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Remanent Polarized Ferroelectric Non-Volatile Random Access Memory

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***Abstract*- Due to low power consumption levels and high operation speeds, FRAM are considered as one of the latest technology for non-volatile random access memory for information storage in modern portable electronic devices such as mobile phones and notebook computers. The characteristics of the ferroelectric film, the main element of the FRAM, are quite important as they determine the quality of the device**.

***Keywords:* Polarization, FRAM, Non Volatile, RAM, Memory**

I. INTRODUCTION

Memories are important and indispensable devices in the electronic industry. Semiconductor memory is divided into two major types. One is volatile memory which loses stored data unless it remains supplied with power from an external source. The other is non volatile memory which retains stored data even its external power supply is disconnected. DRAM (Dynamic Random Access Memory) and SRAM (Static Random Access Memory) are typical volatile memories. DRAM is inexpensive memory but it must regularly refresh its contents with stored data to ensure data is retained [1]. Therefore, it is suitable for systems which require large capacities. SRAM is faster in read/write access and requires no refreshing but it takes up a larger area than DRAM. Hence, it is used for relatively small or medium-capacity applications. Non volatile memory is divided into ROM (read-only memory) that can only be read and RAM (random access memory) that can be read or written. Non volatile types of RAM include NVRAM and BBSRAM, which pretend to be non volatile in combination with another type of memory and a battery for backup purposes [2]. FRAM is a type of ferroelectric random access memory that uses a ferroelectric thin film. Ferroelectric film is polarized by the electric field applied from an external source and remains polarized even with the external electric field removed. This polarization is referred to as remanent polarization. With this nature, FRAM does not lose data when power is removed from it.This characteristic is called non-volatility. Changing the direction of the applied electric field inverts the direction of polarization of the ferroelectric material, capable of updating data. Polarization is an extremely short phenomenon caused by the ionic displacement of atoms making up the ferroelectric crystal structure [3]. Therefore FRAM is superior memory very fast in data read/write speeds. A FRAM cell is created by depositing a film of ferroelectric material in crystalline form between two electrode plates to form a capacitor. This construction is very similar to that of the DRAM capacitor. Rather than storing data as charge on a capacitor like a DRAM, a ferroelectric memory stores data within a crystalline structure [4]. FRAM (ferroelectric RAM) is a random access memory that combines the fast read and write access of dynamic RAM (DRAM) with the ability to retain data when power is turned off (as do other non-volatile memory devices such as ROM and flash memory).. FRAM is a ferroelectric memory and is not affected by magnetic fields as there is no ferrous material.

II. CELL STRUCTURE OF FRAM

There are two major types of FRAM with ferroelectric films integrated as non volatile memory cells [5]:

(i) 1T/1C (2T/2C) Type [1 Transistor / 1 Capacitor (2 Transistor/2 Capacitor)] : This structure is organized by two parts, which are a storage capacitance to retain and a transistor to access like a DRAM cell. Cell information is detected by reading the change in current which results from the change in polarization charges when a voltage is applied to a cell. Therefore, inevitably cell information is lost in each reading cycle during information is read. Because of the destructive reading, cell information must be rewritten during the same cycle.

(ii) MFSFET [Metal Ferroelectric Semiconductor FET]: This configuration can be achieved by using a ferroelectric film instead of silicon oxidized film for the gate oxidized film. Cell's information is written by applying a voltage between the gate electrode and substrate, which polarizes the ferroelectric film. This causes the threshold value of the transistor to change in accordance with the direction of polarity. When a fixed gate voltage is applied, the cell information will be retrieved according to the drain current that corresponds to the transistor threshold caused by the direction of polarity. As a result, the design technologies for this memory have an increased compatibility with those of EEPROM and Flash Memory.

