EIW-10: Thermal Microsensors

The idea of organizing a Europhysics Industrial Workshop devoted to thermal microsensors was born at the Institute for Physical High Technology (IPHT), the former Physical-Technical Institute of the east German Academy of Sciences, were a thermal sensors group has been active for many years. It was taken up by other groups working in the field, notably those at the Swiss Federal Institute of Technology (ETH) in Zurich and at Heimann Optoelectronics GmbH in Wiesbaden, both of which agreed to join the workshop's Organizing Committee, chaired by J. Müller with U. Dillner providing considerable support.

The workshop aimed to bring together scientists from industry and from research institutions for an informal discussion of the state-of-the-art and developments in order to promote a wider industrial application of thermal microsensors. The current trend towards developing new, cost-effective micromechanical technologies (*e.g.*, CMOS-compatible) for manufacturing thermal microsensors was seen as an essential topic. The workshop was therefore of special interest to companies which envisage or foresee the manufacture and application of the various types of thermal microsensors.

There were invited review talks on physical principles (A.W. van Herwaarden, Xensor Integration BV, Delft,), the thermoelectric efficiency of bulk and thin-film materials (F. Völklein, Fachhochschule Wiesbaden), CMOS and micromachining for thermal sensors (H. Baltes, ETH, Zurich), and the applications of thermal microsensors (J. Schiferdecker, Heimann Optoelectronics GmbH, Wiesbaden, Germany). A round-table discussion and short contributions presented by 27 of the 52 participants, who came from Belgium, France, Germany, The Netherlands, Russia, Switzerland, the Ukraine, the UK, and the USA, completed the scientific programme. The ample opportunity for discussions and the secluded but attractive venue (a holiday hotel in Oberhof, a health resort in the Thuringian Forest) clearly helped promote a stronger collaboration between fundamental research and industry in the field of thermal microsensors.

U. Dillner, on the left, with J. Müller.

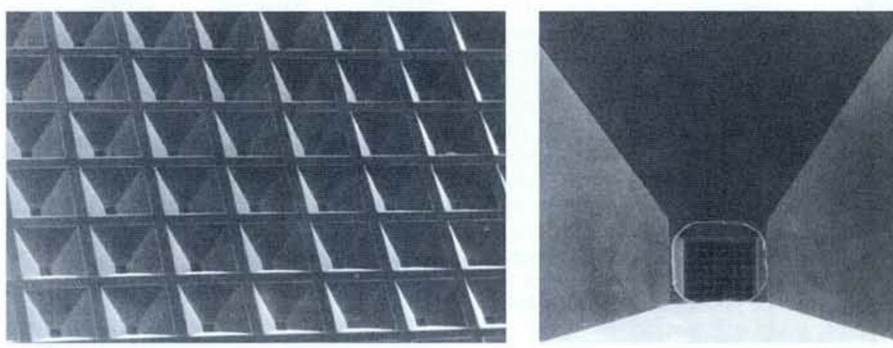
1. Much effort will be spent in evaluating important material properties (thermal conductivity, heat capacity, emissivity, *etc.*) of the functional layers of thermal microsensors and their dependence on thickness and on quantities which are clearly influenced by the manufacturing technology (*e.g.*, doping concentrations and grain size and other structural parameters). This will lead to more realistic thermal simulations for sensor optimization since the results of such calculations (see cover illustration) depend strongly on the quality of input parameters.
2. The potential of thin-film technologies (*e.g.*, as nanostructured films, quantum wells, superlattices) to improve the thermoelectric efficiency of sensor materials will be studied.
3. The development of thermal microsensor arrays and of multisensing chip configurations will be intensified (an example of the latter is the ETH Zurich group's building control chip shown in Fig. 1d).
4. Micromachined free-standing micro-thermopiles consisting of thin wires and showing very fast response times (less than 20 μs) will be improved. The aim is to fabricate the sensors as planar arrays.
5. Technological solutions such as SIMOX wafers, CMOS-compatible infra-red absorbers and porous-silicon technology will be introduced into thermal microsensors.
6. Thermal sensing principles will be employed in designing new chemosensors and biosensors. The arrangement of small drops on thin-film membranes is promising for both microanalytical applications and microcalorimetry as well as for monitoring chemical reactions in small volumes. For instance, recent experiments at the IPHT, Jena, have shown that salt concentrations in solutions can be measured by initiating chemical reaction in droplets supported on a thermopile of the type shown in Fig. 1c.
7. Research dealing with the reliability of thermal microsensors will be intensified since the reliability issue is crucial for the industrial acceptance of new sensor devices.

