Conference Reports

High-T_c Superconductors in Interlaken

With the discovery of superconductivity in a La-Ba-Cu-O compound just two years ago, the IBM researchers *J. G. Bednorz* and *K. A. Müller* triggered an unprecedented scientific race in laboratories around the world for new superconducting materials with yet higher critical temperatures.[1] The first paper by *Bednorz* and *Müller* received little attention until late 1986, when Japanese and American scientists confirmed the Zürich results at the Materials Research Society meeting in December 1986.[2-4] Early in 1987, the group of *C. W. "Paul" Chu* at the University of Houston announced the existence of superconductivity in a Y-Ba-Cu-O compound with a critical temperature as high as 92 K.[5] This was a dramatic breakthrough because for the first time it was possible to observe superconductivity above liquid nitrogen temperatures. *Paul Chu*'s results were confirmed almost simultaneously by research groups around the world[6,7] and soon the superconducting phase was identified as the black 123-compound $YBa_2Cu_3O_{7-x}$ having an oxygen deficient, perovskite-like structure.[8,9]

Special sessions on High-T_c Superconductivity were scheduled at all major conferences in materials science, physics and chemistry, and scientists from all over the world discussed their views on experimental and theoretical aspects of High-T_c Superconductivity. Since then a flood of publications and numerous conferences and symposia have demonstrated the worldwide impact of *Bednorz* and *Müller*'s discovery. Now, not quite a year after the legendary "Woodstock of the Physicists" at the American Physical Society March Meeting, IBM Rüschlikon, the ETH Zürich, the University of Geneva, the University of Neuchatel, the Swiss National Science Foundation, and the Swiss Academy of Science invited experts to the *International Conference on High-Tc Superconductors and Materials and Mechanisms of Superconductivity (HTSC-M²S)* from February 29 to March 4, 1988, in Interlaken, Switzerland About 1150 scientists were welcomed by *Alex Müller* of IBM, Rüschlikon. The conference was designed to provide an overview on all current developments of superconductivity in experimental and theoretical physics, chemistry, and applications. About 95 invited lectures were scheduled, 10 of them given in plenary sessions and about 85 in symposia and panel discussions organized in two parallel sessions. Special panel discussions and short talks on very recent results were organized in the evenings. Around 800 contributed papers were presented as posters in three all day sessions, with two hours in the afternoon reserved for the poster discussions and no other scheduled program in parallel. All invited and contributed papers were refereed during the conference and will be published in a special issue of "Physica C—Superconductivity" approximately three months after the conference.

Highlights were certainly the Tuesday and Wednesday evening sessions on new oxide superconductors. Two new groups of superconducting materials with onset temperatures above 100 K, namely Bi-Sr-Ca-Cu-O and Tl-Ba-Ca-Cu-O, were discussed in invited lectures and additionally scheduled five-minute talks. Bi-Sr/Ca-Cu-O compounds were investigated as early as February 1987 by researchers from the Max Planck Institute for Solid State Research and the Hoechst AG.[10] Superconductivity in Bi-Sr-Cu-O compounds was first reported by *Bernard Raveau* of the University of Caen, France, late in 1987.[11] Many other research groups began experimenting with bismuth substitutions into the 123-compound; *Hirshi Maeda* at the National Research Institute for Metals in Tsukuba, Japan, first announced results on January 22, 1988:[12a] superconductivity at 105 K was claimed, however, the group did not succeed in preparing a single phase sample. In his talk during the Tuesday evening session, *Maeda* gave the nominal composition of his sample as $BiSrCaCu_2O_x$. He reported a steep drop in the resistance vs. temperature curve, starting at about 120 K and leveling off near 105 K; $R=0$ was finally reached at 80 K. This behavior was confirmed by other researchers and is considered to be due to a low-T_c phase ($T_c=80$ K) and a high-T_c phase (T_c near 105 K). Other groups, among them *Art Sleight*'s from DuPont and *Bob Cava*'s from Bell Labs, reported $Bi_2Sr_2Ca_1Cu_2O_{8+x}$ as the superconducting compound, again with indications of low- and high-T_c phases.[12b]

More controversial is the structure of the new Bi-compounds. Several groups made proposals for the structure which do not agree with each other on several points. Some more or less common structural features are: The unit cell is made up of two Bi-O layers followed by five perovskite layers (Sr-O, Cu-O, Ca). Most peaks in the X-ray diffraction spectra can be indexed on the basis of a pseudo-tetragonal unit cell with $a=5.40$ Å, $c=30.83$ Å. An incommensurate modulation along the b-axis is observed by some groups, but that could turn out to be a sample and preparation dependent effect. There do not appear to be Cu-O chains in the new Bi-compounds; consequently the Cu-O and Bi-O planar arrangements are considered important for the superconductivity, in the Bi-compounds as well as in the "old" 123-compound. Preparation of samples follows a "shake and bake" recipe similar to the 123-material, but at lower temperatures (between 800 and

850 °C). A slow cooling to adjust the oxygen content of the samples does not seem to be necessary with the Bi-compounds.

