



# Professor Fujio Masuoka's Passion and Patience Toward Flash Memory

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## 1. Preface



The main feature of Flash Memory is that it can retain data when the power is shut down, which is an indispensable part of a modern electronic system. System designers benefited greatly when the electrically erased and programmed nonvolatile Flash Memory became available. DRAM has been mainly used for the main memory to store the data and program in the computer. DRAM is fast, however, it can no longer retain data when the power is shut down. It is called a volatile memory. Therefore, personal computers have external storage devices of Hard Disk Drive (HDD) at any cost. This replacement of HDD by Flash Memory has been just got started. Flash Memory has a variety of advantages; low cost, light, low power (eco-friendly), vibration free, and resistant to moisture, etc. These good points of Flash Memory have innovatively produced a digital camera, cellular phone, and removal storage card. And now, Solid State Disk (SSD) has been fed directly into a computer in the replacement of HDD.

The rotation speed of HDD limited the computer speed because the rotation speed is restricted mechanically, while the speed of the CPU and DRAM in the computer is getting faster and faster. Flash Memory is able to bridge this gap, so that it is now coming up with the new computer architecture. Therefore, the features of Flash Memory described above are not only the mere replacement of the storage devices, but also the strong connection to the innovative industrial products.

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In Flash Memory, there are, as everyone knows now, NOR-type [1] [2], and NAND-type [3]. The key player for the cellular phone is NOR-type, while the key player of the digital camera, removal storage card, and SSD is NAND-type. And, it is Prof. Fujio Masuoka who is the inventor of both NOR- and NAND-type Flash Memory, and is the key player to develop them up to now.

## 2. Naming Flash Memory

It was the beginning of June in 1984. The incident has been burned on my brain with vivid clarity still now. Several engineers chatted with Dr. Masuoka behind my desk. At that time of 1984, every Japanese semiconductor vendor competed fiercely with each other for developing DRAM, and Toshiba, which aimed at No. 1 DRAM maker, focused every resource on developing DRAM as much as possible. And Dr. Masuoka was a manager for designing all memory products, such as DRAM, SRAM, and EEPROM, etc. To our surprise, Dr. Masuoka was developing a new device under the table in such a busy environment. It was in such an environment where normal people could hardly endure a heavy responsibility. Dr. Masuoka broke the ice to his surrounding engineers, “As I will submit a paper on this new device, which can electrically erase the data at once to IEDM in December, I am looking for its good name...” There was silence for a while, and then Mr. Ariizumi, who used to be SRAM Design Manager, proposed, “Masuoka-san, how about Flash Memory?” “Oh, it’s simple and a very good name! I like it,” shouted Dr. Masuoka, and he shot to Mr. Ariizumi, “By the way, how

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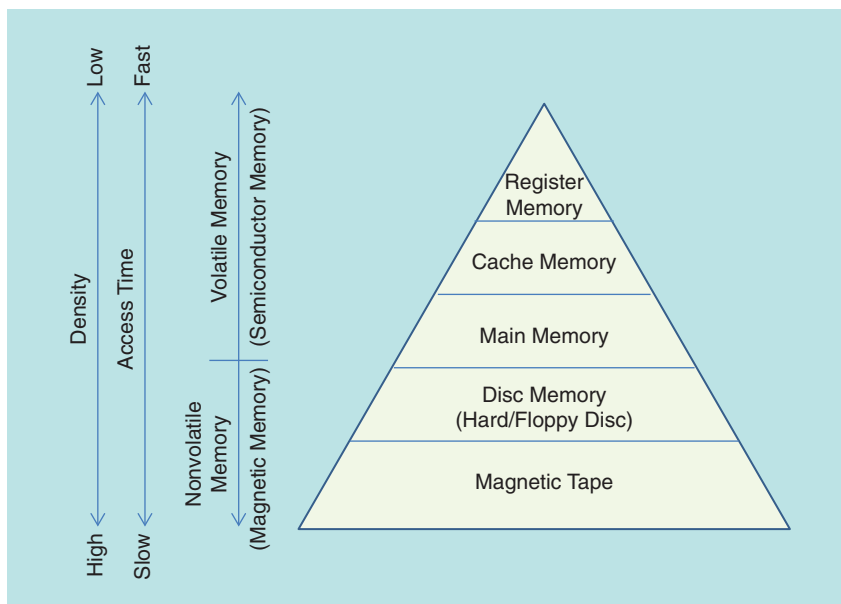
do you hit upon the Flash Memory?” Then, Mr. Ariizumi answered, “The device which Masuoka-san invented is able to erase the whole chip data, so I have imagined a flash which lightens in a camera.” Dr. Masuoka soon submitted a paper with a title of Flash Memory to IEDM [1]. At this time, nobody could further imagine about the revolution of the camera industry, where it was Flash Memory that was used as a storage media for digital cameras and that replaced the conventional film. Flash Memory was such a very friendly name in comparison with the conventional non-volatile memory with a long name of Electrically Erasable and Electrically Programmable Read Only Memory, that Intel liked this name of Flash Memory soon after the IEDM’84, they established the Flash Memory Group led by Dr. Richard D. Pashley.

