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MaNEP Newsletter

Materials with Novel Electronic Properties

Contents:

No 5, Fall 2003

MaNEP is a National Centre of Competence in Research (NCCR) with the University of Geneva as Home Institution
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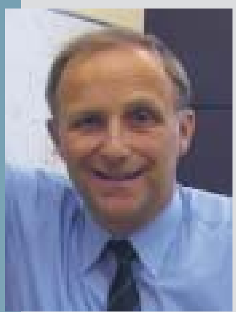
Message of the Director



Superconductivity is one of the many striking phenomena occurring in the materials of interest to MaNEP. One aim is the understanding of this phenomenon and another aim is preparing these materials for applications. MaNEP has important projects in the field of applied superconductivity. In fact there are numerous possible applications of superconductivity and MaNEP works actively to contribute towards this goal by our research and by the education of students in this field. In this issue we focus on one of these projects with a scientific article on "Superconducting wires and tapes for High Field Magnets and Energy Applications" by Professor René Flükiger. This work, which opens up nice perspectives for magnetic resonance studies and in the field of energy systems, is carried out in a fruitful collaboration with the company Bruker Biospin. As a complement for the non-specialist we give a brief historical review on the phenomenon of magnetism and we present four current applications where superconductors are used to produce very high magnetic fields.

We also continue our presentations of the MaNEP groups, this time one group from the University of Neuchâtel, two groups from the University of Geneva and one group from the Swiss Institute of Technology in Zürich. I would like here to take the opportunity to congratulate Professor Giorgio Margaritondo on the one hand and Luca Perfetti on the other for the distinction they have received.

After 2 years of activity the members of MaNEP shall gather in Les Diablerets for a 3 days meeting from September 29 to October 1. This will be the occasion for more than 200 researchers to present and discuss the results of our NCCR obtained so far. It shall also be the moment to look forward towards new and exciting research for the two remaining years of the first phase of MaNEP.

Øystein Fischer

News in Brief

MaNEP Booth at Nanofair 2003

The first international trade show for innovation and market development in the field of nanotechnology recently took place in St. Gallen from September 9th to 11th. This event offered companies and institutions from the fields of science, research and education the opportunity to present their activities within this area. The Nano Conference and a big poster session were held simultaneously and many interesting scientific contributions were presented.

Materials with novel electronic properties are of crucial importance for research and applications in nanotechnology. MaNEP took this chance and was among the 70 companies or institutions present. We had an attractive exhibition stand with two demonstrations, a home-built scanning tunneling microscope and a magnetron sputtering system for thin films growth.

This gave us the opportunity to present our scientific activities and our competences both to the general and specialized public. We further had stimulating discussions with companies involved in this innovative environment.

We got a very positive feedback and this encourage us to participate to Nanofair 2004.

Young PhDs and Post-Docs, Take your Chance !

Stimulate collaborations between our scientific members is one of MaNEPs missions. A key concept in this context is the *Mobile Post-doc Programme* launched last spring, which should drive a dynamic know-how exchange between MaNEPs labs.

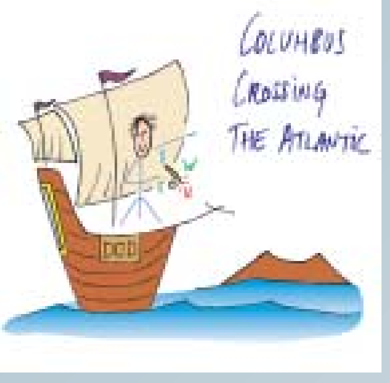
Several new post doctoral positions, so-called *Mobile Post-Docs*, have been opened. The idea is to offer positions to students who wish to make a post-doc in a MaNEP institution. The research may even be carried out in more than one MaNEP lab to take advantage of the many available facilities. However, the post-doc shall not be undertaken in the same institution where the student made his PhD thesis. Candidates are invited to build up a scientific project that clearly favours MaNEP collaborations and to send their proposals to the MaNEP Management (Isabelle.Bretton@physics.unige.ch).

