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Technology Trend of Flash EEPROM

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This paper presents the history of Flash memories and the basic concept of their functions and also reviews a variety of Flash EEPROMs so far. As Flash memories have two influential features, non-volatility and low cost per bit, they are expected to become a driving force after DRAMs to support the semiconductor industry for future thirty years, replacing hard and floppy disks which have a large market.

1. Introduction

The semiconductor business has been skyrocketing since Drs. W. Shockley, J. Bardeen and W.H. Brattain invented a bipolar transistor at Bell Laboratory of the United States in 1947. The transistor had such a great potential to replace vacuum tubes one after another, which were extensively used for a variety of electrical appliances, such as a radio, television set and communication system. Fig. 1 presents a history of the semiconductor business in the world. At the first stage from 1950 to 1970, a bipolar transistor contributed to the semiconductor business as a technology driver for twenty years[1].

The growth rate of the transistor business began to be saturated in 1970, however, a DRAM, a semiconductor memory was pioneered by Intel of the United States. DRAMs have drastically grown by replacing a magnetic memory in a core memory. Thereby, the semiconductor business at the second stage has kept dramatically growing with DRAMs as a technology leader. Now, the semiconductor business requires the third stage driver. The first requirement to become a technology driver is that there is a device to be replaced. There were vacuum tubes for bipolar transistors and core memories for DRAMs. The second requirement is that the device has a large market. There were radios and television sets for bipolar transistors and main memories in computers for DRAMs as a large market.

Table 1 summarizes the requirement for technology drivers. It is believed that the Flash EEPROMs must become a promising device to play the role of the third stage driver because there are hard and floppy disks as devices to be replaced and the market size of hard and floppy disks is several times as large as that of DRAMs. Fig. 2 shows the hierarchy of memory in computer systems and also illustrates the market scale for different kinds of memory devices along the horizontal axis and the performance of each device along the vertical axis. The magnetic storage media remain a strong force in the memory industry because they offer two important features not available with the conventional semiconductor memories such as DRAMs and the non-volatile EEPROMs. One is magnetic memories are non-volatile memories which can retain stored data without the power supply. The other is magnetic memories offer low cost per bit.

However, Flash memories also have above two features so that they are expected to become a driving force to support the semiconductor industry for future thirty years.

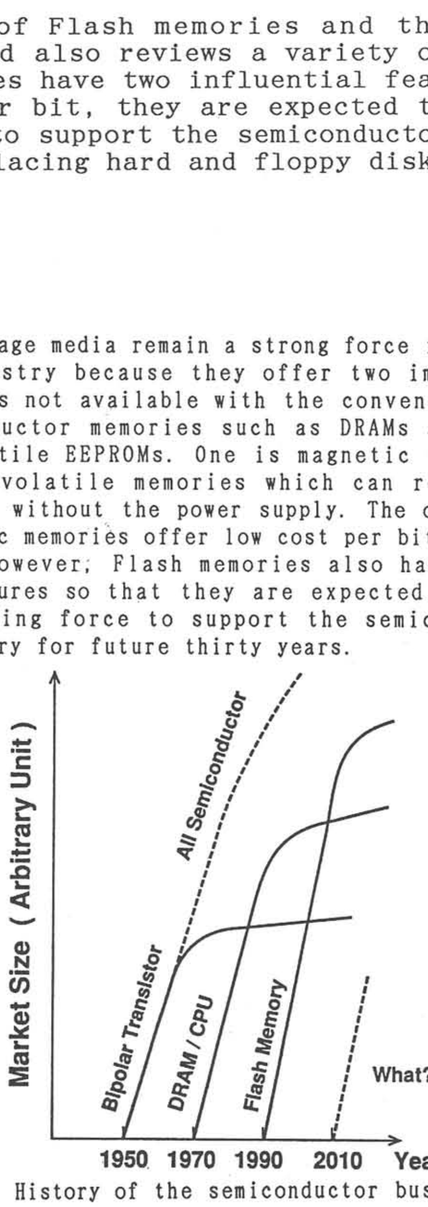

Fig.1 History of the semiconductor business in the world.