## 3. Cultivate Research Scientists with Passion

Dr. Masuoka also put his heart and soul into recruiting many competent engineers. It is because neither an expensive machine nor a fast computer produces a new technology, but people can produce what is new. This was a basic concept of Dr. Masuoka, and he believed a policy that the research and development could be performed by cultivating research scientists. Fresh recruits were not assigned to the worksite for the whole year of entering, but

educated by a special program for becoming a world-class researcher in future. Dr. Masuoka’s program was so severe that a magazine of ‘President’ introduced the strict program as ‘Strict Yacht School’ at that time. “Research must be new. And a researcher must make the evidence. The evidence is 1) Patent, 2) Paper, and 3) Product. And we are doing the work for rewriting textbooks,” we listened to Dr. Masuoka’s teaching every day. Thinking back now, those years were really satisfying moments in my life.

The target of ‘Masuoka Yacht School’ was presenting a paper of everyone’s research result at a world-class conference. The tutors were also all over creation to achieve the target. For example, one of target conferences for presenting the research result is IEDM, which has a competitive acceptance rate of 30%. Dr. Masuoka kindly reviewed the submitting papers over and over again. On one day before the deadline, he returned to his house by the last train, and called to our office at around 2 am in the midnight. “Please read the introduction!” Mechanically, I obeyed to read a few lines. Dr. Masuoka said, “It looks better, but it doesn’t get in. Never give up!” and he hanged up a telephone. Then, we worked through the manuscripts all through the night. The challenge was how to describe the research results visually for making it more comprehensively and making more



**FIGURE 1:** Memory hierarchy in the computer.

impacts on the reviewers. The notification of the paper acceptance made all our time and worked worthwhile. As an example, Table 1 summarizes the IEDM papers presented in 1988 from Dr. Masuoka's group. At that time, all the papers submitted from his group were accepted by as high as 80% acceptance rate. The speakers were instructed to rehearse many times until the current presentation day of IEDM. And we presented our papers on the big stage of IEDM under the chandelier

the world-class journals. The world-class journals are, in our field, IEEE Transactions on Electron Devices, Journal of Solid-State Circuits, and Electron Devices Letters, etc." It was to further elaborate on the research results, and to submit them to the IEEE journals. We could not have a moment relaxation after returning to Japan, and had to work through the research again. Furthermore, we were instructed to write down the paper and patent at home in the midnight and weekend, because we

***Dr. Masuoka has been enshrined in the Consumer Electronics Association Hall of Fame by his great contribution to the earth-conscious electric appliance.***

of the ballroom. As I am one of persons who experienced it, I remember the great pleasure which was far beyond description.

Not only that. No sooner had we presented our papers at IEDM, Dr. Masuoka said, "Listen, the conference digest paper is not a real paper. Your target is to submit the papers to

had our own research work at the company. In this manner, we were trained to become not a salary man who worked only when he was at the company, but become a world-class professional researcher. Every time the paper was published and the patent was granted, Dr. Masuoka put the copied first page into the frame and

presented it on the wall. One day, there was no room for the frames on the wall. And Dr. Masuoka earnestly mentored us to earn the doctor degree if he or she entered Toshiba without Ph.D. I am one of them, and am deeply grateful to Dr. Masuoka.

#### **4. Exceptional Future Vision**

A lot of students visited Dr. Masuoka's laboratory for the job interviews. It was in around 1990, over 20 years ago from now. "Do you like to do jogging while listening to music? If we use the NAND Flash Memory which we develop here, an ear-hook phone can store the music, so that you can enjoy the music while jogging. Cool! Isn't it? Do you like to work with us?" Dr. Masuoka asked the students who came to his laboratory for the recruiting tour. At that time, the Walkman with cassette tapes was the main stream, and nobody thought of jogging with the bulky Walkman, and the CD Walkman, which came to market soon after it, was so weak for vibration that could not sustain jogging. Now, it is a common sense that not only the athletes before the game, but we can do jogging while listening to music. The students might probably have kept up with Dr. Masuoka's questions up here. But they were flabbergasted at his next word, "I will replace the HDD by this NAND Flash Memory!" The students looked confused. Not only the students most people at the company hardly understood this exceptional vision of Dr. Masuoka, because the bit cost of the HDD was three orders lower than that of the NAND Flash Memory at that time. In fact, Dr. Masuoka presented Figure 1 in his book published in 1992 [4]. In the book, it is described that Flash Memory has target devices of the HDD and Floppy Disk which should be replaced, and the market size of the Flash Memory is several times larger than that of DRAM, as shown in Figure 1 of the current hierarchy of the computer. Just the same as Dr. Masuoka's vision over 20 years ago, as mentioned at the beginning of the article, the application of the