Dr. Lara Benfatto will be the first MaNEP Mobile Post-Doc. Lara is a theorist and her research plan foresees collaborations with MaNEP groups of Neuchâtel, Fribourg and Geneva. She will split her work between these three institutions.

From Magnetism to Electromagnetic Fields

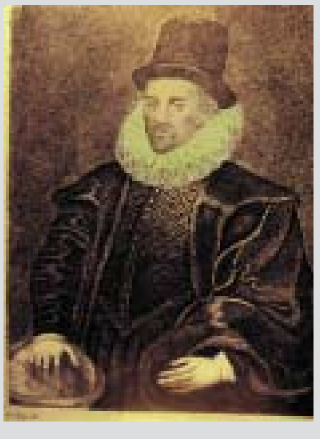
A little History...

Magnets are very common in our everyday environment and their existence has been known for centuries. The ancient Greeks (originally those near the city of Magnesia) and also the early Chinese had discovered strange and rare stones which had the power to attract iron. Around 1000, the Chinese even found that a steel needle could become magnetic when put into contact with one of these stones known as lodestone (magnetic iron ore). Furthermore, when freely suspended such a needle appeared to point north-south: in this way they invented the compass!



The magnetic compass then spread to western Europe and C. Colombus (1451 - 1506) was one of the first to make use of it while crossing the Atlantic in 1492. He even noticed that the needle was deviating from the north (as indicated from the stars) during the trip.

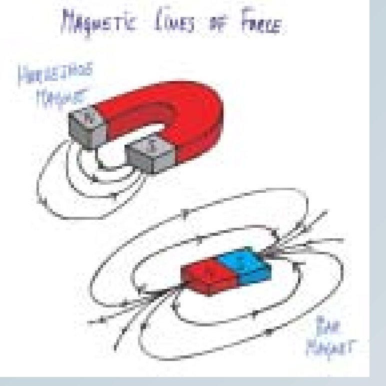
Later, around 1600, W. Gilbert (1544-1603), physician under Queen Elizabeth I of England, published *De Magnete* ("On the Magnet") which rapidly became a standard reference document on electrical and magnetic phenomena. For example, he was the first to make a clear distinction between magnetism and the amber effect (or static electricity as we call it today). Moreover, he linked the polarity of the magnet to the polarity of the Earth and built an entire magnetic philosophy on this analogy. According to Gilbert, magnetism was the soul of the Earth; a perfectly spherical lodestone would spin on its axis when aligned with the Earth's poles, just as the Earth spins on its axis in 24 hours... Although he didn't express an opinion to whether this rotating Earth was at the centre of the universe or in orbit around the Sun, he was after N. Copernicus (1473-1543) one of those who inspired other famous scientists like J. Kepler (1571-1630) and later G. Galileo (1564-1642).



William Gilbert (1544-1603) taken from the title page of the original Latin edition of De Magnete (London, 1600).

But what is Magnetism?

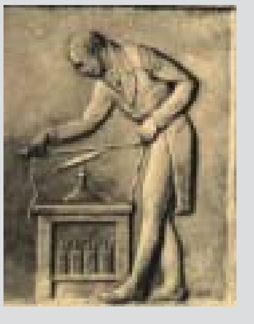
Although everybody is familiar with the properties of magnets, one is generally much less aware of the origin of the magnetism. The concept of magnetism is based on the magnetic field or what is known as a dipole. The term magnetic field describes a volume of space where a detectable and measurable change in energy occurs. The poles are the locations where this field enters a material. A dipole is thus an object which has a magnetic pole at each end with opposite directions. Examples of this include bar or horseshoe magnets which both have a north and a south pole. The magnetic lines of force flow from pole to pole as shown in the sketch and it is easy to feel the attraction or repulsion when one plays with two magnets.



If a bar magnet is cut in two, both pieces remain magnetic. This sectioning with subsequent creation of dipoles is possible down to the atomic level, implying that the source of magnetism lies in the intrisinc properties of the atom itself. Since matter is composed of atoms, all materials are sensitive in some way to magnetic fields. Without going into detail, the source of magnetism lies in the field created by the motion of electrons within the atoms.

