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Chalcogenides for PCM Applications- An Overview

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***Abstract*—Chalcogenide is the term used to reference chalcogen's compounds with elements such as Arsenic, Silver, Copper, Germanium, Indium, Lead etc. Its binary compound is formed from a chalcogen anion with an electropositive element. They have wide usage in different applications due its optical and electrical properties. Some chalcogenides observe thermally forced crystalline amorphous phase changes used for binary encoding. This acts as the ground work of nonvolatile memory devices. Phase change materials (PCM) is present in amorphous phase as well as one or few crystalline phases, and they can be rapidly and repeatedly switched between these phases. The phase change is commonly induced by electrical heating or through optical pulses. The paper gives an overview of the electrical properties of chalcogenides for PCM applications.**

***Index Terms*— Chalcogenides, Phase Change Memory(PCM), Amorphous, crystalline.**

I. INTRODUCTION

Storage systems are unavoidable for computing these days. Memory is a electronic component competent of storing temporary data. Leading non volatile memory is flash memory with the following limitations: Rewrite limitations, price and block erasing. Thus, today's need is to design a memory having fast read, write and erase cycles, low cost, low power, high endurance, scalability, multiple bits per cell and long retention time. PCM conceivably substitutes for flash memory. PCM works on the concept of heating chalcogenide glass to shift its structure between crystalline and amorphous phase.

Chalcogenide- chemical compound formed from chalcogen anion and an electropositive element. Chalcogenides, have unique combination of properties, like strong optical and electrical contrast, fast crystallization, and high crystallization temperature used in PCM devices. Doping can be done in phase change materials by adding one or more elements in several percent limits to obtain very high thermal stability amorphous phase, suitable for high-temperature PCM applications. Crystallization phase is achieved by change in the bonding mechanism. Amorphous materials have ordinary covalent bonding. Bonding mechanism in the crystalline phase, termed resonance bonding is formed when a single half-filled p-band forms two bonds with its neighbors.

The PCM solid-state memory can be cost effective over conventional solid-state memories such as Dynamic Random Access Memory (DRAM) or Flash due to its thin-film nature, very small operating storage media, and simple device structure. PCM requires fewer IC fabrication steps resulting in reduced read write cycles, lesser defects, and greater manufacturing flexibility. Reduced storage area and cell volume result in reduced die sizes without unrealistic topologies, thus helping fabricate more memory circuits per wafer with a process

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that deviates little from a basic CMOS logic flow. Performance of the PCM memory cell provides for near ideal memory properties. The memory storage is nonvolatile (information retention with no power applied). A computer using PCM could be turned off and then turned back on immediately or 10 years later and start right up where the user left off. These PCM computers may not have data loss when the system hangs up or when power is lost as current computers using DRAM and/or Static Random access memory (SRAM). With "instant on" operation, PCM computer users would not have to wait for the system to boot up and reload DRAM (presently several minutes are required after power-on where nothing useful is done). Using a PCM memory without power required to maintain memory while operating or in standby provides substantial competitive advantages for portable applications where battery size and operating time are key competitive metrics.

II. Properties of chalcogenides

Phase change elements occur in one amorphous phase and few crystalline phases. Rapid and repeated switching between these phases is typically brought about by heating through optical pulses or electrical heating. The optical and electronic properties can vary significantly between these phases. The merger of optical and electrical contrast and repeated switching allows data storage. The phase change switching methodologies in contemporary research include thermal switching and filamentary discharge, electronic mechanism, flip flop mechanism, nucleation and growth and growth of nuclei without dendrites[1].

