

FRAM Overview and Usage (WhitePaper)

Fujitsu Semiconductor Memory Solution Limited

■ Introduction of FRAM overview

Customers often tell us they want to learn what kind of memory FRAM is, and how FRAM is actually used.

In reply to the above customers' voices, this document introduces overviews of FRAM in accordance with the table of contents below.

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1. FRAM Overview

■ What is FRAM

First, we explain what FRAM is.

FRAM is a semiconductor product in electronics components. Semiconductor products have various kinds of devices such as microprocessors, logic devices, analog devices, and memory devices. FRAM is one of memory devices like DRAM and Flash memory.

FRAM stands for Ferroelectric Random Access Memory. It is also called ferroelectric memory as it uses ferroelectric elements to store data.

■ FRAM, a Non-volatile Memory

Memory devices, semiconductor products to store data, are mainly divided 2 types. One is the "Volatile memory" that features stored data are disappeared at power off. DRAM is famous as a volatile memory.

Another type is the "Non-volatile memory" that features stored data are not disappeared at power off. This means data are written to the memory at once, the data do not change without erasing or re-writing. FRAM is a Non-volatile memory as the same as Flash memory.

Fig.1: Positioning of FRAM

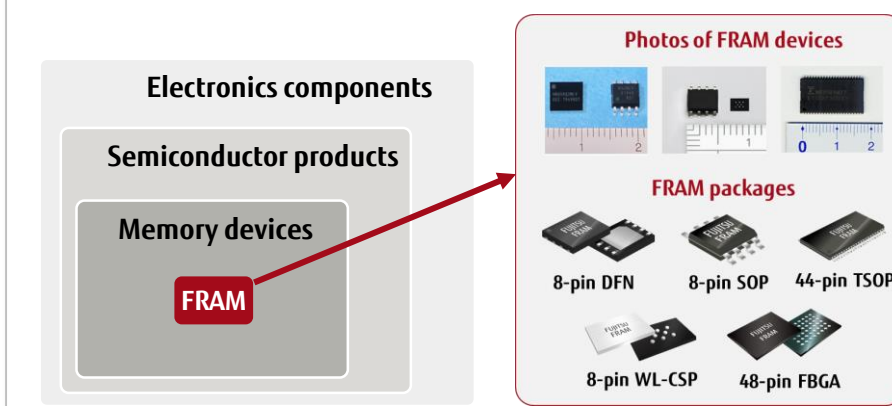
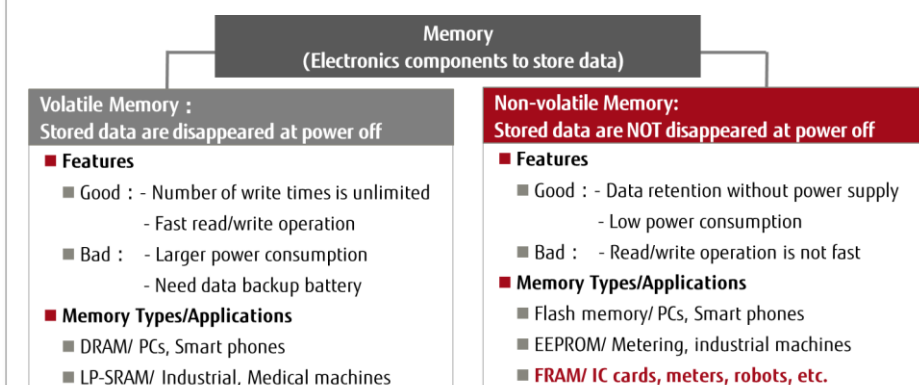