III. BASIC OPERATION OF FRAM

A ferroelectric material is characterized by reversible spontaneous polarization arising from non centrosymmetric arrangements of ions in its unit cells, which produces a permanent electric dipole moment. Adjacent dipoles also tend to orient themselves in the same direction to form a region called ferroelectric domain [6]. Ferroelectricity is most commonly observed in ABO3 perovskite structures as shown in Fig. 1. Above the Curie temperature these materials have a centrosymmetric structure and hence do not exhibit any spontaneous polarization. This phase is known as paraelectric phase. As the temperature is lowered below the Curie point phase transformation takes place from paraelectric state to ferroelectric state. The center ion is displaced from its body center position and the cubic unit cell deforms to one of the noncentrosymmetric structures such as tetragonal rombhohedral or monoclinic structures. The polarization response with the electric field of these materials is highly non-linear and exhibits a hysteresis loop as shown in Fig. 2. As the applied electric field is increased, the ferroelectric domains, which are favourably oriented with respect to the electric field, grow at the expense of other domains [7]. This phenomenon continues until total domain growth and reorientation of all the domains has occurred in a direction favourable to external field. At this stage, the material is assumed to possess saturated polarization (P_{sat}). If the electric field is removed at this point some of the domains do not reorient into a random configuration and thus leaving the material still polarized. This polarization is known as remanent polarization (P_r). The strength of the electric field required to return the polarization to zero is called the coercive field (E_c). Although these features of a ferroelectric material could be used in a wide range of applications the primary focus of the recent research is directed towards development of non-volatile random access memories. At zero applied fields, there are two states of polarization ($\pm P_r$), which are equally stable. Either of these two states could be encoded as "1" or "0" and since no external field is required to maintain these states the memory device is non-volatile. Obviously to switch the state of the device a threshold electric field greater than coercive field is required. Since ferroelectric materials have very high coercive fields (in the order of kV/cm), it is necessary to fabricate these materials in the form of thin films in order to be able to switch the domains from one orientation to the other [8].

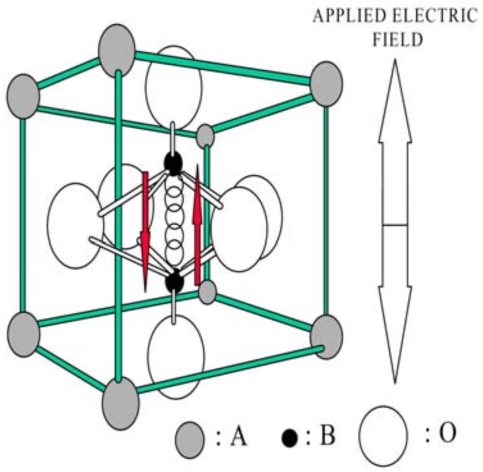

Fig. 1. ABO3 perovskite unit cell

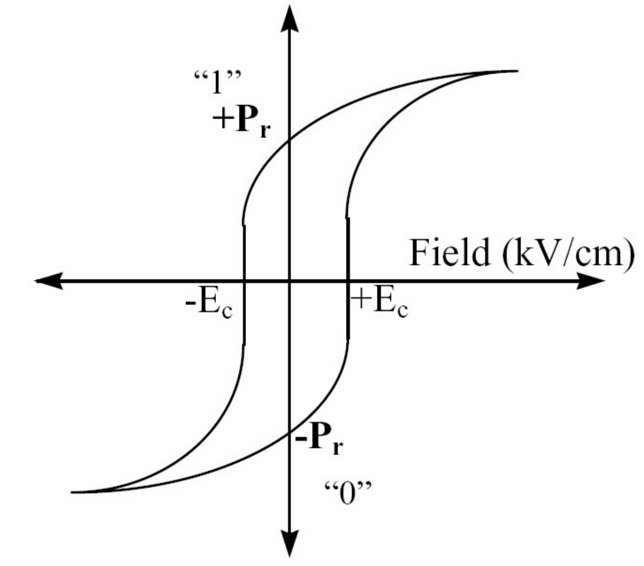

Fig. 2. Polarization hysteresis loop

IV. FERROELECTRIC MATERIALS

An ideal material for use as a FRAM should have high remnant polarization, low coercive voltage, and a reasonable Curie temperature. Many ferroelectric materials [9] have been considered for FRAM, including PZT, SBT, Bi4Ti3O12, LiNbO3, Pb(Mg,Nb)O3, PbTiO3, BaTiO3, KNbO3, SrBi2(Ta,Nb)2O9 and BaMgF4.

Following characteristics are required for a ferroelectric thin film:

(i) Remanent polarization is preferable to be large, so that a large polarization reversal current can be derived from a small-area capacitor.

(ii) Dielectric constant is preferable to be low, because a high dielectric constant material produces a large displacement current and it disturbs detection of the polarization reversal current.

(iii) Coercive field is preferable to be low for the low voltage operation of FRAM.

(iv) Fatigue is such a phenomenon that the remanent polarization becomes small when a ferroelectric film experiences a large number of polarization reversal. It is preferable that the film is fatigue-free for switching over cycles for 10-year operation.

(v) Retention time is necessary to be longer than 10 years. Imprint is such a phenomenon that the polarization of a ferroelectric film is not reversed perfectly by a single pulse when many pulses with opposite polarity have been applied previously, and thus this phenomenon is preferable to be as small as possible.

