



Issue #2 April, 2010

Optical, mechanical and electro-optical design of the innovative SMARTIEHS system

From the Editor

In the 1st issue of our newsletter we presented the SMARTIEHS project and our ambitious objectives. Now, we want to let you know a little bit more our system.

In this issue you will discover the base principles of the system and how it works. We will present the optical, mechanical, and electro-optical design of this innovative interferometric inspection system for massive parallel inspection of M(O)EMS. The second year of the project is almost ended and the first encouraging results are coming. We performed the first measurements with two single channel demonstrators and the multi channel system will be ready soon. You will find all this in the next issues; by now enjoy yourself knowing our system's details.

Inspection Concept

By introducing a wafer-to-wafer inspection concept the parallel testing of several dozens of M(O)EMS structures within one measurement cycle becomes possible. To obtain this an exchangeable micro-optical probing wafer is

adapted and aligned with the M(O)EMS wafer under test. The probing wafer comprises an interferometer array. The configuration, spacing and resolution of the interferometer array are designed for each specific application. Furthermore also the illumination, imaging and excitation modules are modular and can be moved from one interferometer array to the other.

The modules can thus be interchanged if the spatial distribution of the MOEMS structures or changed functionality requires this.

The inspection system is mounted on a commercially available wafer handling and positioning system (SUSS prober – PA 200 with probe shield). The M(O)EMS wafer is mounted and positioned using the wafer chuck of the prober. Figure 1 shows a sketch of the prober and the inspection system integrated on the prober.

The instrument configuration is shown in Figure 1. It comprises the two different interferometer arrays. The left side shows the low coherent interferometer and the right side the laser interferometer array. The light sources are arranged in an array and positioned on

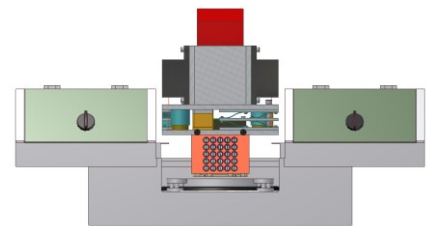


Figure 1 - CAD 3D representation of the SUSS test station (PA200) for M(O)EMS testing, with the inspection system attached at the scope mount of the prober

each side of each interferometer unit. The light is guided by a beam splitter towards the probing wafer. The interference signals are generated in the micro-optical interferometers which are fabricated in a

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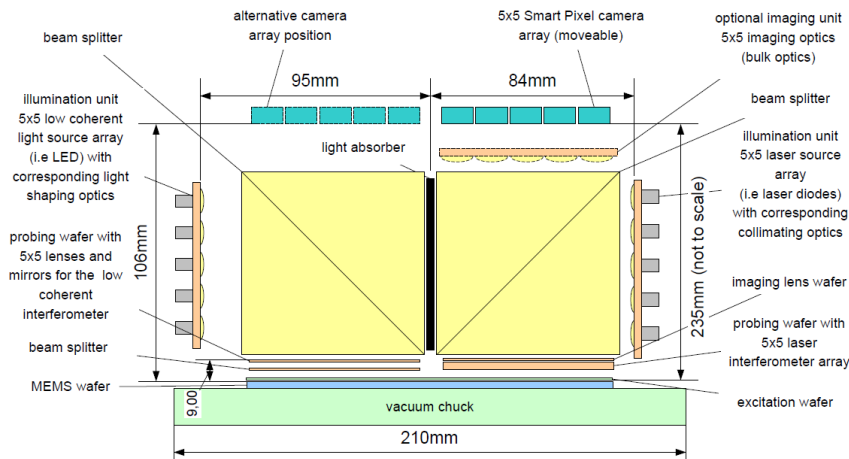


Figure 2 - SMARTIEHS instrument configuration: Side view with dimensions. The vacuum chuck is part of the SUSS prober used for mounting the M(O)EMS wafer.

regular matrix on a 4-inch wafer stack. Two different interferometer approaches are pursued; a refractive Mirau type and a diffractive Twyman-Green type interferometer. The refractive design will be used for low coherence interferometry to measure the shape and deformation of the M(O)EMS structures. The diffractive design will be applied for vibration analysis using laser interferometry to find the resonance frequency and spatial mode distribution. Furthermore the LI will be applied to measure shape and deformations on smooth surfaces.

