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LIMMS: Laboratory for Integrated MicroMechatronic Systems. A Joint Research on Micromechatronics between the "Centre National de la Recherche Scientifique (CNRS)" and the "Institute of Industrial Science (IIS)"

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In 1994, the "Centre National de la Recherche Scientifique (CNRS)", the main French research association having 25,300 staff members and the Institute of Industrial Science of The University of Tokyo decided to settle a joint research project on Micromechatronics. Micro miniature machines and motion systems are investigated in a joint laboratory, the Laboratory for Integrated MicroMechatronic Systems (LIMMS) at IIS. Since 1994, 29 French researchers are involved in the project and stay in LIMMS for one to three years conducting scientist research with IIS faculty members and research staff.

1. Presentation of the joint laboratory: LIMMS.

In 1994, the "Centre National de la Recherche Scientifique (CNRS)", the main French research association, and the Institute of Industrial Sciences (IIS) of The University of Tokyo decided to settle a joint research project, and had created a joint laboratory: the "Laboratory for Integrated MicroMechatronic Systems". Within the LIMMS, cooperative research work is carried out in the field of Micromechatronics both by French researchers issued from CNRS laboratories and by professors and researchers from the "Research Group on Micromechatronics" of IIS. At the Roppongi site, the LIMMS welcomes CNRS permanent researchers for stay durations of 2-3 years. These CNRS researchers are dispatched in the laboratories of the IIS research group of Micromechatronics. Each French researcher manages a research project, which is performed jointly with an IIS professor, the LIMMS manager and the CNRS laboratory from which the researcher is issued. To ensure a successful approach, each research project has to meet the mechatronics experiences and interesting process capabilities development from IIS, in one hand, and the expertise domain of the CNRS laboratory, in the other hand.

In addition, LIMMS welcomes post-doctoral fellow supported by the Japanese Association for the Promotion of Science (JSPS). The post-doctoral fellowship is usually for 2 years duration.

In standard regime, up to six CNRS permanent researchers and an equivalent number of post-doctoral fellows will be selected in France to join the LIMMS.

Cooperation with other partners is welcome and the common goal is to create an active international research center.

The technical topics of the joint research are related to Micromechatronics: integration of micro-machines and micro-electronics into a complete integrated system. The research projects cover micromachining technology, extremely fine mechanical machining, new kinds of actuators/sensors development, atomic scale microscopy systems as well as the investigation of manipulation and possible utilization of functional molecules and semiconductor nanostructures by using micro machined tools. Basically the technical projects will combine the technological know-how of the IIS group of excellence in Micromechatronics and some expertise domains of CNRS laboratories such as optics, microwaves, acoustics, etc.

2. Key dates of the project and LIMMS organization.

In 1992, The CNRS was trying to promote its own research in micro technologies by launching an internal project which aimed to group several laboratories on a realization of micromechatronics systems. At the same time, the CNRS office in Tokyo was promoting cooperation between CNRS and Japanese scientific

institutions.

In February 1993, a visit of French scientists to Japanese institutes working on micro technologies was organized. At the same time the idea of creating a French-Japanese joint project on micromechatronics was proposed in December 1993 to the Institute of Industrial Science of The University of Tokyo and received with a great welcome.

In February 1994, a visit of the 3 founding CNRS laboratories, the Institute of Electronics and Microelectronics of Northern France (IEMN) in Lille, the Institute of Micro techniques of Franche Comte (IMFC) in Besançon and the Laboratory for the Analysis and the Architecture of systems (LAAS) in Toulouse and of the CNRS headquarters was organized for the IIS professors of the Research Group on Micromechatronics.

On May 1994, the LIMMS office was officially inaugurated by the CNRS General Director, Pr. François KOURILSKY and the President of the University of Tokyo, Pr. Hiroyuki YOSHIKAWA At that date, a letter of intention for cooperative research plan was signed.

On June 1994, in Paris, the CNRS and The University of Tokyo have signed a general agreement on joint research in the frame of which the LIMMS enters. After several months of discussion, the final constitutive agreements and related organization rules were signed on February 1995.

