MaNEP Newsletter

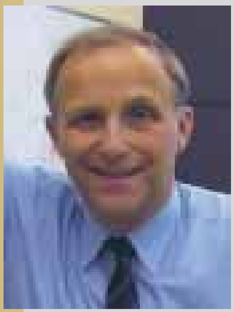
Materials with Novel Electronic Properties

Contents :

No. 3, Fall 2002

MaNEP is a National Centre of Competence in Research (NCCR) with the University of Geneva as Home Institution
The NCCR are managed by the Swiss National Science Foundation on behalf of the Federal Authorities

Message of the Director



After one full year of operation MaNEP has been put on firm ground and on September 10 an official inauguration took place, with the participation of Martine Brunschwig Graf, State Councillor for Public Education in Canton of Geneva, Heidi Diggelmann, President of the National Research Council of the Swiss National Science Foundation and Maurice Bourquin, rector of the University of Geneva. We also used this opportunity to organise open days for high school children in Geneva and an open day for the broader public. For both events a large number of participants turned up. It was rewarding to observe the enthusiasm of the participants and especially that of the younger participants. This encourages us to continue our commitment to education, training and communication. In this context I would also like to mention the Wright Colloquium 2002 « Entering the Nano-World » organised on November 18-22, 2002 by the H. Dudley Wright Foundation, on a topic close to the scientific interest of MaNEP.

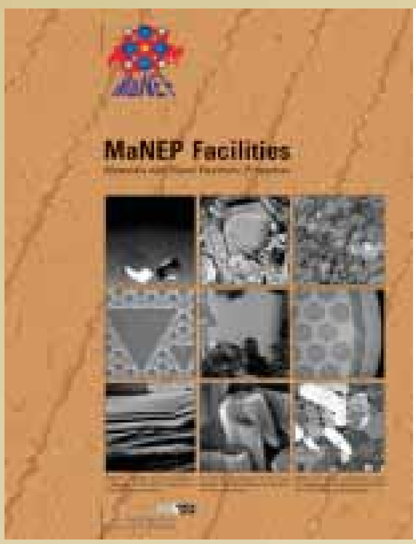
The main theme of this issue is Scanning Probe Microscopy, with one article for non-specialists and a scientific article by Dr. Morten Eskildsen on how this technique can be used to study the new superconductor MgB_2. We also continue our presentation of MaNEP groups, this time from ETHZ, EPFL, UNIGE and BRUKER Biospin. MaNEP is dedicated to make its contribution to Knowledge and Technology transfer. As a part of our effort in this field we present here our new catalogue of MaNEP facilities, which shall be useful both to enhance the synergies between the MaNEP groups as well as an instrument for our communication with our external partners. A special thanks to Dr. Olivier Kuffer and Dr. Martin Kugler who are the persons behind this catalogue.

Øystein Fischer

Knowledge & Technology Transfer

New catalogue of «MaNEP Facilities»: A collaboration catalyst

Since the beginning of MaNEP, a strong research effort has started within the network. The objectives are to reach a fundamental understanding of the properties of novel materials and to prepare the ground for future applications. MaNEP benefits not only from the know-how and the competencies of the scientists involved, but also from the different techniques and apparatus available. Taking advantage of this unique network will undoubtedly contribute to build MaNEPs strength.



In that context our knowledge and technology transfer strategy is to initiate the dialogue and to stimulate new collaborations on two levels: within MaNEP and with Swiss industry. Indeed, we believe that the complementarity of the labs participating in MaNEP holds a tremendous potential for innovative approaches based on direct collaborations. On another hand we set up an information network gathering private companies having interest in our research activities, which can also lead to fruitful collaborations.

The classical communications tools, such as meetings, websites and newsletters are very useful to activate networking. We however went one step further and created a reference document, the **MaNEP Facilities** catalogue, that will be published beginning of 2003. It contains: a directory of the materials synthesized within MaNEP; a description of all experimental devices; and a summary of the theoretical competencies. The information is presented in brief files, including keywords, specifications, present use and the address of a contact person. The catalogue will be available to all the members of the research and the industrial networks.

