MaNEP SWITZERLAND

Newsletter of the National Centre of Competence in Research - Materials with Novel Electronic Properties

Editorial

After almost three years of activity MaNEP research is progressing as recently shown through the impressive poster session at the Swiss Physical Society Meeting in Neuchâtel.

Spring heralds new beginnings and this year we are proud to present our new logo and newsletter. Research is our main activity, but we are also focussing our efforts towards communication with the aim of promoting research and enhancing MaNEP visibility and identity. Sharing MaNEP's research fields with the general public is an important challenge.

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Ferroelectricity and its applications

Ferroelectric materials possess unique properties such as pyroelectricity and piezoelectricity useful for a wide range of technological applications, from non-volatile memories to sensors and actuators [1]. Maintaining the continual rate of miniaturization of such devices presents many challenges, and requires a fundamental understanding of the behaviour of ferroelectrics at nanoscopic scales revealing a fascinating new physics.

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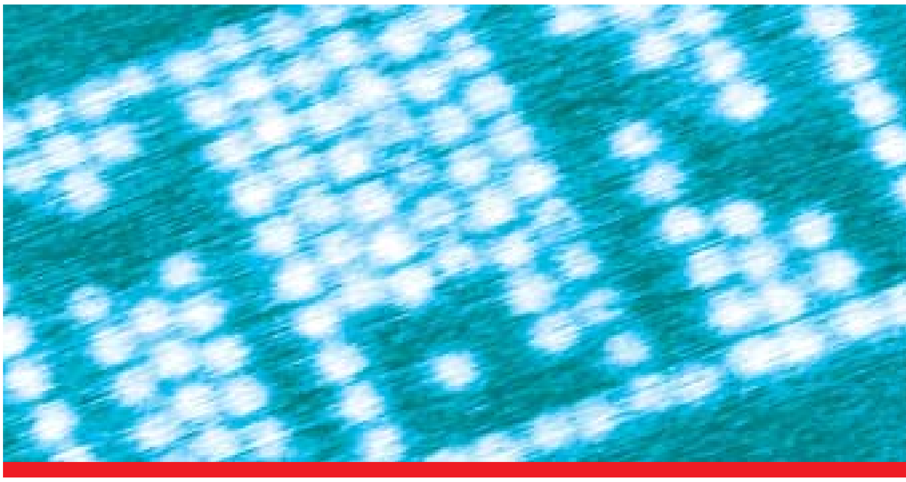

Nr. 6, spring 2004

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MaNEP proposes summer internships opened to young students in physics. These summer tranining courses are made possible thanks to our advancement of women's programme.

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Giorgio Margaritondo was recently nominated Vice-president for Academic Affairs of the Ecole Polytechnique Fédérale de Lausanne (EPFL).

Mid May our colleague Maurice Rice has become Professor emeritus at ETH Zurich, where he has been a faculty member for the last twenty-two years.

Editorial

Prof. Øystein Fischer, Director

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We believe that diffusing scientific knowledge will be an appropriate way of stimulating and interesting future generations of scientists in the field of solid state physics and in particular materials with novel electronic properties. We therefore considerably developed our website recently: a new section has been created where specific subjects are described with educational and interacting illustrations. We thus intend to highlight some of our fundamental and applied research progress in the framework of today's technology.

In this issue, we present and discuss the latest results obtained by Prof. Jean-Marc Triscone in the field of ferroelectric materials. These materials already have an increasing impact in the developement of novel electronic devices and we present some of the main perspectives.

I finally take the opportunity to acknowledge Giorgio Maragritondo and Maurice Rice for their past and future contributions at the forefront of research. ■

With my best wishes
for a fruitful summer

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MaNEP News ... MaNEP News ...

Women in Physics

2004 Summer Internships

This year MaNEP offers to female students in the third or fourth year of their physics studies the possibility to spend one month within a MaNEP research team. These internships will be organised with financial support between July and September 2004.

It has been shown worldwide that the number of women working in the field of physics research seems to be limited due to barriers in their career paths. Barriers among those mentionned include the difficulty of balancing private life with a scientific career and and also a certain self-confidence lack in their real scientific possibilities. The aim of these internships is to help the women to build the necessary self-confidence to have an equal chance to make a scientific career.