A glass wafer containing mini-lenses produced by standard micro-fabrication processes is used for the imaging of the interference fringes towards the camera. A distributed array of 5x5 smart pixel imagers detects the interferometric signals. The signal processing is based on the “on pixel” processing capacity of the

smart pixel camera array, which can be utilized for phase shifting or envelope maximum determination. Each micro-interferometer image will thus be detected by a 140 x 140 pixels sub-arrays distributed in the imaging plane.

An excitation system for the M(O)EMS structures is needed for active testing. A glass wafer consisting of Indium Tin Oxide (ITO) electrodes is applied for electrostatic excitation of the resonance frequency of the structures. For the measurement of deformation the active area on the M(O)EMS is excited either electrostatic by the ITO wafer or using a tailor made pressure chuck

Mechanical Design

The semiautomatic prober system SUSS PA200 supplies a chuck movement in x, y, z and rz (r - rotation). This is used for the positioning and horizontal scanning of the M(O)EMS wa-

fer. Furthermore the scope adapter of the prober can be moved in x, y and z. This adapter is used to mount the inspection system.

Figure 3 shows a CAD 3D representation of the inspection system. The system can be divided into two main components – a drive unit and an optical unit. The drive unit carries the high precision drive and the springs.

The raw positioning of the inspection system in z is done by the scope drive. However the linearity and positioning accuracy of the scope drive is not sufficient for the interferometric measurements.

Therefore a separate high precision drive unit is designed. This ensures the parallel alignment of the probing wafer with the M(O)EMS wafer by adjusting rx and ry. Furthermore the high precision drive has to perform a highly uniform movement and positioning in z. LCI requires a scan over a range of 1mm with a linearity

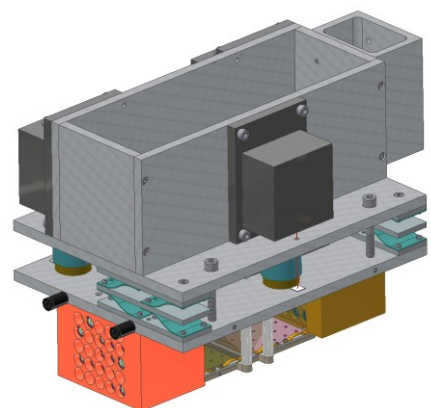


Figure 3 CAD 3D representation of the inspection system, above: drive unit, below: optical unit



of 1%. LI requires positioning accuracies with a measurement error <10nm and a high frequency position stability in the nanometer range.

Those high requirements are realized in the design concept by integrating three single drive subsystems. A voice coils based driving system is selected to obtain a travel range of 1mm. Three commercial interferometer systems deliver position signals with an accuracy of 3nm which enables a positioning accuracy of 10nm. The controller of the drive system will be realized by a rapid controller prototyping system, e.g. dSpace.

The two interferometer modules are mounted on the optical unit. The design enables various adjustment possibilities of the different optical components.

The mechanical guiding in z direction is realized by three parallel leaf spring systems. The doubled configuration of leaf springs compensates a possible movement in x- and y-directions. Hence, the leaf spring system assures a guided movement only in z as required. The leaf springs are pre-stressed to compensate the weight of the optical unit

Optical Design

The optical unit of the inspection system consists of two optical modules, one containing the LI array and one the LCI array. Figure 4 shows a CAD 3D

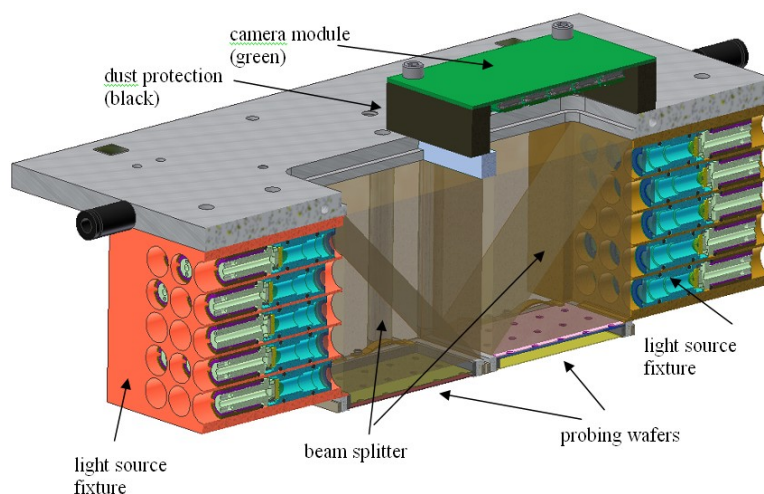


Figure 4 Optical unit of the inspection system consisting of the LCI module (left) and the LI module right. The smart pixel camera (on top) is moveable between the two modules. It is shown in the position for detection of the laser interferometer signals.

representation of the optical unit.

