# Stacked Chalcogenide Layers for Phase Change Memory

Santosh Kurinec [1*], Archana Devasia[1], David Cabrera[1], Simone Raoux[2], David MacMahon[3], and Kristy A. Campbell[4]

[1]Electrical and Microelectronic Engineering, Rochester Institute of Technology, Rochester, New York 14623, USA
[2]IBM T. J. Watson Research Center, Yorktown Heights, New York 10598, USA
[3]Micron Technology, Manassas, Virginia 20110, USA
[4]Electrical and Computer Engineering, Boise State University, Boise, Idaho 83725, USA
[*]E-mail address: skkemc@rit.edu

**ABSTRACT**

Bilayer chalcogenides composed of Ge-chalcogenide (GeTe or $Ge_2Se_3$) and Sn-chalcogenide (SnTe or SnSe) are explored for phase change memory applications. Cells with these bilayers have been fabricated using tantalum as the top and the bottom electrodes. All devices exhibit threshold switching behavior. It is observed that SnTe based devices exhibit lower threshold voltage, lower current at threshold, higher resistance margin and less variability in the SET state as compared to SnSe based devices. Using time resolved x-ray diffraction (XRD), it has been demonstrated that stacked phase change memory films exhibit both structural and compositional dependency with annealing temperature. By the incorporation of a Sn layer the phase transition characteristics of Ge-chalcogenide thin films can be tuned. Clear evidence of thermally induced Ge, Sn and chalcogen inter-diffusion has been observed using high-resolution transmission electron microscopy (HRTEM) and parallel electron energy loss spectroscopy (PEELS). The study reveals the temperature limitations for each stack.

**Key words**: phase change materials, bilayer chalcogenides, inter diffusion

## 1. INTRODUCTION

By using a layered arrangement originally proposed by Campbell et al. [1], it is possible to induce phase change response in materials, which normally do not exhibit such behavior, and thus form new materials which may have desired threshold voltage and programming current properties. The insertion of a metal-chalcogenide layer results in an ohmic contact and provides a better adhesion of the Ge-chalcogenide layer to the electrode. Also, through the incorporation of a metal containing layer, the phase transition characteristics of the memory layer can be tailored in order to obtain in-situ a material with optimized phase change properties. This paper summarizes the results on four types of cells and demonstrates the role played by structural and chemical inter-diffusion between the layers.

## 1I. EXPERIMENTAL RESULTS AND DISCUSSION

Thermal evaporation of Ge-chalcogenide (GeTe or $Ge_2Se_3$, 99.999% purity) of 30 nm thickness was carried out, followed by 50 nm thick Sn-chalcogenide (SnSe or SnTe, 99.999% purity). Thickness was monitored in-situ by means of a crystal monitor and then verified using cross-sectional scanning electron microscopy (SEM). Two terminal phase change memory (PCM) cells employing these bilayers were fabricated using silicon nitride as the dielectric employing a three level photolithographic process. The stacks were examined using time-resolved XRD at the National Synchrotron Light Source at Brookhaven National Laboratory. The incident beam wavelength was 1.797Å. XRD measurements were carried out while samples were heated at the rate of 1˚C/s under flowing Helium to different temperatures. As-deposited films of GeTe and $Ge_2Se_3$ were found to be amorphous while SnSe and SnTe were crystalline. It is inferred from XRD and TEM/PEELS analyses that inter-diffusion of Sn into the memory layer lowers its phase transition temperature. As an illustration, Fig. 1 shows a decrease in rhombohedral to cubic transition temperature of GeTe to ~ 290-300˚C which is attributed to Sn incorporation as shown in the PEELS elemental area scans shown on the right. A similar observation is made on $Ge_2Se_3$ based stacks, which shows

intermixing and reduction in crystallization temperature of GeSe phases. The films were capped with $Al_2O_3$ deposited by atomic layer deposition for TEM analysis to prevent Se volatilization. Table I lists the electrical results obtained on these four different stacks. Effective threshold field is calculated assuming complete stack thickness. The actual threshold field of the memory layer would be higher (~ 1.6 times) if negligible voltage drop across the metal chalcogenide layer is assumed. It is observed that the devices using SnSe as the metal chalcogenide layer exhibit higher threshold voltage and higher current at threshold. This may be explained in terms of higher resistivity of SnSe, which exhibits semiconducting behavior as opposed to that of SnTe which is metallic. This observation is verified through measurements of resistivity versus temperature for SnSe and SnTe.

