Heavy Ions Radiation Effects on 4kb Phase-Change Memory

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Phase-Change Memory

Based on **Phase-Change Materials**: 
*Ex*: Ge$_2$Sb$_2$Te$_5$ (GST), GeTe, etc.

- **Amorphous** phase (*logic state 0, RESET*)
- **Crystalline** phase (*logic state 1, SET*)

Memory programming relies on temperature profile control and not on charge storage

The crystallization temperature ($T_c$) can be tuned by engineering the material composition (Ge or N enrichment)

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PCM & radiation hardness

Radiation effects on the external circuitry

Devices belonging to the same WL or BL are affected by radiation, even if they do not lie in the irradiated region.

Radiation effects on scaled PCM

Partial amorphisation due to the temperature increase generated by the heavy-ions impinging on the active layer of 45 nm PCM

Fig. 3 Color map of the value of the cells of a MOS-chip array irradiated with a 30 Mrad SiO2 proton beam. Region A is the irradiated zone and Region B is the area were the cells show a change in current of more than 1 A with respect to the pre-irradiation condition [3].

Fig. 4 Schematic of a phase change memory device hit by a heavy ion along the word line [4].

Radiation effect on chalcogenide materials

GST and Ge-rich GeSbTe (GGST)

1. As deposited (amorphous)
2. Annealed at 450°C (polycrystalline)

Radiation effect on 4kb matrices

SET and RESET distribution

1. GST vs Ge-rich GeSbTe (w=100nm)
2. GST vs Interfacial Layer-PCM (w=300nm)

Irradiation beam specifications

- 8.3 MeV/u Au\(^{26+}\)-ions (E=1.635 GeV)
- Flux: 5E8 ions/cm\(^2\) sec
- Fluences: 10E9, 5E10, 10E12, 5E12, 7E12, 1E13 ions/cm\(^2\)
- Fluences: 10E9, 5E10, 10E12 ions/cm\(^2\)
1. The SET state in GST faces a structural relaxation at a fluence of $10\text{E}9$ ions/cm$^2$ plus amorphisation at $5\text{e}10$ ions/cm$^2$

2. The GST RESET resistance decreases with increasing fluence

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**Fig. 5** Median and ±σ for SET and RESET distributions in GST 4kb arrays before and after irradiations at increasing fluences.

**Fig. 6** XRD patterns of GST crystalline layers before (REF) and after irradiations at increasing fluence.

**Fig. 7** TEM (left) and nano-diffraction patterns (right) analyses of as-deposited amorphous GST after irradiation at a fluence of $10^{13}$ ions/cm$^2$.

**Fig. 8** XRD patterns of GST amorphous layers before (REF) and after irradiations at increasing fluence.
SET and RESET states in GGST show structural relaxation at both fluences.

Both the resistance window and the amorphous phase in the RESET state are preserved making GGST more stable than GST based devices thanks to its higher $T_c$.

Fig 9 Median and ±σ for SET and RESET distributions in GGST 4kb arrays before and after irradiations at increasing fluences.

Fig 10 XRD patterns of GGST crystalline layers before (REF) and after irradiations at increasing fluence.

Fig 11 XRD patterns of GGST amorphous layers before (REF) and after irradiations at increasing fluence.

Fig 12 TEM/EDX and nano-diffraction patterns analyses of crystalline GGST after irradiation at a fluence of $7 \times 10^{12}$ ions/cm$^2$. The Ge cartography (left) shows that the Ge segregation induced by the annealing process remains unchanged after irradiation. However, the irradiation reduces the size of the crystallites as evidenced by few and low intensity nano-diffraction patterns identified (right).
**GST vs IL-PCM**

- Strong reduction in RESET current for IL-PCM wrt GST
- The higher SET resistance in IL-PCM is an evidence of the smaller contact area created during the programming of the cell.

**Fig. 13** Resistance-vs-Current characteristics comparing a standard GST device with an IL-PCM. IL-PCM shows a high current reduction wrt GST in devices featuring same critical dimension (electrode area $\sim 3 \times 10^3 \, \mu m^2$).

**IL-PCM shows a higher radiation tolerance due to the « smaller » contact area between heater and PCM**

**Fig. 14** Median and ±σ for SET and RESET distributions in GST and IL-PCM 4kb arrays before and after irradiations at increasing fluences.

**Fig. 15** Schematic of the zx-plane of an IL-PCM showing in red the programmed region, demonstrating the contact area reduction.