The light source illuminates the M(O)EMS object via a cube beam splitter. The centre of the illumination aperture is thus aligned with the centre of the imaging lens and the centre of the object along the optical axis. The optical axis is deflected 90° by the beam splitter. The centre of the active area in the corresponding camera images the M(O)EMS structure under inspection.

Care has been taken to mount the probing wafers without introducing tension in the wafers. Any bending of the wafers will introduce variations in the optical path length in the interferometers and misalign the optical system.

Illumination

The light sources have an adjustable beam angle. The light source can be eccentrically ro-

tated and moved along the optical axis. Thus the illumination can be conditioned. The illumination modules are configured as a matrix of light sources, i.e. light emitting diodes (LED) or laser diodes (LD). Alternatively, a single source can be distributed over the entire test wafer area. The designs described in this paper are based on the matrix approach. Figure 4 shows the position of the light source array in a 3D representation

Smart pixel camera

The smart pixel camera modules can be individually focused. This enables the compensation of deviations of the nominal focal lengths that may occur in the production of the mini-lenses. Figure 5 shows an example of the mechanical arrangement of the camera for this case. By allowing for a production tolerance of ±4% in focal lengths, each smart cam-

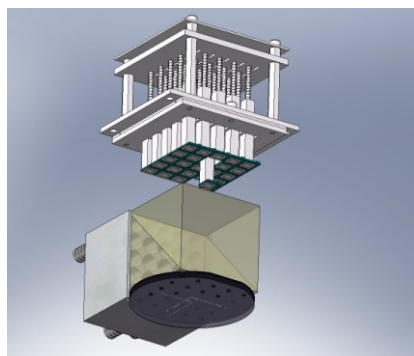


Figure 5 CAD 3D representation of one of the optical units connected with the camera array.

era imager needs an adjustment of $\pm 20\text{mm}$. The imaging optics has a magnification of 9x. The imaging system is designed without an intermediate image. The field of view is $600 \times 600 \mu\text{m}^2$.

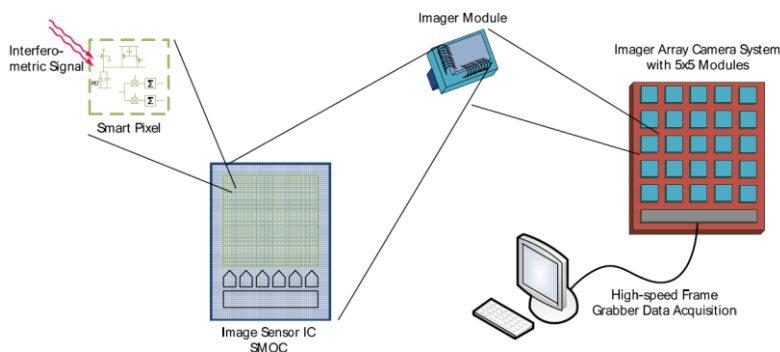


Figure 6 - Configuration of the smart-pixel camera

Figure 6 shows the configuration of the imager array camera. The smart pixel imagers are placed in a 5x5 matrix at the camera module which transfers the images via a high speed frame grabber to the PC. The pitch between the imager chips is adapted to the interferometer pitch.

Each of the 5×5 interferometric channels is equipped with a smart-pixel CMOS imager for

detection of the optical signal. Every imager features 140×140 pixels (150×150 including black and reference pixels), which increases the parallelism to a total resolution of about half a million interferometric sub-channels.

The object measurement time of LCI with scanning of the optical path length is usually limited by the frame rate of the detector imager. The interferogram is an amplitude modulated signal containing the depth information of the sample in its envelope. For every scan distance corresponding to the period of the optical system, i.e. half of the illumination peak wave length, several

frames are acquired limiting the scan speed to some micrometers per second.

