E\PCOS 2023
EUROPEAN PHASE CHANGE AND OVONIC SIMPOSIUM
ROME, ITALY – 17-20 SEPTEMBER 2023

Flexible Electronics Applications of Ge-rich and Selenium Substituted Phase-change Materials in Non-volatile Memories

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ABSTRACT

The crystallization properties of Ge-rich GeSbTe (GST) and selenium substituted GeSbSeTe (GSST) alloys are investigated and the materials' applicability for use in flexible memory devices is assessed. The electrical and structural properties of Ge-rich GST and GSST are measured as a function of temperature, where the high temperature stability of the amorphous phase is demonstrated. Finally the electrical switching of a Ge-rich flexible memory device is shown and simulations of GSST undergoing phase switching in a memory architecture suitable for integration into flexible electronics is demonstrated.

Keywords: Ge-rich, electrical properties, flexible memory

1. INTRODUCTION

Phase change memories (PCMs) show promise for use in low-cost and flexible integrated circuits (FlexICs) as non-volatile data storage [1], with potential applications for Internet-of-Things electronics and wearable technology. Some potential compositions for use in flexible PCMs are Ge-rich GST alloys. Germanium enrichment causes a higher crystallisation temperature than the archetypal composition of GST-225 [2], leading to better data retention properties. A high crystallization temperature also enables the amorphous state to withstand a wider range of high temperature manufacturing processes, in turn making the development of a simple write-once memory, in which a single switch from amorphous to crystalline state is used, more straightforward. However, for re-writable applications, Ge-rich GST compositions have the potential to undergo unwanted recrystallisation in the amorphisation operation. This is because low-cost FlexICs often use much longer pulse durations compared to conventional memory cells. Therefore, materials like GST alloys – which are optimised for rapid switching – may recrystallise too readily upon cooling. To overcome this challenge selenium substituted GST compositions are suggested. These materials have a significantly reduced crystallisation speed – so potentially preventing unwanted crystallisation during amorphisation - whilst still offering a high crystallisation temperature [3].

2. EXPERIMENTAL

Amorphous films of GST and Se-substituted GST (GSST) were deposited on Si/SiO_2 substrates using magnetron sputtering. Three compositions were investigated – GST with ~ 50% Ge content, GST with >50% Ge content and GSST. Films of thickness 100 nm were heated up to 350°C with a programmable hotplate using a ramp of 450 ^{o}C/hr. During heating, in-situ measurements of the film electrical resistivity were taken using a 4-point probe. Furthermore, crossbar memory devices were fabricated using GST with ~50% Ge content. These devices have a 1µm x 1µm active phase-change region, and electrical testing was performed on them to demonstrate switching. Finally, the application of GSST compositions to a pore-cell architecture is investigated using a joint finite-element and phase-change modelling approach.

3. RESULTS & DISCUSSION

Fig. 1a shows electrical resistivity as a function of temperature for Ge-rich GST compounds and GSST. The Ge-rich GST compounds and GSST have higher crystallization temperatures than the standard GST-225, maintaining amorphous resistivity up to temperatures >210ºC for Ge-rich compounds and 280ºC for GSST. Crossbar memory cells were fabricated on Si/SiO_2 substrates using ~50% Ge-GST. Fig. 1b shows an image of these cells with a cross-section of 1µm x 1µm which can actively undergo phase-switching. Fig. 1c shows the I-V characteristic of these cells, a threshold voltage of around 0.5 V is observed. Having successfully demonstrated switching, these crossbar cells are now being fabricated and tested on flexible polymer substrates for flexible memory applications. Finally the switching properties of GSST in a pore cell structure on a polyimide substrate was simulated. An amorphous area was melted into the pore, and subsequently a 2 V, 140 µs pulse was used to recrystallise this amorphous region, see Fig. 1d. The extended time required for the crystallisation to occur is due the significantly reduced crystallisation rate of GSST. This helps overcome the issue of unwanted re-crystallisation upon cooling during relatively short amorphisation operation.

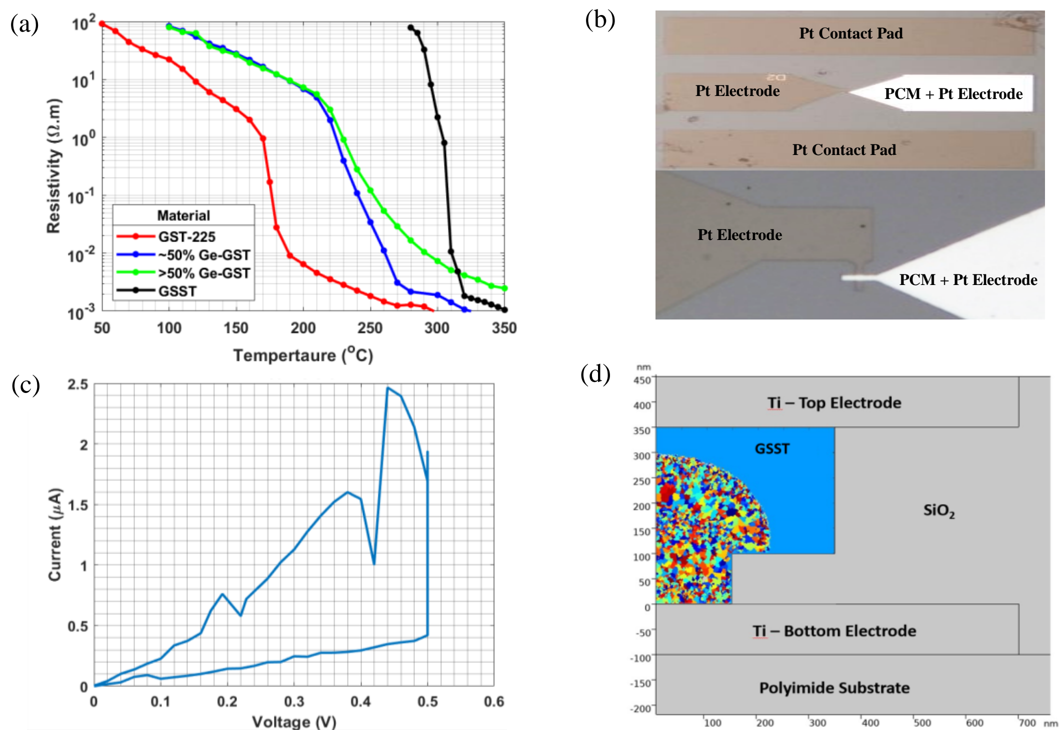

Fig. 1 *(a) Electrical resistivity as a function of temperature for GST-225, Ge-rich compositions and GSST. (b) Crossbar memory structure. (c) I-V characteristic of the crossbar cells. (d) Phase distribution inside a* GSST *pore cell after a 2 V, 140 µs pulse re-crystallises an amorphous mark melted into the pore. Different colour regions represent different crystallite grain orientations, and the extended blue area is also crystalline.*

4. CONCLUSIONS

Ge-rich GST and selenium substituted GSST have been shown to have an increased crystallisation temperature and amorphous thermal structural stability compared to conventional GST-225. Here the operation of memory devices suitable for use in low-cost FlexIC memory architectures is demonstrated using experimental and simulation methods.

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