Although it is very important to encourage to study physics early in the academic system, the internships proposed within the advancement of women programme of MaNEP will hopefully help the candidates in progressing their careers and stimulate their professional development. ■

More details on...
www.manep.ch/en/nccr/aow.html

EMPA working with SONY

Scientific success leads to further cooperation

The "nanotech@surfaces" Laboratory at EMPA has established a worldwide reputation over the past few years as the specialists in the field of electron emission from carbon nanostructures (more on page 5). The lab's success in this area has recently resulted in a cooperative project with Sony Display Technology (Japan), in which EMPA will offer support to the world's largest manufacturer of consumer electronics in the development of field emission flat displays. An EMPA staff member will remain on site in Japan for several months to facilitate the knowledge transfer process. ■

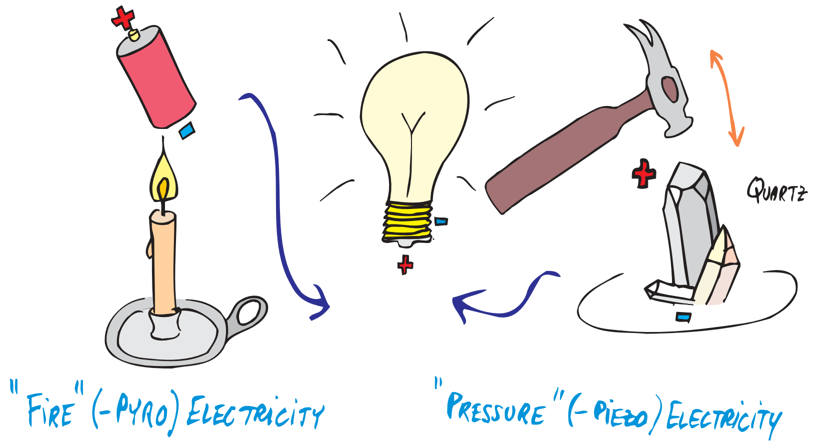
From Rochelle salt to PZT

Edison with cylinder phonograph, one the first application of piezoelectric materials (end of 19th century). Source Edison National Historic Site.

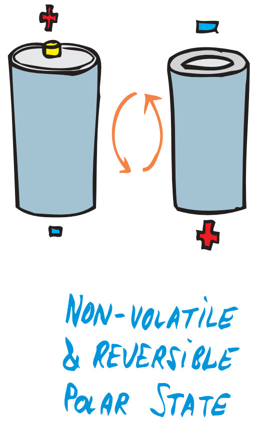
Ferroelectricity was discovered in the beginning of the century by J. Valasek in Rochelle salt (potasium sodium tartrate) which was originally produced in France in 1665 by an apothecary Pierre Seignette. Rochelle salt was originally used in medicine as a mild purgative. Crystals of Rochelle salt were easily grown and were subsequently used in piezoelectric devices such as crystal microphones and phonograph pickup cartridges. Historically, ferroelectricity was discovered after piezoelectricity and pyroelectricity, two related polar properties exhibited by ferroelectric materials (see definitions below). It is only in 1945 that the first ferroelectric material with a perovskite structure, the ceramic $BaTiO_3$ (barium titanate), was found by B. Wul and I. M. Goldman. This discovery triggered considerable efforts in search of additional ferroelectrics having the same structure. A significant progress in applications was made possible after the discovery of lead zirconate titanate - $Pb(Zr,Ti)O_3$ or PZT - with a very strong piezoelectric response, and a large remanent ferroelectric polarization. Lead-based materials have since become the dominant compounds in this field. ■

? *Pyroelectricity*

? *Piezoelectricity*



? *Ferroelectricity*



Pyroelectricty was probably first observed in tourmaline by ancient Greeks, but quantitatively investigated only in the eighteenth century, during the early studies of electrostatics. Sir David Brewster, a Scottish scientist, was the first to use the term pyro (fire) electricity in 1824 when describing this phenomena in one of his numerous and famous contributions to the Encyclopaedia Britannica. Pyroelectric materials have a spontaneous polarization whose amplitude changes under the influence of temperature gradients. The discovery of PZT triggered many applications based on this phenomenon, such as infrared detection, thermal imaging (absorption of energy resulting in polarization changes) and dielectric bolometers. ■