Superconductivity in Tl-compounds, discovered by scientists of the University of Arkansas,[13] was discussed by *Paul Chu* from the University of Houston and *Paul Grant* from the IBM Almaden Research Center, San Jose, among others. The compounds were synthesized at 950 °C and subsequently quenched in air and the composition was given as $Tl_2Ca_2Ba_1Cu_2O_x$. Both *Chu* and *Grant* pointed out that thallium is extremely toxic and great care must be taken in working with these substances. *Grant* presented resistivity curves and magnetometer data that showed complete superconductivity at $T = 118$ K; on Wednesday night he announced that he had obtained new data from his lab via telefax showing bulk superconductivity at $T = 125$ K in the Tl-compounds. Spontaneous applause—and once again a little "Woodstock" atmosphere could be felt. Minutes later, in the conference center lobby, *Paul Grant* was surrounded by reporters, a picture usually associated with politicians rather than scientists.

Even though much was said about the new Bi- and Tl-compounds, most of the invited and contributed papers covered aspects of superconductivity in the "old" 123-compound $YBa_2Cu_3O_{7-x}$. During the symposium on crystal chemistry and structure detailed studies of the interdependence of structure, oxygen content, and superconductivity were presented. A panel discussed oxygen vacancy ordering, oxygen deficiency, and twinning. The role of twinning in the mechanism of superconductivity is still controversial. Processing and preparation of high-T_c superconducting materials were covered by three symposia: growth and properties of single crystals, superconducting glass properties, and thin films. Many posters also addressed the preparation of large single crystals, films of various thicknesses and on a variety of substrates, and dense, polycrystalline samples. Two symposia were scheduled to discuss electronic properties, including panel discussions on thermal and optical properties. Substitutions for Y and Cu, antiferromagnetic ordering, and magnetic flux penetration were presented during the symposium on magnetic properties. An entire evening session was devoted to the discussion of resonance experiments. It became clear that the frequency assignment for the Cu sites in nuclear quadrupole resonance (NQR) experiments will remain controversial until it is possible to reliably calculate the electric field gradient (EFG) at the respective Cu sites. The point charge calculations currently employed were considered insufficient. Various potential uses of high-T_c superconductors were presented and discussed in the symposium on applications. It was pointed out that even for applications such as superconducting connections on circuit boards a critical current density of at least 10^5 A cm^{-2} is absolutely essential. Consequently, many lectures and posters discussed the improvement of the critical current density, the role of grain boundaries for the critical current density, etc. Models on mechanisms, resonant valence bond and related models, bosonic models, and new ideas on theory were presented and debated during two symposia and two evening sessions.

The HTSC-M^{2}S conference demonstrated that one year after the discovery of the 90 K superconductors the interest in these substances is still enormous. Our knowledge of these compounds has grown considerably. Some controversies, e.g., about the existence of a distinct 60 K superconductor with 6.6–6.7 oxygens per formula unit, have been resolved. Great efforts are currently being made to find ways to increase the critical current densities in polycrystalline samples or thin films, predominantly deposited on $SrTiO_3$ substrates, that already exhibit high critical current densities. Particularly interesting work is being conducted at the IBM laboratory in Yorktown Heights, NY, where researchers are working on micro-patterning to "write" superconducting structures in thin films, e.g., loops for use in SQUIDs. New high-T_c superconducting materials will, without doubt, continue to play a significant role in the development of the field. The trend points towards increasingly complex structures. As *Paul Chu* put it "... one layer gives a T_c of 30 K, two give 60 K, three layers give 90 K, and now we have four layers and 120 K". The importance of this lies not only in the higher T_c, but also in the fact that scientists now have different structures available for their studies and so will be able to pin-point the common features in the different substances. This will ultimately help the theorists in their search for the "right" mechanism. *Robert Schrieffer*, summarizing the leading theoretical approaches, talked about conventional phonon mechanisms and charge fluctuations, but also mentioned such exotic concepts as half-fermions and x-ons ("... that's anything you like!"). But after the recent 30% isotope effect found by *Keven Ott* from Los Alamos National Lab, a conventional phonon-mediated mechanism must be re-examined.