On June 1999 in Tokyo, the CNRS General Director Pr. Catherine BRECHIGNAC and the President of the University of Tokyo, Pr. Shigehiko HASUMI, renewed this General Agreement

3. Why LIMMS? The CNRS view point.

3.1 General presentation of CNRS.

The "Centre National de la Recherche Scientifique (CNRS)" is the French government agency for basic Research and is, by its size, the largest European fundamental research organization. CNRS gathers up to 25,300 staff members including 11,500 researchers and 13,800 engineers, technicians and administrative assistants. CNRS is strongly associated with University and the research is organized within 1250 laboratories distributed all over France.

The CNRS research activities are organized around 7 scientific departments, ranging from basic mathematics and physics to human sciences and the LIMMS belongs to the "Engineering Science" department. The research performed in the engineering department focuses on signal and information processing, process engineering, mechanics, fluids and health engineering. Among the research priorities, we find microtechnologies in such a good place that it was a strong motivation to establish the LIMMS project.

3.2 CNRS interest.

The motivation of CNRS in LIMMS was strongly supported by two statements, a general and a scientific one. Generally speaking, concerning the equilibrium between scientific exchanges between Japan and France, the number of French researchers in Japan was much lower than the number of Japanese researchers in France. Moreover, even if the willingness to have strong collaboration with Japan was very well established, the way the French researchers organized their stay in Japan did not give the corresponding impact. The French researchers were usually distributed into numerous Japanese laboratories and their technical activities were also widely spread. The return in France was usually organized individually so, unfortunately, the technical feedback was lowered and the basic collaboration willingness was not so well visible.

For the above-mentioned reasons, the interest to have a clearly identified joint laboratory became obvious; therefore, CNRS felt the priority to organize the scientific exchanges and joint projects on an other base. The covered scientific activities have to be included in a new, long range and potentially very attractive research field. Micromechatronics and Microsystems were chosen mainly because they meet two requirements: first, these activities were and are clearly within the CNRS Engineering Sciences department research priorities; second reason, Japan was and is always strongly engaged in microsystem research programs.

Among the possible partners, the IIS of the University of Tokyo presented the main advantage to have organized its micromechatronics activities within a coherent frame: the "Research Group on Micromechatronics". This group, is now gathering 7 laboratories, presents all the excellent technological means to fulfill the CNRS scientific interest and to produce long-term research. Moreover, since the first contacts, the idea to create a joint laboratory received a extremely favorable welcome from IIS previous Director, Pr. Fumio HARASHIMA.

So, as the planned collaboration with IIS fulfilled all the basic CNRS motivations, from the CNRS view point there was a strong will to create LIMMS.

4. IIS's interest in LIMMS.

4.1 General interest.

The concept of LIMMS was and is always very much in coherence with IIS general policy. The first policy is the fusion of different disciplines. In contrast to the Faculty of Engineering where both undergraduate education and research at the graduate school level are performed, the IIS focuses mainly on research in conjunction with industries as well as in the graduate school. Each faculty, no matter how young it is, has an independent laboratory

in which state-of-the-art topics in various engineering fields are studied. Many of these topics are categorized as interdisciplinary or transdisciplinary research; it means that the study cannot be completed within one conventional engineering discipline. IIS encourages faculty members to form research groups in order to tackle the problem. There are several research groups on specific subjects such as anti-earthquake engineering and intelligent mechatronics. Micro mechatronics systems which is the main research topic in LIMMS, also requires collaboration among electrical and electronic engineering, mechanical engineering, chemical engineering and material science. A research group, Research Group Of Excellence (RGOE) on Micromechatronics, was established in 1992 and has been active in the field of micro systems and micromachines. The LIMMS provides IIS with the opportunity to enhance the activity further.

The second policy is the international exchange and collaboration. The IIS has made international agreements on research cooperation with foreign universities and research institutions, which of course, include CNRS. Some of the faculty members were invited from foreign countries and in 1999, more than 180 foreigners stay in IIS as students and visiting scientists. Since research topics are becoming more and more global, the importance of international exchange keeps growing. The LIMMS is very unique among many international activities. A substantial number of senior and post-doctoral researchers stay in IIS to investigate a well-defined subject for several years. Close interaction between French and Japanese researchers is to be expected through experimental works and discussions. Both of us are willing to take the opportunity to learn each other's culture and way of thinking. Collision and fusion of different cultures are expected to stimulate the birth of innovative breakthroughs.