Piezoelectricity was discovered later, around 1880, by Pierre and Jacques Curie who were the first to demonstrate the generation of electricity (surface charges) on well prepared crystals of quartz as a result of mechanical pressure. Inversely, when a voltage is applied across a piezoelectric material, it can undergo a mechanical distortion in response. The beginning of the twentieth century gave birth to most of the classic applications of piezoelectrics, such as quartz resonators, accelerometers and those already mentioned above. After world war II and following the discovery of PZT, the advances made in material science allowed the development of numerous applications based on tailored piezoelectric properties. ■

All ferroelectrics are piezoelectric and pyroelectric, but they additionally possess a reversible, non-volatile macroscopic spontaneous electric dipole moment in the absence of an external electric field. In simple, words ferroelectric crystals can be seen as an assembly of batteries with a particular orientation, which remains stable unless an external electric field is applied to change its direction. Their polar state is a consequence of the structural transition from a high-temperature, high-symmetry paraelectric phase to a low-temperature, low-symmetry ferroelectric phase. These materials also behave as high dielectric-constant insulators useful in the developement of capacitors and energy storage materials. ■

MaNEP SWITZERLAND

Probing microscopic properties of materials with novel electronics properties with muons

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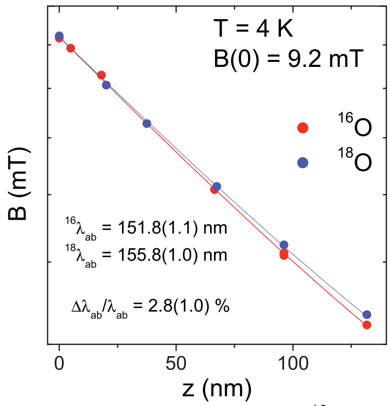
The research interest of the group of Prof. Keller is focused on the study of microscopic magnetic properties and oxygen isotope effects of high-temperature superconductors and related materials by various complementary experimental techniques such as, SQUID and torque magnetometry, as well as resonance techniques (NMR/ NQR/ EPR/ μSR). Prof. Schilling and his group focus on thermal transport and vortex-related phases in type-II superconductors.

The novel low-energy μSR method developed by PD Dr Morenzoni and coworkers at PSI is a main tool in the research field of the group. Low-energy muons of tuneable energy can be implanted at a controllable (10-200nm) depth beneath the surface of the sample. This allows to study directly the distribution of local magnetic fields in thin samples, multi-layers, near surfaces, and as a function of depth below surfaces. At present PSI is the only place in the world where low-energy μSR experiments can be performed.

Prof. Schilling and his collaborators are currently investigating the contribution of the lattice (or molecule) vibrations to the heat transport in low-dimensional systems. The thermal Hall effect as a reliable probe for the electronic transport of heat, and the thermodynamics of different vortex phases in type-II superconductors are further research topics. ■



Magnetic field penetration profiles for a ^{16}O substituted and a ^{18}O substituted $YBa_2Cu_3O_{7-\delta}$ film measured directly by the low energy muon technique, clearly showing a pronounced isotope effect on the magnetic penetration depth.

References:
R. Khasanov et al., Phys. Rev. Lett. 92, 057602 (2004).
R. Khasanov et al., Phys. Rev. B 68, 220506 (2003).

High-resolution spectroscopies of strongly correlated and low-dimensional materials

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Understanding the electronic origin of macroscopic physical properties is a prerequisite to design new materials tailored to specific applications. In Lausanne, and at synchrotron radiation laboratories worldwide, we investigate the effects of electronic correlations, electron-phonon interactions, and confinement in solids by high energy electron and x-ray spectroscopies.

