MEMS Device Technology for Ubiquitous Services

Hiromu Ishii[†]*, Hiroki Morimura, and Junichi Kodate*

Abstract

This paper introduces microelectromechanical systems (MEMS) device technology at NTT Laboratories as a key hardware technology for achieving ubiquitous services based on novel functions in various fields such as information communications, security, and biotechnology.

1. Introduction

MEMS stands for microelectromechanical systems. It is an enabling technology that uses semiconductor microfabrication processes to develop integrated devices containing movable mechanical elements and electrical elements from the submicrometer level up to sizes of about one millimeter. MEMS promises to provide key high-performance devices featuring energy-saving characteristics, compact configurations, and high accuracy applicable to a diverse range of fields such as information communications, security, and biotechnology.

No doubt many readers have heard of the 1966 science fiction film “Fantastic Voyage”. To save an important person suffering from a blood clot in the brain, a submarine with a crew including doctors and scientists is shrunk to microscopic size and injected into the person’s bloodstream in an effort to destroy the clot. At the time of the film’s release, this was a completely fantastic idea, as the name of the movie implies. Of course, sending people into a person’s body is just a fantasy, but the idea of treating the body from the inside is starting to take shape through devices such as ingestible endoscopy capsules.

The microdevice concept dates back nearly 50 years to a famous lecture entitled “There’s Plenty of Room at the Bottom” given by Richard Feynman, who later was a joint recipient of the Nobel prize, at a 1959 meeting of the American Physical Society held at the California Institute of Technology [1]. In that lecture, Feynman mentioned the possibility of micromachines consisting of several thousand atoms. The lecture title means that there are still unexplored regions at the submicroscopic scale that mankind should investigate through science and technology. A chronology of inventions and discoveries that have become a basis for MEMS-related technologies is given in **Fig. 1**. Also given are the years of Nobel prizes awarded in recognition of these groundbreaking efforts. We can see that a number of great inventions and discoveries in the microworld that have become the basis for information communications and biotechnology of the present were made in the ten-year periods before and after Feynman’s lecture. These include the invention of the transistor, proposal of basic principles underlying integrated circuits, discovery of the double-helix structure of DNA, and invention of the laser.

We can view MEMS as technology for integrating in the microworld these inventions and discoveries of 20th-century science and technology for use in information communications, biotechnology, and other fields, and as a means for fabricating 21st-century devices and systems. At present, MEMS-related development proceeds on a field-by-field basis, such as optical-MEMS for optical communications, RF-MEMS for wireless communications including cell phones (RF: radio frequency), and bio-MEMS for medical care and biotechnology.

---

† NTT Microsystem Integration Laboratories
Atsugi-shi, 243-0198 Japan
Email: jishii@aecl.ntt.co.jp