Fig.2: Classification of Memory Devices



■ FRAM Structure

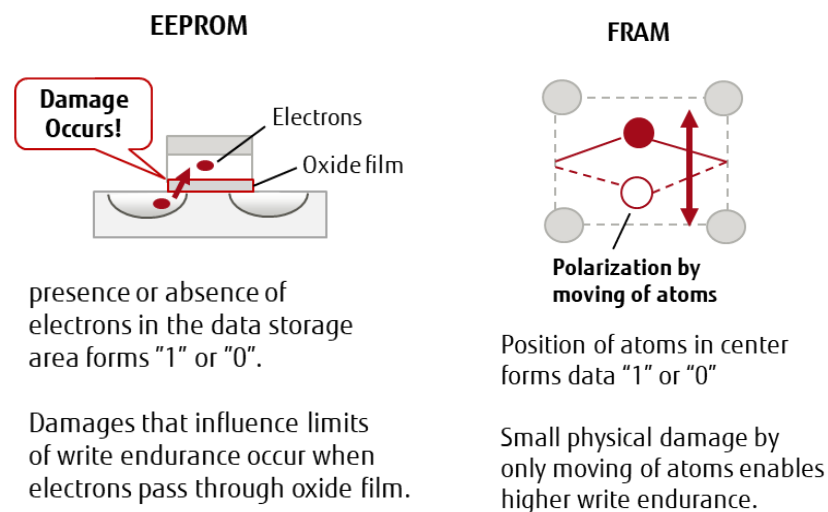
FRAM is a memory using ferroelectric elements. Its cell structure and method to store data are different from other conventional Non-volatile memory devices such as EEPROM and Flash memory. Of course, judgement method of stored data "1" and "0" is also different.

EEPROM of conventional Non-volatile memory judges "1" or "0" data by state of the memory cell being charged or discharged. (Left figure in Fig.3)

While, FRAM judges by the state of electric polarization caused by the movement of atoms in the molecule. (Right figure in Fig.3)

The characteristics of this ferroelectric property gives FRAM four major benefits: "Non-volatility", "High read/write endurance", "Fast writing speed", and "Low power consumption".

Fig.3: Cell Structure of EEPROM and FRAM



2. FRAM Lineup

■ FRAM Lineup

Our FRAM family has three interfaces. I2C and SPI are compatible with EEPROM and Parallel is compatible with SRAM. Memory density ranges from 4K bits to 8M bits.

The operating temperature is -40°C to $+85^{\circ}\text{C}$ for most products, but recently we are adding products that operate up to $+125^{\circ}\text{C}$ for automotive and industrial automations. Regarding the specifications of each FRAM device, please confirm its datasheet respectively.

■ Remarkable Products

4Mbit FRAM operating up to $+125^{\circ}\text{C}$

Since July 2020, we developed 4Mbit FRAM MB85RS4MTY, which has the largest density in FRAM products operating up to 125°C . Evaluation samples are currently available.

This new FRAM product is a non-volatile memory that guarantees 10 trillion read/write cycle times and low active currents of 4mA even at 125°C high-temperature environment. It is optimal for industrial robots and automotive applications such as advanced driver-assistance systems (ADAS).

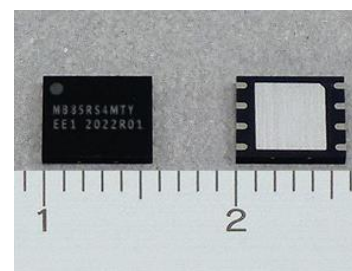
Table 1: FRAM Lineup

Interface	I2C	SPI	Parallel
Density	4K to 1Mbit	16K to 4Mbit	256K to 8Mbit
Supply Voltage	1.8 to 3.6V 3.3V Max. 5.5V	1.8 to 3.6V 3.3V Max. 5.5V	1.8 to 3.6V 3.3V
Operating Temperature	-40°C to $+105^{\circ}\text{C}$	Higher: -40°C to $+125^{\circ}\text{C}$ General: -40°C to $+85^{\circ}\text{C}$ Lower: -55°C to $+85^{\circ}\text{C}$	-40°C to $+85^{\circ}\text{C}$
Package	SOP, SON	SOP, SON, DFN, WL-CSP	SOP, TSOP, FBGA

[As of February 2021]

Fig.4: 4Mbit FRAM operating up to 125°C

Package Photos



Suitable Applications



3. FRAM Features

■ Four FRAM Features

FRAM has four outstanding features that other conventional memory products don't have. The features are: "Non-volatility", "High read/write endurance", "Fast writing speed", and "Low power consumption".

By the four features, FRAM can satisfy customers' requirements to memory devices like getting more data and protects writing data.

■ Comparison to Other Memory

Table 2 shows comparison to other memory devices of EEPROM, Flash memory, SRAM which are replaceable with FRAM.