Electromagnetic Fields

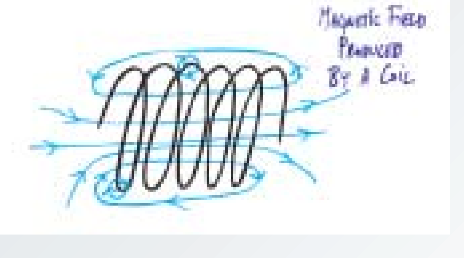
Magnets are not the sole source of magnetism. As previously stated, a flow of electrical charge (for example an electric current flowing in a wire) causes a compass positioned nearby to deflect. This was the experiment performed by H.C. Oersted in 1820 which demonstrated the possibility to produce magnetic fields: these fields are known as electromagnetic fields. Oersted also noticed that the field strength is proportional to the electrical current within the wire and that the field direction depends on the direction of the current.



H.C. Oersted doing his famous experiment. (Deutsches Museum)

Since this discovery much effort has been applied to develop different designs in order to produce increasing magnetic fields. The figure below illustrates a wound coil which produces an uniform magnetic field in its center with a strength not only proportional to the current but also the number of loops in the coil.

The scientific article in this newsletter shows the latest progress in the development of superconducting wires which can produce very high electromagnetic fields. On page 7, we will discuss the use of superconducting materials for high field production and some related applications.



MaNEP

Geometrical and Electronic Structure at and Near Surfaces of Materials with Novel Electronic Properties

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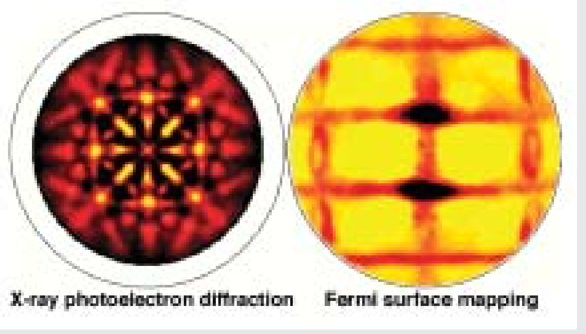
The aim of our research is to understand the electronic structure and the interplay between electronic degrees of freedom and the geometrical arrangement of atoms in materials with novel electronic properties. Since our experiments are based on photoemission (and in the future also on scanning probe microscopy) we are sensitive to materials properties in an area close to the surface defined by the escape depth of the electrons.

Angle-resolved photoemission is applied in two distinct energy regimes, either using ultraviolet photons to map valence bands and Fermi surfaces or by exciting core electrons with soft X-rays to obtain local, real-space information on the geometrical structure around the emitting atom (X-ray photoelectron diffraction).

Materials are on the one hand produced within MaNEP, e.g., charge density wave compounds (CDW's) (H. Berger, EPFL) and thin ferroelectric films (J.-M. Triscone, Geneva) and on the other by *in situ* evaporation on single crystal surfaces. For the CDW's the main interest is the driving mechanism behind the CDW formation, whereas for the thin ferroelectric films we explore the minimal thickness necessary to still exhibit ferroelectricity. *In situ* evaporation of thin films has been used to study hydrogen concentration induced switching optical properties.



X-ray photoelectron diffraction and Fermi surface mapping on a thin ferroelectric film (left) and a charge density wave compound (right), respectively.

References:

[1] J. Hayoz et al., Phys. Rev. Lett. ***90****, 196804 (2003).*
[2] M. Bovet, et al., Phys. Rev. B ***67****, 125105 (2003).*
[3] R. Fasel, P. Aebi, Chimia ***56****, 566 (2002).*

