collective modes in cuprates with higher numbers of CuO_2 planes in the elementary cell and with the microscopic theory of phonon anomalies. The doctoral student J. Chaloupka is now active in the theory of superconductivity in cobaltites and other strongly correlated compounds.

At about 1998, J. Kolacek from the Department of Magnetics and Superconductors of IP ASCR became interested in the high-frequency vortex dynamics, magneto-conductivity, and far-infrared magneto-transmission in high-temperature superconductors and conducted, together with P. Lipavsky and others, the theoretical study of basic magnetic and electrical properties of individual vortices and vortex matter. This group has published several important theoretical studies, *e.g.*, of charge profile in vortices [28], electric field in stationary superconductors [29], and Bernoulli potential at a superconducting surface [30]. They also modified Ginzburg-Landau theory of superconducting surfaces [31] and Josephson relation [32] with respect to the influence of electric fields inside the superconductor.

In the beginning of 90s, after joining IP ASCR, V. Plechacek continued the research of high-temperature superconductors and in 1994 he founded CAN SUPERCONDUCTORS, a private company offering high-temperature superconducting products. The product range consists of Bi-2223 superconducting current leads, Bi-2223 magnetic shields for SQUIDs, Bi-2223 rings for fault current limiters, and $YBa_2Cu_3O_{7-x}$ targets for superconducting thin film deposition. Already at its inception, CAN SUPERCONDUCTORS has developed melt-textured REBaCuO levitation disks, which soon became the most important product of the company. Among other products, the company sells now worldwide superconductivity demonstrations kits for educational purposes [33].

Recently, unconventional superconductivity has entered the scene in several laboratories. J. Poltierova-Vejpravova and her colleagues from the Department of Condensed Matter Physics at the Faculty of Mathematics and Physics, Charles University, Prague, started in 2004 the research of heavy fermion superconductors derived from $CePt_3Si$ [34]. This was the first superconductor without a center of symmetry in the crystallographic structure at which magnetic ordering coexisted with the unconventional heavy-fermion superconductivity. The group is studying the effects of

- substitution of Pt by Ru, Rh, Pd, Cu, Au, Ir, and of Si by C, Ge, Al, B elements,
- material purity and homogeneity (using an ultrapure Ce purified by electro-transport in solid phase)
- system scale or morphology (crystalline form, amorphous metal, nanocrystal, *etc*.) on the superconductivity appearance and properties.

P. Hubik, J. J. Mares, and others from the Department of Semiconductors IP ASCR have recently investigated the unconventional superconductivity of boron-substituted diamond-based systems [35]. A new technological basis for preparation of dielectric, metallic, and superconducting thin films by sputtering, thermal and electron evaporation in clean vacuum is now under construction there.

To summarize the present status, only a few small teams devoted to a deep study of various aspects of superconductivity survived after the research boom in 90s. In some cases, superconductivity now enters the scene in context of a complex behavior of some novel materials, *e.g*., heavy fermions or diamonds. One company, CAN Superconductors, is on the market with high-T_c superconducting products.

IV. Funding of Research, Collaborations

The present Czech financial support of superconductivity research is inadequate and incommensurate with the importance of this subject in physics and the previous national achievements in this field. Let’s look at financial research resources in the Czech Republic in more detail. The research is funded predominantly from the state budget. The, so called, institutional support is spent mostly for salaries and maintaining buildings and labs. The rest is not sufficient to create a new research infrastructure. Individual research projects are supported by national grant agencies. The budget of these agencies, provided also by the state, is not big enough to equip new laboratories with modern technology and experimental techniques. Even for the operational and material costs of the grants the available funds are insufficient. The biggest problem, however, resides in the practical absence of the industrial and research funding. Our industry is now running extremely well and is driving all the national economy to high annual performances. Continuously, there is a huge investment by foreign companies to create new industrial units. In the average, however, not much top high-technology is involved. The companies rely more on know-how import from abroad than on the local research. Practically no money flows from the industrial companies to the research sector, either basic or applied.

All the groups presently involved in superconductivity research are closely collaborating with foreign partners. Regular bilateral international joint research programs are, however, rather rare. This gap is filled partially by various European collaboration mobility programs, like Vortex funded by the European Science Foundation (ESF) or European Network for Superconductivity (SCENET) financed from FP, in the past, and, newly, Nanoscience and Engineering in Superconductivity (NES). European and overseas foundations such as the Alexander von Humboldt, the Marie Curie, and the Fulbright also help a lot. We highly appreciate offers of, *e.g*., the European High Magnetic Field Center, ESFR Grenoble, and other big Europen research facilities enabling us to perform our experiments. Generally, it is quite difficult for the small groups or individuals to successfully compete for projects in FP7. The largest potential of the European scientific collaboration would be in integrating the Czech research community within fruitful and mutually profitable cooperation. However, it should go beyond the presently prevailing mobility projects to full-fledged joint research programs financed independently of the national resources.

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