You can see that FRAM has better features of "Guaranteed write cycles" and "Write cycle time" than EEPROM and Flash memory of Non-volatile memory. Then, although SRAM needs data backup battery for data retention, FRAM does not need it because of non-volatile memory.

From the above reason, FRAM has advantages to other conventional memory devices.

Fig.5: Four Memory Features Required

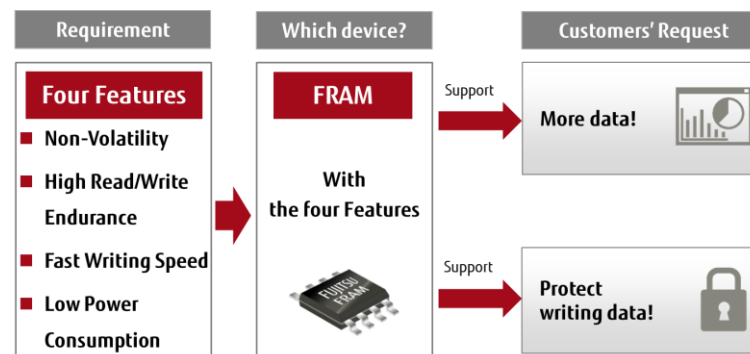


Table 2: Comparison to Other Memory

	FRAM	EEPROM	Flash memory	SRAM
Memory Type	Non-volatile	Non-volatile	Non-volatile	Volatile
Data Backup Battery	No	No	No	Yes
Guaranteed Write Cycles	10 trillion	1 million	100 thousand	Unlimited
Write Method	Overwrite	Erase + Write	Erase + Write	Overwrite
Write Cycle Time	150ns	5ms	10µs	55ns
Booster Circuit	No	Yes	Yes	No

3. FRAM Features

■ FRAM Feature — High Read/Write Endurance

From now we explain each FRAM feature more detail. First is "High read/write endurance".

"High read/write endurance" means that memory can read and write data so many times. The higher this figure, the more data you can read and write.

FRAM guarantees a maximum of 10 trillion write times, equivalent to 10 million times of EEPROM's of 1 million times. Though some of new EEPROM guarantees 4 million write times, difference to FRAM's figure is still large.

10 trillion write times means you can rewrite data in very short periods of time, once every 0.03 milliseconds for 10 years continuously. In other words, under normal usage, this value means almost unlimited, with FRAM, you can obtain much more frequent and accurate data than using EEPROM.

By using FRAM with this excellent feature, customers can collect data with high frequency and accuracy. Therefore, customers can see the true behavior of data by knowing complex data curves that they could not see before.

Fig.6: Rewrite Counts after 10 years

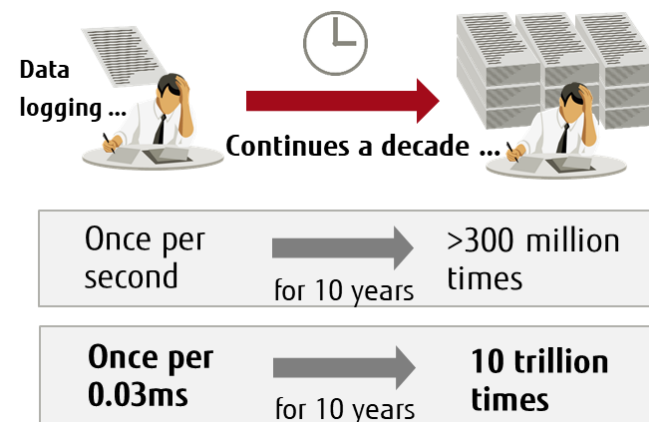
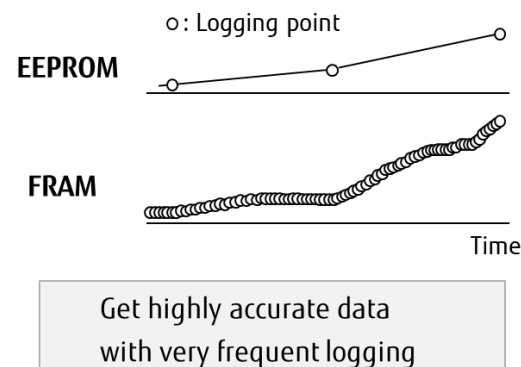


Fig.7: Difference by Data Logging Frequency



3. FRAM Features

■ FRAM Feature — Fast Writing Speed

Next, we move on to "Fast writing speed".