V. FERROELECTRIC THIN FILMS DEPOSITION TECHNIQUES

Several methods are currently being used for depositing thin films which can be classified into three groups [10]:

(i) Physical vapor deposition (PVD): e.g. RF sputtering and pulsed laser deposition.

(ii) Chemical vapor deposition (CVD): e.g. metalorganic chemical vapor deposition (MOCVD) PECVD, LSCVD.

(iii) Chemical solution deposition (CSD): e.g. sol-gel.

VI. F-RAM OPERATION

The basic storage element is a ferroelectric capacitor. The capacitor can be polarized up or down by applying a field as shown in Fig. 3.

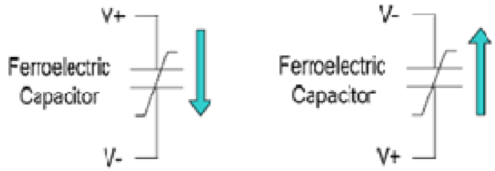

Fig. 3 Ferroelectric Capacitor Polarization

The ferroelectric capacitor symbol indicates that the capacitance is variable and is not a traditional linear capacitor. When an electric field is applied there will be no change in polarization due to which ferroelectric capacitor will not be switched. Hence, it will behave like a linear capacitor. If it is switched, there is an additional charge induced, hence the capacitance must increase. The ferroelectric capacitor is combined with an access transistor, a bit line, and a plate line [11] to form the memory cell as shown in Fig. 4.

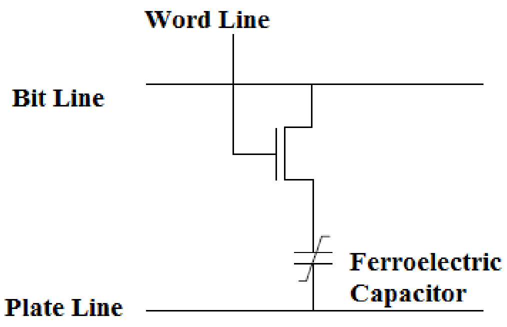

Fig. 4 F-RAM Memory Cell

A. Writing Operation

Writing "1" or "0" data to a cell requires the application of the voltage +Vcc or −Vcc to both electrodes of the ferroelectric capacitor. For writing to the 1T/1C cell, the word line (WL) is selected which means that the transistor is on and a voltage (Vcc) is applied between the bit line (BL) and the plate line (PL) as shown in Fig. 5.

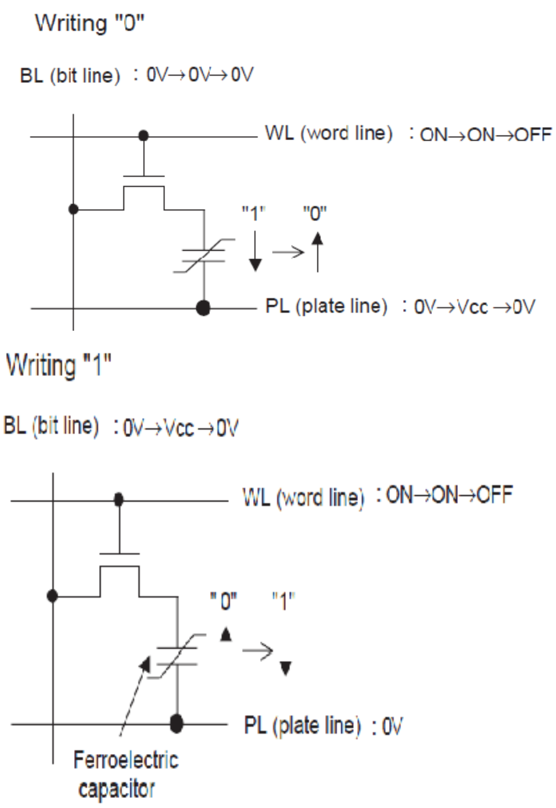

Fig. 5 Writing on a 1T/1C Cell

Adding this voltage to the ferroelectric capacitor causes data to be written. Writing "0" data is accomplished by making BL = 0 V and PL = Vcc, whereas "1" data is written by making BL = Vcc and PL = 0 V. After writing, data is retained even if the selected word line becomes unselected which means that the transistor is off.

B. Reading Operation

When reading "1" or "0" data from a cell, BL must be precharged to 0V to retain the high-impedance condition. Now, WL is selected and Vcc is applied to PL. By applying a voltage to the ferroelectric capacitor, the data can be read out. If the cell holds "0" data, the polarization is not reversed but the relatively slight movement of the electric charge (j0) causes BL to charge up by ΔVL. If another cell holds "1" data, polarization is reversed, causing a major movement of the electric charge (j1). This causes BL to charge up by ΔVH. The sense amplifier holds the reference voltage (Vref) established between ΔVL and ΔVH is connected to BL. In this manner, ΔVL which has a lower voltage level than Vref can be further reduced to 0V and ΔVH which has a higher voltage level than Vref can be raised further to Vcc. The post-amplification bias states of the ferroelectric capacitor are:

(i) Vf = +Vcc with BL = 0 V and PL = Vcc when reading "0" .