Angle-resolved photoemission (ARPES) with very high energy resolution gives us a uniquely detailed view of the elementary electronic excitations in low-dimensional metals, high-Tc superconductors, heavy fermions, artificial nanostructures. It also reveals the often subtle changes associated with electronic instabilities, like charge-density-wave or Mott metal-insulator transitions. This powerful approach has instigated similar efforts within MaNEP, and is complementary to other optical, transport and magnetic studies.

We are also involved (at ESRF - Grenoble) in the development of novel spectroscopies like high-resolution photoemission with hard x-rays, and resonant inelastic x-ray scattering (RIXS) which provide truly bulk-sensitive information, namely in materials under high pressure. With J. Mesot (PSI) and in partnership with the Swiss Light Source, we have proposed the ADRESS soft x-ray beamline, which will be one of the most advanced instruments for the spectroscopy of solids. ■

References:
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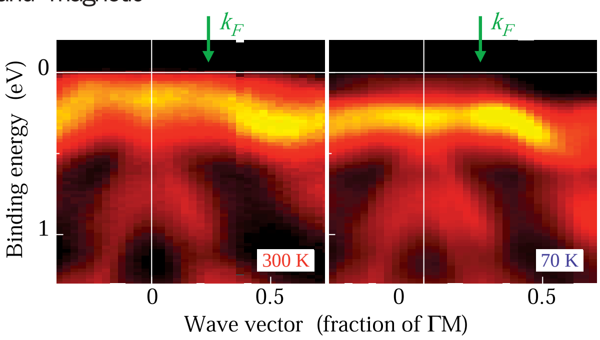
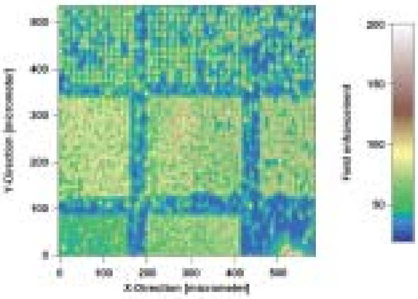
L. Perfetti et al., Phys. Rev. Lett. 90, 166401 (2003).
G. Ghiringhelli et al., Phys. Rev. Lett. 92, 117406 (2004).



ARPES view of the metal-insulator Mott transition in the layered material 1T-$TaSe_2$.

The investigation of the electronic properties and the electron field emission behavior of carbon nanostructures are at the center of our research group. Of particular interests are the influence of point defects on the local electronic structure of sp^2 coordinated carbon and the electron field emission properties of carbon nanotubes (CNT), CNT thin films, and well ordered CNT arrays.



SAFEM field enhancement mapping of regular CNT arrays of different spacing with emitter densities ranging from 100'000'000 cm^{-2} (lower left) to 350'000 cm^{-2} (upper right).

In recent years carbon has attracted much interest as a possible post-silicon electronic material, due to the variety of stable allotropes with completely different electronic properties. In particular, the discovery of the CNT in 1991 has motivated a large number of studies of their electronic and mechanical properties in view of potential applications for electronic devices on the nanometer scale.

Carbon nanostructures and the role of hydrogen for novel electronic materials

The field emission of electrons is regarded as one of the first application of CNT with a major economic impact. The main reason for the success of CNT field emitters can be seen in the relative ease and the low cost approaches to produce planar electron emission cathodes. The performance of a planar field emission cathode will be mainly determined by following four parameters: Cathode emission current density [Acm^{-2}], Emission site density (ESD) [cm^{-2}], applied field for operation [$V\mu m^{-1}$] and temporal stability or life time of the cathode. These parameters are connected by a complex relation between the geometrical structure of the field emission cathode as well as the CNT materials and electrical contact properties to the substrate. Using the homebuilt scanning anode field emission microscope (SAFEM) we are able to investigate all the relevant emission properties down to the micrometer scale in order to gain more insight in the mechanisms determining the performance of the field emission cathode. Currently we are involved in different projects with industrial partners as Thales S.A. (France), SONY Corp. (Japan), and Mapper Lithography (Netherlands) to develop devices based on CNT field emitters. ■

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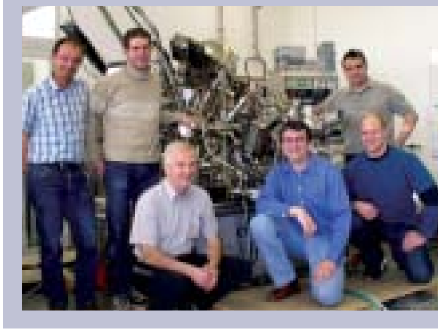

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P. Ruffieux et al., Phys. Rev. Lett. 84, 4910 (2000).
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O. Gröning et al., CHIMIA 56, 553 (2002).
P. Gröning et al., Adv. Eng. Mat. 5, 541 (2003).