Time to completion of write operation in FRAM is shorter than EEPROM's. This means FRAM has faster writing speed.

EEPROM needs up to 5ms for writing as it needs a time consuming erase operation before the writing operation. On the other hands, FRAM does not need this erase operation and only overwrites data. It's simpler, therefore, the write time is as shorter as 150ns, which is over 33 thousand times faster than EEPROM. With this fast writing, even if a sudden power outage occurs, the write operation can be completed before power outage.

In actual, we performed data writing failure test over 100 times using our demo-boards. As the result, it observed that FRAM had no writing error but EEPROM had one writing error per three tests. Even from this test, we confirmed that write errors are unlikely to occur in FRAM even in a sudden power outage.

Fig.8: Flow in Data Write Operation

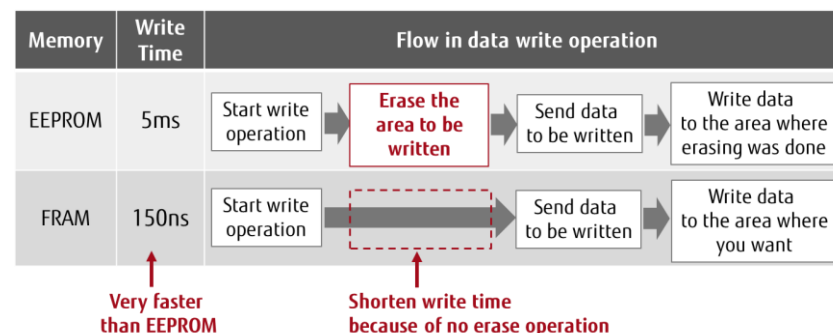
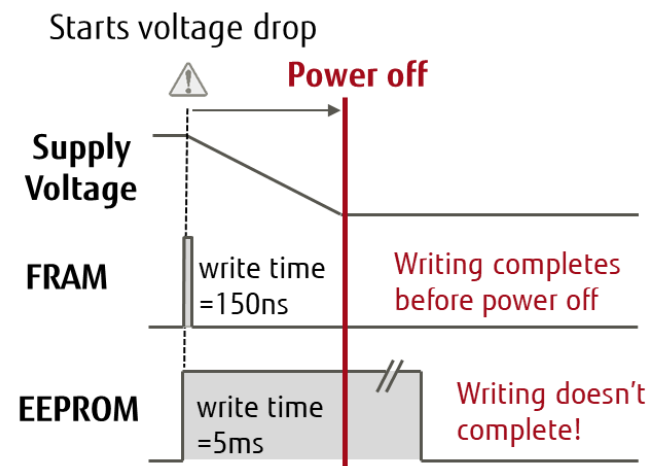


Fig.9: Comparison of Write Time at Power Off



3. FRAM Features

■ FRAM Feature — Lower Power Consumption

The third feature is “low power consumption”.

When we focus on write operation, FRAM can reduce power consumption by 92%. This is because the writing time of FRAM is much shorter than that of EEPROM.

Differences depend on conditions, but FRAM can contribute to reduce power consumption of a customer's end products when run with very frequent data logging.

In addition, FRAM is a non-volatile memory and does not need data retention current like SRAM. Therefore, customer will no longer need the data backup battery by replacing SRAM with FRAM.