Table 1 Requirement for technology drivers.

New Devices	Replaced Devices	Market
Bipolar Transistor	Vacuum Tube	Radio Television Set
DRAM/CPU	Core Memory	Computer
Flash Memory	Hard• Floppy Disk	Computer• Personal Machine

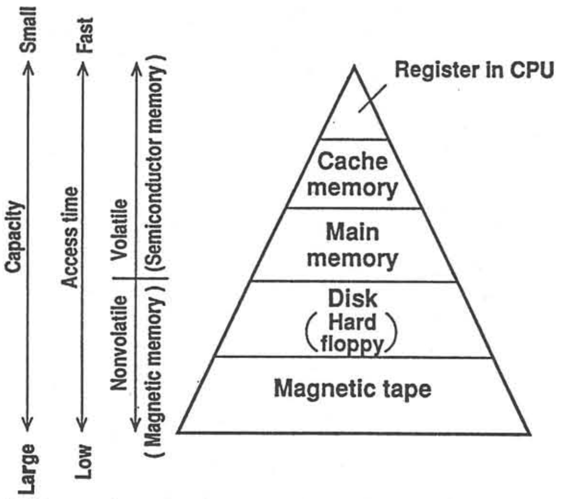

Fig. 2 Hierarchy of the memories in a computer system.

2. Flash EEPROM

A high bit cost was an unavoidable barrier for the conventional non-volatile EEPROMs to replace magnetic hard and floppy disks as memory devices because each bit consisted of two transistors, one select transistor and one memory transistor. The larger occupied area per bit costs the higher since the cost of semiconductor memory is proportional to its occupied area.

A Flash EEPROM was proposed as one of the solutions[2][3]. Fig. 3 shows the first Flash EEPROM, which consists of triple layers of polysilicon. The first polysilicon is used for the erase gate located between the field oxide and floating gate. The second poly silicon layer works as the floating gate which is the same as that in a UV-EPROM. The third polysilicon layer functions as a word select line during programming and reading. The cell is programmed by the same channel hot-carrier injection mechanism as that used in a UV-PROM. Flash erasing is achieved by using field emission of electrons from the floating gate to the erase gate. The select enhancement transistor is used as a stopper of DC current path for an over-erased cell. As a result, Flash EEPROMs achieve a single transistor per bit and perform chip erase rewrite functions, offering a low cost production. Fig. 4 compares the first proposed Flash EEPROM, the ultra-violet erasable UV-EPROM and the conventional EEPROM. Both Flash EEPROMs and UV-EPROMs occupy the much smaller cell area than the conventional EEPROMs, however, UV-EPROMs require ceramic packages with glass for the transmission of ultra-violet radiation. Conversely, Flash EEPROMs can erase the cell data electrically, so that they are able to be enclosed in plastic packages which cost much less than the ceramic ones with glass. Therefore, Flash EEPROMs can be produced at a lower cost than UV-EPROMs, although both occupy the same area per bit.

Intel presented the 256kbit Flash memory chip at the 1988 ISSCC[4]. The structure of Intel's Flash memory is the same as UV-EPROM, as shown in Fig. 5. Intel's cell is programmed by a hot electron injection mechanism and erased by field emission of electrons from the floating gate to the source, same as Toshiba's.

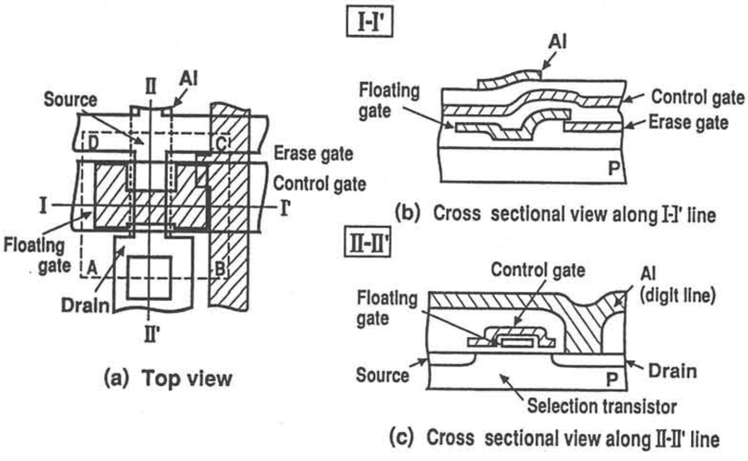

Fig. 3 Original Flash EEPROM proposed by Toshiba.