Fundamental excitations of strongly correlated matter

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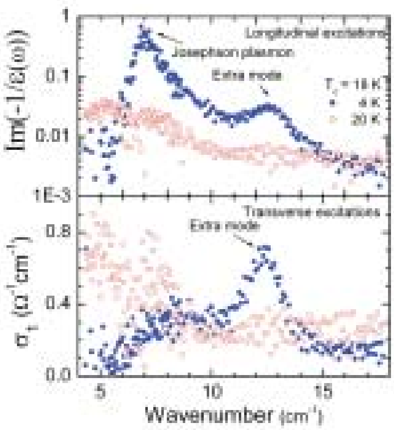

$SmLa_{0.8}Sr_{0.2}CuO_4$ has an alternation of SmO and LaO tunneling barriers between the CuO_2 planes along the c-direction. In addition to the c-axis Josephson plasmon, which has been observed in almost all cuprate materials, two other collective modes appear in the superconducting state. These correspond to the excitons in the superconducting state, which were predicted in 1966 by A.J. Leggett. $SmLa_{1-x}Sr_xCuO_4$ is the first superconductor in which this type of excitons has been observed.

The interest of the group is to explore materials with strongly correlated electrons, and to contribute to the understanding of their properties. We use spectroscopic tools, in particular optical techniques, to probe the excitations from the ground state.

Examples are the investigation and subsequent falsification of the inter-layer tunneling model of high Tc superconductivity, the study of the partial f-sum rule related to the kinetic energy of the valence electrons, the study of quantum critical behaviour, and the prediction and detection of a variety of novel collective modes.

Fourier transform infrared spectroscopy, infrared ellipsometry and ellipsometry in the visible domain are used. These spectrometers are equipped with cryostats of our own design, which is radically different from commercially avaible optical tail designs, and which allows a precise, stable and reproducible positioning of our samples in the temperature range from 4 to 400 Kelvin in a vacuum of 10^{-10} Torr. In addition user facilities in Trieste, at the Paul Scherrer Institute and in Grenoble are used to study the optical absorption in the X-ray region and to perform experiments under intense magnetic field conditions. ■

References:

D. Dulic et al., Phys. Rev. Lett. 86, 4144 (2001).
H. J. A. Molegraaf et al., Science 295, 2239 (2002).

Nanoscale Ferroelectrics

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UNIVERSITÉ DE GENÈVE

The research interests of the group of **Prof. J.-M. Triscone** at the University of Geneva are focused on the growth and study of epitaxial oxide films and heterostructures with unconventional electronic properties. The materials are primarily oxides, in particular superconductors and dielectrics / ferroelectrics.

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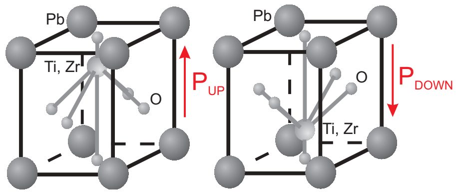
Recently, ferroelectricity in ultra-thin films and superlattice structures has been found far below originally expected length scales, opening up a whole new regime of device characteristics. Concurrently, the integration of ferroelectric oxides in epitaxial heterostructures with magnetic, superconducting or metallic oxides, as well as on silicon, has created the possibility of oxide based electronics. Finally, atomic force microscopy (AFM) allows control of individual ferroelectric domains, providing a practical tool both for fundamental studies and novel applications of nanoscale ferroelectricity. Below, we briefly touch on the main questions in the field today.

How thin can a ferroelectric be?