The developed smart-pixel architecture allows the demodulation of the electro-optical signal at the detection level with demodulation frequencies up to 100 kHz. The demodulated signal is averaged over a few periods and then read out to the control system. The data volume is drastically reduced

and the depth scan speed is increased without the need of a high imager read-out frame rate.

Figure 7 shows the I-Q direct demodulation principle implemented within every pixel. The optical signal striking a pixel is detected and converted into an electrical signal on the photo diode. A background suppression circuit avoids saturation of the pixel at high illumination levels and small input signal contrast. The signal is integrated and sampled. These signal samples are multiplied by a signal of the same frequency and averaged on two paths, phase shifted by $\pi/2$ with respect to each other. A sample and hold stage in both circuit branches allows simultaneous demodulation and read-out, which means that while the stored values are read out of the imager pixel field, the input signal is demodulated to already generate the next values. The outputs of the two paths are read out of the imager to the PC and the envelope amplitude is calculated. A three-dimensional model of the imaged object is then generated from this data.

The versatile electronic circuit at the pixel level not only allows amplitude demodulation but also the extraction of the modulation phase. Furthermore, conventional grey-level images can be acquired. The architecture is therefore well suited not only for LCI but also for phase-stepping LI and vibrometry.

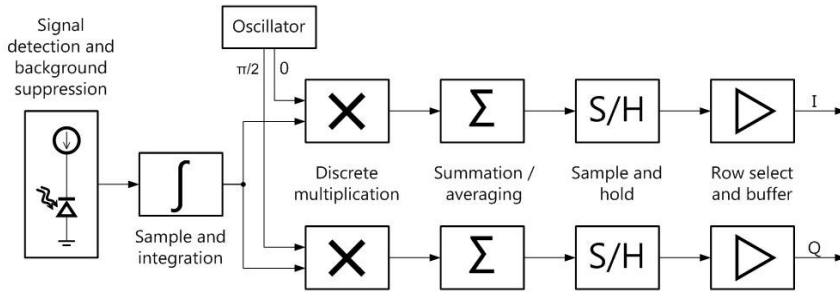
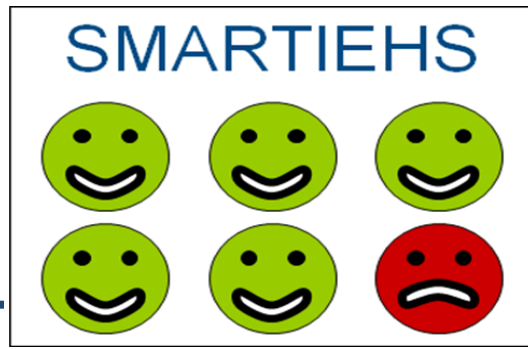


Figure 7 I-Q direct demodulation principle of the smart-pixel.

Low Coherence Interferometer

For low coherence interferometry a micro-optical approach of a Mirau configuration is applied. The illumination is realized by an array of Light-Emitting Diodes (LED). Each illumination system consists of an LED, a lens and an aperture. The LED is slightly defocused imaged onto the imaging lens. Camera and illumination aperture are, seen from the object side, “virtually” positioned in the same vertical and horizontal position.

Figure 8 (top) shows the preliminary design of the interferometer array. It consists of 2 separate wafers. The lens wafer is carrying the imaging lenses and the reference mirror. The beam splitter wafer is a glass wafer with a partly reflective coating on the upper side.

The imaging lens consists of a refractive micro-fabricated mini lens with a diameter of 2,5mm. The beam splitter wafer divides the incoming light into a reference beam and an object beam. The reference beam is reflected by the reference mirror positioned in the centre part of the lens. The ob-

ject beam is reflected back from the M(O)EMS structure under test. Both beams are interfering in the beam splitter wafer. The interference fringes are imaged onto the camera, where the smart pixels detect and demodulate the interference signal.

Laser Interferometer

LI has a Twyman-Green interferometer configuration as it is proven to be an efficient setup for active full-field M(O)EMS

testing. A Twyman-Green interferometer is a two-beam interferometer, illuminated by a beam with a plane waveform generated by a point source and a collimator. The preliminary design of the LI is shown in Figure 8 (bottom). The illumination system is realized by a laser diode matrix and an aspheric lens. One laser diode is dedicated to one interferometer channel.