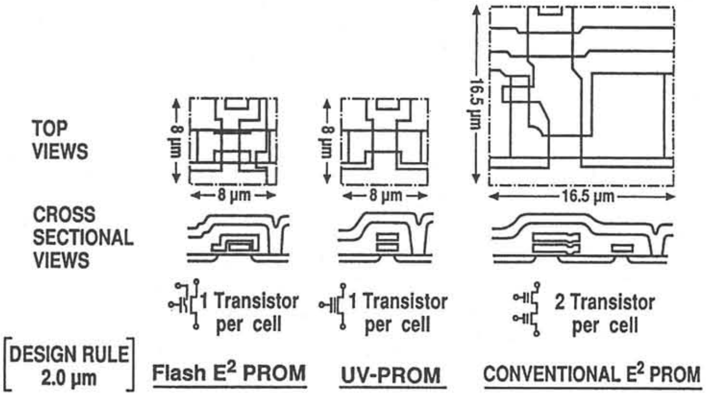

Fig. 4 Comparison between new device and conventional devices.

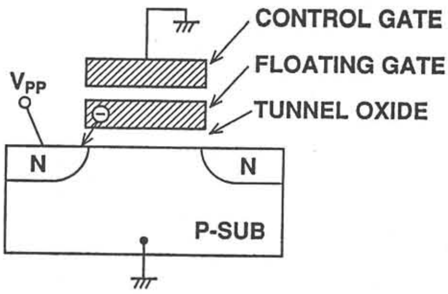

Fig. 5 Intel's Flash memory cell.

3. NAND EEPROM

If Flash memories are to completely replace magnetic hard and floppy disks, they must rewrite the same sector units as the magnetic memory devices. This block rewritable function requires a small-divided peripheral circuit which enlarges the chip size of Flash memories since the original Flash memories remain compact by performing large-block erase functions. In order to solve these problems, Toshiba proposed a NAND EEPROM, the NAND structured cell of which arranges eight memory transistors in series, as shown in Fig. 6[5][6]. The NAND structured cell, fabricated by the conventional self-aligned double poly-silicon gate technology, has only one memory transistor, one forth select transistor and one sixteenth contact hole area per bit. This technology realizes a small cell area without scaling down the device dimensions, which is half of that of DRAMs', as shown in Fig. 7. NAND EEPROMs use Fowler-Nordheim Tunneling for both erase and write operations, enabling the device to adopt a 5V power supply for data writing with a charge pump circuit provided on chip[7].

Fig. 8 presents a micro-photograph of a 5V only 16M bit NAND EEPROM with 4K byte sector erase, which is currently produced by Toshiba. The die and cell sizes of 132.23mm^2 and 4.07um^2 are accomplished in a 0.7um ground rule. Table 2 compares the performance of NAND EEPROMs and other kinds of memories. Cost is still the most important issue in the memory fields and also it simply depends on the area per bit which memory cell occupies. Consequently, NAND EEPROMs hold a substantial potential as memory devices.