Specific Heat of Novel Materials in High Magnetic Fields and at High Pressures

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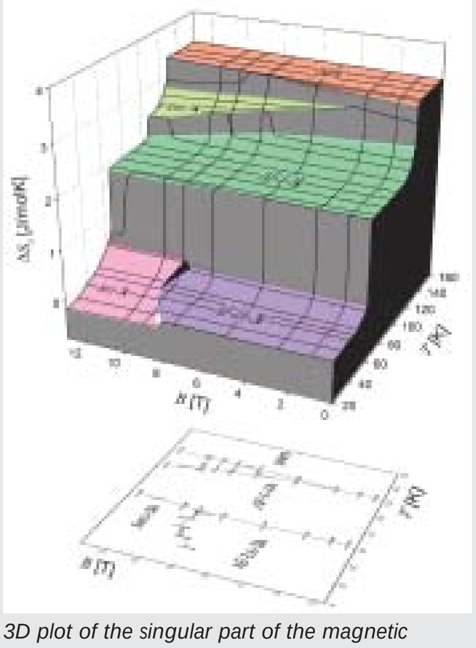
Our laboratory specialises in thermodynamic studies of superconductors and new materials. Specific heat as a function of temperature (1-300 K), magnetic field (0-16 T), and pressure (0 to over 10 GPa) is a basic characterisation that has gained renewed interest as it allows unconventional properties of superconductors to be assessed in the bulk.

Most novel materials are only available as microscopic single crystals or thin films. This has challenged traditional experimental techniques. In addition to adiabatic and relaxation calorimetry, alternating heating, heat-flux, and magneto-calorimetry have been implemented in Geneva. Thin film and high pressure experiments are at various stages of development [1]. Several classes of materials have been studied in our laboratory: A15, Chevrel phases, cuprates [2], UAs [3], MgB_2 [4], etc. Specific heat is well suited for studying transitions versus temperature, magnetic field and pressure, and to characterise their anisotropy and their critical behaviour. Recently, it has given bulk information on the melting of the vortex lattice, on the d-wave symmetry of Cooper pairs in high temperature superconductors, and confirmed the two-gap structure of MgB_2. More generally, as a volume-sensitive probe, it complements research based on surface-sensitive spectroscopies.



3D plot of the singular part of the magnetic entropy of UAs. Each line along the T (or B) direction is a specific heat (or magnetocaloric) run. The phase diagram is shown below.

References:

[1] F. Bouquet et al., Solid State Commun. ***113****, 367 (2000).*
[2] B. Revaz et al. Phys. Rev B ***58****, 11153 (1998(; Y. Wang et al., Phys. Rev B 63, 094508 (2001).*
[3] T. Plackowski et al., Phys. Rev. B ***67,*** *184406 (2003).*
[4] F. Bouquet et al., Physica C ***385****, 192 (2003).*

Quantum Condensed Systems

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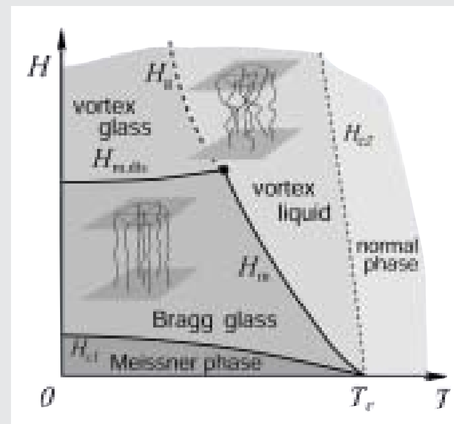
We study superconductivity and superfluidity on the meso- and nanoscale. The group's interest spans the fields of Vortex Matter in strongly fluctuating superconductors, novel phases in quantum degenerate trapped Fermi- and Bose gases, and superconducting structures for quantum computing.

Thermal fluctuations and quenched disorder drive numerous phase transitions in the vortex system of strongly type II anisotropic superconductors. Understanding melting, decoupling, and glassyness of this soft-matter system broadens our knowledge in statistical physics and helps in the technological advancement of materials [1].
Cooling atoms to the nano-Kelvin regime allows for the realization and study of new thermodynamic phase transitions and their associated phases, with an interesting synergy emerging between the fields of quantum atom optics and condensed matter physics. At present the focus is on bosonic/fermionic/mixed gases subject to an optical lattice with new phases (Mott-insulator, BCS-superfluid, supersolid) observed in experiments or proposed theoretically [2]. In superconducting devices the quantum liquid is protected from decoherence by the superconducting gap — specially tuned structures hold the promise to serve as quantum bits in future quantum computing devices. Quiet and well protected qubits can be obtained with the help of π-junctions and particular geometries exploiting symmetry and frustration [3].

