Evaluation of the Potential of Emerging Memory Technologies

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ABSTRACT *With a concern towards the scalability and energy consumption of the traditional computer memory system, significant study is done to find a novel memory technology with highly desired features like good scalability, low power consumption, operation speed trade-off, low operating voltages, high endurance and density. In addition the cache/memory/storage hierarchy has also now become a bottleneck for advanced computing systems. Today we see the unfolding of Universal memory technology that has technological advancements to overcome shortcomings of present memory technologies. But to be considered for increased focus, these memory technology need to demonstrate good performance with an understood storage mechanism and be scalable multiple generations.*

This paper is a comparative study rather a detailed road mapping of the new memory technologies. This will help categorize the promising candidates on performance/efficiency grounds. These findings have important implications for replacing traditional memory technologies.

1. Introduction
Over the past 3 decades umpteen memory technologies have been developed but DRAM, SRAM and Flash remain to be the most dominant memory types. But all three of these memory technologies have their pros and cons. DRAM has high capacity and high density and delivers the highest performance (latency / speed), with practically infinite endurance, yet it is volatile and has to be refreshed every few milliseconds, raising power consumption.[1] NAND Flash is non-volatile, relatively cheap and can be scaled High but is significantly slower than DRAM and has a very low endurance. SRAMs are fast, but are volatile and have large memory cells, reducing capacity. For the very reason that no single memory technology fulfills all requirements of an ideal memory, research work is persistently in quest of new technologies that recoup for shortcomings of any particular type..Here a new concept called “Universal Memory” launches itself. The expected characteristics of a universal memory include high-density (low-cost), high-speed (for both read and write operations), long retention time, low-power (both access and standby powers), random-accessibility, non-volatility and scaling better than current technologies. [2]Fortunately, research over these years has provided an insight to the weaknesses of the current memory technologies and therefore defining a basis for judging long-term potential of the present and emerging memory technologies.

This paper reviews recent research efforts on the emerging memory technologies that are vying to become the next generation memory.

2. Literature Review
In recent years, emerging nonvolatile memories have been earnestly studied and for the likelihood for future memory evolution the hypercritical question to be answered is that on which technological grounds these traditional memories (the most prevalent forms of random access memory today, dynamic random-access memory and static random-access memory) are working inefficiently and what makes this.

Many propitious candidates, such as PC-RAM, ZRAM, R-RAM, STT-RAM and memristor, have gained notable attention of late and are being assiduously scrutinized, which promise to radically change the landscape of memory systems. These new technologies will probably result in more complex memory hierarchies, but are likely to allow the construction of memory chips that are non-volatile, low-energy and have density and latency close to or better than current DRAM chips, improving performance/efficiency and allowing memory systems to continue to scale up.[3]

i. PCRAM
Phase change memory is revolutionizing the way subsystems are arranged, providing an all-encompassing technology that can meet designers’ diverse needs in a single memory device. Phase change memory is a type of non-volatile memory that is much faster than the common flash memory, from 500 to 1,000 times faster, and it also uses up to one half the power. [4]

PCM technology has the potential to provide inexpensive, high-speed, high-density, high-volume nonvolatile storage on an unprecedented scale. In addition, PCM chips are expected to last several times as long as currently available flash memory chips and may prove cheaper to mass-produce.

ii. RRAM
Resistive random-access memory (RRAM) is widely hailed as the “most likely to succeed” in the race to develop a new, more scalable, high capacity, high performance and reliable memory. Compared to traditional Flash memory, RRAM is faster and requires lower voltage, enabling its use in both embedded and SSD application. RRAM requires less energy to operate and leaves room for a greater number of write cycles for a longer lifespan, depending on the components being used. With the ability for high and low levels of resistance, this allows RRAM to store different values on the chip to make up bits of data.

