Role of Non-Volatile Memories in Automotive and IoT Markets

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Abstract: *Semiconductor devices have been critical to recent innovations in the automotive industry. The improvements in the fuel-efficiency, safety, luxury, communication and Advanced Driver Assistance Systems (ADAS) in automotive world wouldn't have been possible without semiconductor integrated circuits. On-chip embedded flash is a key component in automotive microcontrollers (MCU) and certainly one of the most challenging elements to master. This paper addresses the role of non-volatile memories for automotive and Internet of Things (IoT) markets.*

Keywords: Embedded flash; Microcontrollers, Automotive; Internet of Things, IoT; Non-volatile memories; SuperFlash; MCU; NVM; OTP; MTP; FTP; Antifuse; Floating-gate memories; Charge-trap memories.

Introduction

Automotive applications have been a major growth catalyst for semiconductor integrated circuits (IC) over the last decade. There are multiple growth drivers for semiconductor IC contents in automotive vehicles. First of all, automotive vehicle demand fueled by a middle class has been increasing in BRIC (Brazil, Russia, India and China) countries. Second, government regulations for safety, fuel efficiency, and a reduced carbon footprint are forcing auto manufactures to put more control units in the vehicles. Third, consumer demands for added convenience and infotainment also means more control units. All of these factors combined are fueling the growth of semiconductor contents in the automotive vehicles. Automotive vehicles have multiple Electronic Control Units (ECU) for powertrain, safety, infotainment etc. controls. Each ECU can have multiple microcontrollers (MCU), which store the instruction code in a non-volatile memory.

The Internet of Things (IoT) is centered on providing distributed intelligence, sensing and connectivity to electronics around us. Distributed intelligence is provided by an MCU which stores the specific instruction code for an application in a non-volatile memory.

Embedded NVM Space and Usage

Before diving deeper into the non-volatile memory (NVM) usage in the IoT and automotive MCU devices, let's go over a map of the various types of non-volatile memories and understand how they fit into various applications. Figure 1 maps the various types of NVMs across endurance (x-axis), which is a measure of how many times the memory can be written, and memory density (y-axis). There are generally five types of in-field programmable NVMs available, OTP, FTP, MTP, EEPROM and embedded flash. An OTP (one-time programmable) memory by definition can be written once and is generally used for configuration bits, analog trimming, performance calibration, security bits etc. In some cases an OTP memory can be used (with multiple bits instantiations) as an FTP (few-times programmable) memory. The second in the figure is a true MTP memory, which is either based on an ONO stack or a single-poly floating-gate to build a poor man's multiple-time programmable non-volatile memory, but has limitation in the endurance side and because of its large cell size, is not cost effective beyond 16kb range. The third one in the figure is traditional EEPROM, which is suitable for data-storage applications as it is cost effective for small densities and offers high endurance. The last, but not the least, is embedded flash memory which has proven to be the most effective solution for both data-storage and code-storage solutions, and can meet the endurance requirements of most applications with endurance north of 500K and has been a the most adopted type of memory for microcontrollers, smartcards and various specialized controllers.

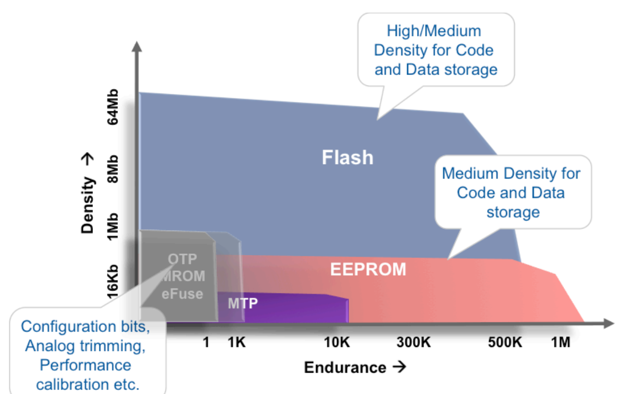

Figure 1. General Embedded NVM space and usage

	Embedded Flash	OTP	MTP
Endurance	Up to 500K	1	~1K
Bitcell size	Small	Small	Large
Data Retention	20 Years@150C	20 Years@125C	10 Years@85C
Programming Time	~10us	~50us	~50us
Erase Time	2ms to 10ms	N/A	10ms
Programming mechanisms	FN/HCI	Oxide rupture, Electro-migration, HCI	FN/HCI
Storage Element	Floating-Poly, Charge-trap layer	Resistance, Floating-poly	Floating Poly, Charge trap layer
Usage Mode	Code Storage, Data Storage	Configuration Bits, Security Bits, Analog Trimming	Code Storage

Figure 2. Types of Embedded NVMs

Figure 2 above further illustrates the various types of NVMs and associated storage elements, programming and erase mechanisms of non-volatile memories.