Gathering a unique diversity of high technologies and a huge horizon of expertise, our objective is that the document becomes not only a collaboration catalyst, but also MaNEPs business card.

We would like to thank all MaNEP members who helped us collecting the content of this catalogue. If you want to obtain more information, feel free to contact Dr. O. Kuffer or Dr. M. Kugler, MaNEP Knowledge and Technology Transfer.

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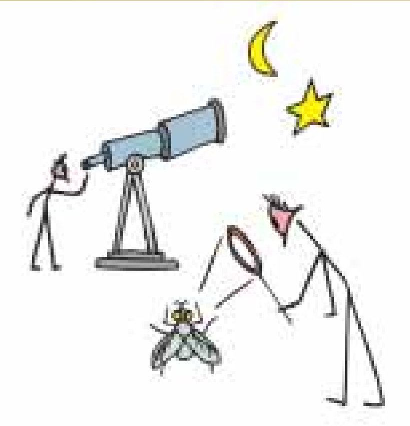
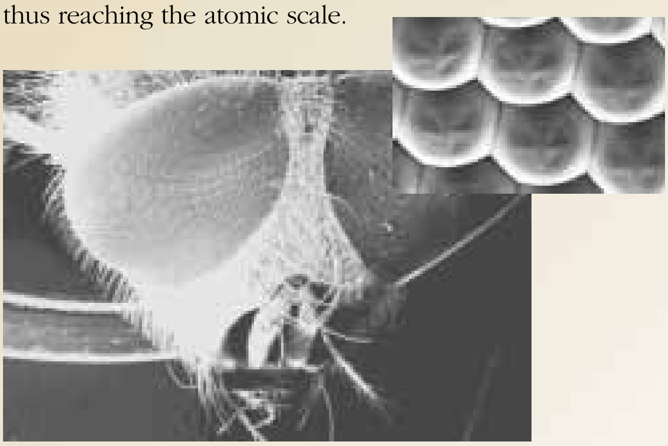
Scanning Probe Microscopy

Over the centuries mankind has always been attracted by the observation of the infinitely distant and the infinitesimal small. Inventing the **magnifying glass** (XV[th] century) and later the **optical microscope** (XVII[th] cent.), a hidden and fascinating world became visible: the matter at small scales. In classical microscopy the resolution is however limited to the wavelength of the radiation: about half a micrometer for visible light. This frontier further challenged the human inventiveness...



After the discovery of wave mechanics in 1923 by L. de Broglie, it appeared that the particles constituting matter – electrons, neutrons, protons – actually behave like waves. With this insight, E. Ruska and M. Knoll replaced in 1932 the light source of an optical microscope by an electron source. The **electron microscope** was invented. An electron beam is scanned over the surface and the image is constructed from the detection of the diffused electrons.

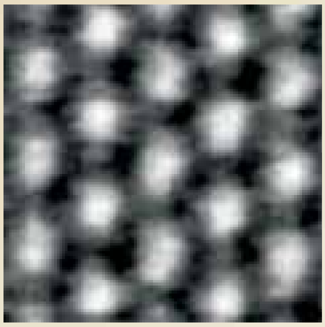
Since electrons have a wavelength 3-5 orders of magnitude smaller than visible light, the surface of an object can be imaged with much more details. Today it is a very powerful laboratory instrument used in various fields such as biology, material science, microelectronics and physics. The most sophisticated instruments have a resolution of about 0.2 nanometers (one nanometer [nm] = one millionth of a millimeter) thus reaching the atomic scale.



Electron microscope images of the eye of a fly. One single eye facet is about 3 microns in diameter.