(ii) Vf = 0 V, meaning that the cell has a zero bias with BL = Vcc and PL = Vcc when reading "1".

The complete process of reading the data as shown in Fig. 6. The minimum achievable access/cycle times are primarily driven by the capacitance of the memory cell. The time it takes to switch the ferroelectric capacitor is nearly instantaneous and, therefore, switching mechanisms does not contribute to the overall cycle time.

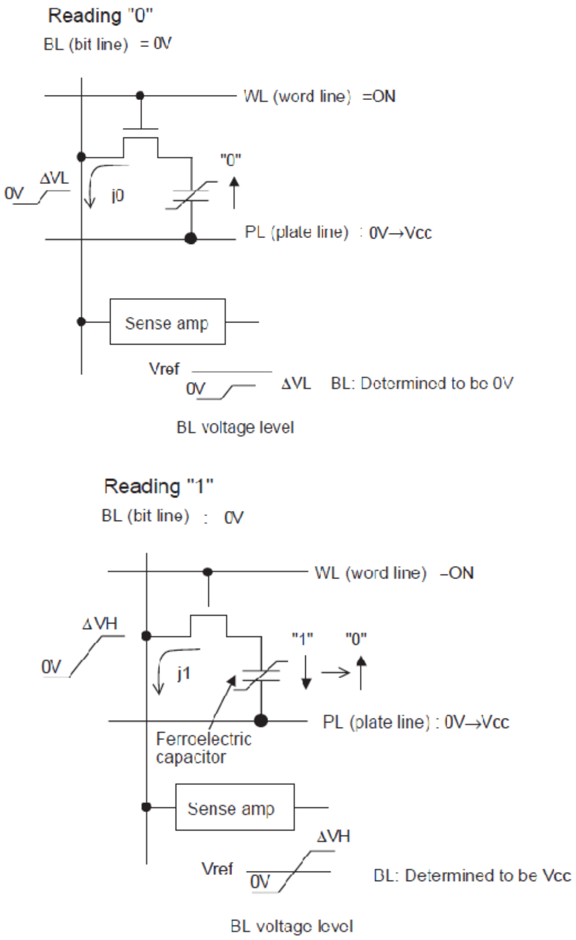

Fig. 6 Reading on a 1T/1C Cell

The sensing scheme is similar to DRAMs because both F-RAM and DRAM sense charge. The charge in a DRAM is stored in a linear capacitor that leaks and requires refresh. The charge in an F-RAM is stored as state in the crystal and is, therefore, non-volatile and requires no refresh. Like DRAMs, F-RAMs have a cycle time, so the minimum time between back-to back random addresses is equal to the cycle time, not the access time. Today, typical cycle times are less than 200ns and in the near future should be less the 100ns.

VII. ADVANTAGES

The main advantages of FRAM over other non-volatile memories are fast write and erase access times on the order of nanoseconds, low operating voltages around 5 V, long write/erase lifetime (106 times higher than the EEPROM and flash memories), wide operating temperature range (-180 to 350 degree centigrade) and high radiation hardness required for military and space applications [12]. In principle, the FRAM could replace the SRAM in cache memory, DRAM in main computer memory and EEPROM in the lookup tables. Because the FRAM has faster access speed and no mechanical wear problems, it could also replace the hard disk as the mass storage device. Therefore, these researches mainly aim to develop the high density RAM as future memories

VIII. APPLICATIONS

It is fast memory with a very low power requirement, it is expected to have many applications in small consumer devices such as personal digital assistants (PDA), handheld phones, power meters, and smart card, and in security systems. FRAM is faster than flash memory. The integration of FRAM and CPU in a chip makes it possible to create an extremely secure system, allowing data encryption for e-commerce transactions over the Internet, as well as personal authentication through public keys. The incorporation of large density FRAM makes it possible to carry out multiple applications and store large amounts of data, and makes it ideal for use in multifunctional IC cards.

IX. CONCLUSION

Ferroelectric random access memories (FRAMs) are the new generation future memories due to high speed, low cost, low power, non volatility and good compatibility with the existing integrated circuit(IC) technology. It offers higher endurance (the number of read and write cycles a memory can undergo before losing the ability to store data) to multiple read and write operations.

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