References:
[1] G. Blatter and V.B. Geshkenbein, in `The Physics of Superconductors', eds. K.H. Bennemann and J.B. Ketterson (Springer, Berlin, 2003).
[2] H.P. Büchler, et al., Phys. Rev. Lett. ***90****, 130401 (2003).*
[3] L.B. Ioffe, et al., Nature ***415****, 503 (2002).*



High-Tc cuprates are anisotropic and strongly type II superconductors where thermal fluctuations and quenched disorder play an important role. Vortex Matter then appears in several thermodynamic phases, weakly disordered Bragg-glass, vortex-liquid, and possibly a strongly disordered vortex-glass.

Electronic Properties of Low Dimensional Materials

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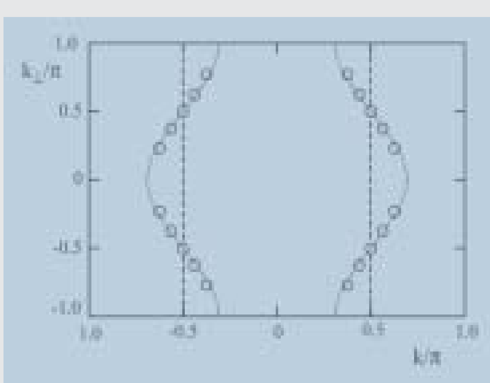
The group works on the theory of condensed matter, in connection with various experimental groups. The research activities include the study of strongly correlated electronic systems, ab initio calculations, and disordered elastic systems (e.g. in vortex lattices or for domain walls in magnetic systems or ferroelectrics).

Under MaNEP, the main activity is to understand the properties of low (i.e. one- or two-) dimensional interacting systems (such as organic conductors, carbon nanotubes, quantum wires). Indeed in low dimensional systems interactions lead to an unconventional state (Luttinger liquid in one dimension), quite different from the canonical Fermi liquid of normal metals. One of the questions is to understand how to go from such a state to a more conventional Fermi liquid by coupling low dimensional systems. Another important issue is to understand the unusual transport properties of such systems. This is of special importance for the mesoscopic realizations of such interacting electronic systems (nanotubes, quantum wire or Wigner crystal) for which such transport measurements are the main probe of the physical properties.



Coupling Luttinger liquids gives back a Fermi surface and quasiparticles [1]

References:
S. Biermann et al. Phys. Rev. Lett. ***87*** *276405 (2001).*
T. Nattermann et al. Phys. Rev. Lett. ***91*** *056603 (2003).*

Scientific Article

Superconducting Wires and Tapes for High Field Magnets and Energy Applications

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D. Eckert, Bruker Biospin, Fällanden, Switzerland

Various new methods are being developed for improving the critical current density of superconducting tapes and wires based on Nb_3Sn for high field NMR magnets, and (Bi,Pb)2223 tapes and MgB_2 for energy applications above 20 K. An unique device has been built for measuring the effect of the stresses caused by the Lorentz forces on the critical current densities of industrial superconducting wires and tapes in magnets operating at fields of 17 T and above, whilst carrying up to 1'000 A.

Research Group

UNIVERSITÉ DE GENÈVE

BRUKER BIOSPIN

The group of Prof. R. Flükiger is active in various domains of fundamental and applied materials research. A major objective is the preparation of high purity polycrystals and single crystals of complex metallic and oxide superconducting materials. Various techniques, e.g. SQUID magnetometry and magnetization as well as electrical resistivity, are used to characterize their physical properties, at fields up to 17 T.

A second activity is focused on the development of superconducting Nb_3Sn wires and (Bi,Pb)2223 tapes in view of their application in industrial magnets producing magnetic fields well above 21T. The activity also involves new developments on MgB_2 wires. This work is performed in collaboration with Bruker Biospin (Fällanden, CH), the world leader in high field magnets for Nuclear Magnetic Resonance (NMR).