The interferometer is formed from two wafers. The top wafer is a thick glass wafer with a diffractive optical element DOE1 etched on the surface. This grating diffracts the incident collimated beam in order to illuminate the beam splitting diffraction structure DOE2. The second wafer is also a glass wafer and contains DOE2, DOE3 and a mirror surface. DOE 2 divides the incoming light in ob-

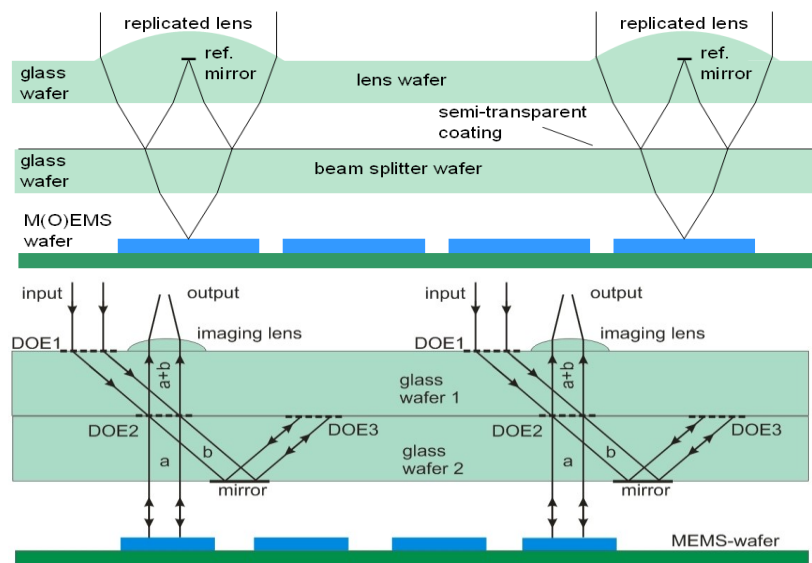


Figure 8 Preliminary design of the low coherent Mirau interferometer configuration (TOP) and the laser based Twyman-Green interferometer configuration in a matrix approach (BOTTOM).




ject and reference beam. The transmitted light of DOE2 forms the reference beam. The DOE3 plays a role of a reference mirror. The diffracted light of DOE2 is directed towards the object surface and forms the object beam. Both beams are recombined by DOE2 and interfere. The interference pattern is imaged by the imaging lens integrated on the glass wafer surface and captured by the camera. The full image of the smart pixel camera consists of the matrix of sub-images given by the interferometer matrix.

The consortium

The partners involved in the project are: SINTEF Information and Communication Technology (Norway) CSEM SA (Switzerland), FEMTO-ST CNRS (France), FRAUNHOFER IOF (Germany), HELIOTIS AG (Switzerland), Institute of Micromechanics and Photonics (IMP) at Warsaw University of Technology (Poland), Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH (IMMS) (Germany), and TECH-FAB SRL (Italy)

In the previous issue you discovered SINTEF, our project coordinator, and CSEM; now is time for FEMTO-ST and Fraunhofer - IOF

FEMTO-ST

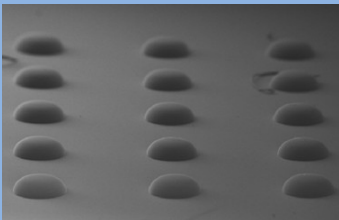


FEMTO-ST is a Carnot Institute and contains 5 research departments specialized in optics, mechanics, microelectronics, microsystems and material sciences, representing a potential of 535 scientists. FEMTO-ST participates in the SMARTIEHS project through the *Département Micro Nano Sciences & Systèmes (MN2S)*.

The scientific scope of MN2S encompasses all technical fields relevant to the highly multidisciplinary world of micro-nano sciences and technologies, including phononics, microoptics, MEMS and MOEMS, material science at the micro & nano scale, micro & nano fabrication and micro & nano scale instrumentation. It is one of the most significant French groups in this field. The research focus is the development of miniature optical sensors made using batch-fabrication processes (silicon technology and III-V materials). This activity combines the integrated optics with micromechanical structures and offers new integration potentials for sensing applications and also atomic clock applications. MOEMS group was and is involved in several European research programs such as Marie Curie, GROWTH and IST programs of the EU, NATO program, and mobility programs such as SOCRATES. The group has cooperation in Europe and overseas (Switzerland, Germany, Poland, Japan, etc.) .