J. Müller, U. Dillner, *IPHT, Jena*

IPHT, Jena

Staking Out the Future

The Institute for Physical High Technology in Jena not only exemplifies the considerable effort spent on reviving applied physics research in east Germany but also provides a fascinating insight into areas where scientific and technical opportunities are believed to lie.



Recent Achievements at the IPHT, Jena. A miniaturised evolution machine for molecular biotechnology: scanning electron micrographs (courtesy: J.M. Köhler) of part of an array, etched in a 4" silicon wafer, of microsieves where each compartment has a 150 μm^2 bottom membrane with 49 pores. A huge variety of different molecules are synthesized in regular way and in parallel by sequentially filling each of the 6000 compartments with a series of chemical reactants. The device can be used for chemical analysis and to determine strategies for synthesizing new molecules. Other IPHT achievements include:

– Optical fibres	9 W fibre laser
	Simulation of polarization-mode dispersion
– Thin-film thermopiles	Precision AC-DC convertors
– Superconductors	Cost-effective, 10 GhZ Josephson effect voltage standard
	First intrinsic high-T_c thin-film Josephson junction
	Highest recorded surface resistance for TBCCO-type high-T_c films
	Large melt-textured YBCO high-T_c samples by levitation melting

The former Physical-Technical Institute (PTI) of the Academy of Sciences of the German Democratic Republic in Jena found itself with a new name, a new legal status, a significantly reduced staff, and a new mission following Germany's reunification. S. Methfessel and B. Elschner steered the institute during the difficult period from 1 January 1992, a few months after the former GDR ceased to exist, to mid-1993. The main challenge was to find a new, stable role that covers the "middle ground" between the industry-oriented Fraunhofer Institute and the essentially basic research orientated Max-Planck Institute.

The PTI's strengths and weaknesses were evaluated and a plan drawn up which was firmly backed by local and regional governments seeking to re-establish the Jena-Erfurt area as vigorous centre for high-technology industry. Modern precision optics started in Jena and at reunification VEB Carl Zeiss

The IPHT's Beutenberg complex photographed earler this year. The soon to be completed clean-room facility is the last building on the left.

Jena, one of the two rival Zeiss companies, employed 27000 in Jena alone. The State of Thuringia oversaw restructuring and transformation of the *combinat* into Jenoptik and Jena-Optronik. It also provided significant investment, with the two companies and various spin-offs becoming important nuclei, along with Jena's Friedrich-Schiller University and several distinguished institutes such as the PTI itself, recreated as the Institute for Physical High Technology (IPHT), the Hans-Knöll Institute for Research on Biomaterials, the Institute for Molecular Biology, and the Fraunhofer Institute for Applied Optics and Fine Mechanics. Several of the institutes consolidated all or part of their activities to the Beutenberg science park on the outskirts of Jena that has become a principle focus for revived industry and research activities.

The PTI, which was well known for its work in plasma physics, magnetic materials, glass-fibre optics, and infrared sensors, had some 300 staff members at reunification. The plan is to stabilise the number at around 160, including 90 permanent positions with a significant number of temporary posts to provide flexibility and training opportunities (things that tended to be lacking in the past). Managing the transition remains difficult for most of today's approximately 180 staff members hold temporary positions, with funds for 50 of the 140 posts covered by Turingia due to end within the next two years. Some two-thirds of the IPHT's annual operating budget (28 MDM in 1993 including about 10 MDM for capital investment) presently comes from Thuringia, while the federal government supports through its research ministry — the BMFT — some 7 MDM of regular project funding. A further 1.5 MDM come from industrial contracts, mostly for work carried out in consortia. Expansion of the project work, including European Union projects, is vital, and the ground is being prepared for this. Major new investments include refurbishment of the institute and a new, almost completed, 15 MDM clean room equipped for circuit design, pattern generation and microfabrication, testing, and materials characterization. E. Hoenig from the Siemens research centre in Erlangen who was appointed IPHT Director in June 1993 says that the new facilities will offer "an environment allowing us to be really competitive". He also became a department head and it is in this capacity that he serves as the Director, for under the IPHT's new structure the position rotates among the four department heads, who also hold university appointments. As an association with a Board of trustees controlled by the State of Thuringia, the IPHT has adopted other organizational features common to most institutes in western Germany, including an independent scientific council.

