Abstract—In this study it is shown that Conductive Bridging Random Access Memory (CBRAM) might be sensitive to Total Ionizing Dose (TID) depending on the manufacturing process. TID levels at which sensitivity occurs for one of the studied processes are still very high, showing that CBRAM technology is a very interesting solution for future Non Volatile Memory (NVM) technologies to be used in space.

Index Terms—chalcogenide glass, total ionizing dose, memristors, programmable metallization cell, PMC, electrochemical metallization, ECM, nanoionic memory, cation, CBRAM radiation effects, resistive switching, ReRAM, cation.

I. INTRODUCTION

Conductive Bridging Random Access Memory (CBRAM) cells are resistance switching elements using electrochemically active metals like copper (Cu) or silver (Ag) diffusing through a solid-state electrolyte [1-4]. They are used in novel types of nonvolatile memory circuits and are thought to be great candidates to replace flash technology [5], [6]. In addition to nonvolatile memory, these devices can be used in a variety of other applications such as electronic circuits that perform neuromorphic computation. CBRAM cells have been demonstrated to be extremely resilient to total ionizing dose (TID) up to Megarad levels of absorbed dose [7-9]. This TID resilience has been demonstrated on both Cu-SiO₂ devices [10] and Ag-GeS (both CMOS process compatible and commercially available), as well as Ag-GeSe devices [7-9]. It has also been shown [7] that the retention of 128 kbit CBRAM based memory circuits is superior than traditional flash-based memory circuits, with no variation of supply current for TID up to 5 Mrad [4].

In this work the first observation of TID-induced failure of a CBRAM cell is presented. Two different manufacturing processes have been investigated that exhibit a different radiation response. In the first section of this article, a description of the CBRAM cells investigated in this work is provided. In the following experimental section, the resistance switching characteristics of CBRAM devices made with the two different processes are presented after exposure to gamma rays. In the last section, a discussion is provided concerning the TID reliability of devices depending on their manufacturing process.

II. CBRAM CELLS: MATERIALS, STRUCTURE, DESCRIPTION

The CBRAM under investigation are presented in Fig. 1, where a cross section (Fig. 1.a) and a top view microphotograph (Fig. 1.b) of an individual cell are given. These cells are also known as programmable metallization cell (PMC) in the literature. The CBRAM cells investigated in this paper are “active metal/electrolyte/inert metal” devices made of a silver doped Ge₃₀Se₇₀ chalcogenide glass that acts as a solid-state electrolyte (Ag-ChG in Fig. 1.a). The cells have an active top silver electrode, and an inert bottom nickel counter electrode. In this work, two different manufacturing processes (labeled as processes A and B) have been used to manufacture two sets of devices. Both processes utilize an initial 60 nm thin layer of Ge₃₀Se₇₀ chalcogenide glass film thermally evaporated. Silver is deposited on top of this Ge₃₀Se₇₀ layer in order to obtain the solid-state electrolyte and the top electrode [1-4]. The ChG and silver are thermally evaporated in a Cressington 308 thermal evaporator.

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Fig. 1: (a) cross sectional view of CBRAM cells implemented on top of an SiO₂/Si wafer. A nickel blanket film forms the common bottom electrode to the devices that are implemented and patterned on top of vias wet-etched through an additional SiO₂ layer. b) top view of a CBRAM cell manufactured at ASU

Different sets of CBRAM cells from both processes have been irradiated with cobalt-60 gamma-rays in the Gammacell 220 irradiator at Arizona State University. Exposures were conducted at room temperature and with sample electrodes left floating during exposure (no bias applied during exposure) [7]. A TID of 11.5 Mrad(Ge₃₀Se₇₀) has been reached on parts from process B and a maximum TID of 10 Mrad(Ge₃₀Se₇₀) was attained on samples from process A. Samples were step stressed, meaning that electrical characterizations were performed at several dose levels below the maximum dose in order to retrieve the evolution of the switching characteristics with increasing dose. The devices were electrically characterized on a probe-station by performing DC current-voltage sweeps with an Agilent 4156C parameter analyzer. The voltage between the electrodes is swept from -1 V to 1 V. The varying voltage is applied on the active anode of the CBRAM cell, while the inert cathode is fixed at 0 V. Current-voltage (I-V) measurements were performed prior to and shortly after the irradiations.