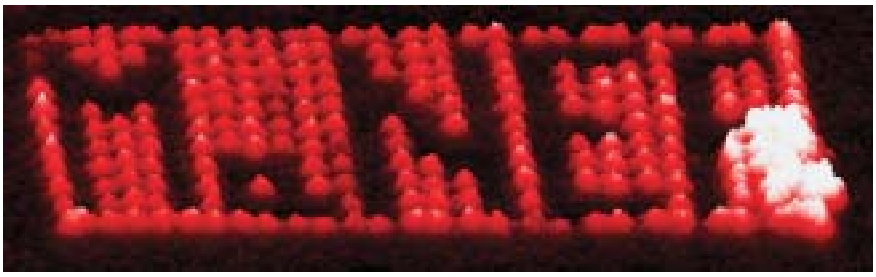
Although ultra-thin ferroelectric films can be advantageous for many applications, the evolution of ferroelectric polarization with thickness remains an open question. In MaNEP, we are studying the ferroelectric properties of films only a few unit cells thick, using high resolution x-ray diffraction and x-ray photoelectron diffraction in collaboration with the group of Ph. Aebi at the University of Neuchâtel. Our experiments, showing a decrease in ferroelectric polarization in thinner films [2], are in agreement with recent ab-initio studies by J. Junquera and Ph. Ghosez (University of Liège). Our results show that films as thin as 2 nm (5 unit cells) remain ferroelectric. Further polarization control can be achieved by alternating epitaxial layers of different materials, also investigated in MaNEP, raising the possibility of novel artificial ferroelectrics tailored to specific applications.



Tetragonal PZT has two possible polarization states, P_{UP} and P_{DOWN}, due to the relative displacement of positive and negative charges in the unit cell.

Can ferroelectric oxides be epitaxially grown on silicon?

A key target on the way to high quality epitaxial oxide film applications is the ability to integrate these materials, in thin-film form, with the existing mainstream Si-based technology. The development of an epitaxial $SrTiO_3$ buffer layer [3] has now made this integration possible. In MaNEP the pursuit of this research is being implemented in collaboration with the HES, Genève, promising numerous opportunities for scientific and technological applications.



An 11x28 array of ferroelectric domains at 6 Gbit/cm^2 density, written to spell out MaNEP with 12V pulses applied for 200 ms. The domains have radii of ~50 nm. A surface particle is visible in the lower right corner.

Can ferroelectric polarization be controlled with nanoscale precision?

The remanence (stability) of ferroelectric polarization combined with the high resolution and localized focus of AFM have made these systems very interesting both for fundamental studies of ferroelectricity and for non-volatile memory applications. By applying voltage pulses to a metallic AFM tip scanning a uniformly pre-polarized area, we can create arrays of individually addressable, non-volatile, fully reversible domains with densities up to 30 Gbit/cm^2, at least an order of magnitude higher than current hard-drive capacity [4] (see Figure). We have also investigated AFM written ferroelectric domain structures for a prototype high GHz range surface acoustic wave device [5]. Nanoscale studies in collaboration with T. Giamarchi have identified the mechanism for domain wall motion as a disorder-controlled creep process [4], implying high stability of the ferroelectric domains, useful for devices requiring long retention times. We have confirmed this by following a variety of ferroelectric domain structures for up to 4 months, with no change in size, random nucleation, or backswitching observed.

Can electronic nanofeatures be realized using ferroelectric field effect?

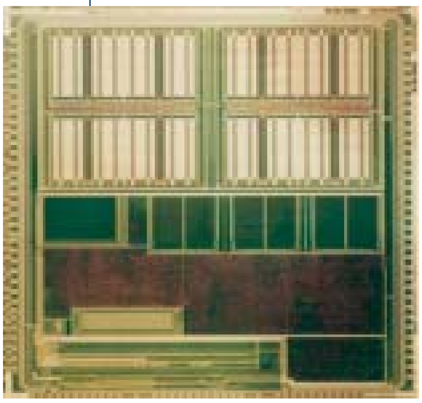
The screening of the ferroelectric field can be used as a mechanism to control the charge carrier density in very thin oxide films used as underlying electrodes, modulating for instance, the superconducting transition temperature or the nature of the electronic behaviour (superconducting/normal/insulating). Combined with local polarization switching, this could allow nanoscale electronic features to be fabricated in oxide heterostructures. ■

