

Recent Studies in the field of Molecular Electronics and Bioelectronics in Japan.

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This article will provide a brief review of the history and present targets in the field of molecular electronics and bioelectronics in Japan along with my personal impressions.

In 1981, F. L. Carter of the Naval Research Laboratory, U.S.A., proposed a new concept for advanced electronics that uses molecules and their assemblies called "Molecular Electronics Devices (MEDs)". At that time, the discussion of post-silicon devices was a hot topic because LSI-based microprocessors fabricated using the conventional lithographic techniques had already been predicted to reach to their technical limits in accord with Moore's law. The π -conjugated polymers and charge-transfer complexes were already being considered as future materials for fabricating nanometer-scale wiring and molecular-size transistors and memories. However, MEDs were still only a dream, since we had yet to develop the tools necessary to fabricate nano-devices.

In the meantime, some important engineering methodologies for use in molecular handling were developed. One was the Organic Molecular Beam Epitaxy (OMBE) technique, which enables molecules to adsorb on a clean single-crystalline surface one by one in ultra-high vacuum. Another was the Langmuir-Blodgett (LB) technique, in which one can stack monomolecular films on a solid substrate from the water surface. Both techniques allowed us to have molecularly ordered ultra thin films on a solid support.

In 1986, G. K. Binnig and H. Rohrer were awarded the Nobel Prize for the development of Scanning Tunneling Microscopy (STM). Subsequently, several other scanning probe microscopes, such as the atomic force microscope and the near-field optical scanning microscope, were introduced. Thus, we had finally obtained the tools needed to manipulate individual atoms and molecules.

In step with the worldwide movement towards the study of molecular engineering and bioelectronics, Japanese scientists working in industry, academia, and national institutes established in 1985 a new scientific organization devoted to the field of "Organic Molecular Engineering" as part of the Japanese Society of Applied Physics (JSAP). This group was the predecessor of the present division known as Molecular Electronics and Bioelectronics (M & BE). The constituent members belonged to not only JSAP but also The Chemical Society of Japan (CSJ), The Society of Polymer Science, Japan (SPSJ), The Institute of Electronics, Information and Communication Engineers (IEICE), and The Institute of Electrical Engineers of Japan (IEEEJ). The annual meetings of JSAP were the venue for the presentations of approximately 40 to 50 papers in one special session of "Organic Electronics" in the field of Applied Physics, and in seven regular sessions of "Fundamental Properties and Molecular Design", "Fabrication and Characterization", "Functional Materials and Devices", "Liquid Crystal", "Biological Applied Physics", "Medical Engineering", and "New Fields and New Materials".

In 1991, the small "Organic Molecular Engineering" group was formally recognized as the M & BE division of JSAP. Subsequently, publication began of the special journal "Molecular Electronics and Bioelectronics" that is written in Japanese (see Fig. 1). The periodic journal is distributed to all the members of the division. At the first annual meeting in 1991, six sessions were organized: 1) Fundamental phenomena and molecular design; 2) Fabrication and characterization; 3) Electrical properties and devices; 4) Optical properties and devices; 5) Liquid crystalline; and 6) Biological application. In those days, second and third harmonic generations (SHG and THG) in

nonlinear optics (NLO) with organic substances were the main areas of study in this field in Japan. The main targets of these studies were the development of optical devices for use in fast-photoswitching and wavelength conversion applications. Organic compounds were still not passive compartments in the electronic or optical devices compared with inorganic materials. However, their multiple optical properties, such as NLO, photochromism, thermochromism, electroluminescence, etc., were quite attractive.

In 1987, C. S. Tang of Eastman Kodak, U.S.A., and T. Tsutsui and S. Saito of Kyushu University, Japan, independently developed light emitting diodes composed of organic dyes. Afterwards, organic electroluminescent (EL) devices piqued the interests of industry. The annual meetings held by JSAP and the special symposiums on organic EL devices organized by the M & BE suddenly attracted large audiences. It did not take much time for the first EL display to come to market. A Japanese manufacturer introduced in 1989 a monochromatic and small display for use in car audio systems, while full-color EL displays would first hit the market in 2002 as mobile

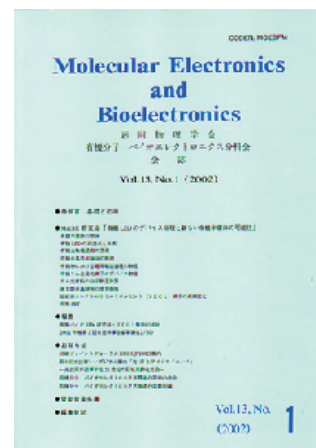


Figure 1. Periodical published by M & BE Division.

phone displays.