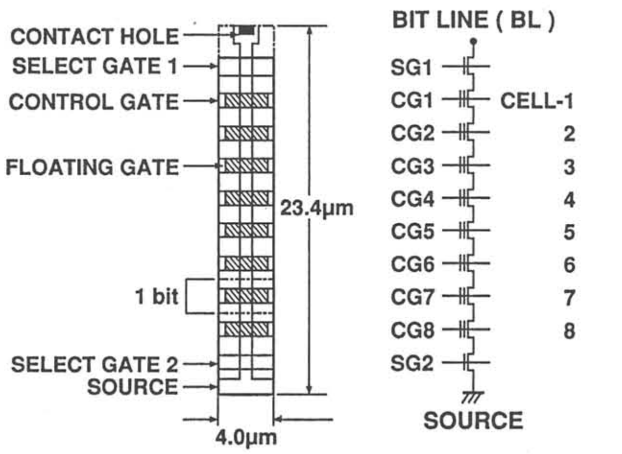

Fig. 6 Top view and equivalent circuit of the NAND EEPROM cell which arranges 8 memory transistors in series.

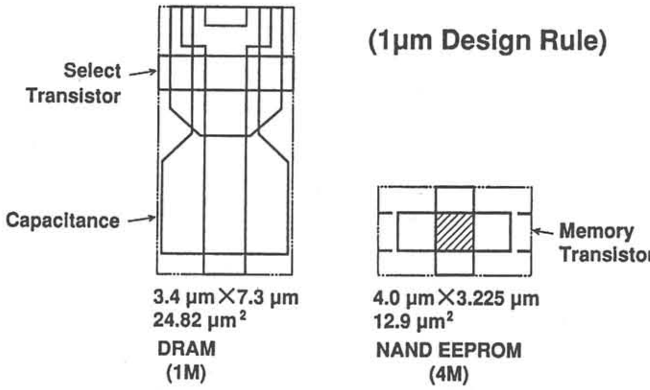

Fig. 7 Comparison of the cell size between DRAM and NAND EEPROM in a 1um ground rule.

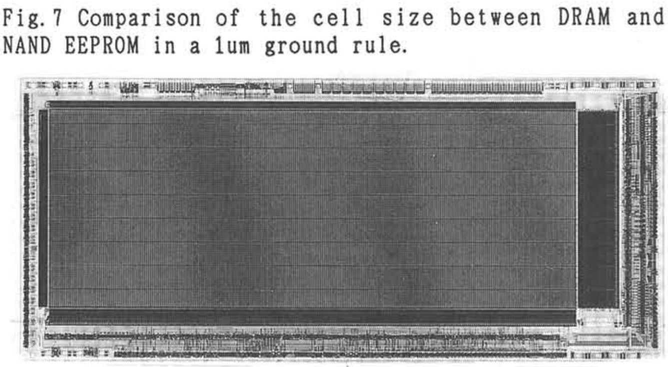

Fig. 8 Chip microphotograph of 16Mb NAND EEPROM.

Table 2 Comparison of NAND EEPROM with other types of memories.

Memory / Item	Semiconductor				Magnetism
	DRAM	Conventional EEPROM	Flash EEPROM	NAND EEPROM	Disk memory
Non-volatility	NO	YES	YES	YES	YES
Cell area ratio	2	6	2	1	More than 100
Read time ratio	1	1	1	10	10^5
(Example of value)	(50nsec)	(50nsec)	(50nsec)	(500nsec)	(5msec)
Number of permissible rewrites	∞	10^4 times	10^4 times	10^5 times	∞
Need of drive unit	None	None	None	None	Yes

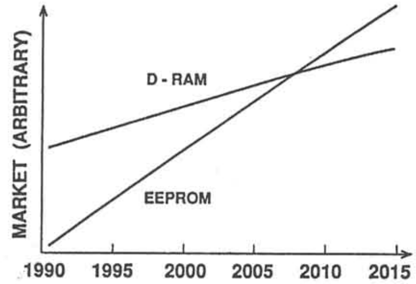

Fig. 9 Prediction for EEPROM developments.

4. Conclusion

DRAMs have been leading computer memories since they started to replace core memories. Flash EEPROMs are such promising semiconductor memories that they can have a substantial potential to replace hard and floppy disks, which are still served by the only magnetic memories as storage functions. Therefore, it is strongly expected that EEPROMs successfully inherit an ultra large market from the magnetic storage devices, which is five times as large as that of DRAMs', as Fig. 9 indicates a prediction for EEPROM developments.

References

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