iii. MRAM or STT-RAM
MRAM, also known as magneto resistive RAM or magnetic

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RAM, is a type of non volatile RAM memory which uses magnetic charges in order to store data. This is different from SRAM and DRAM, which use electric charges to store data. The advantage of MRAM is that it retains data when power is turned off. It requires only a small amount of electricity to be able to store data bits. Replacing DRAM with MRAM could prevent data loss and enable computers that start instantly, without waiting for software to boot up. Thus it is a potentially revolutionary universal memory technology that combines the capacity and cost benefits of DRAM, the fast read and write performance of SRAM, the non-volatility of Flash, and essentially unlimited endurance

There are several other emerging Non-Volatile Memory (NVM) technologies under research namely FRAM, NRAM, CBRAM, SEM, Polymer, Molecular, Racetrack, Holographic and Probe. Most of these technologies are in different stages of maturity. Although most of these technologies are still in early prototyping stages, their expected properties in terms of density, latency, energy and endurance are already estimated.

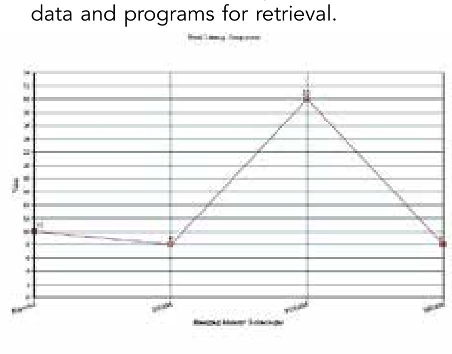
In the present work, the study is limited to three of these technologies: Phase-Change RAM, Resistive RAM (including Memristors) and Magneto resistive RAM (including Spin-Torque Transfer RAM). All these fall into the category of the most actively researched today, and considered most promising of being commercially feasible.

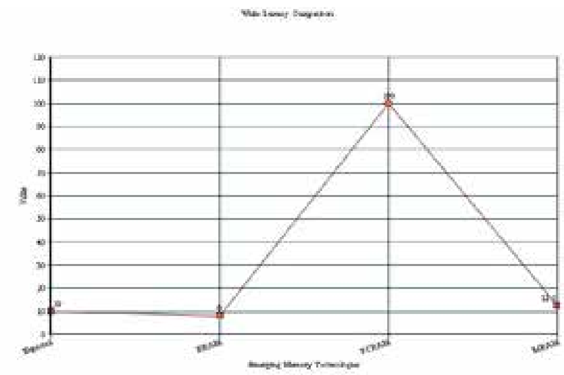
3. Comparitive Study

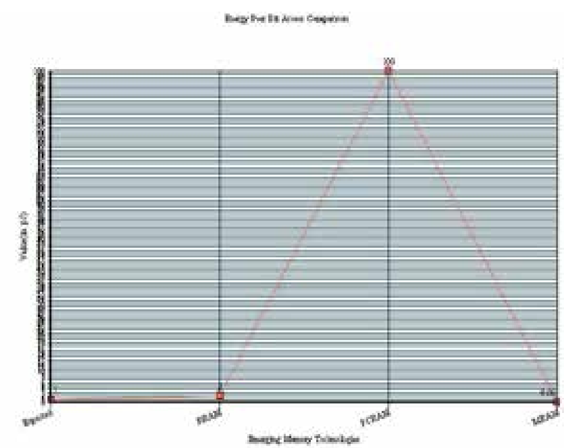
According to the research study by Chris H. Kim, University of Minnesota : Spin-transfer torque RAM and phase-change RAM are vying to become the next-generation embedded memory, offering high speed, high density, and non-volatility.[5] This study discusses new opportunities and challenges presented by these two memory technologies with a particular emphasis on modeling and architecture design. [6]