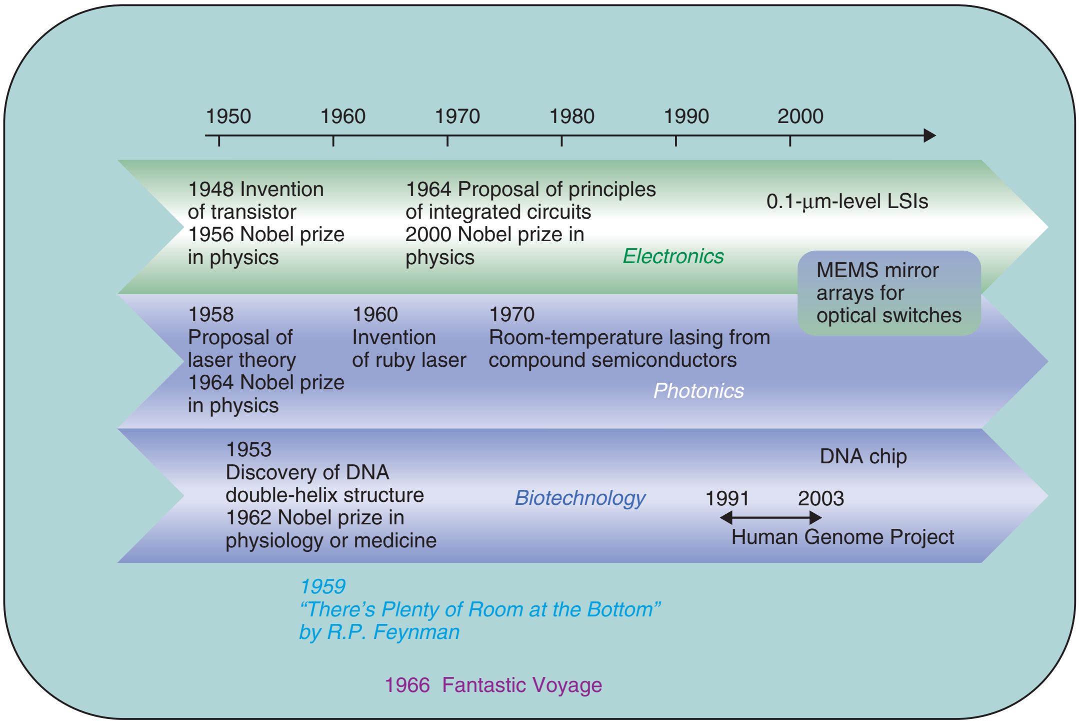

Fig. 1. Major scientific/technological inventions and discoveries related to MEMS.

2. MEMS and technology gap

NTT Microsystem Integration Laboratories has the mission of creating key hardware-oriented technologies to achieve a network environment that can provide safe, secure, and enjoyable broadband and ubiquitous services, as promoted by the NTT Group. At these laboratories, MEMS is positioned as a platform technology for creating ubiquitous services.

The graph in **Fig. 2** shows device design rule on the horizontal axis and film thickness on the vertical axis. RF-MEMS and optical-MEMS devices lie in the intermediate region between miniature devices like LSIs (large-scale integrated circuits) and Jisso technologies[*1] like multichip modules and printed wired boards. Jisso technologies have an important role in enabling MEMS devices with microscopic movable mechanical elements to interface with the outside world. Existing technologies used for Jisso, however, target elements with sizes of several micrometers to several millimeters or more, and they cannot by themselves be used to fabricate tiny MEMS devices.

If, however, submicrometer LSIs and MEMS devices using LSI fabrication technology can be fabricated and integrated on a silicon substrate, we can expect even greater downsizing and greater functionality including enhanced intelligence in MEMS devices. Yet, technology for fabricating LSIs is specialized for ultramicrofabrication, and it too is not necessarily applicable to the fabrication of MEMS devices. This leaves MEMS devices lying in a technology gap between LSIs and Jisso technologies. Consequently, despite the great expectations that MEMS has been generating, only a few MEMS devices have been successful in business, such as inkjet printer heads.

3. Seamless integration technology

To fill in this technology gap, NTT Microsystem Integration Laboratories is developing technology that uses the silicon technology cultivated with LSIs as a core technology for fabricating and converging ultrafine LSIs and MEMS devices on a silicon wafer

---

[*1] Jisso technologies: Use of the Japanese word *jisso* is being promoted to describe certain packaging technologies. The meaning is not limited to the conventional narrow meanings of mounting soldered components on printed wired boards, but is to have a wider range of meaning to combine and integrate all related technologies of materials, electronic components, and printed wiring boards via system design technology that serves comprehensive optimization for system integration.

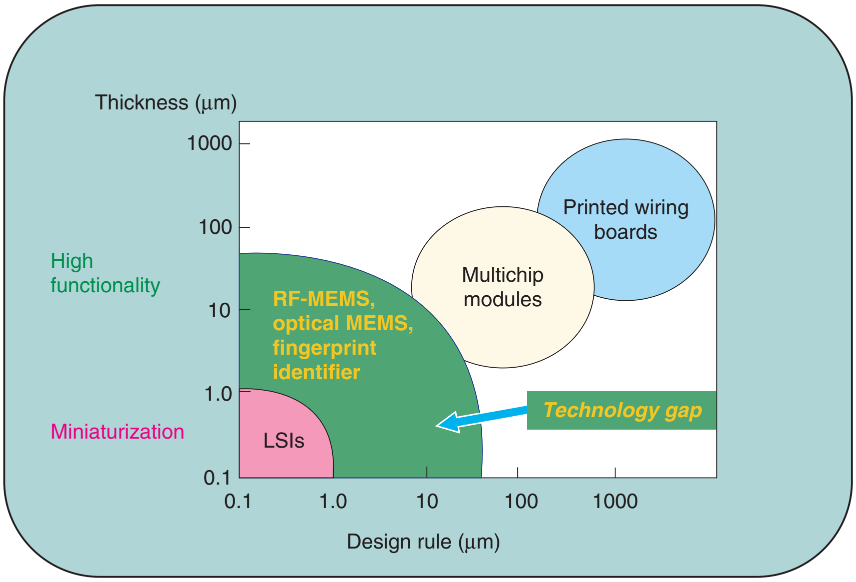

Fig. 2. Device technology and dimensions.