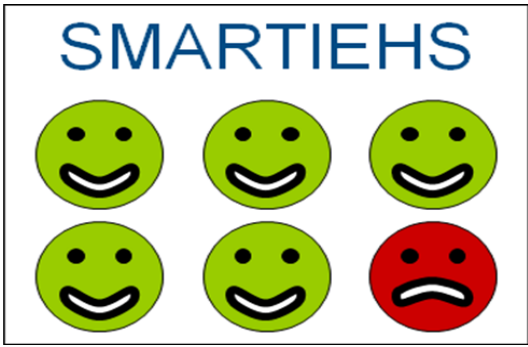
FEMTO-ST has an important technological platform: 850 m2 class 100/1000 clean room area including mask and wafer processing equipment, nanofabrication equipments and characterization devices. This technology platform, called MIMENTO, is now labeled as the 5th national technological center in micro-techniques and nanotechnology.

Technology equipment contains: 1 micron photolithography facilities, wafer etching bench, thin film deposition/growth (sputtering, evaporation, PECVD and electro-plating), oxydation furnace, dry etch, deep RIE for Si and quartz, Si and III-V RIEs, wafer bonding, focused ion beam, mechanical and optical characterization, ellipsometry, AFM and SNOM microscopes, optical microscopes, packaging equipment, planarization system, etc.

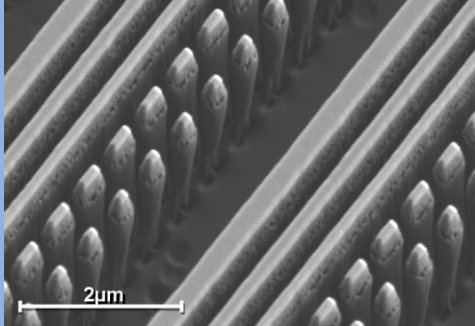


SEM image of glass microlenses





Fraunhofer IOF Jena Tailored Light



SEM-image of a binary blazed grating with sub-micron features for a space application

The Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. is a link between science and industry, that is between the research and the application of its results. The Fraunhofer Institute of Applied Optics and Precision Engineering (IOF) is one of 59 non-independent research institutes belonging to the Fraunhofer-Gesellschaft. Research and development at Fraunhofer IOF focuses on optical systems technology with a view to continually improving the control of light from generation via guiding and manipulation up to its application. The project SMARTIEHS is handled in the Center for Advanced Micro- and Nano-Optics (CMN-Optics) belonging to the department Micro-Optical Systems. The members of this group have more than 10 years experience in design and fabrication of optical micro- and nano-structures and components up to the module level.

Within former projects competencies have been built up concerning a broad range of fabrication technologies, such as wafer scale reflow and replication for microlenses, various lithographic origination technologies including electron-beam- and laser-lithography, fabrication of single- and multimode waveguides, prisms and waveguide coupling gratings, and many others. A dedicated technological basis is available at the Fraunhofer IOF's clean room facilities including an electron-beam writer SB350 OS (Vistec), laser writer DWL400 (Heidelberg Instruments), various dry etching machines (RIE, IBE), mask aligner for up to 8" substrate sizes with UV-replication option, and numerous characterization and inspection tools.

The CMN-Optics group is working on the continuous improvement of the available technologies for the realization of novel optical structures especially in the field of elements having characteristic feature sizes in the sub-wavelength region.

Come and visit us in the upcoming events!

Tell us your need for high throughput quality tests; let us know what are your real wishes

- SMARTIEHS will be present at **ICT 2010**:
27-29 September 2010,
Brussels Expo, Belgium



MORE INFOS ?! contact:

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In the next ISSUE

In the next issue we will show you the **first measurements results** we did with the two single channel demonstrators for LCI and LI. Furthermore we will update you on the development of the **multi channel prototype**.

You will discover other two of us:

- **Heliotis**
- **IMF (Warsaw University)**

See you in Brussels at **ICT 2010** and at our next newsletter: **September 2010**

In the mean while, check for any news, stay updated or satisfy your curiosity on our website:

www.ict-smartiehs.eu