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Integrated Ferroelectrics—Materials, Processes and Applications

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Abstract Integrated Ferroelectrics is an area of research which has received much attention recently. Its applications include important areas such as GaAs MMICs, high dielectric constant DRAMs, and non-volatile memories. This paper reviews the state-of-the-art of the processes used in synthesis, deposition and integration compatibility with semiconductors. A review of the device physics of ferroelectric thin-films is also included in order to elucidate the operation and limitations of these devices. Applications are discussed and shown to provide new functions heretofore unexplored in many device areas.

INTRODUCTION

Since 1984[1] there has been renewed interest in integrating ferroelectric thin-films in semi-standard integrated circuit processes. The initial drive for this type of work came out of the possibility of making non-volatile memories using the polarization reversal properties of ferroelectric materials[2]. Thin-film ferroelectric memories have been made using the class of materials known as Perovskites[3]. These memories reached the 256Kbit level this year,[4] but fundamental problems still persist. Currently, interest in high dielectric constant materials for ULSI (greater than 64Mbit) DRAMs has brought ferroelectrics to the forefront of materials research for microelectronics. In order to achieve a breakthrough in high dielectric constant DRAMs, the value of the dielectric constant must be larger than 300 and remain constant up to a very high dispersion frequency (greater than the clock rate of the device). This is only possible using certain ferroelectric solid solutions with broad temperature windows and low impurity impact to a standard CMOS process.

This paper reviews this area which circa 1988 became known as Integrated Ferroelectrics. The review includes recent results[5] of switching (non-volatile) ferroelectrics which do not show fatigue up to 10^{12} read/write cycles (with 10 Mhz test pulses); also, retention capability at 100°C for at least 80 days have been measured - the extrapolation leads to more than 10 years. A review of post work in PZT (Lead Zirconate Titanate) is used to point out the differences between PZT solid solutions and this new proprietary family of materials (known as the Y1 family[6]). Device models are used to show the fundamental differences between devices made using this new material and PZT. Applications of BST (Barium Strontium Titanate) to GaAs-based devices are discussed.[7] Emphasis is also placed on ULSI DRAM applications of BST. A survey of materials and processes currently in use in this area is also included in this paper.[8]

NON-VOLATILE MEMORY APPLICATIONS

The most attractive features of ferroelectric random access memories are: (1) Symmetric read/write times; (2) Low voltage (approximately 2-3 volts); (3) Large noise margins; (4) High speeds (30-40 nsec switching times in devices of 10,000 μm^2); (5) 1T/1C cell architectures; and, (6) non-volatility. The problem areas are: (1) Interactions between the semiconductor processes - especially metallizations, etching and passivation - and the ferroelectric material; and (2) Limiting instabilities such as fatigue,[5] waiting time effects, imprint[8] and; high temperature retention.[8] One could also add the lack of well thought-out product family definition to this list. The promises of ferroelectrics lead researchers to propose so many variations in product targets that the technology cannot easily fulfill.

For the short space allowed in this extended abstract, comments on Figure 1 and 2 summarize the state-of-the-art in non-volatile ferroelectric memory cells. Figure 1 shows an hysteresis loop of a ferroelectric cell built using the Symetrix proprietary Y1 material. This loop is repeated 10^{12} times at 10 Mhz without any degradation. The fatigue curve [2 P_r = charge vs log(t)] is shown in Figure 2. It is clear that fully saturated loops are now easily obtainable. In the presentation, retention at 100°C and other parameters will be shown.

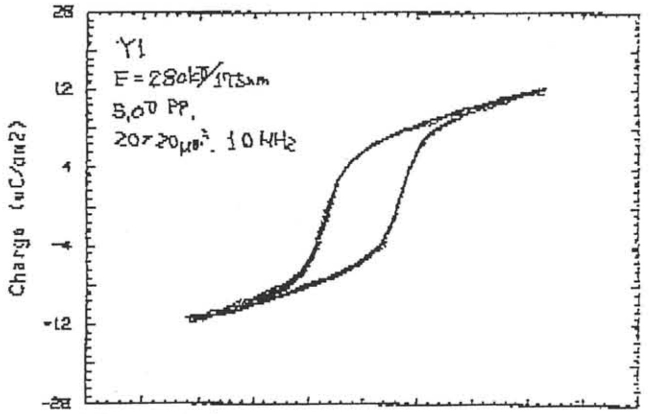

FIGURE 1

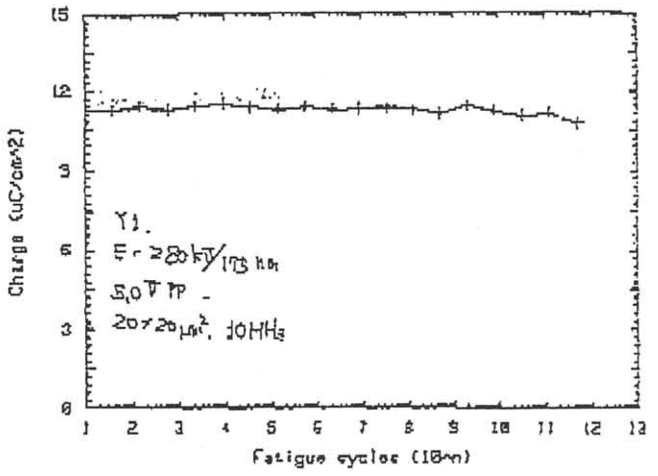

FIGURE 2

In summary, Integrated Ferroelectric devices have finally arrived to the market place. Non-volatile and DRAM applications will soon follow. Device reliability has increased with fundamental breakthroughs as evidenced in the Y1 data.

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