Flash Memory is unlimited, such as not only iPhone and iPad of Apple use the Flash Memory, but also the HDD's in the personal computers are getting replaced by the SSD's. And now, the Flash Memory is penetrating into the Enterprise industry. The world-wide market size of the NAND Flash Memory last year surpassed \$30B. In the near future it is expected to become more than \$100B, which is unmatched in the history of the world, when all the HDD's in the personal computers are replaced by the SSD's, and the HDD's of the data station of Google and FaceBook, etc. are partially replaced by the SSD's. This is because the market share of not only the semiconductor memory but also the HDD is accounted. And also, many power stations in the world can be saved by replacing the HDD by the SSD. For this is what the final target of the NAND Flash Memory is all about, and there is no doubt at all that the NAND Flash Memory is earth-conscious 'Green Technology'. On the other hand, the NOR Flash Memory is used for not only cellular phone, but also every home electric appliance which uses a battery or electricity, such as the water heater, refrigerator, and air conditioner, starting with the

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engine control machine of the automobile for the emission control in the United States.

Dr. Masuoka has been enshrined in the Consumer Electronics Association Hall of Fame by his great contribution to the earth-conscious home electric appliance and automobile. This is a remarkable accomplishment because Dr. Fujio Masuoka is the third Japanese to be awarded, after Mr. Konosuke Matsushita, a founder of Panasonic and Mr. Masaru Ibuka, a founder of Sony.

**TABLE 1. THE IEDM PAPERS PRESENTED IN 1988 FROM DR. MASUOKA'S GROUP.**

### 1988 IEDM

1. Shiota, Riichiroh; Endoh, Tetsuo; Momodomi, Masaki; Nakayama, Ryojo; Inoue, Satoshi; Kirisawa, Ryouhei; Masuoka, Fujio, "An accurate model of subbreakdown due to band-to-band tunneling and its application," Page(s): 26-29.
2. Sakui, Koji; Hasegawa, Takehiro; Fuse, Tsuneaki; Watanabe, Shigeyoshi; Ohuchi, Kazunori; Masuoka, Fujio, "A new static memory cell based on reverse base current (RBC) effect of bipolar transistor," Page(s): 44-47.
3. Takato, Hiroshi; Sunouch, K.; Okabe, Naoko; Nitayama, Akihiro; Hieda, Katsuhiko; Horiguch, F.; Masuoka, Fujio, "High performance CMOS surrounding gate transistor (SGT) for ultra high density LSIs," Page(s): 222-225.
4. Sunouchi, Kazumasa; Takato, Hiroshi; Nitayama, Akihiro; Hieda, Katsuhiko; Horiguchi, Fumio; Masuoka, Fujio, "Double LDD concave (DLC) structure for sub-half micron MOSFET," Page(s): 226-229.
5. Momodomi, Masaki; Kirisawa, Ryouhei; Nakayama, Ryojo; Aritome, Seiichi; Endoh, Tetsuo; Itoh, Yasuo; Iwata, Yoshihisa; Oodaira, Hideko; Tanaka, Tomoharu; Chiba, Masahiko; Shiota, Riichiro; Masuoka, Fujio, "New device technologies for 5 V-only 4 Mb EEPROM with NAND structure cell," Page(s): 412-415.

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- [2] F. Masuoka, M. Asano, H. Iwahashi, T. Komuro, and S. Tanaka, "A 256K Flash EEPROM using triple polysilicon technology," in *Proc. IEEE ISSCC*, 1985, pp. 168-169.
- [3] F. Masuoka, M. Momodomi, Y. Iwata, and R. Shiota, "New ultra high density EPROM and Flash EEPROM cell with NAND structure cell," in *IEEE Tech. Dig. IEDM*, 1987, pp. 552-555
- [4] F. Masuoka, "Flash memory makes a big leap," *Kogyo Chosakai*, vol. 1, pp. 1-172, 1992.

Department of SoC R & D Center to develop 90 nm, 70nm, and 55 nm NAND Flash memory design. He moved to Sony Corporation in 2004, and served as a General Manager of Memory System Department. In 2007, he moved to NAND Products Group, Intel Corporation, where he was a Research Scientist. In 2009, he became a Visiting Professor of Tohoku University. In 2010, he joined Micron as Sr. Architect and Technologist-Memory Innovations. Also, since 2009, he has been a part-time professor of Waseda University, Tokyo, Japan.

Dr. Sakui is a member of the IEEE Electron Device Society, and served a Memory Coordinator for ITC (International Test Conference) in 2001, and a Technical Program Committee for NVSMW (Non-Volatile Semiconductor Memory Workshop), currently IEEE IMW (International Memory Workshop) from 1998 to 2012. He holds 90 US patents granted, and published over 24 technical papers. He received Kanagawa Governor Patent Award in 1997 and Kanto District Patent Award in 2005. In 2012, he became an IEEE Fellow, with the accompanying citation: "for the contribution to NAND flash memories."

### About the Author

**Koji Sakui** received the B.E. and M.E. degrees, both in instrumental engineering, from Keio University in 1979 and 1981, respectively, and the ph.D. degree from Tohoku University in 1995.

In 1981, he joined the Toshiba Research and Development Center, where he was engaged in the circuit design of DRAM's. Since 1990 he has been engaged in the development of high density NAND Flash memories. He managed Flash Memory Design

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