Programmable Metallization Cells in Memory and Switching Applications

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Programmable metallization cells (PMCs), also called electrochemical metallization cells (ECMs), are metal–electrolyte/insulator–metal (MEM/MIM) structures. Their operation is based on the formation and dissolution of conductive filaments between oxidizable and inert electrodes via ion transport mechanisms and electric field dependent electrochemical reduction-oxidation (redox) reactions [1]. The formation and dissolution of metal elements on or in solid electrolyte/insulator has led to a wide range of applications such as memory, RF switches, micro-electromechanical systems (MEMS), microfluidics, and optical devices [2,3].

Ag- or Cu-doped chalcogenide glasses (ChG), such as Ge-S or Ge-Se, are solid electrolytes with high ionic conductivity. When these ChG solid electrolytes are inserted between a Ag- or Cu-containing anode and an inert conducting cathode, metal cations formed at the anode move toward the cathode under the influence of an applied electric field and are electrodeposited at the cathode. The electrodeposit grows towards the anode to form a conductive link between the electrodes. The link has a conductivity that is much higher than the surrounding material and hence it reduces the resistance of the structure by several orders of magnitude. The resistance of the conducting link depends on the total number of metal ions that are reduced, which in turn depends on the charge supplied by the external circuit. Thus, the on-state resistance can be controlled by programming current and time and this means that it is possible to create multiple discrete resistances levels to represent more than one binary digit per cell [4]. Figure 1 shows the programmable resistance effect in a PMC device, based on a Ag-Ge-S electrolyte between Ag and W electrodes, in series with a MOSFET for two different supply voltages (V_A = 1.5 V, 2.0 V) and three programming currents (I_D = 50, 100, 200 µA) [1].

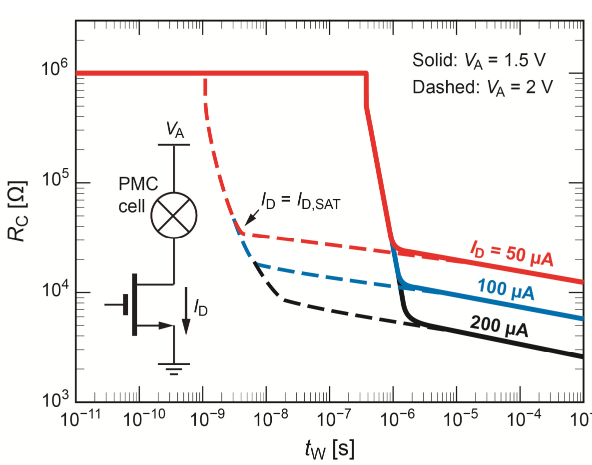

Fig. 1. On-state resistance as a function of programming current, programming pulse width, and cell voltage for a PMC element in series with a MOSFET access device (from [1]).

The asymmetric electrode arrangement (oxidizable on one side of the device, inert on the other) allows the resistance-change process to be reversed by applying an opposite bias to that used for programming. This dissolves the conducting pathway via oxidation of the metal in the filament.

The ChG-based PMC device has a number of interesting characteristics beyond its low energy switching. The structure is also extremely radiation hard. Figure 2 shows the cumulative distributions of ON- and OFF-state resistances of PMC elements that were programmed after exposure to various total-ionizing doses (TIDs) of gamma radiation from a ^{60}Co source. Over 20 PMC elements were tested before and after each dose interval. The only obvious change in the devices after a very large TID of 10 Mrad is a small upward shift in OFF-state resistance.

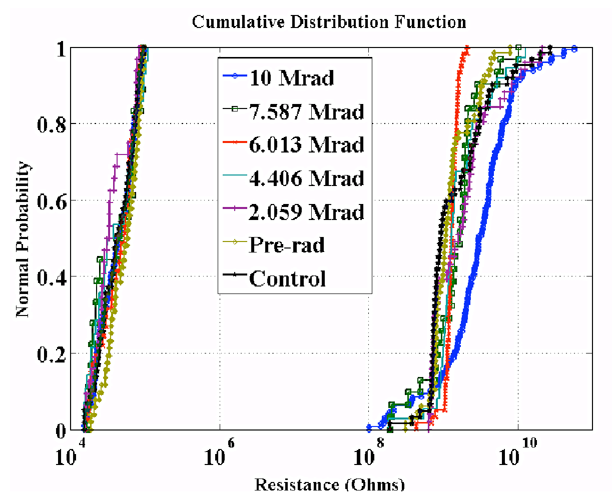

Fig. 2. Cumulative distributions of ON and OFF-state resistances of a PMC device for various gamma radiation total-ionizing doses.

PMC is currently being used as the technology platform for Conductive Bridging Random Access Memory (CBRAM®), a commercial non-volatile memory product [5]. CBRAM® is classified under the category of ionic resistive random access memories (ReRAM) and has gained significant attention in the semiconductor industry. The International Technology Roadmap for Semiconductors (ITRS) in 2011 [6] identified CBRAM as one of a small number of viable candidates for next-generation nonvolatile memory.

This presentation will discuss advances in PMC memory development, including the results of further radiation experiments, and will also highlight other uses of the technology in switching applications.

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