Corresponding Author:
Prof. René Flükiger
rene.flukiger@physics.unige.ch

References

D. Uglietti et al., presented at EUCAS 2003, Sorrento (Italy).

V. Abächerli et al., Physica C 372-376, 1325 (2002).

R. Flükiger et al., Physica C 385, 286 (2003).

Introduction

The development of advanced superconducting tapes and wires is of considerable industrial interest for various kinds of magnets. The main activity is concentrated on magnets for Nuclear Magnetic Resonance spectroscopy (NMR), an analysis technique with growing potential for research in pharmacology, biology and biochemistry. Since a higher resonance frequency (allowing a higher resolution) is correlated to the magnetic field strength, B, there is an evident need for magnets producing the highest possible fields. The highest field achieved so far is 21 T at 2 K (corresponding to a frequency of 900 MHz) in an NMR magnet from Bruker BioSpin (Fällanden, ZH) which consists of Nb_3Sn wires. A worldwide effort is underway to reach 1 GHz, which is a very challenging goal.

On the other hand, future energy applications, such as transformers, power cables, motors or fault current limiters can only be economically operated at temperatures well above 20 K, which can be obtained by two-step refrigerators, i.e. without liquid Helium. Superconducting materials such as Bi,Pb(2223) or $YBa_2Cu_3O_7$, with T_c values of 110 and 92 K, respectively, are the appropriate choice, while the recently discovered MgB_2 seems to be reserved to niche applications.

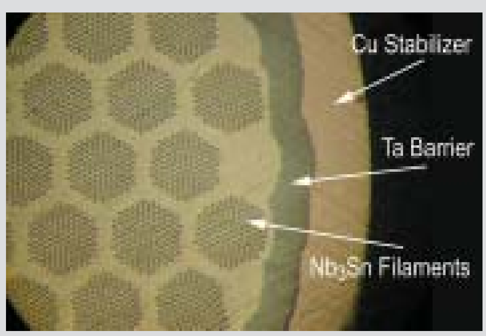


Fig 1. Cross section of a $(Nb,Ta,Ti)_3Sn$ wire fabricated in our laboratory (GAP).

Nb_3Sn Multifilamentary Wires for High field NMR magnets

Nb_3Sn has an excellent magnetic relaxation behavior and is at present the only superconducting material allowing a magnet to operate in the so-called "persistent mode", i.e. in a closed superconducting circuit. Quaternary $(Nb,Ta,Ti)_3Sn$ wires produced by the bronze route are currently optimized to reach the ultimate limits of current capacity at B > 21T. As an example, the whole fabrication process of a wire with 14'641 filaments, including 3-fold hot hydrostatical extrusion and the subsequent wire drawing to a final diameter of 1.25 mm, was performed in our laboratory (Fig. 1). A record critical current density of J_c (non-Cu) = 285 A/mm² at 17 T and 4.2 K was obtained. Further progress is expected by using improved Cu-Sn bronzes.

Bi,Pb-2223 Tapes and MgB_2 Wires

Ag sheathed (Bi,Pb)2223 tapes with 19 filaments have been fabricated, and the variation of J_c vs. strain has been measured for the first time on an industrial, high current tape, exhibiting 700 A at 4.2 K, 0 T. In contrast to Nb_3Sn wires, the tape geometry is essential, due to the anisotropy of the (Bi,Pb)2223 phase. The tapes with the highest J_c values, 3.5 x 10⁴ A/cm² at 77 K and 0 T, present a high degree of texturing for the *c* axis (≈ 5°), while no texture has so far been achieved in the *a,b* plane. Further developments are under work to find new solutions to this problem.

Strong anisotropy effects on J_c have also been observed in Fe/MgB_2 tapes: at 6 T and 4.2 K, a decrease by a factor of 20 was observed for B perpendicular to the filament surface. A new result is that the textured grains are only located at the filament surface, as a consequence of the deformation process. Since the surface grains in round wires have their *c* axis oriented in the radial direction, i.e. normal to the surface, it follows that a round wire symmetry is preferable for MgB_2 conductors.