In 1999, we shuffled the sessions to create six regular sessions: 1) Fabrication, characterization and fundamental properties; 2) Molecular electronics; 3) Molecular photonics; 4) Liquid crystal; 5) Polymer and soft materials; and 6) Biology, medical engineering, and biotechnology. Two special sessions were added to complement the above; (A) Organic EL and (B) Self-assembly.

As shown in Table 1, the themes of the symposiums organized by M & BE, as part of the annual JSAP meetings, have gradually shifted from basic and fundamental research regarding the future of molecular electronics and bioelectronics, to themes highlighting the study of applications for organic devices. Next year, we are planning to introduce two new special sessions, "Molecular and bio-nanotechnology" and the "Organic electronic devices", to replace "Organic EL" and "Self-assembly".

In March 2000, we had the first joint symposium on molecular electronics with CSJ entitled "The future aspects and remaining subjects for molecular electronics in the 21st Century – Molecular design and synthesis, and from device to computer". During that symposium, nearly 200 participants closely discussed one topic, the breakthroughs in nanoscale devices, especially the single molecular devices.

Meanwhile, we held the first international conference on molecular electronics and bioelectronics (M & BE1) at Awaji island in March of 2001. At this conference, we held five sessions with 259 participants from eight countries. The titles of the sessions were: 1) Molecular nanoelectronics; 2) Fabrication and characterizations of organic thin films; 3) Optoelectronic and EL devices; 4) Bioelectronics; and 5) Single molecular electronics. These meetings presented a good opportunity for researchers to discuss the worldwide

upsurge in interest in the field of molecular electronics and bioelectronics. Presently, we are planning to hold the second international conference on molecular electronics and bioelectronics (M & BE2) in the spring of 2003. Further information will appear on our home page, <http://annex.jsap.or.jp/support/division/MandBE/>.

Recently, the Japanese government as well as industrial concerns have begun to provide significant assistance to the study of nanotechnology and biotechnology. These are two areas that are positioned as promising candidates to represent the future of technology and science. We believe that the groundwork that we have established to create an interdisciplinary field of science and technology, an amalgamation of chemistry, physics, electronics, and bioscience, will help us to take the lead in the international competition in this new nano-world.

Table 1. The number of presentations and titles of symposium held by M&BE during JSAP annual meetings.

Time (Place)	Presentation (Number of Sessions)	Symposium (Title of Symposium)	
Spring, 1986 (Nihon Univ., Narashino, Chiba)	39(1)	0	
Autumn, 1986 (Hokkaido Univ., Sapporo)	40(1)	11	"Biomimetic and Molecular Device Materials"
Spring, 1987 (Waseda Univ., Tokyo)	45(1)	8	"Molecular Devices"
Autumn, 1987 (Nagoya Univ., Nagoya)	73(7)	11	"What is Molecular Electronics and Bioelectronics?"
Spring, 1988 (Hosei Univ., Tokyo)	111(7)	15	"Molecular Recognition – Toward Bioelectronics–" "Recent Aspects of Biological and Medical Measurement"
Autumn, 1988 (Toyama Univ., Toyama)	96(7)	14	"Precise Control of Functional Organic Materials and Their Properties" "Molecular Ultrathin Films"
Spring, 1989 (Chiba Univ., Chiba)	145(7)	16	"Recent Progress in Organic Nonlinear Optical Materials and Device Processing"
Autumn, 1989 (Fukuoka Institute of Technology, Fukuoka)	119(7)	10	"Layered Structure and Physical Properties of Smectic Liquid Crystal"
Spring, 1990 (Toyo Univ., Asaka, Saitama)	223(7)	17	"Organic thin film electronic devices focused into electroluminescence" "New development in characterization techniques of organic thin films"
Autumn, 1990 (Iwate Univ., Morioka)	184(7)	46	"Organic Thin Film Device of Electroluminescence" "New Phase in Characterization Techniques of Organic Thin Films"
Spring, 1991 (Tokai Univ., Shonan)	268(7)	19	"New Development in Orientation-Controlled Molecular Films" "Ultrathin Film Electronics with Well-Defined Molecular Orientation" "How to measure indirectly Brain Function"