4.2 Scientific interest.

The LIMMS project has many features in terms of scientific research. Making small machines such as an artificial ant is one of human dreams for a long time. One can see milliard of possibilities of micro miniature machines; medical micromachines going into veins to cure the affected parts from inside of our body, scientific micromachines manipulating molecules or atoms, and a bunch of environmental micromachines purifying a polluted area. As described earlier, a research group, RGOE on MicroMechatronic, was established in 1992 and has been active in the field of micro systems and micromachines. The purpose of the micromechatronics research is to integrate micromachines and microelectronics into a complete mechatronics system, which works in the micro world. The research projects cover from micromachining technologies using both semiconductor processes and extremely fine mechanical machining to micro motors and actuators based on novel principles. Ultra-precision control down to atomic dimensions and intelligent motion control using advanced sensing scheme are also investigated. The prospective application includes bio-medical engineering, micro robots, micro optics, micro fluidic systems and information storage and retrieval devices. However, in 1994, the research activities had focused mainly on fabrication processes and control schemes for micromachines. On the contrary, research on Microsystems in the CNRS laboratories involving LIMMS was more application oriented. The reason is that they have strong background in application areas such as optics, precision metrology and microwave applications. Because directions of the research were complementary between both parties, it was natural and beneficial for us to form a joint project.

5. Previous and Current members

The IIS host Professors and their related field are given in the table 1.The LIMMS welcomes and has welcomed twelve permanent researchers. Their name and French laboratory are reported in table 2. Seventeen post-doctoral researchers (Table 3) have been and are welcomed, in the frame of the CNRS-JSPS Agreement. Miss Yumi HIRANO, CNRS, ensures the LIMMS secretariat since September 96.

6. Current Scientific Projects

6.1 Measurement of Inner Surface Profiles in High Aspect-Ratio microholes

Researchers: E. Lebrasseur, T. Bourouina, J.B. Pourciel, T. Masuzawa, M. Ozaki and H. Fujita

The team studies a characterization method to measure the inner dimensions of high aspect ratio microholes (figure 1), typically 100 microns in diameter and 1 mm in depth. Micro probes with an integrated force-sensitive element have been fabricated using silicon technology (figure 2). Vertical surface profiles are measured by the deflection at the end of a cantilever beam due to contact force when the cantilever scans the inner surface of the hole. Two force sensing methods have been developed: one is based on piezoresistive detection and the other on frequency shift of mechanical resonators.

6.2 Electromagnetic Actuation for Optical MEMS

Researchers: G. Reyne, Y. Takahashi, P. Helen, H. Maekoba, T. Bourouina and H. Fujita

Electromagnetic force enables long-range as well as wireless actuation. The group is developing two applications to integrate electromagnetic actuators on optical microsystems. One of the two projects is collaboration with Anritsu Corporation to develop electromagnetic actuation for a resonant scanner. The other project aims at optimizing and integrating magnetic bi-stable operation for

Table 1 IIS Host Professors

IIS host Professeur	Related field
Pr. Hiroyuki FUJITA and Hiroshi TOSHIYOSHI	Micoelectromechanical Systems by IC Process
Prf. Takahisa MASUZAWA	Micromachining and Metrology
Pr. Hideki KAWAKATSU	Nanotechnology
Pr. Toshiro HIRAMOTO	Advanced Micromachined Electronic Devices
Pr. Hideki HASHIMOTO	Micro robotics and Man-Machine Interface
Pr. Yasuhiko ARAKAWA and Takao SOMEYA	Nanophotonics and Quantum Optics
Pr. Teruo FUJII	Microfluidic

Table 2 French permanent researchers from CNRS (Current members are written in bold)

