Presented at 2004 Asia-Pacific Data Storage Conference (APDSC'04), Taoyuan, Taiwan (September 27-30, 2004).

Novel Storage Mechanisms Using Ovonic Phase Change Materials

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ABSTRACT

Ovonic phase change materials [1] first invented by S.R. Ovshinsky in the early 1960's are widely used in CD-RW, DVD rewritable, and now in BD rewritable optical storage disks. The Ovonic Universal Memory (OUM) [2], also based on similar phase change materials, is receiving increasing commercial attention in leading semiconductor companies worldwide, and first products are announced for 2004[3]. The changes in the properties of these materials between the amorphous and crystalline structures provide the basis for information storage. In the case of optical storage, the large change in optical constants is used. In electronic non-volatile memories, the large change in electrical conductivity is used. We now describe a unique, new type of non-volatile storage mechanism that is provided by these materials. The readout in these Ovonic devices is via electrical conductivity, and in addition to storage, the mechanism also enables computation in a manner emulating biologic processing in the human brain. We can use this new mechanism to create processing units that go far beyond the von Neumann paradigm where both storage and processing are performed in a single device [4].

INTRODUCTION

The conductivity of phase change materials can increase by six orders of magnitude when crystallized from an amorphous starting structure. In a fabricated device structure factors including contact resistance, crystal configurations and thermal management lead to measurable resistance differences of between two and three orders of magnitude. The "U" curve shown in Figure 1 describes the function of the device, showing how the device resistance changes after the application of pulses of various amplitudes. Resistance levels between the highest and lowest are readily programmable, providing multi-state storage capability (Fig 2). These characteristics form the basis of both binary and multi-level storage in OUM, with attributes of low voltage operation, long programming life, high speed and others. A basic new mechanism of operation of Ovonic Phase change devices is found on the left side of the graph in Figure 1. We can use this energy accumulation regime of operation to store information in a new multiple-bit-per-device manner, and more importantly, since it has neurosynaptic capabilities, as the key building block in a cognitive information processor having adaptive and intelligent operation, which we call the Ovonic Cognitive Computer. Such devices clearly show plasticity, which is the basis for pure cognitive operation.

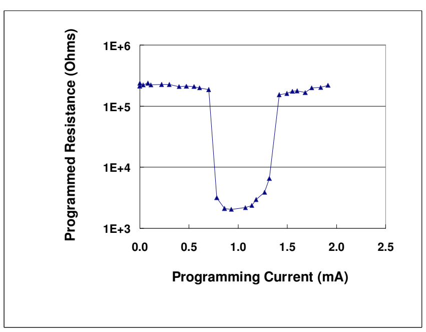

Figure 1

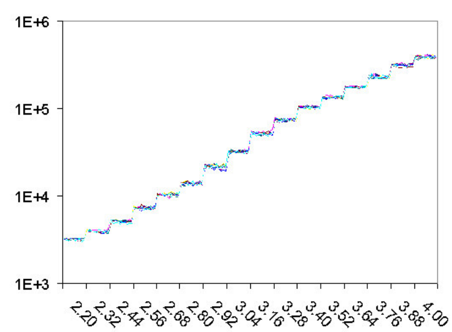

Figure 2

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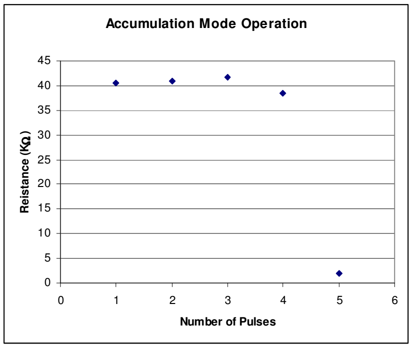

Figure 3

RESULTS

The low resistance crystalline state can be achieved by a single pulse of appropriate amplitude and duration. If the total time of the crystallization pulse is parsed into multiple shorter pulses, the device will crystallize to a state having essentially that same resistance when the cumulative time of the shorter pulses reaches the time of the single longer pulse. This is a novel way to encode and store information. Figure 3 shows how the resistance of a device is changed from that of the initial amorphous state to that of the crystalline state by applying five pulses of the same amplitude. We can achieve this result using other numbers of pulses, as long as the total time for crystallization accumulates to the value used in a single pulse. We have shown analogous behavior is also possible in optical storage [5].

DISCUSSION

The simplest model for the behavior is based on incremental crystal growth. After application of each of the information containing pulses there is additional crystal growth. However, after the first few pulses the individual crystallites do not form a conductive path between the two electrical contacts, and the resistance is essentially unchanged. Since the inherent conductivity of the material in the amorphous structure is so low, even when the current must pass through only a small distance of amorphous material the device resistance is high. The resistance decreases dramatically when the number of pulses reaches the time used in the single pulse, because the crystallites have reached a percolation limit. In this state, there are paths through the phase change material between the two electrical contacts where current can travel completely through crystalline material. This transition from before to beyond the percolation limit leads to a large decrease in device resistance. By this mechanism information can be passed to the next stage in a cognitive circuit.

By measuring the device resistance using a comparator and applying successive pulses, the point when the resistance goes below a threshold value can be determined, and then the state of the device has been determined. This read mechanism is destructive, but the importance of the device lies in the fact that the read process is also a computation process. The device operation is a semiconductor analog to the biologic processes involved in cognitive process in the human brain, where neurons accumulate input pulses from synaptic connections and then fire when a threshold is surpassed. The Ovonic Cognitive Devices both store information and process it, leading to application in advanced cognitive computation.

CONCLUSIONS

The Ovonic Cognitive Device is a nanostructured device that stores information using a novel new mechanism and process. It provides a means of multi-bit storage, providing increased storage density in semiconductor memories. Due to its inherent plasticity, it is the key building block in the Ovonic Cognitive Computer.

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