The IPHT is concentrating on fibre optics for communications and sensors, laser-assisted processing and laser process monitoring, cryoelectronics, microsensors and systems, and high-T_c superconducting materials for electronic devices in the context of a major industrial consortium. A well-balanced project portfolio (see figure) will hopefully promote efficient synergies and stable budgets. Major initiatives include a "mini-foundry" to produce reasonably priced superconducting electronic circuits (including low-T_c types) and two electron-beam writing machines. The latter will be used to make both micro-optic devices with characteristic lengths below the wavelength of light and novel electronic devices (*e.g.*, single-electron tunnelling devices). Introducing the output from basic research into industry has become the dominant theme of virtually everything the IPHT tackles, the input from academic research being assured especially by two of the 15 new BMFT "innovation colleges". Given this motivation its is perhaps not surprising that the institute was largely responsible for launching and organizing the successful Europhysics Industrial Workshop on thermal microsensors — a fairly specialised and important topic, but one that has been chosen by the IPHT in staking out its future success.

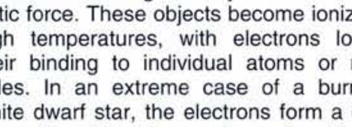
QUARK MATTER

New Round of Experiments Underway

Quantum electrodynamics (QED) describes how charged particles interact by exchanging photons to account for bound aggregates, ranging from atoms and molecules to solid materials held together by the electromagnetic force. These objects become ionized at high temperatures, with electrons loosing their binding to individual atoms or molecules. In an extreme case of a burnt-out white dwarf star, the electrons form a continuous Fermi liquid — a plasma in which the electrons are deconfined from their low-temperature bound states.

Quantum chromodynamics (QCD) describes how quarks interact by exchanging gluons, and helps explain bound aggregates of two or three quarks that we call hadrons (pions, kaons, protons, neutrons...) which are held together by the strong force. So QCD is an extended analogy of QED. It needs to be clarified whether the formal analogy with QED for cold objects extends to finite-temperature behaviour. QCD predicts that a plasma of quarks and gluons can exist where the colour-bearing constituents circulate freely in a hot vacuum that is transparent to colour (they are deconfined).

The only tool at hand to reach the conditions for deconfinement lies in the collision of heavy ions leading to a very hot and possibly thermalized quark-gluon plasma extending over the volume of the colliding ions. This phase will expand and cool until a phase transition is reached where the partons recombine into a hot hadron gas; the new hadrons keep interacting until further expansion finally lets them escape. So understanding the interesting part of the process (*i.e.*, the passage from the plasma state to its characteristic phase transition into hadrons) is shrouded by a pre-equilibrium partonic phase and subsequent hadronic rescattering. A decade of intense theoretical work has sought signals that might pin down the transient plasma and its phase transition. Two approaches have emerged, based on looking either at features established during the initial phase or at hadrons produced in the later stages.



A simple model for the formation of the quark-gluon plasma envisages compression of hadrons in a vacuum. As the density increases, the hadrons start interacting and eventually merge into one another. The small vacuum bubble associated with each individual hadron fuses into a large bubble within which the constituent quarks can move over large distances. The same happens if a dilute hadron gas created in a high-energy collision is heated up (thermalized). A combination of compression and heating occurs in heavy-ion collisions.

First Round Encouraging

It appeared in the early 1980's that collisions of relativistic heavy ions in existing accelerators would most likely give the energy densities required for the formation of the elusive quark-gluon plasma. Moreover, data-taking involving the hundreds of secondary events produced in a typical collision appeared manageable. So a first round of fixed-target experiments got undeway using medium-sized ions (S, Si) accelerated to centre-of-mass energies per nucleon-nucleon collision of 20 GeV at CERN and of 5 GeV at the Brookhaven National Laboratory (BNL), USA. The energy densities sought were attained and there have been encouraging signals that some thermalization seems to be taking place: nucleus-nucleus collisions cannot simply be considered as mere superimpositions of nucleon-nucleon collisions. There is no doubt that a new state of matter is created, with a density 10-times that of hadronic matter. But one does not yet know if there is a phase transition between two very different forms of dense matter, as expected by QCD.

Second Round Starts

CERN proposed in 1988 a second round of fixed-target experiments based on adding several new accelerator systems and upgrading existing accelerators to produce Pb ions at 17 GeV per nucleon, BNL having recently extended its work to the heaviest ions at