French CNRS Researcher	French Laboratory	Stay at LIMMS/CNRS-IIS
Dr. Michel de LABACHELERIE	IMFC, Besancon	until June 1995
Dr. Moussa HOUMMADY	IMFC, Besancon	Jan.1995 - August. 1997
Dr. Dominique COLLARD	IEMN, Lille	Jan. 1995 - September 1997
Dr. Christophe GORECKI	IMFC, Besancon	October 1995 - October 1998
Dr. Elisabeth ORSIER	CEA/LETI, Grenoble	March 1996 - September 1997
Dr. Patrice MINOTTI	IMFC, Besancon	September 1996 - October 1998
Dr. Bruno LE PIOUFLE	LESIR/ENS Cachan, Rennes	October 1997 - October 1999
Dr. Jean Philippe GOUY	IEMN, Lille	April 1998 -
Dr. Stanislas KRAWCZYK	LEOM, Lyon	September 1998 -
Dr. Tarik BOUROUINA	IEF, Orsay	November 1998
Dr. Gilbert REYNE	LEG, Grenoble	May 1999 -
Dr. Jean-Bernard POURCIEL	LAAS, Toulouse	November 1999

Table 3 French post-doctoral researchers (Current menbers are written in bold)

French Post-doctoral researcher	PhD French Laboratory	Stay at LIMMS/CNRS-IIS
Dr. Dominique CHAUVEL	IEMN, Lille	Feb. 95 - Jan 97
Dr. Christian BERGAUD	LAAS, Toulouse	March 95 - Dec. 96
Dr. Franck CHOLLET	IMFC, Besancon	March 95 - March 97
Dr. Lionel BUCHAILLOT	IMFC, Besancon	Oct. 95 - March 97
Dr. Etienne FARNAULT	IMFC, Besancon	March 96 - March 98
Dr. Philippe LANGLET	IEMN, Lille	Sept. 96 - Dec. 97
Dr. Eric BONNOTTE	IMFC, Besancon	Feb. 97 - Feb. 98
Dr. Amalia GARNIER	Louis Neel, Grenoble	Feb. 97 -Feb. 99
Dr. Jean PODLECKI	CEM, Montpelliers	March 97 - March 99
Dr. Gilles BOURBON	IMFC, Besancon	July 97 - July 98
Dr. Patrick SURBLED	IEF, Orsay	Feb.98 – Feb 00
Dr. Philippe HELIN	IEMN, Lille	March 98 – March 00
Dr. Sabry KHALFALLAH	LAAS, Toulouse	March 98 – Dec 99
Dr. Anne-Françoise OBATON	LPCML, Lyon	Jan. 99 – Jan 00
Dr Agnes TIXIER	IEMN, Lille	Jan. 99-
Dr Eric LEBRASSEUR	LPCML, Lyon	May 99 -
Dr Laurent GRISCOM	Univ. Rennes	April 00 -

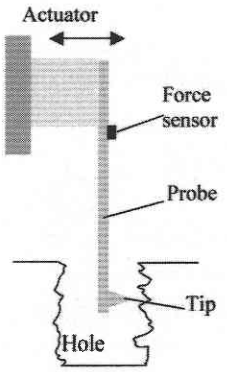

Fig. 1 Measurement of inner dimensions of deep holes with long probes

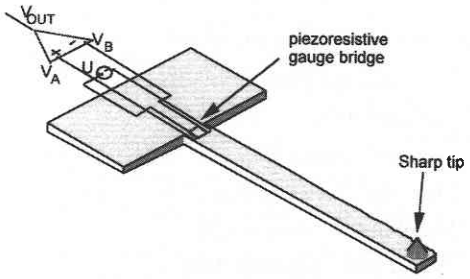

Fig. 2 Structure and operation principle

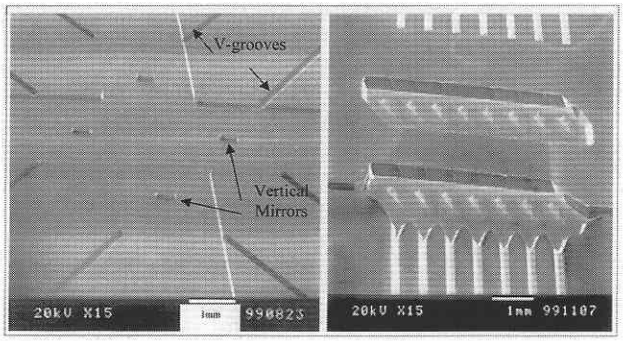

Fig. 3 Examples of optical structures for selfaligned matrix switch. 2×2 bi-directional (left) and 1×8 (right)

optical switches.