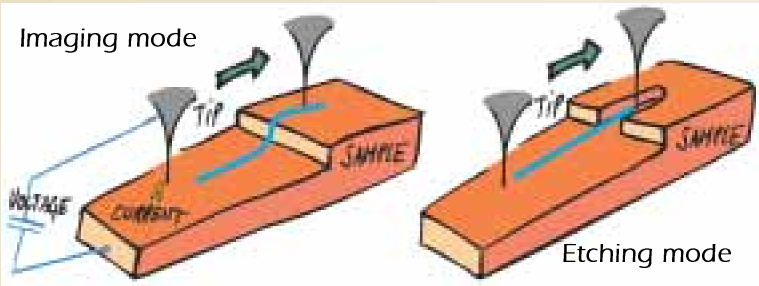
In 1981, G. Binnig and H. Rohrer from IBM research laboratory in Rüschlikon invented a new type of imaging instrument, **the scanning tunneling microscope** (STM). It is nowadays a widespread surface science technique owing its popularity to the wide range of possible applications, a simple concept, and the ability to obtain a direct real space image of conducting surfaces. Its most striking feature is the extremely high spatial resolution of the order of 0.01 nanometer that can be achieved, allowing to image and even to manipulate individual atoms.

The main difference between this technique and the ones mentioned above is that there is no need for any lenses, light or electron sources.



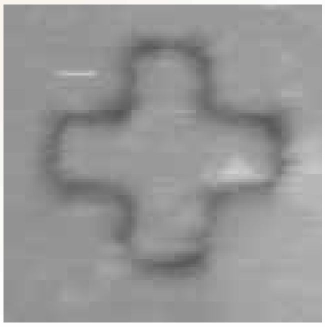
STM image, one nanometer wide, showing the regular arrangement of carbon atoms at the surface of graphite.

It is the tunnel effect, a quantum mechanical property, that provides the physical foundation for this technique. All you need is to apply a small voltage between a sharp metallic tip and the investigated surface, both separated by a vacuum barrier (see left sketch below). If this barrier is about a few atomic diameters thick, electrons are able to “tunnel” through it and a current will flow. Controlling this tunneling current is the difficult challenge achieved by G. Binnig and H. Rohrer and rewarded with the Nobel Prize in 1986. The current depends exponentially on the barrier distance. Hence, by scanning the tip over the surface at a constant current or barrier distance, the record of the vertical tip motion will reflect the surface topography. Moreover, this instrument can be used as a spectroscopic tool, allowing to investigate the electron distribution in a conducting material. This powerful mode called scanning tunneling spectroscopy can for example differentiate a normal from a superconducting region within a sample, as demonstrated in the scientific article of this newsletter.



In summary, the STM provides an eye and a nose at the nanometer level, and this is not all of it !

In the example shown on the right sketch, the instrument can in appropriate conditions be used to modify or etch matter. Indeed, the last figure demonstrates that the STM can be used as a nanomechanical shovel !



The smallest Swiss cross of the World is 25 nm wide and has been manufactured by etching trenches into a surface of a superconductor by STM (A. Takagi, PhD thesis, Geneva).

The success of this technique rapidly gave birth to a large family of instruments generally referred to as **scanning probe microscopes**. Each member of the family uses a different type of interaction between the probing tip and the sample. The most popular ones are the STM, the **atomic force microscope** (see group of Prof. J.-M. Triscone on next page) and the **scanning near-field optical microscope**.

Growth, Characterization and Physical Properties of Unconventional Metals and Oxides

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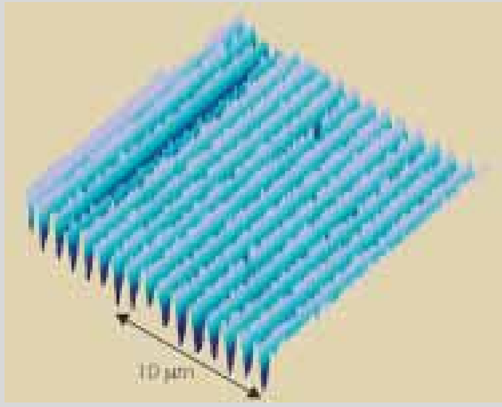
The group's research focuses on a range of unconventional metals and correlated oxide systems, including dielectric and ferroelectric insulators, ferromagnetic metals and superconductors. The materials are fabricated as single crystals, epitaxial thin films, and heterostructures, and studied using standard transport, local probe and high pressure techniques.