A final comment is that, as with other superconductor meetings to date, the HTSC-M^{2}S conference in Interlaken was dominated by physicists and chemists. Only a few materials scientists presented papers or gave talks. There is still a wide gap between basic research and applications, such as interconnects, power transmission lines, or Josephson devices. The future of these applications depends on the materials properties of these substances, and it will be up to the materials scientists to fill the wide gap between basic research and applications.

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... and Bad Nauheim (FRG)

A symposium on the structure and microstructure of high-temperature superconductors was held on April 21–22, 1988, in Bad Nauheim, Federal Republic of Germany. The aim of this comprehensive two-day symposium, organized by the Deutsche Gesellschaft für Metallkunde and chaired by *H. C. Freyhardt*, Göttingen, was to assemble an interdisciplinary group of scientists (physicists, chemists, crystallographers and materials scientists) and provide a forum for discussions devoted to the structure, microstructure, preparation and shaping, and applications of ceramic high-temperature superconductors (HTSCs). Leading scientists from Europe, the United States and Japan were invited to summarize the achievements in the field and to provide an evaluation of recent progress and unresolved problems.

The following lectures were presented: Structural aspects of mixed valence copper oxides and their relationships with superconductivity (*Raveau*, France)/Oxygen stoichiometry in pure and 3d-metal-doped $YBa_2Cu_3O_{7\pm y}$ (*Greene*, USA)/Structural aspects of the new Bi and Tl based high-T_c superconductors (*Batlogg*, USA)/Physical properties of high-T_c superconductors (*Steglich*, FRG)/On the microstructure of high-T_c superconductors (*Heeger*, FRG)/High-resolution transmission electron microscopy; principles and results on $YBa_2Cu_3O_{7-x}$ (*Gruehn*, FRG)/Phase diagrams of non-stoichiometric superconducting oxides (*Hauck*, FRG)/Crystal growth of high-T_c superconductors (*Hosoya*, Japan)/Bulk materials, shaping and prospects for applications (*Krauth*, FRG)/Application of high-T_c thin films in microelectronics (*Rogalla*, Netherlands).

In addition to the ten review talks, the latest results were presented on about 50 posters which were discussed in two plenary sessions. While the structure and properties of HTSCs were at the center of numerous discussions during the first day, the interest on the second day focused on "the real problems", as *H. E. Hoenig* from Siemens put it, namely preparation, shaping and applications. Controversies concerning the structure of the Bi-based superconductors do still exist, as a very lively discussion at the end of the first day showed.

The key quantity for HTSC applications in energy technology and superconducting electronics is the critical current density J_C. Based on magnetization curves of sintered, polycrystalline ceramic superconductors, the critical current density within a single grain was estimated to be of the order of 10^6 Acm^{-2} at T=4.2 K. The reason for the much lower J_C in sintered samples—typically 100–1000 Acm^{-2}—is considered to be the *weak links* between the grains in these materials. Defects such as voids, cracks and micro-cracks, second phase, including grain-boundary segregations and oxygen deficiency were also listed as reasons for the degradations of the transport properties. While the critical current densities in sintered HTSC materials are presently too low for most applilcations, J_C values in thin films prepared by a variety of methods are much more promising. However, not only the current carrying capability but also the film morphology must be considered; applications in superconducting electronics require very flat film surfaces for multiple stacked layers. The surface of epitaxially grown films or films made by laser ablation is too rough for applications in superconducting electronics. A further problem associated with thin films of HTSCs is the substrate-film compatibility. Evidence for Mg–Cu interdiffusion of $YBa_2Cu_3O_7$ films on MgO substrates was shown, and the necessity for passivation layers, e.g. silicon nitride on silicon substrates, was suggested. Various methods for the structuring of films were discussed, mostly for the fabrication of Josephson junctions. Because of the small coherence lengths in the HTSC materials, these Josephson junctions are difficult to prepare. Thus superconducting chip-interconnects seem much more likely applications at present than on-chip application of Josephson switching elements.

At this symposium the necessity of an interdisciplinary approach to the problem of high-T_C superconductivity became clear once again. Exact determination of the physical properties of these materials requires samples of higher phase purity and, of course, larger single crystals. Thorough investigations of preparation and shaping of these interesting substances are an important prerequisite for technological applications.

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