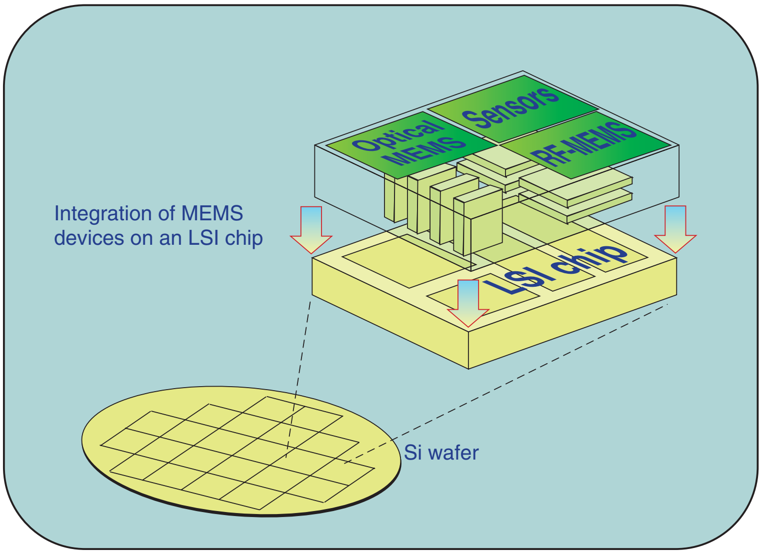

Fig. 3. Concept of seamless integration technology.

while providing a seamless bridge to Jisso technologies. This seamless integration technology (SeaiT), as it is known, aims to achieve smooth convergence between the heterogeneous functions performed by microelectronics and micromachines [2], [3].

As shown in **Fig. 3**, seamless integration technology for converging LSI and MEMS is intended to fabricate microscopic MEMS devices and wiring with a size of 10 µm to 1 mm made of metal or silicon in a layered manner. This calls for fabrication technology that will produce little damage to the LSI. Specifically, it must be a low-temperature process and must not use dry etching, which could damage LSIs, for example. Accordingly, to form MEMS structures without incurring such damage, we are developing low-temperature plating techniques as well as 10-µm-level thick-film multilevel interconnection technology using photosensitive organic resins and other advanced materials [4].

4. Toward high-yield and high-reliability MEMS devices

MEMS devices feature microscopic movable mechanical elements. A typical example is the switches in RF-MEMS devices. To prevent damage to movable parts and achieve high-yield fabrication of these devices, we need a technology that can protect movable parts until their packaging is completed. To this end, we are developing a spin-coating film transfer and hot-pressing (STP) technology [5], i.e., a film-growth technology for sealing movable parts, to be used from the materials/process stage to the device stage.

Microscopic movable mechanical elements can also become affixed to an electrode and stop moving in the course of being driven an excessive voltage. This "sticking" phenomenon is a particular problem for MEMS devices having movable parts. Once sticking occurs, the movability cannot be restored, so it is important that this problem is addressed if MEMS devices having movable mechanical elements are to become practical. Studies are now being performed on a technique for preventing sticking and achieving high-reliability driving of MEMS devices by coating movable parts and electrodes with electrodeposited organic thin films [6].

5. MEMS devices in development

Seamless integration technology enables the formation on LSIs with structures having dimensions or thicknesses that are hard to achieve by existing technologies. This should lead to highly functional MEMS chips featuring an array of MEMS devices or MEMS that integrate new functions that could not be achieved with LSIs or existing MEMS devices alone.

With the aim of providing safe and secure ubiquitous services, NTT Microsystem Integration Laboratories is developing a MEMS fingerprint authentication sensor [7], a MEMS mirror array as an element of a MEMS optical switch module [8] (a key device in the next-generation network), and an RF-MEMS chip for wireless terminals [9]. The other selected papers in this issue describe seamless integration technology in more detail and introduce these MEMS devices.

6. Conclusion

Looking to the future, we plan to develop various MEMS devices and increase their level of integration and functionality with the aim of refining our seamless integration technology and achieving safe, secure, and enjoyable ubiquitous services.

References

[1] R. P. Feynman, "There's Plenty of Room at the Bottom," J. MEMS, Vol. 1, No. 1, pp. 60–66, 1992. http://www.its.caltech.edu/~feynman/plenty.html

[2] H. Ishii, S. Yagi, K. Saito, A. Hirata, K. Kubou, M. Yano, T. Nagatsuma, K. Machida, and H. Kyuragi, "Microfabrication Technology for High-speed Si-based Systems," Proc. Micromachining and Microfabrication, SPIE, Vol. 4230, pp. 43–51, 2000.