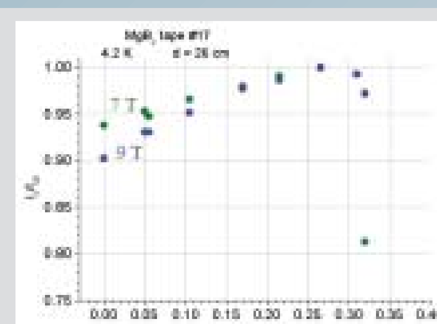


Fig. 2 J_c vs. strain for a Fe/MgB_2 tape at 4.2 K and various applied fields.

Fe sheathed MgB_2 wires have been prepared with J_c values of 1x10⁴ A/cm² at 4.2 K and 7 T. The variation of J_c versus strain for Fe/MgB_2 wires is similar to that of Nb_3Sn and shows a maximum at 0.26% strain, (Fig. 2), thus indicating a potential for applications. Future improvements will involve a higher degree of texturing deeper inside the filaments, as well as in-situ reaction techniques, allowing the addition of SiC nanopowders.

Superconductors and High Magnetic Fields

Use of Superconductors

Electromagnetic fields produced with conventional conductors are used almost everywhere in today's technological environment, in particular in electric motors, transformers or power generation systems. The use of superconductors in energy efficient devices is very promising although the cooling costs could remain a limitation.

Superconductors are used today in various kinds of applications using high magnetic fields such as Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance spectroscopy (NMR). Other applications are under development: high current generators, current leads, energy transfer superconducting cables, fault current limiters, motors, transformers, energy storage systems and also electronic devices. Since superconducting wires are very efficient conductors (being able to carry much higher current densities than normal conductors), it is possible to design coils made from such materials which can produce very high, stable and uniform magnetic fields. Moreover, superconducting generators half the size of a copper wire generator are about 99% efficient; conventional generators are around 50% efficient.

Four spectacular applications which make use of superconducting magnetic fields are illustrated below.

Magnetic field strengths

Three different types of magnets exist: permanent, superconducting, and pulsed magnets.

Neodymium-iron-boron and ternary samarium-cobalt alloys are currently the strongest known permanent magnets and can produce fields of about 1 Tesla (the Tesla T is the international unit of magnetic field strength: one Tesla is about 20'000x the earth magnetic field).

Superconducting magnets are a kind of electromagnet producing a magnetic field from the flow of electric current through a material with no resistance. A superconducting magnet can reach field strengths above 20 T.

Finally, pulse magnets can provide even higher magnetic field up to 72 T, but their use is limited to research laboratories.

Magnetic Levitation

The so-called "MagLev" trains such as the Yamanashi train have been under development in Japan for the past two decades. The train levitates above a track using superconducting magnets, with the advantage of eliminating friction. This allowed to reach very high speeds up to 552 Km/h (April 14, 1999).

The Yamanashi MLX01 test line in Japan is 19 Km long.

Conventional MRI System

Medical Imaging

Magnetic Resonance Imaging (MRI) has been up to now the most successful application of superconductors. This medical imaging technique provides very precise diagnostics with high spatial resolution (without any surgical intervention on the patient). 2 T systems are presently installed worldwide and progress is going on: an operational full body MRI system reaching 7 T has recently been setup.

High Resolution Spectroscopy

Similar to MRI, Nuclear Magnetic Resonance spectroscopy (NMR) is probably the most common technique used to determine detailed molecular structures in chemical industry and in biotechnology, as for example genetic material (DNA and RNA) and other complex molecules used to develop new drugs. With the advent of molecular biology the demand for spectrometers with increasingly high resolution would not be satisfied without superconducting magnets.

NMR Magnet 900 MHz, 21 T

Ship Propulsion Motor

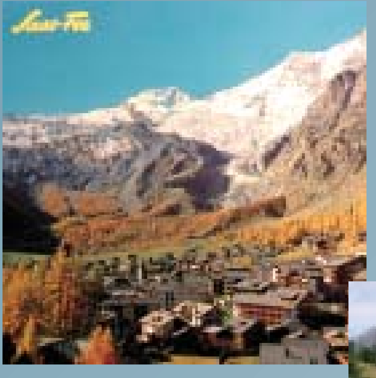
The American Superconductors Corporation (www.amsuper.com) is developing 5MW ship propulsion motors using high temperature superconductors (under test summer 2003). This technology presents the following advantages: inherently quieter motors, 25% of the volume of a standard motor, lower operating cost, 30% of the weight, equivalent prices and higher net efficiency.