Fig.10: Power Consumption in Data Writing

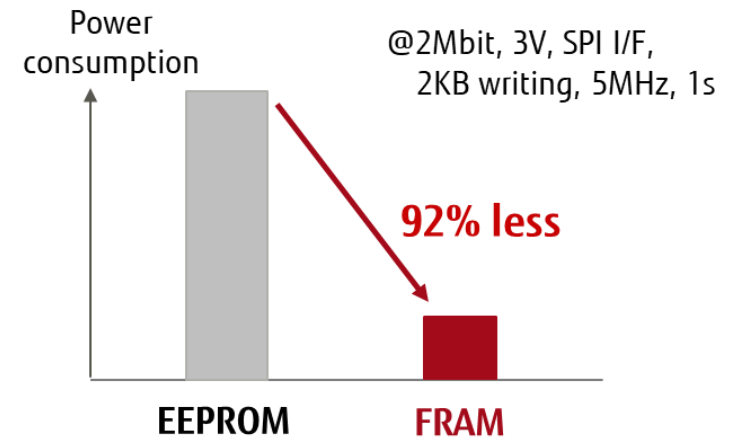
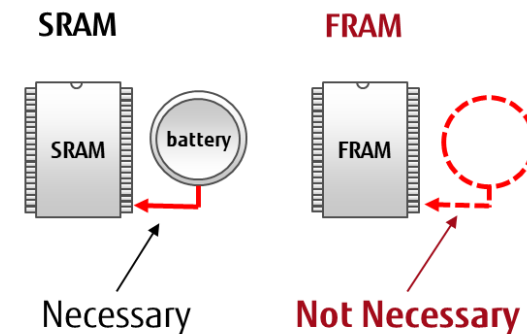


Fig.11: Necessity of Data Retention Current



4. History of FRAM

■ Quantity of FRAM Shipped

Even recently, some customers asking us if FRAM devices in production have been shipped to the industrial market.

We started mass production in 1999, and the total number of products shipped to the market has reached almost 4 billion units over 21 years. FRAM is not as familiar as the DRAM and flash memory of memory devices, but it is a reliable memory with mature production experience.

■ Receiving awards on FRAM

Table 3 shows history of receiving awards on FRAM. (Awards name and organizer are in Japanese.)

We received 11 awards in 15 years from domestic academic societies and government agencies. Reasons for receiving the award include novelty of memory, realization of mass production, and contribution to domestic industry by developing new memory.

In this way, our FRAM development and mass production are highly evaluated from outside.

Fig.12: Quantity of FRAM Shipped

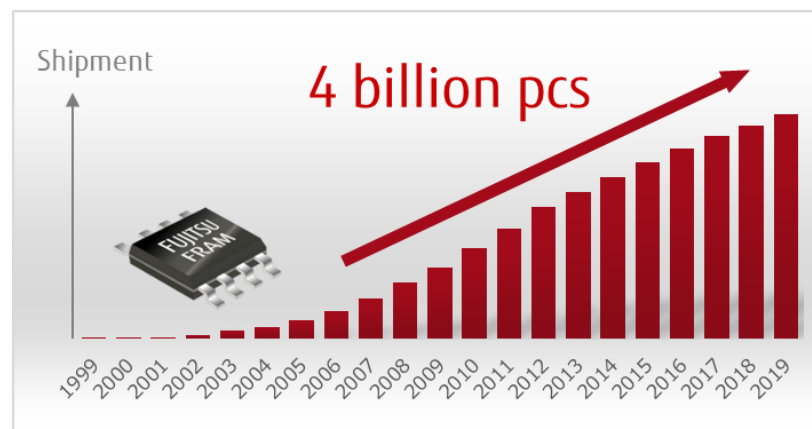


Table 3: Receiving Awards on FRAM

Year	Award Name	Organizer
2001	第8回LSIデザイン・オブ・ザ・イヤー優秀賞	半導体産業新聞社
2004	CORPORATE INOVATION AWARD	ISIF
2004	文部科学大臣表彰 研究功績者（研究功績者）	文部科学省
2007	第2回 ものづくり日本大賞 優秀賞	経済産業省等
2011	産学官連携功労者表彰 日本経済団体連合会会長賞	内閣府等
2013	応用物理学会フェロー表彰	応用物理学会
2013	文部科学大臣奨励賞、電気科学技術奨励賞	電気科学技術奨励会
2014	大河内記念技術賞	大河内記念会
2014	文部科学大臣表彰 科学技術賞（開発部門）	文部科学省
2014	第14回 山崎貞一賞	材料科学技術振興財団
2015	紫綬褒章	内閣府

5. FRAM Usage

■ FRAM Usage

FRAM is used in a variety of applications for consumers and in enterprise. Fig.13 shows the categories of applications in which FRAM has been used.

Especially, FRAM has been adopted in applications for infrastructure and industries which support services vital to general public. For example, FRAM has been used as memory for updates of information in IC cards, data logging of power usage in smart meters, and logging of 3-D positioning data in industrial robots. The keyword in applications using FRAM is "Frequent data logging".