Atomic force microscopy is used to study domain wall motion in epitaxial ferroelectric thin films, and explore possible applications, including non-volatile memories and ultra high frequency surface acoustic wave filters. Heterostructures alternating ferroelectric layers with superconducting or metallic oxides are used for local field effect experiments exploiting the non-volatile ferroelectric polarization field, while ferroelectric/dielectric structures with controlled periodicity allow new "designer" materials with tailored properties to be fabricated. A diamond anvil cell technique is used to study epitaxial oxide thin films at very high hydrostatic pressures. The electronic properties of heavy fermion systems close to phase transitions are tuned and studied using high pressure techniques.



GHz surface acoustic wave filter written with atomic force microscopy.

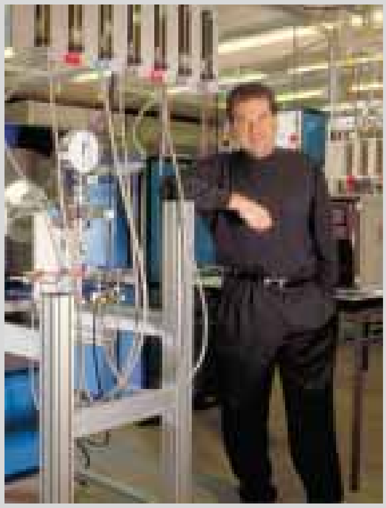
References:

[1] T. Tybell et al., Phys. Rev. Lett. 89, 097601 (2002).
[2] S. Gariglio et al., Phys. Rev. Lett. 88, 067002 (2002).
[3] F. Le Marrec et al., Appl. Phys. Lett. 80, 2338 (2002).
[4] D. Jaccard et al., Phys. Letters A299, 282 (2002).

Growing Unique Crystals for Research

H. Berger and Prof. G. Margaritondo – http://ipmc.epfl.ch
IPMC - Faculté des sciences de base, EPFL, CH-1015 Lausanne

The laboratory for crystal growth in Lausanne plays a very special role within MANEP. It produces a wide variety of high-quality single crystals that are used for research programs by groups throughout the world, including several MANEP members. In many cases, the laboratory is the only available supplier of the material, and as such its products are in very high demand.



For information, helmuth.berger@epfl.ch.

The growth of high-quality single crystals is a sophisticated scientific enterprise with some magic-touch overtones. The head of the laboratory, Helmuth Berger, has worked for more than 30 years in this highly specialized domain that supports the research activities of many of his colleagues. The best known specialty of the laboratory is the growth of low-dimensional crystals. The most famous at present are of course layered high-temperature superconductors. The laboratory grows a variety of materials in this family, including pure and doped BCSCO with a variety of dopants such as Pb, Pr, Dy, Y etc., as well as YBCO-based specimens. The production of layered crystals goes well beyond high-temperature superconductors and includes many other families such as II-V compounds, chalcogenides, iodides, chlorides and organic materials. Quasi-one-dimensional crystals are also widely produced, including transition metal selenides or sulphides. The quality of such crystals is so high that they can be used for the most demanding experiments, such as studies of non-Fermi-liquid behavior by high-resolution photoemission. Although famous worldwide for its low-dimensional crystals, the laboratory also produces other types of specimens. For example, it was recently able to obtain unique crystals of transition metal oxides (anatase) as well as very large high-quality single crystals of fullerenes.