References:

[1] C. H. Ahn, K. M. Rabe and J.-M. Triscone, Science 303, 488 (2004).
[2] C. Lichtensteiger et al., cond-mat/0404228 (2004).
[3] A. Lin et al., Appl. Phys. Lett. 78, 2034 (2001).
[4] T. Tybell et al., Phys. Rev. Lett. 89, 097601 (2002).
[5] A.K.S. Kumar et al., to appear in Ferroelectrics .

Applications of ferroelectrics

Although for the moment several technological issues, such as fabrication costs and read-out times, make the nanoscale control of ferroelectricity described by Prof. Triscone and his collaborators a purely research topic, it could eventually lead to ultra-high density nonvolatile memory devices, capable of retaining data during power loss, and with very short boot-up times. Ferroelectric thin films also play an increasingly important role in other aspects of modern technology. In particular, their piezoelectric, dielectric and pyroelectric properties have been exploited in diverse applications, from accelerometers (airbags), ferroelectric random access memories (FeRAMs), electro-optical devices (thermal imaging), high frequency devices for medical imaging (ultrasonic-based imaging) and surface acoustic wave (SAW) devices (high frequency telecommunication filtering), to embeded Smart Systems (active vibration control) and many more. Our purpose here is not to make an exhaustive list but rather to highlight some of the interesting recent developments.



FeRAM chip, courtesy of Fujitsu MicroElectronics Europe

Ferroelectric Random Access Memories

Ferroelectric Random Access Memories (FeRAMs) are non-volatile ferroelectric-based memories. The information is stored using the two stable polarization states of PZT capacitors. Such memories present the advantage of having a higher speed in write mode than today's conventional memories, low power consumption and high endurance. Although their integration in conventional CMOS technology is continuously being improved, another limitation encoutered in processing such memories lies in the difficulty of obtaining reliable preformance and material characteristics when considering ultra-dense/small capacitors. In other words, the best availble FeRAMs on the market are "only" 256Kb, but the demand and related market for low density FeRAM is huge enough to allow their mass production. For example, Fujitsu has already shipped more than 150 millions FeRAM devices to the market since 1999. The CMOS integration is now at 1Mb, with mass produced devices to be made available within the year (now sampling). Several examples of application of FeRAMs are smart card chips (credit cards or prepayment cards), cellular phone (memory, audio/video strorage), play stations and other emerging applications such as electronic tickets or new identification cards.

Ultrasonic devices for medical imaging

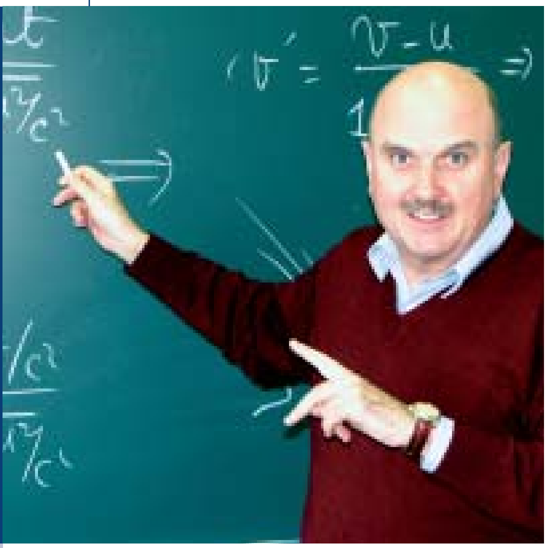
Today, the universally familiar ultrasound non-invasive imaging system is the preeminent method for in-utero fœtal imaging. This technology, unknown 30 years ago, was again made possible by the development of piezoelectric-based array transducers and their miniaturisation, since increasing resolution requires increasing number of sensors inside a same detector size. Today 1.5D - 2D detector arrays are commercially available, and continuing advances will soon provide real 3D imaging systems. Other novel medical application using ferroelectrics include the development of focused surgery transducers and non-invasive medical therapies.