[3] H. Kyuragi, H. Ishii, and K. Machida, "Seamless Integration Technology for System Devices," NTT R&D, Vol. 50, No. 7, pp. 450–455, 2001 (in Japanese).

[4] H. Ishii, T. Minotani, Y. Royter, S. Yagi, K. Kudou, M. Yano, T. Nagatsuma, K. Machida, and H. Kyuragi, "Microfabrication Technology for Millimeter-wave Photonic Systems on Si," IEEJ Trans. SM., Vol. 124, No. 4, pp. 136–142, 2004.

[5] K. Machida, H. Kyuragi, H. Akiya, and K. Imai, "Novel Global Planarization Technology for Interlayer Dielectrics using Spin on Glass Film Transfer and Hot Pressing," J. Vac. Sci. Tech., Vol. 16, No. 3, pp. 1093–1097, 1998.

[6] T. Sakata, H. Ishii, Y. Okabe, M. Nagase, T. Kamei, K. Kudou, M. Yano, and K. Machida, "Anti-Sticking Effect of Organic Dielectric Formed by Electrodeposition in Microelectromechanical-System Structures," Jpn. J. Appl. Phys., Vol. 44, No. 7B, pp. 5732–5735, 2005.

[7] N. Sato, K. Machida, H. Morimura, S. Shigematsu, K. Kudou, M. Yano, and H. Kyuragi, "MEMS Fingerprint Sensor Immune to Various Finger Surface Conditions," IEEE Trans. Electron Devices, Vol. 50, No. 4, pp. 1109–1116, 2003.

[8] H. Ishii, M. Urano, Y. Tanabe, T. Shimamura, J. Yamaguchi, T. Kamei, K. Kudou, M. Yano, and Y. Uenishi, "Fabrication of Optical MEMS Switches Having Multilevel Mirror-drive Electrodes," Jpn. J. Appl. Phys., Vol. 43, No. 9A, pp. 6468–6472, 2004.

[9] K. Kuwabara, N. Sato, T. Shimamura, H. Morimura, J. Kodate, T. Sakata, S. Shigematsu, K. Kudou, K. Machida, M. Nakanishi, and H. Ishii, "RF CMOS MEMS Switch with Low Voltage Operation for Single-Chip RF LSIs," Tech. Dig. IEDM 2006, pp. 735–738, IEEE, 2006.

Hiromu Ishii

Senior Research Engineer, Supervisor, Group Leader, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.S., M.S., and Dr.Sc. degrees in chemistry from the University of Tokyo, Tokyo, in 1982, 1984, and 1996, respectively. He joined the Atsugi Electrical Communication Laboratories, Nippon Telegraph and Telephone Public Corporation (now NTT) in 1984. He has been engaged in R&D of atomic layer epitaxy, chemical vapor deposition, and multilevel interconnection processes for ULSIs. He is currently working on the development of new device integration technologies using MEMS. He is a member of the Japan Society of Applied Physics (JSAP), the Physical Society of Japan, the Chemical Society of Japan, the Electrochemical Society, and IEEE.

Hiroki Morimura

Senior Research Engineer, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.E. degree in physical electronics, the M.E. degree in applied electronics, and the Dr.Eng. degree in advanced applied electronics from Tokyo Institute of Technology, Tokyo, in 1991, 1993, and 2004, respectively. He joined NTT in 1993. He has been engaged in R&D of low-voltage, low-power SRAM circuits, fingerprint sensing circuits, and single-chip fingerprint sensor/identifier LSIs. He is currently researching circuit design technologies for CMOS-MEMS. He received the 2004 CSS Best Paper Award and the 2006 IEICE Best Paper Award. He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, and JSAP.

Junichi Kodate

Senior Research Engineer, Supervisor, MEMS Devices Research Group, Smart Devices Laboratory, NTT Microsystem Integration Laboratories.

He received the B.E. and M.E. degrees in electrical engineering from Tohoku University, Miyagi, in 1989 and 1991, respectively. He joined NTT LSI Laboratories in 1991. Since 2003, he has been engaged in the development of RF CMOS circuits and RF-MEMS devices. His current interests include RF circuits and MEMS devices including RF-MEMS, integrated MEMS devices and its applications. He is a member of IEEE, IEICE, and JSAP.