These examples cover a small part of the production. The laboratory continuously explores the growth of novel materials, and new results are obtained almost every week. In many cases, the new growth projects are performed in collaboration with future users and respond to their specific requirements. Quite often, on the other hand, the laboratory produces novel materials on its own, opening new avenues for research. The stock of materials includes several hundreds different compounds, and constitutes a precious resource which is made available on demand to researchers throughout Europe and beyond.

Superconducting Wires for High Field NMR Applications

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The world-wide family of Bruker companies sells different kinds of analytical instruments covering a wide range from X-Ray, infrared or mass spectroscopy to magnetic resonance imaging or electron paramagnetic resonance. Being the largest of the Bruker companies, Bruker BioSpin AG in Fällanden, ZH, produces Nuclear Magnetic Resonance (NMR) systems as they have been used for chemical and molecular structure analysis for over forty years. Recently, NMR systems became powerful enough for the investigation of biomolecules with hundreds or even thousands of atoms. This opened NMR methods to Life Science applications and it was a great pleasure for us to see that this year's Nobel Prize winner for chemistry, Prof. Kurt Wüthrich, was awarded "for his development of nuclear magnetic resonance spectroscopy for determining the three-dimensional structure of biological macromolecules in solution".

50th 16.4 Tesla NMR magnet (700 MHz) celebrated at Fällanden in October 2002

In order to achieve the enormous sensitivity of NMR experiments, the various parts of the spectrometer have to meet the highest standards. Not only the electronic components, e.g., RF amplifiers, receivers and digital filters must be carefully designed but also the high performance superconducting magnet is a key part of the NMR system. These magnets produce a magnetic field with excellent spatial homogeneity and ultra high stability. Such extreme performance can only be reached using high quality superconducting wires in combination with an advanced magnet design.
Currently, the maximum achieved field is mainly limited by material factors as, for instance, the critical current. Therefore, the development of a new generation of high field superconducting magnets depends strongly on the availability of new wires with improved superconducting and mechanical properties.

Low temperature part of a multipurpose cryostat insert for measurements below 1 K.

Influence of Externally Controlled Parameters on the Properties of Metals with Strong Electron Interactions

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This MaNEP project combines some of the research efforts of the groups of H.R. Ott and Leo Degiorgi. The activities of these groups are based on a broad range of experimental techniques, probing transport, thermal- and microscopic properties of materials of interest, including superconductors, unusual magnetic materials, materials close to a metal/insulator transition, as well as low dimensional systems with spin- and charge degrees of freedom.
At present, the main efforts are devoted to studies of the influence of external magnetic fields and pressure on some properties of hexaboride compounds and to measurements of transport and magnetic properties of low dimensional systems. Surprising magnetotransport properties and related unusal scaling features have recently been discovered in $Eu_{1-x}Ca_xB_6$ compounds and their relevance with regard to spin dependent electronic transport (spintronics), a research area of high current interest, is now explored in more detail. The link to theoretical activities within MaNEP is particularly strong in studies of transport and magnetic properties of low dimensional spin systems where recent experimental results indicate a very effective transport of energy via spin excitations in spin chains and -ladders, as well as quantum critical behaviour of other selected spin systems.

References:

[1] A.V. Sologubenko et al., Phys. Rev. B 64, 054412 (2001).
[2] S. Broderick et al., Phys. Rev. B 65, 121102(R) (2002).

Scientific Article

Vortex Imaging in Magnesium Diboride

Morten Ring Eskildsen, University of Geneva, Switzerland

Research Group

UNIVERSITÉ DE GENÈVE

The main interest of the group of Prof. Ø. Fischer at University of Geneva is the study of the electronic properties of materials characterised by strong interactions between the conduction electrons.

Examples of materials are superconductors, in particular high temperature superconductors, magnetic materials and in general low dimensional materials.

The main focus of the group is to understand the basic properties of such systems. However, many of these materials are also potentially interesting for various applications and within the group we also address some of these aspects.

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The discovery of superconductivity in magnesium diboride (MgB_2) with a critical temperature of 39 K has created a lot of interest [1].

