Thermally Stable, Low Current Consuming Gallium and Germanium Chalcogenides for Consumer and Automotive Memory Applications

D.W. Hewak, C.C. Huang, B. Gholipour and K. Knight
Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, United Kingdom

S. Guerin, B. Hayden and G. Purdy
Ilika Technologies Ltd, Kenneth Dibben House, Chilworth, Southampton, SO16 7NS, United Kingdom

Abstract The phase change technology behind rewritable optical disks and the latest generation of electronic memories has provided clear commercial and technological advances for the field of data storage, by virtue of the many well known attributes, in particular scaling, cycling endurance and speed, that chalcogenide materials offer. While the switching power and current consumption of established germanium antimony telluride based memory cells are a major factor in chip design in real world applications, often the thermal stability of the device can be a major obstacle in the path to the full commercialisation. In this work we describe our research in material discovery and characterization for the purpose of identifying more thermally stable chalcogenides for applications in PCRAM.

1. INTRODUCTION

Our particular interest in this work is the thermal stability of new chalcogenide alloys to potentially outperform the commonly used Ge:Sb:Te (GST) within phase change memory cells. It has been indicated that GST based phase change memory devices with a high level of scaling may suffer from very poor thermal stability [1]; moreover as applications of GST based memory cells extend to harsh operational environments such as aerospace and automotives, device performance as temperatures fluctuates will be compromised. These factors along with high current consumption of memory cells based on this alloy pose the biggest obstacle in realising the full commercial potential of PCRAM. Improved stability has already been obtained using Ge-doped Sb:Te [1] and also by replacing Ge completely by Ga [2] and this allowed device operation at 100^{o}C. To date, phase change functionality has been demonstrated in a wide range of chalcogenide materials however GST is the most commonly used and most studied. It is the objective of our work to assess a wider range of fundamentally different chalcogenide alloys with a particular focus on both performance and temperature stability.

2. MATERIALS

In the past year, we have synthesized and characterized a range of chalcogenide glass families, in particular materials based on Ge:Sb, Ge:Sb:S, Ga:La:S and Ga:La:Te as well as the well known Ge:Sb:Te (GST) family; thus encompassing well known phase change materials as well as more novel compositions. Work with traditional phase change materials was used as a bench mark with which the electrical and thermal properties of more novel compositions could be compared. For the Ga:La:Te, which inherently offer higher thermal stability the full ternary was deposited by physical vapour deposition and all compositions on the phase diagram were screened using high throughput techniques, For the first time, Ga:La:Te alloys were deposited and glass formation demonstrated over the majority of the

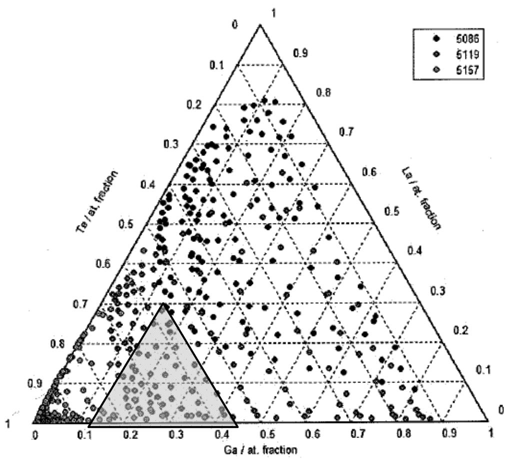

Figure 1. Compositional spread of the Ga:La:Te glass system characterized by high throughput screening methods. The shaded area identifies a region exhibiting crystalline to amorphous phase transition exhibiting a resistance difference of over four orders of magnitude.

phase diagram [3,4]. Particular promise was obtained with compositions containing a relatively high proportion of Te and Ga to La, where resistivity measurements revealed four order of magnitude difference between the glass and crystalline phases (see figure 1). It could also be shown that the average temperature of the amorphous to crystalline phase transition was 50-100K higher for these phases over standard GST composition. The Ge:Sb:S family of materials were deposited by chemical vapour deposition with the ratio of Ge to Sb varying from 0 to 100 mol%. Sulpur content for these materials ranged from 0% to 64 mol% [5]. Each material family provided clear phase change functionality, while the properties of individual components governed their suitability for a particular switching regime.