Then, we have experience in more than 200 different applications with customers from over 50 countries worldwide so far.

Fig.13: Applications using FRAM

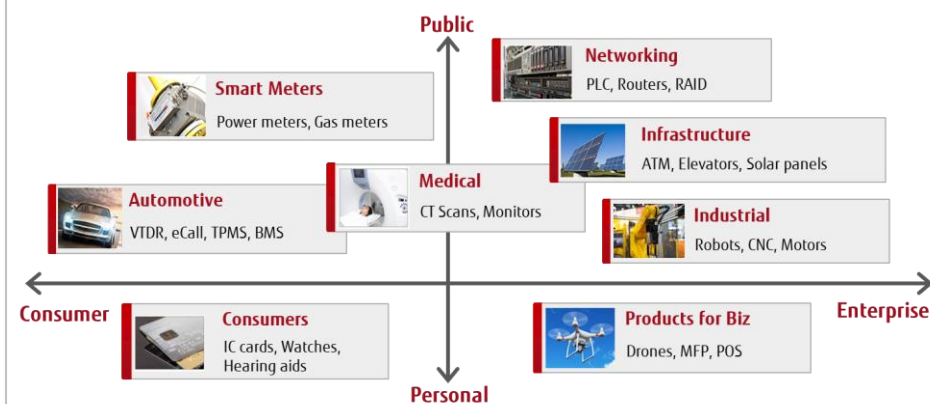


Fig.14: Business Opportunities



5. FRAM Usage

■ Automotive

Regarding FRAM usage, we explain some actual cases of each application category. First is FRAM usage in Automotive applications.

Our FRAM is utilized in car infotainment systems, such as car navigation systems and drive recorders. For these applications, it is necessary to record drive data to the memory in real-time.

Furthermore, it can also be used for vehicle emergency call systems, commonly known as "eCall". FRAM has essential features of advantages as fast writing speed and non-volatility that can protect driving data if an accident occurs.

FRAM can also be used for real-time data logging of air pressure sensors for Tire Pressure Monitoring System (TPMS) and for that of temperature sensors for Battery Management System (BMS) in electric vehicles.

Fig.15: FRAM Usage - Automotive



5. FRAM Usage

■ Industrial (for factory)

Next, we explain how FRAM is used in "industrial products", which are mainly used in factories.

The "motors", "rotary encoders", "industrial robots", and "machinery tools" run 24/7. In other words, information such as position data and rotational counts are repeatedly stored onto memory in real-time. Therefore, the memory has to have the capability of fast writing speed and high read/write endurance.

Also, if a temporary power outage occurs at factory, failure to record accurate machine position data at the time of the outage can result in significant losses, such as the loss of productions in the process lines. However, if data are quickly finished recording into the memory at the outage, the damage can be minimized. Therefore, it is very important to choose memory which has the capability of fast writing speed.

For such reason, our FRAM has gone into industrial machines and process monitoring systems.

Fig.16: FRAM Usage – Industrial for Factory



5. FRAM Usage

■ Infrastructure

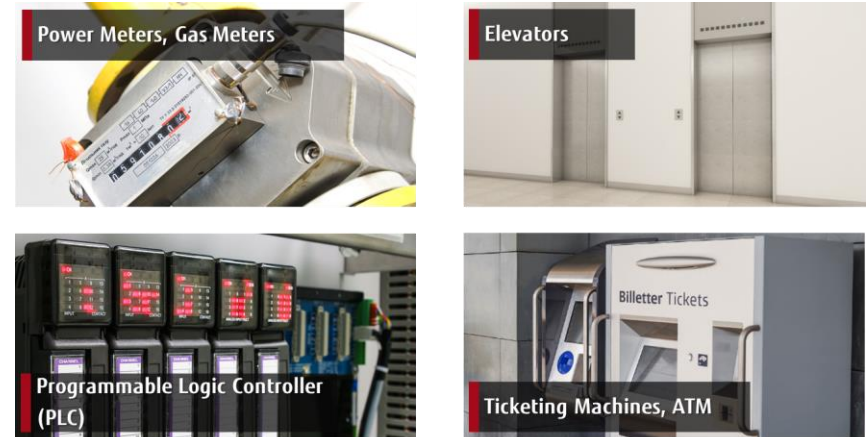
FRAM is also used for "infrastructure" equipment that supports society.