5MW Rotor Assembly with Exciter (Courtesy of American Superconductors)

Events

For your Diaries !

Year 2004 will soon be upon us and we are taking this opportunity to announce two events.



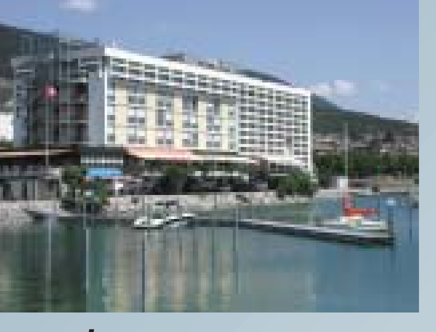
Summer School 2004
Saas Fee - September 6-11, 2004.

MaNEP will organize a Summer School on the Physics of Materials of Novel Electronic Properties. The event will take place at the "Kultur- und Kurszentrum Steinmatte" in Saas Fee which has a very pleasant half-moon shaped lecture room. This will undoubtedly be an ideal environment for MaNEP junior scientists to enter the field .

Registration and further information will be available beginning of 2004 on the MaNEP website.

Topical Meeting 2004
Neuchâtel - February 6th, 2004.

The 3rd MaNEP Topical Meeting will take place in Neuchâtel and be on Spectroscopy of Materials with Novel Electronic Properties. This one day meeting will allow MaNEP scientists involved in the field to present and discuss their most recent results.

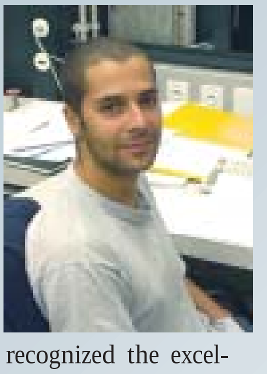


Scientific Awards

Congratulations !

We have great pleasure in announcing two new awards received recently within the MaNEP scientific community.

Giorgio Margaritondo is the recipient of the 2003 SKORE-A (Swiss-Korean Outstanding Research Efforts Award) - jointly with Professor Jung Ho Je of the Postech Institute of Science and Technology (POSTECH) - for a longstanding collaboration on «Coherent X-ray Imaging in Medicine and Materials Science». The prize was presented at a ceremony in Bern by State Secretary Charles Kleiber for Switzerland and Professor Ho-Koon Park, Korean minister for Science and Technology. In the framework of this collaboration, a Swiss-Korean-Taiwanese beamline was recently inaugurated at the Pohang synchrotron source. This facility is now open to all MaNEP members.



Luca Perfetti was selected by the EPFL as the recipient of the 2002 prize for the best PhD thesis. The award ceremony will take place during the «Journée de la Science» on November 28, 2003. This prestigious prize recognized the excellent level of Perfetti's work on photoemission spectroscopy of highly correlated systems, entitled «Angle-resolved Electron Spectroscopy of Strongly Correlated Electron-Phonon Systems». This research discovered several unexpected properties of low-dimensional solids by using photoemission spectroscopy at high resolution and an innovative theoretical analysis. Photoelectron spectroscopy of strongly correlated systems has been since the beginning an important component of MaNEP.

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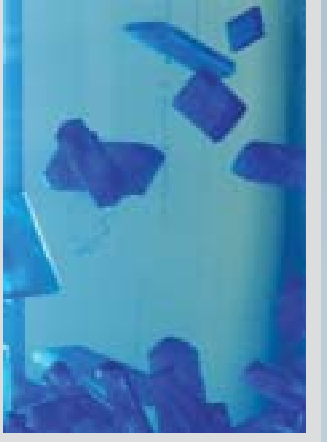
Cover Picture



Micrograph of copper tartrate crystals grown by diffusion in sodium silica gel.

H. Berger et al., EPF Lausanne, Switzerland.

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