Chronology of NVM Usage in Microcontrollers

The non-volatile memory usage in the microcontrollers and smartcards has gone through significant changes over time. Figure 3 below illustrates the chronological order of NVM usage in various types (automotive, industrial, consumer) of microcontrollers. Originally, microcontrollers used some type of mask ROMs for code-storage and an external EEPROM for data-storage applications. ROM has inventory issues and the program (instruction code) can't be changed in-field so it is not convenient and not preferred by chip-designers. An OTP memory (based on oxide breakdown, floating gate or poly-fuse) provided some relief to the designers as it can be programmed during wafer-sort and, in some cases, minor updates can be done in the field, but it still requires another EEPROM (external or internal) for data-storage applications. With the dual-NVM approach chip-designers need to manage two types of non-volatile memories, which could be very challenging for production ramp-up.

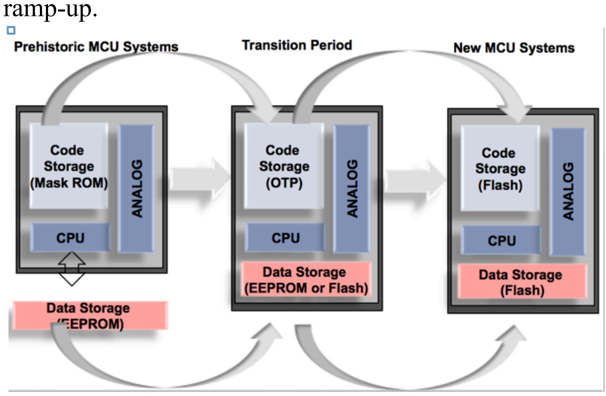

Figure 3. Embedded Memory Usage in Microcontrollers

The most popular choice of NVM is an embedded-flash memory which can be used for both code-storage and data-storage applications with some differences in the block architecture, but both blocks are done with the same bitcell which simplifies product qualification and production ramp-up. Most recent microcontrollers are being designed with an embedded flash.

Embedded Flash for Automotive and IoT

Even though in most cases the underlying embedded flash bitcell is same for IoT and automotive applications, there are significant differences between the embedded flash memory macro. The table below summarizes high-level specification differences between an automotive and IoT flash memory block. Most of these parameters in the table are self-explanatory, but some of the understated items are (a) the need for extensive qualification [2], (b) design for test (DFT), and (c) extensive documentation requirements for an automotive embedded flash for safety-critical applications.

Table 1. Embedded Flash Memory requirements

	Automotive	**IoT**
Junction Temp	-40C to 170C	-40C to 85C/125C
Humidity	Up to 100%	Minimal
Endurance	100K	100K
PPM	~0	~100
Product Life Time	20 years	~10 years
Access Time	~10ns	~25ns
Power Requirements	Medium	Stringent (NFC)
Sector Erase/Program Time	Medium	Short to Medium
Data Retention	20 years	10 years
Documentation	Comprehensive	Standard
Manufacturing Supply	Long Term	Short to Medium Term
Density	Up to 16MB	Up to 2MB
IO Configuration	Up to x128	Up to x32
Design for Test	Standard	Extensive

The AEC-Q100 standard specifies the temperature range for various automotive grades [4]. As an example, junction temperature for an auto grade 0 device can go up to 170C for certain duration during the lifetime of the product. In contrast to that, most of the IoT and smartcard devices operate within 125C junction temperature range.