In smart meters, gas meters, and water meters, keeping continuous data logging is very important for stable and secure billing. Therefore, these meters require semiconductor memory device which guarantees high write endurance.

Furthermore, even if a power outage occurs, it is necessary to write data immediately before the data get lost.

Infrastructure equipment such as PLCs, elevators, ticketing machines, and ATMs require memory featuring high read/write endurance and fast writing speed for the same reasons. Highly reliable FRAM is ideal to meet these requirements.

Fig.17: FRAM Usage – Infrastructure



5. FRAM Usage

■ Consumer/Business

In last, there are some FRAM usage cases for consumer and business use.

In applications such as contactless IC cards, FRAM operates quickly even with a very small power supply. Even in battery-operated applications such as "smart watches," FRAM helps to extend battery life with the feature of lower power consumption.

FRAM has adopted in many multi-function printers, MFPs, to log copying history, and in drones to store flight data.

■ FRAM Usage Summary

Table.4 summarized how memory is used in the applications which we mentioned so far.

The "Four futures" in the right column of the table are essential for memory to support the functionality of the applications. FRAM does have all four features.

Fig.18: FRAM Usage – Consumer/Business

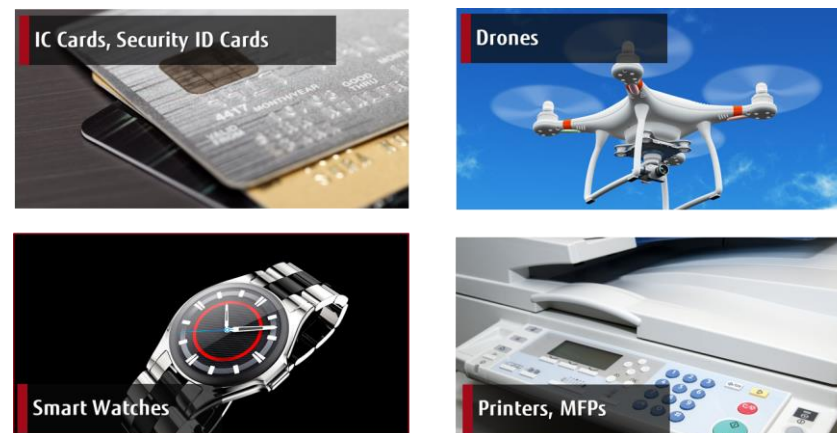


Table 4: Summary of FRAM Usage

Summarized as four features			
No	Applications	Requirements to Memory	Required Features
1	Automotive	Driving data logging in real time Writing data protected in accident	Non-volatility, High read/write endurance, Fast writing speed
2	Industrial	Positioning data logging in real time Writing data protected in power outage	
3	Infrastructure	Continuous logging of data from sensors Writing data protected in accident	
4	Consumer	Frequent read/write of data Low power to extend battery life	High read/write endurance, Low power consumption
5	Products for biz	Continuous data logging in real time Writing data protected in power outage	Non-volatility, High read/write endurance, Fast writing speed

6. FRAM Solutions to Customer Issues

■ Customer Issues and Solutions by FRAM

If you are using EEPROM or SRAM in your products and have any of the following issues, please consider our FRAM for your solutions.

- 1) Need to log data more frequently, but cannot because of limitation of memory spec
- 2) Need to protect data while being written from sudden power outage
- 3) Want to move to battery-free solution

We believe our FRAM can solve many issues.

■ FRAM Compatibility and Support

FRAM is pin-compatible to EEPROM in 8pin SOP package and electrical control commands are almost the same. 4Mbit FRAM with parallel interface is pin-compatible to low power SRAM in 44pin TSOP.