A. Variation of resistance

PCM using chalcogenides is based on change from crystalline to amorphous state and vice versa. Crystalline state is the 'on' state with low resistivity and Ge-Se-Te is characterized by low conductivity and high optical reflectivity. The amorphous phase is the 'off' state with high resistance and low optical reflectivity. The transition between these states is the important property of PCM to store bits of data. [1]

B. Thermal switching

The glass transition temperature of multicomponet chalcogenide alloys are in range of 150-350°C.This leads to instability. Studies reveal that heating plays an insignificant role in reversible switching. Threshold switches are more stable and give up to 10^{14} operations under pulse conditions. Field accelerated electrons emit phonons due to thermal effects an attempt to attain equilibrium. The switching paradox is from electronic effects. Threshold switches from the field, stripping chalcogen lone-pair electrons and subsequent fill of lone-pair induced traps, while memory switching results from local structural rearrangements in less cross-linked chalcogenides under excitation conditions. [1]

Bulk metal chalcogenide glassy semiconductor $Cu_1(AsSe_{1.4}I_{0.2})_{99}$ has current-controlled negative resistance. It's switching characteristic with the memory shows strong reduction in electrical resistivity and threshold voltage due to the existance of the metallic element copper and increase in ambient temperature [2]. Experimental results of prototypical phase change material $Ge_2Sb_2Te_5$ under constant voltages have shown continuous increase of current prior to switching at sufficient voltage levels. Thus, there is a scope to inspire new theories on the attributes of threshold switching in future [3].

C. Electrical switching

Electrical switching behavior of chalcogenide with other material properties such as glass transition and crystallization temperature, activation energy for crystallization, electrical resistivity etc are experimented. Study on electrical switching parameters of chalcogenides help in identifying proper compositions of chalcogenides as good memory materials. Electrical switching of chalcogenide glasses can be a monostable or bistable phenomenon exhibiting memory or threshold switching respectively. Threshold switching materials are generally selected to be stable against devitrification and no phase change happens in the filament during switching. Since the low resistance state of memory material involves the crystallization of the current carrying filament memory compositions have to be chosen to promote devitrification. Experiments reveal that poor structural cross links, weaker bonds and more lone pair interactions favor memory switching in chalcogenide glasses.[4]

Electrical switching studies of amorphous $Si_{15}Te_{74}Ge_{11}$ thin film show interesting changes in the crystallization in the active volume with changes in the input energy supplied. The changes in crystallization are reflected in the set resistance value that can be explored for multilevel PCM cells [5]. The switching threshold voltage and the crystallization temperature of Ge-Se-Te ternary alloy depend on the Se content. But the switching voltages of Ge-Se-Te ternary alloy are relatively lower than $Ge_{50}Te_{50}$ which improves PRAM power consumption. Electrical switching studies of $Si_{15}Te_{75}Ge_{10}$ reveal the existence of multiple switching states with different SET resistances. The multiple resistance levels obtained can be used for multi bit storage in PCM [6]. Multilevel PCM cells have boundary resistance thresholds and the resistance of the cell tends to vary with time due to either mechanical relaxation forced by the reduced density in the amorphous state, or the existence of a large concentration of low mobility states [7]. The drift in resistance is due to electronic switching and the drift exponent changes with the thickness of the chalcogenide film [8].

D. Structural Transition

The transition from the crystalline state to amorphous state and back in $GeSb_2Te_4$ Phase change material by computer simulation procedure indicates multiplicity of the amorphous phase as opposite to the uniqueness of the crystalline phase. In particular, in $Si_{12}Ge_{10}As_{30}Te_{48}$ switching glass two types of ordering(Quasi crystalline state) have been pointed out. The type of transformation depends on the type of material used in switching. [9]. Determination of the physical parameters governing the early stages of the amorphous-to-fcc transition in Ge2Sb2Te5 evidences all the kinetic parameters (steady-state nucleation rate, growth velocity, transient time, and incubation time) are enhanced. The structure of the fcc Ge2Sb2Te5 contains large disorder and the amorphous-to-fcc transition is driven by flips of Ge atoms. These findings suggest a key ingredient for tailoring the kinetics of crystallization of the chalcogenide alloys, and a general aspect of the phase change mechanisms in materials with high disorder level [10].

III. Conclusion

The paper summarizes some of the properties of chalcogenides useful for PCM application. The properties if chalcogenides reveal that they are most promising material for PCM applications. The electrical properties of chalcogenides depend on the compositions of the material selected. Proper selection of the materials will attain the required properties of chalcogenides for its use in PCM applications.

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