III. EXPERIMENTAL RESULTS

The I-V characteristics obtained on devices from process A (Fig. 2.a) and process B (Fig. 2.b) are different because the choice of fabrication steps yields solid-electrolytes (Ag-ChG layer in Fig. 1.a) with different conduction properties. It is observed in Fig. 2 that prior to radiation exposure, devices fabricated in either process demonstrate excellent resistance switching (see dashed line representing resistance values on Fig. 2), but the range of resistance that can be obtained for these two processes are different. With Process A, the devices can be switched at much lower currents and the resistance range is much larger. The erase process for process A parts is also faster. Lastly, the voltage at which the device is switched from its low resistance state (LRS) to its high resistance state (HRS) (i.e. the threshold voltage) is also slightly different for both processes.

Fig. 2: Current-voltage (red solid line, left y-axis) and resistance-voltage characteristic (blue, dashed line, right y-axis) (a) Process A, (b) Process B
A. TID testing of PMCs manufactured with two different processes

TID testing was conducted on samples from both process A and B. High resistance and low resistance states were extracted from the DC current-voltage characteristics after exposure. Devices from process A can be effectively switched after exposure to a TID of 10 Mrad. The HRS and LRS levels obtained from continuous cycling of one, representative, irradiated 10 μm diameter CBRAM cell from process A are presented in Fig. 3.

The irradiated part was successfully switched 500 times before the test was stopped. Similar behavior has been observed on several parts from process A. Devices from process B were also tested after exposure to TID, and the results of a step stressed exposure are presented in Fig. 4. It is observed that the devices from process B can be switched for TID levels up to 5 Mrad(Ge<sub>30</sub>Se<sub>70</sub>), but once a TID of 6 Mrad(Ge<sub>30</sub>Se<sub>70</sub>) is reached, resistance switching failure occurs. This can be seen in Fig. 4 where data obtained on exposed devices (Fig. 4.a) are compared to data collected on control devices (Fig. 4.b). In Fig. 4.a, it is shown that at TID lower than 6 Mrad(Ge<sub>30</sub>Se<sub>70</sub>), the HRS and LRS values are well separated and the parts are effectively exhibiting resistance switching. For TID values higher than 6 Mrad(Ge<sub>30</sub>Se<sub>70</sub>), both HRS and LRS are equal and higher than their original value, at very high resistance levels (see Fig. 4.a). When both HRS and LRS are equal, the device is not switching anymore. The relatively uniform response of the control parts demonstrates that irradiation is the cause of part failure in process B parts. These results suggest that process A is much better suited for operating in very high ionizing dose environments than parts from process B.

IV. DISCUSSION

In this work it was discovered that resistance switching of CBRAM cells can be impacted by ionizing radiation. This is the first time that this is observed on CBRAM cells and, resistance switching cells. This is the case for process B, particularly for TID higher than 4.5 Mrad(Ge<sub>30</sub>Se<sub>70</sub>). For devices fabricated in process B, a large increase in the resistance of the CBRAM cells results and this response is surely related to a TID modification of the electrolytic properties of the silver doped chalcogenide glass. For process A however, no failure are observed and the cells still operate after a very high TID level of 10 Mrad(Ge<sub>30</sub>Se<sub>70</sub>) is reached.

However, despite the loss functionality of process B parts, it is worth noting that these CBRAM cells exhibit a very good radiation hardness compared to common non-volatile memory cell technologies, as failure is
observed at 4.5 Mrad, which is a very high total dose.

REFERENCES