In addition to the high T_c, this material has turned out to be very interesting from a fundamental point of view, since it is the first clear example of a two-band/two-gap superconductor. Using scanning tunneling spectroscopy (STS) we have performed the first vortex lattice imaging in MgB_2 [2].

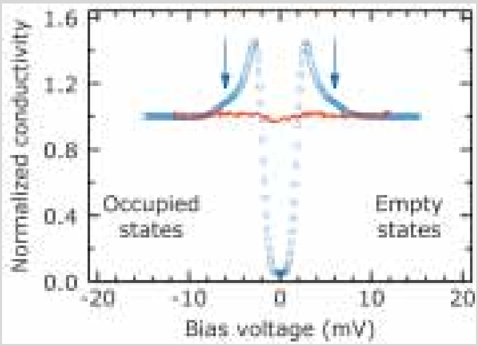

Fig. 1. Differential conductance spectra, tunneling parallel to the *c*-axis of MgB_2 at 2 K. The superconducting spetrum (blue) was measured in zero magnetic field, and the normal spectrum (red) was measured in the center of a vortex.

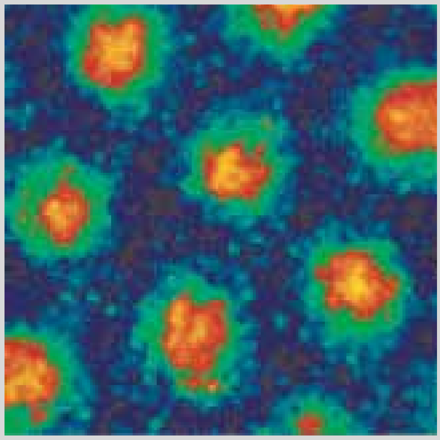

Fig. 2. Spectroscopic image 250 x 250 nm of the hexagonal vortex lattice in MgB_2 for 0.2 T.

Introduction

One of the characteristics of superconductivity is the opening of a gap in the electronic spectrum at the Fermi surface, which can e.g. be measured by tunneling spectroscopy. We have used a scanning tunneling microscope (STM), which is capable of measuring the spectrum on a local scale with atomic precision. Hence, in addition to measuring the superconducting spectrum, the STM is capable of imaging spatial modulations of the superconducting state. Such a modulation can for instance be induced by an applied magnetic field, which in a type-II superconductor such as MgB_2 will introduce vortices consisting of a normal core surrounded by circulating supercurrents, and threaded by a magnetic flux totalling one flux quantum $\phi_0 = h/2e$.

Results

Before going into details it is important to stress that a prerequisite for the results shown here, is the availability of highly homogenous samples. Such single crystals of MgB_2 has recently become available within the MaNEP network, from the group of Janusz Karpinski at ETH in Zürich.
Fig. 1 shows (in blue) a superconducting spectrum with clear coherence peaks at ±3 mV. The measurements were performed, tunneling parallel to the crystalline *c*-axis. In this configuration the spectrum contains essentially only contributions from one of the two band (π-band), with only a small admixture of the second band (σ-band) showing up as a shoulder at ±6 mV indicated by the arrows. Shown by red in Fig. 1, is a spectrum recorded in the so-called normal region at the centre of a vortex. Here the differential conductance is constant, meaning a perfect ohmic behaviour.

It is clear that the spectra at respectively the bulk of the superconductor and in the vortex cores are very different, and measuring the conductance at zero bias voltage one is able to distinguish between the two. In Fig. 2, we show a spectroscopic image, obtained by measuring the zero bias conductance as a function of position after application of a magnetic field of 0.2 T. This shows a hexagonal vortex lattice.

Summary and outlook

In addition to the vortex lattice imaging shown here, additional interesting results were obtained and reported in ref. [2]. We have now started measurements tunneling parallel to the basal plane, in which case both superconducting gaps are observed. Other work on MgB_2 within the MaNEP network is reported in refs. [3-6].