6.3 Self-Aligned Vertical Mirrors and V-Grooves Applied to a Self-Latching Matrix Switch for Optical Networks

Researchers: P. Helin, M. Mita, G. Reynes, T. Bourouina and H. Fujita

The group is developing a new and low-cost method to fabricate M*N matrix switch using wet etching of silicon. A self-aligned batch process was performed to fabricate vertical mirrors and V-grooves in (100) silicon wafer (figure 3). A self-latching system with electromagnetic force was developed and demonstrated to have no power consumption in holding the ON-OFF positions. Promising performance levels such as an insertion loss below 0.5 dB, sub-millisecond switching time (0.4 ms) and reliable

6.4 3D Microsystem Packaging for Interconnecting Electrical, Optical and Mechanical Microdevices to the external World.

Researchers: A. Tixier, Y. Mita, S. Oshima, J.P. Gouy, and H. Fujita

The research group is proposing a 3-dimensional microstates (3DM) packaging solution that integrates electrical, optical and mechanical microdevices. The packaging solution relies on precise machining of silicon pieces by means of ICP-RIE. In order to realize a pigtailed silicon platform with 8 WDM (wavelength division multiplex) filters, the team fabricated a motherboard with electrical connections, a V-groove board for the optical fibers to be mechanically aligned in the motherboard, a micromachined filters bar, and a receptacle board for interconnecting the filters bar to the motherboard. The motherboard has a recess in which the V-groove board is set. The V-groove board has a rectangular opening to which the receptacle board is inserted to get connected with the motherboard. These pieces are mechanically assembled with a pair of tweezers. Optical characterization of the 3DM has shown a clear tuning effect and insertion losses of less than 6 dB.

6.5 2D Micro-optical Scanner Based on Magnetostrictively Actuated resonator

Researchers: T. Bourouina, A. Gamier, H. Fujita, T. Masuzawa, T. Hiramoto, E. Orsier (CEA-LETI), J.C. Peuzin (Laboratoire de Magnetism Louis Neel CNRS)

One of the challenges facing the implementation of microsystems is supplying power without wires. The team has fabricated and successfully operated a new 2-dimensional micro optical scanner based on contactless magnetostriction (MS) actuation using only one coil. A Si cantilever coated with a sputter-deposited MS film (Terfenol-D or TbDycoFe alloy) is vibrated simultaneously in both bending and torsion modes at high frequencies (10-50 kHz). It exhibits the maximum optical depletion of +/-12 degrees at an excitation field of 4 mT; this is only 2% of the saturation field of the MS material. The compactness magnetic actuation enabled an easy wireless vacuum encapsulation that gave Q-factors of up to 1400, improving the vibration amplitude 4 times more than that in air. The first goal of the work was to evaluate magnetostriction actuation.

6.6 GaN and Related Compound MEMS and MOEMS

Researchers: S.K. Krawczyk, T. Someya, Y. Arakawa and H. Fujita

The objective of this work is to explore the potential of GaN and related compounds for MEMS and MOEMS applications. The group is developing demonstration devices comprising vertical or planar active/passive GaN optical components integrated with mechanical components. These devices include: (1) tunable light