We prepare simulation models (Verilog model or IBIS model) to support evaluation of our FRAM products at customers. In addition, Customers can buy the FRAM products through online. Please visit our website below:

<https://www.fujitsu.com/global/products/devices/semiconductor/memory/fram/>

Fig.19: Customer Issues and Solutions

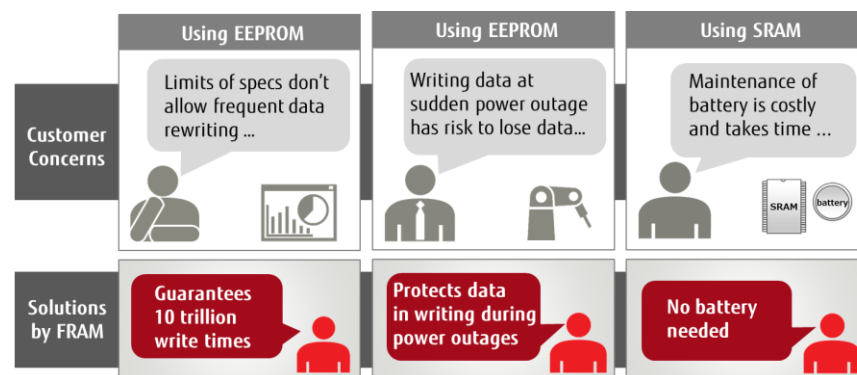
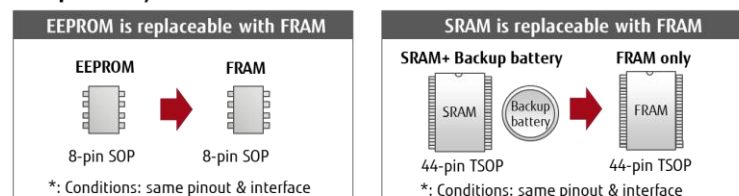


Fig.20: FRAM Compatibility and Support

■ Compatibility with EEPROM and SRAM



■ Support to evaluate our FRAM device



■ Missions of Our company via FRAM products

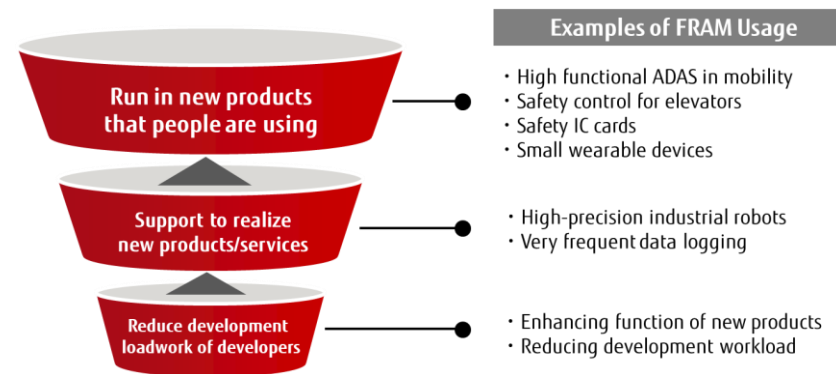
FRAM is just one of memory device in electronic components. However, we believe that we can contribute to society if we can offer FRAM products to customers as factors maximizing features and functions of end-products.

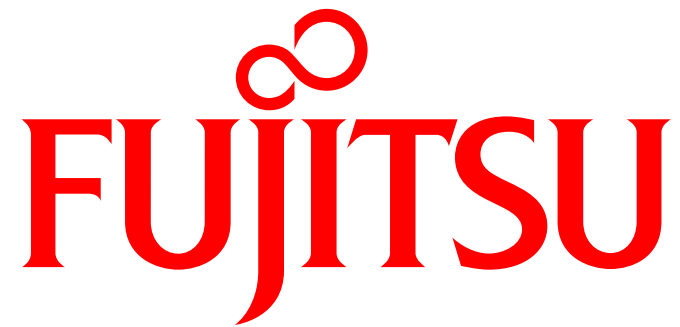
Flow of the contribution of FRAM to society are:

- 1) Reduces development loadwork of design engineers
 - Contributing to developers(people) by providing good electronics components
- 2) Supports customers to realize new products/services
 - Contributing to customers(enterprise) by development support of new product using FRAM
- 3) Runs in new products that people in public are using
 - Contributing to society by spreading convenient products/services in public

We think our one of missions of our FRAM is to contribute to society through customers' applications.

Fig.21: Contributing to society by FRAM





shaping tomorrow with you