References

[1] J. Nagamatsu *et al.*, Nature 410, 63 (2001).
[2] M. R. Eskildsen *et al.*, Phys. Rev. Lett. 89, 187003 (2002).
[3] M. Angst *et al.*, Phys. Rev. Lett. 88, 167004 (2002).
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[5] A. Perucci *et al.*, Phys. Rev. Lett. 89, 097001 (2002).
[6] F. Bouquet *et al.*, Phys. Rev. Lett. 89, 257001 (2002).

A basic introduction on scanning probe microscopy is given at the beginning of the Newsletter.

TO PLAY DOMINOES WITH MOLECULES

Would it be possible to develop a computing process based on the motion of molecules rather than a flow of electrons? A group of the IBM's Almaden Research Centre in the USA, has shown that the answer might be YES.

The scientists have first arranged carbon dioxide molecules in atomic precise configurations using the tip of a scanning tunnelling microscope. They have then propagated information by tossing a single molecule with the tip. Like a row of toppling dominoes, the molecules trigger a cascade along a defined path. Would playing dominoes with molecules be of any use? Manipulating these arrangements of molecules, it has been possible to achieve complex functionalities, like a multiple-input sorter, by combining logical gates as well as the crossover and fan-out units needed to connect them. Compared to the same sorter designed with cutting edge CMOS 9S technology, the molecular cascade implementation requires an area 260'000 times smaller. Even if CMOS densities were to continue to double every 2.5 years, it would take 45 years to shrink to the size of the molecular cascade device. "Although very slow, this new device is truly nanoscopic.", says J.-M. Triscone, deputy director of MaNEP, who adds "Even if this approach is finally not used, it illustrates the imagination of the scientists and the fantastic potential of molecular manipulations and nanosciences in general. Presented by Don Eigler at the Wright Colloquium in Geneva in November, this fascinating research got an immense popular success".

Reference:

A. J. Heinrich et al., Science **298** (2002), 1381.

A QUANTUM NOT GATE

In today's computers, the information is stored by "bits" having two possible states, 0 or 1. The quantum computer is a distant dream based on "qubits" (the quantum analogues of the classical bits) which promises a richer set of states, hence opening new ways to boost processing power. Based on the rules of quantum mechanics, the qubit could be, for example, simultaneously in the 0 and 1 states, as a consequence of the principle of superposition. But there is a snag: simple logical operations are prohibited by the quantum rules.

Therefore, through a Slovak, Italian and Irish collaboration, the recent achievement of an optimal quantum universal NOT gate constitutes a milestone in quantum information. This operation which, for a classical computer, is a simple inversion, requires, for the quantum case, a complex experimental set-up including a mode-locked pulsed laser with time resolution of the order of 0.1 picoseconds. Nevertheless, this result is considered as a major progress in the field. "This experimental realisation, as well as its cousin, the optimal quantum cloner, pushes quantum information processing with photons to its fundamental limits", says M. P. Samuelsson, senior scientist of the MaNEP research network.

Reference:

F. De Martini et al., Nature **419** (2002), 815.

NANOTUBE X-RAY SOURCE

X-ray sources could soon be smaller and cooler thanks to carbon nanotubes. A team from North Carolina, USA, has demonstrated that X-ray generators could be made of carbon nanotubes [1].

This discovery could significantly modify the design of X-ray tubes which have not changed much in a hundred years: a metal filament (cathode) is heated over a thousand degrees Celsius to emit electrons which are accelerated to a metal target (anode) where they produce X-rays. In the new design, the cathode is covered with nanotubes pointing toward the anode. Electron field emission occurs at room temperature when a high voltage is applied between the two electrodes. The resulting flux of X-rays is sufficient for practical medical imaging (see figure). The new device could be made much smaller than classical X-ray tubes. Operated in continuous or pulsed mode it produces more focused X-rays and has a sharper time response. P. Gröning, from the University of Fribourg, points out that "the lifetime of carbon nanotubes based field emitters is an issue: many problems remain to be solved". This aspect has been discussed by the MaNEP group of Fribourg in a recent publication [2].