Ultrasound fœtal image at 14 weeks gestation.

Active damping

The company Siemens AG in Germany has recently developed damping units based on multilayer piezo actuators for trains using the tilting technology. Active damping of train bogies is necessary to improve the performance of such high speed trains. The optimization of speed versus trajectory control coupled with comfort and security questions represent the key issues of this technology. Although the use of PZT-based multilayered piezolectric damping was not straightforward for such high load applications, significant progress was recently achieved. Other "lighter" applications of active and adaptive embedded damping units have been developed for use in vibration reduction/ control inside tennis racquets and skis.

Two project leaders at a glance



Professor **Giorgio Margaritondo**, a member of MaNEP , was recently appointed Vice-president for Academic Affairs (provost) of the Ecole Polytechnique Fédérale de Lausanne (EPFL). His tenure begins in October 2004 and coincides with a major reform of the EPFL: the fusion of the two vice-presidencies for research and for teaching affairs. The new vice-presidency for academic affairs will thus coordinate and support the activities in both areas – a challenging task, in particular if one considers the ongoing "Bologna" reform, the many new interdisciplinary initiatives at the EPFL and the expansion in the student body.

The new vice-president has a long experience in academic and research management. He was associate director of the Wisconsin Synchrotron Radiation Center in the 1980s, scientific director of the Elettra laboratory in 1995-98, director of the EPFL Institute of Applied Physics and Chair of its Physics Department until 2001. He is at present the dean of the School of Basic Sciences at the EPFL. The MaNEP members send to Professor Margaritondo their best wishes for this new challenge: his role in the EPFL research will certainly facilitate the national collaborations that are the backbone of our centre of competence. ■

End of March 2004, our colleague and mentor **Maurice Rice** has become Professor emeritus at ETH Zurich, where he has been a faculty member for the last twenty-two years. Maurice Rice has been a key member of MaNEP since its beginning.

Maurice's name is connected with a large number of important papers shaping the field of modern condensed matter theory. The analysis of superconductivity in one and two dimensions, the Brinkmann-Rice theory of the Mott transition in correlated metals, the collective dynamics of pinned charge density waves à la Lee-Rice-Anderson, or the Zhang-Rice singlets giving a basis to the t-J-model describing the high-Tc cuprates, are a few examples among the many seminal papers which became standard knowledge in our field.

Maurice did his graduate studies in Cambridge and then went for a postdoc with Walter Kohn in San Diego. Over the next fifteen years he continued his career at Bell Labs, becoming research head of the theory group in 1975 and department head of surface sciene in 1978. In 1981, Maurice moved to Switzerland to become professor at the Theory Institute of ETH Zurich. In the intervening years he built a new group in condensed matter theory which he shaped in his own characteristic way. A large number of students have gone through his training and went on with successful careers in academia and in industry.

For his seminal contributions to many diverse aspects of condensed matter physics Maurice was honored with the Hewett-Packard Europhysics prize and the Bardeen-prize. He was elected as a member of the Royal Irish Academy, the National Academy of Sciences of the US, and he is a Fellow of the Royal Society. In addition, he holds an honorary doctor degree of the National University of Irland.

In mid May we celebrated his transition to his emeritus status at ETH Zurich. We are looking forward to his continued participation and his insightful contributions to our scientific community. ■

Forthcoming Events

MaNEP will organise, sustain or participate to the following events. Find all the details on... www.manep.ch/en/events/

MaNEP 3rd Review Panel,
Geneva Home Institution,
June 22-23, 2004.

"La Nuit de la Science",
Parc de la Perle du lac, Geneva,
July 3-4, 2004.
Theme : "Mesurer, compter".

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

Nanofair 2004,
St-Gallen,
September 14-16, 2004.

"Journée Boussole", High school student's day, Geneva,
September 22, 2004.

Workshop "Computational Methods for Strongly Correlated Systems and Nanomagnetics",
Lugano,
September 26-October 1, 2004.

50th anniversary of CERN,
Geneva Physics Department,
October 23, 2004.

"Journée des filles",
Daughter's day, Geneva,
November 11, 2004.