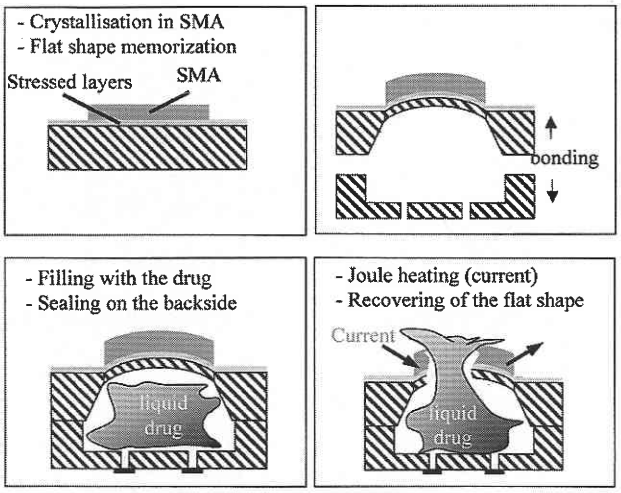

Fig. 4 Principle of the opening mechanism

sources and detectors for UV spectroscopy and high-temperature operation, based on GaN photo-detectors, LEDS and VCSELS integrated with electrically controlled vertical optical cavity', (2) GaN sensor for multi-channel spectral analysis', (3) pressure sensors that use planar GaN optical guides and Mach-zehnder interferometers located over a membrane. Modeling and simulation results indicate the feasibility of the projected devices, and test structures have been designed. Process development is in progress to fabricate demonstration devices. This work has implications for harsh-environment applications as well as biological/chemical analysis, environmental control, and solar-blind detector applications.

6.7 Implantable Microsystems for Drug Delivery

Researchers: P. Surbled, B. Le Pioufle and H. Fujita

Most implantable drug delivery microsystems under study present reliability problems as all the drug is contained in one microreservoir. The LIMMS group's approach is to develop a safe design looking like blister-packed pills, in which the drug is shared in thousands of independent microreservoirs. A one-shot valve, whose rupture is ensured by shape memory alloy actuation (figure 4), closes each one. SMAs have been optimized for operation just above the body temperature. An original actuation mechanism has been developed and successfully tested for the drug delivery microstates

6.8 Bio-Microsystem for Cells Manipulation: Application to the Gene Transfection

Researchers: B. Le Pioufle, P. Surbled, A. Tixier, H. Nagana, Y. Murakami*, E. Tamiya*, H. Fujita (* JAIST)*

The motivation of this work is to increase efficiency of gene transfection techniques. The work is collaboration between LIMMS and JAIST (Japan Advanced Institute of Science and Technology), with the LIMMS members working on micromachining aspects of the bio-microsystem and the JAIST researchers contributing expertise on biochemistry and biology. The group aims at developing a microchambers array capable of trapping ill cells (figure 5), treating them to insert the appropriate gene, controlling the insertion, and eliminating non-transfected cells. The bottom of the chambers is covered with gold for antibodies immobilization, while the outer pad of the clambers is made of polyimide (or other hydrophobic and biocompatible materials). The researchers have overcome the two main difficulties: 1) trapping isolated cells on specified parts of the microstates by means of antibodies, and 2) materializing high-density array of thin microcapillaries leading DNA up to the trapped cells.

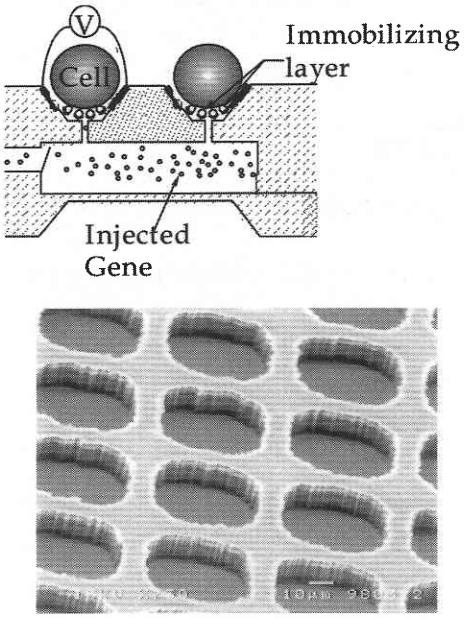

Fig. 5 Gene transfection system Microchambers array

7. Conclusion

LIMMS is a successful example of international collaboration in scientific research. More than 125 publications and communications during the last 5 years are obtained over more than 20 joint projects. Moreover, The IEEE MEMS2OOO international conference held on January 23-27 in Miyazaki, Japan accepted four papers submitted by LIMMS research groups, showing the high standard of research being pursued in the joint research framework. Challenging new projects are beginning, such as those on microfluidics. All the French post-docs have found a job after their LIMMS stay, previous CNRS LIMMS members continue to investigate micromechatronics in their home labs in France in collaboration with Japanese laboratories. Both the French and Japanese sides feel benefits from the collaboration.