Time (Place)	Presentation (Number of Sessions)	Symposium (Title of Symposium)	
Autumn, 1991 (Okayama Univ., Okayama)	204(7)	13	"Neural Network and its Application" "Interface Controlled Organic Thin Films"
Spring, 1992 (Nihon Univ., Narashino, Chiba)	249 (7)	19	"Dynamics and Device Performance of Liquid Crystals" "Organic Second Harmonic Nonlinear Optical Devices"
Autumn, 1992 (Kansai Univ., Osaka)	192 (7)	13	"Molecular Machine in Biological Organism" "Electronic Device Application of Conductive Polymers"
Spring, 1993 (Aoyama Univ., Tokyo)	262(7)	12	"Molecular Electronics" "Phthalocyanine as Optoelectrical Material"
Autumn, 1993 (Hokkaido Univ., Sapporo)	225(8)	12	"Fabrication characterization and application of two-dimensional protein assemblies" "Molecular nanotechnology (II)"
Spring, 1994 (Meiji Univ., Tokyo)	260(8)	11	"Ion conduction in liquid crystal and high purity liquid crystal device" "Biomimetic technology"
Autumn, 1994 (Meijo Univ., Nagoya)	213(8)	11	"Frontier study in fullerene – Function and application of fullerene thin film –" "Measurement of human body"
Spring, 1995 (Tokai Univ., Shonan)	296(8)	19	"Contact point between medical treatment and engineering" "Progress of organic nonlinear optical materials in last decade"
Autumn, 1995 (Kanazawa Institute of Technology, Kanazawa)	224(8)	17	"Observation and manipulation of biological supramolecules" "Electrical and optical properties of organic nano-structures"
Spring, 1996 (Toyo Univ., Asaka, Saitama)	286(8)	15	"Organic electroluminescent device – For practical use –" "Recent progress in liquid crystal display – Performance improvement by new mode"
Autumn, 1996 (Kyushu Sangyo Univ., Fukuoka)	240(9)	12	"New progress in self-assembled monolayer – LB, MBE and SAM –" "Magnetic effect and control of organic molecules and biological materials"
Spring, 1997 (Nihon Univ., Funabashi, Chiba)	308(9)	13	"Ultrahigh density molecular memory" "Motion in living things – From bacterium to human being –"
Autumn, 1997 (Akita Univ., Akita)	243(9)	14	"Self-aggregation and application of proteins" "Physical properties and application of organic fine particles"
Spring, 1998 (Tokyo Univ. of Technology, Tokyo)	293(9)	12	"Polysilane"
Autumn, 1998 (Hiroshima Univ., Hiroshima)	251(8)	14	"Application and future development of near-field optical microscope in organic and biological fields" "Micro-organism living in extreme environment – Potential of micro-organism –"
Spring, 1999 (Tokyo Univ. of Science, Noda, Chiba)	292(8)	13	"Functions of biological molecules in water" "Organic non-crystalline solids"
Autumn, 1999 (Konan Univ., Kobe)	227(9)	12	"New front of imaging technique in medical engineering" "Recent aspect of organic photonics – Control and application of radiation field –"
Spring, 2000 (Aoyama Univ., Tokyo)	282(8)	12	"Nanotechnology and DNA" "Nano-interface-controlled molecular electronics"
Autumn, 2000 (Hokkaido Institute of Technology, Sapporo)	250(8)	7	"Development and application of carbon nanotubes"
Spring, 2001 (Meiji Univ., Tokyo)	307(8+1)	9	"Molecular synchronization – Molecular synchronized materials and their device and system application –"
Autumn, 2001 (Aichi Institute of Technology, Nagoya)	265(8)	12	"Frontier of surface plasmon bio-sensor" "Nanotechnology approached from biology – Potential of artificial supramolecules –"
Spring, 2002 (Tokai Univ., Shonan)	403(9)	31	"Towards the organic semiconductor devices" "Recent technology and its application of scanning probe microscopy for nanotechnology" "Organizing and functioning of interface"