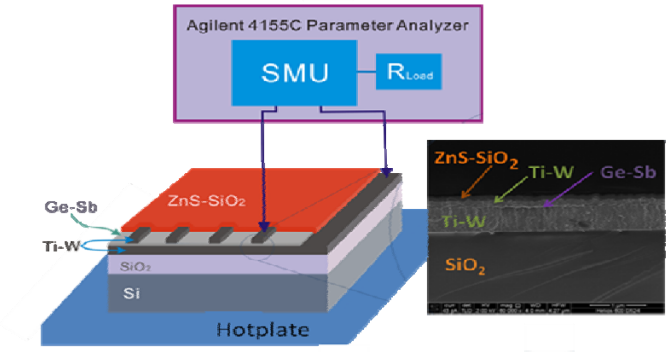

Figure 2. Apparatus used for electrical characterization as a function of temperature, showing device schematic and scanning electron microscope image of actual device

3. METHODOLOGY AND RESULTS

Automated primary screening of materials over the full compositional ranges deposited took place. Here the composition, thickness and resistivity were characterized which included measurements following annealing of this films at temperatures up to 400°C. To assess device performance at elevated temperatures, a series of device based studies have been conducted with the most promising alloys (figure 2). Ga:La:S glasses for example exhibit characteristic thermal properties over 200°C higher than Ge:Sb:Te alloys. Figure 3 left shows a typical measurement in which the threshold voltage as a function of temperature is plotted for both a Ga:La:S and Ge:Sb:Te (GST) device. For the GST device, functionality (loss of threshold switching) occurred at approximately 160°C whereas for this example, repeatable threshold switching continued to 250°C with the Ga:La:S device. Although this data only indicates enhanced temperature operation in a prototype device rather than real world application, it does clearly indicate that significant difference in temperature stability can be achieved through compositional modification.

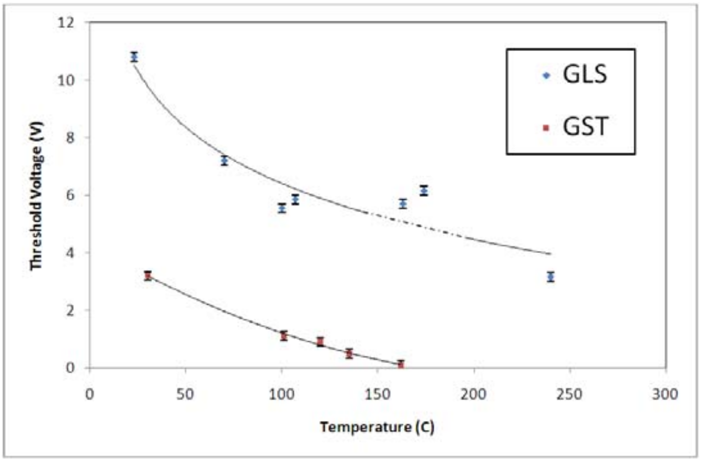

Figure 3. Apparatus used for electrical characterization as a function of temperature, showing device schematic and scanning electron microscope image of actual device

4. SUMMARY

We reveal enhanced temperature stability in phase change alloys identified through high throughput screening of families of chalcogenide alloys. Work in progress is fully quantifying a range of chalcogenides to provide optimized materials for commercial memory based devices.

5. REFERENCES

1. C Wang et al, “Phase-Change Characteristics and Thermal Stability of GeTe/Sb2Te3 nano composite Multilayer Films”, **Jap. J. App. Phys.** 48 (2009) 115505
2. Z Wu et al, “Improved stability of a phase change memory device using Ge-doped SbTe at varying ambient temperature”, **App. Phys. Lett**. 96 (2010) 133510
3. European Patent Number 1969602, Phase Change Memory Materials, Devices and Methods, 24 March 2010.
4. R.E. Simpson et al, “High throughput synthesis of chalcogenide materials for data storage”, ***EPCOS'05*** Cambridge (2005)
5. C.C. Huang et al, **“**Optical properties of CVD grown amorphous Ge-Sb-S thin films ***J.Non-Crystal****. Sol.* 356 281 (2009)