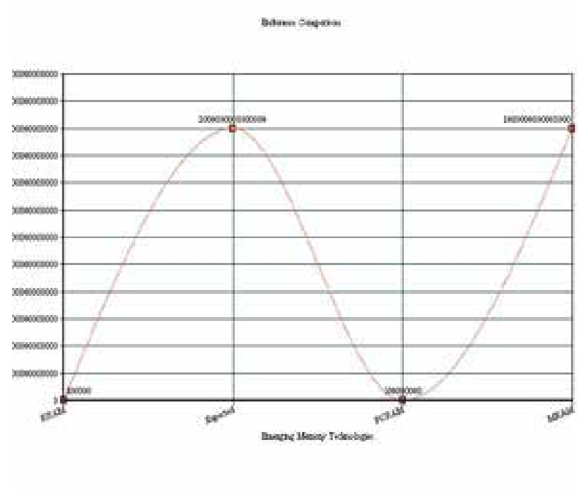
Several other researches in the field of emerging memory technologies focus on the scaling, cost and leakage power of memory. But this paper will focus on finding a better replacement to the current memory technologies on basis of five different criteria.

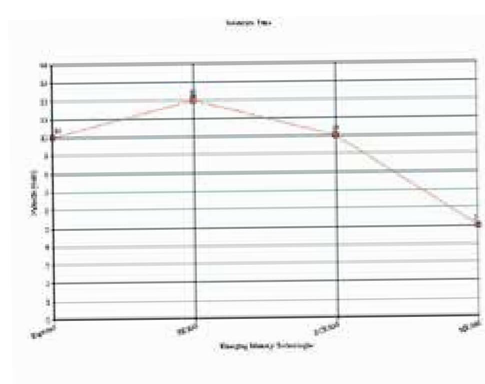
1. Read Latency: the speed for reading values from a memory cell.
2. Write Latency: the speed for writing values to a memory cell.
3. Dynamic Power: Related to the energy spent per bit access.
4. Endurance: the number of write cycles that a memory cell endures before eventually wearing out.
5. Retention Time: The capacity of memory to preserve data and programs for retrieval.











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4. Analysis

On analysing the graphs following deductions can be made:

1. PCRAM is not fast enough and does not have the necessary endurance. But probably with some more enhancements PCRAM could be used as a low-power, highly dense main memory.
2. STT-MRAM cannot achieve high densities. MRAM has similar performance to SRAM, similar density to DRAM but much lower power consumption than DRAM, and is much faster and suffers no degradation over time in comparison to flash memory. It is this combination of features that some suggest makes it the "universal memory", able to replace SRAM, DRAM, EEPROM, and flash.

3. RRAM has very limited endurance. If RRAM can be made to have high endurance, it can replace both PCRAM and STT-MRAM for all levels: cache, main memory and disks, becoming a truly universal memory. But this is still a challenge and there is no clear roadmap indicating if this will happen.[7]

All the three can potentially be used as persistent storage if their cost/bit goes down enough, which might happen if they become widely adopted and manufactured in large scale. These technologies can allow the construction of memory chips that are non-volatile, low-energy, highly dense and with latency close to or better than current DRAM chips.

Summarising the whole, despite their inability to meet all of Universal Memory requirements, these technologies promise to improve current memory hierarchies, and allow memory systems to continue scaling up. No single memory technology of today can satisfy all requirements of low cost, high density, low energy, low latency and high endurance. For this reason, we use memory hierarchies to obtain a performance similar to the faster technology and cost similar to the cheaper technology. But one of the drawbacks of universal memory hierarchy is complexity.

5. Conclusion

In the study it was noted that none of the current technologies under development have the complete set of attributes to radically simplify memory systems.

Based on present study, conclusions are derived on the impacts of these technologies on current memory systems. The ideal future memory technology should be non-volatile, low-cost, highly dense, energy-efficient, fast and with high endurance. Such ideal technology would eliminate the need for complex hierarchies in the memory subsystem. The adoption of one or more of these NVM technologies will bring significant changes to memory systems. Some of these changes will be transparent to software applications and operating systems, but others will probably not. We still need to understand carefully the impacts of such changes and how to prepare for them. This work tries to make a contribution in this direction.

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