X-ray images of a fish and a humaniod hand taken using Polaroid™ films placed behind the objects which were 30cm away from the nanotube x-ray source. Detailed bone structures are clearly resolved [1].

Reference:

[1] G. Z. Yue et al., Applied Physics Letters **81** (2002), 355.
[2] O. Gröning et al., Chimia **56** (2002), 553.

Events

MaNEP Inauguration

On september 10th 2002 MaNEP celebrated its inauguration after 14 months of existence. The event took place at the leading house, the Department of Condensed Matter Physics (DPMC) of the University of Geneva. Local and federal authorities were invited in presence of MaNEPs community.

Mr. Maurice Bourquin, Rector of the University warmly welcomed the audience before giving the floor to MaNEPs director, Mr. Øystein Fischer, who presented an overview of the programme and spoke about its general goals. The public then had the opportunity to hear contributions from Mr. Gregor Haefliger, Head of the National Research Institutions of the Federal Office for Education and Science, from Mrs. Heidi Diggelmann President of the National Research Council of the Swiss National Science Foundation, and from Mrs. Martine Brunschwig Graf, State Councillor for Public Education of the Canton of Geneva.

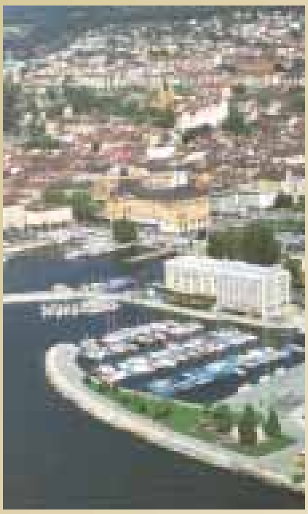
The participants also heard a scientific presentation from Miss Céline Lichtensteiger, PhD student at the University of Geneva. The last contribution was from Mr. Malcolm R. Beasley, Professor at Stanford University USA, and current director of the Center for Materials Research at Stanford.

The event allowed the community of MaNEP to present its research activities with a special effort to make science accessible to the general public. For this purpose, MaNEP produced a short educational film «Voyage en classe perovskite». The audience had the privilege of viewing the premier. Furthermore, a dozen scientific demonstrations were specifically prepared for this event and presented by enthusiastic young researchers.

These efforts were particularly rewarding during the open house days which followed the inauguration. During these 3 days, the DPMC had about 40 high school classes and over 500 Geneva citizens visiting the labs. They showed a great interest in solid state physics, and were especially impressed by the magic demonstration in which a superconducting train is levitating above a magnetic rail.

These days were a great success thanks to all the people involved in the organisation and in particular thanks to the help of the «Passerelle Science-Cité».

To discover the photo album of these events or to download more information, please visit **www.manep.ch**



Topical Meeting, February 10th 2003

MaNEP will have its first Topical Meeting on Non-Fermi Liquids and Low Dimensional Systems at Hotel Beaulac in Neuchâtel. This one day meeting will allow MaNEP scientists to debate on their most recent results.

The workshop will be opened by Prof. T. Giamarchi from the University of Geneva, who recently joined MaNEP as a Project Leader. Ten contributed talks will follow with extralong time for discussions.

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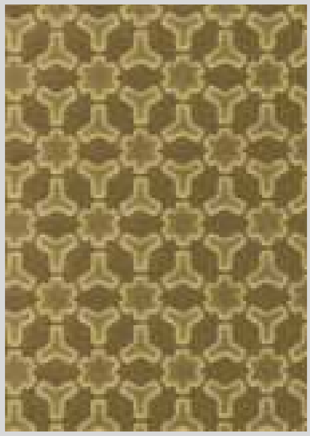
Cover Picture



Scanning Electron Microscope image of an array of SNS Josephson junctions on a dice lattice.

P. Martinoli et al., University of Neuchâtel, Switzerland.

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