Embedded Flash Technology Scaling

As an example, figure 4 below highlights the various circuit components of an embedded SuperFlash® memory block. The primary components of a SuperFlash memory block are memory array, high-voltage (HV) blocks such as charge pump and switches, analog blocks such as sense amp and reference circuitry, and digital control blocks. Generally, the HV blocks don't scale with technology nodes because the voltage required to erase and program (erase and program together constitute a write operation) doesn't scale down, therefore the HV design rules don't scale either. Most of the area scaling (Figure 4) is achieved by scaling the memory array and the digital bocks of the flash memory macro.

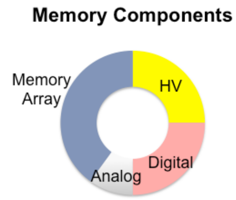

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Figure 4. Embedded Flash Components

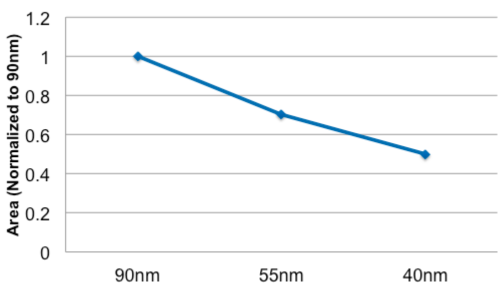


Figure 5. Embedded Flash Area Scaling (normalized)

Embedded Flash Memory Landscape

Embedded flash and EEPROM memories have been around for many decades and most of the integrated device manufacturers (IDMs) built their own version of embedded flash and EEPROMs. The table below [5] illustrates various types of embedded flash memories that are being used for MCU (both automotive and IoT) and smartcard applications. Figure 6 is a sample of the embedded flash memories being used in today's advanced microcontrollers.

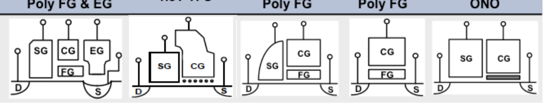
	1.5T Poly FG & EG	1.5T TFS	1.5T Poly FG	1T Poly FG	1.5T (1T,2T) ONO
					
Scaling, R&D	40 -> 28 nm	40 -> 28 nm	40 -> 28nm	40-> 28nm	40 -> 28 nm
Key drivers	SST & licensees and 100+ users	FSL	Infineon	ST Micro/FSL	Renesas, CY, Spansion,
VCC=1.2V fast read capability	Yes	-	Need Vread >2V (SGOX – scalling challenges)	Need Vread > 2V (to avoid over-erase)	-
P/E	SSI/FN to EG 100K-1M	SSI/FN to CG 10K-100K	SSI/FN to Channel, 10K-100K	CHEI/FN to channel 100K	FN/FN, HEI/FN, SSI/HHI, 1K-30K
1-0 VT window	>10V	~3V	~6V	~3-4V	~4V
Scaling Challenges	FGOX, HV/CG-EG	Low Q, O-NC-O, HV	SGOX, FGOX, HV/Vread	Low Q,FG CD (PD), FGOX, HV/ Vread	Low Q, ONO

Figure 6. Embedded Flash Landscape

An embedded flash memory for an automotive application must exhibit a wide threshold (Vt) window, excellent program-disturb (immunity for untended program operation) characteristics and data retention characteristics.

Conclusion

Embedded flash is a key component of automotive/IoT MCUs and smartcard devices and one of the most difficult circuit blocks to master. Generally, the qualification of the MCU or smartcard device is contingent upon qualifying that on-chip NVM. The reliability of the MCU or smartcard strongly hinges upon how reliable the on-chip embedded flash is. Therefore, it is critical to use a reliable and production-proven non-volatile memory. There are various types of non-volatile memories available in the market, but the floating-poly based embedded flash memories have been around the longest and provide excellent data retention and endurance characteristics desired by MCU/IoT and smartcard applications.

References

1. V. Tiwari, "Driving Down the Memory Lane," Flash Memory Summit, 2015.
2. V. Kottler, "Automotive Requirements to Non-Volatile Memories – A Holistic Approach to Qualification," IEDM 2016.
3. N. Do, "eNVM Technologies Scaling Outlook and Emerging NVM Technologies for Embedded Applications,",IMW 2016
4. http://www.aecouncil.com/AECDocuments.html
5. A. Kotov, Leading Edge Embedded Non-Volatile Memories, eNVM Conference 2015