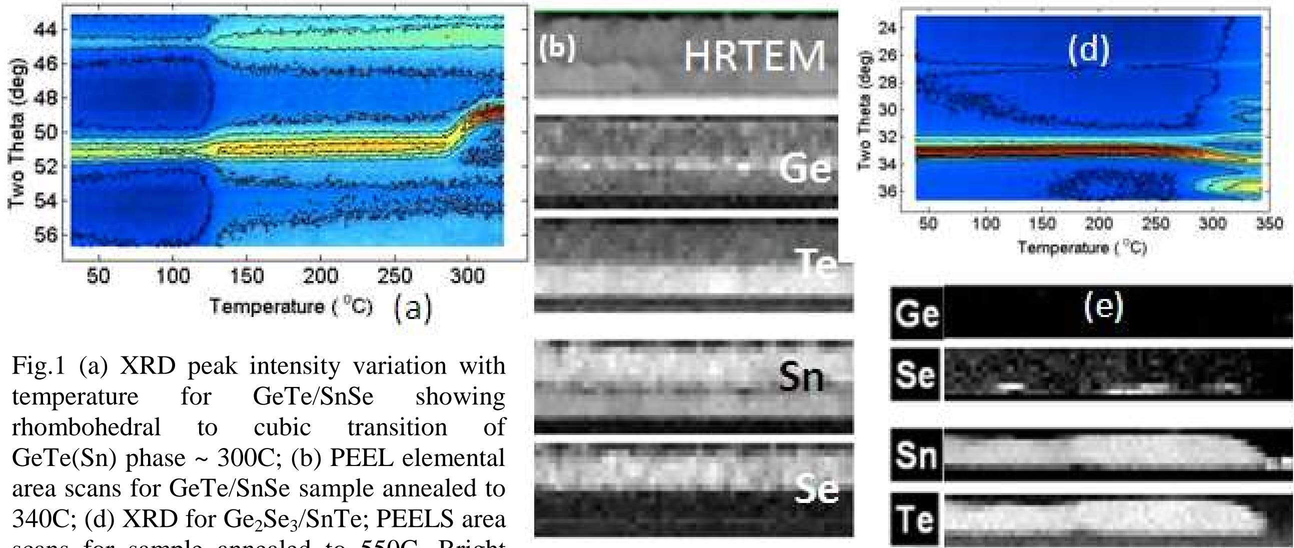


Fig.1 (a) XRD peak intensity variation with temperature for GeTe/SnSe showing rhombohedral to cubic transition of GeTe(Sn) phase ~ 300C; (b) PEEL elemental area scans for GeTe/SnSe sample annealed to 340C; (d) XRD for $Ge_2Se_3$/SnTe; PEELS area scans for sample annealed to 550C. Bright regions indicate higher concentration.

| Bilayer | Effective Threshold Field V/μm | Current Density at Threshold μA μm$^{-2}$ | Resistance ON/OFF Ratio | Crystallization and Structural Transition Temperature $^0$C |
|---|---|---|---|---|
| GeTe/SnTe | 25 | 3 | $10^{-5}$ | 170 |
| GeTe/SnSe | 64 | 110 | $10^{-2}$ | 170/ 300 |
| $Ge_2Se_3$/SnTe | 40 | 0.75 | $10^{-5}$ | 300-350 |
| $Ge_2Se_3$/SnSe | 71 | 95 | $10^{-3}$ | 300-350 |

**Table I:** Effective threshold fields, current density and on/off resistance ratio in PCM cells fabricated. The phase change film crystallization temperature and subsequent structural phase transition temperatures are listed in the last column.

## ACKNOWLEDGEMENTS

This research has been supported by NASA EPSCoR grant NNX07AT60A. The work was carried out in part at the National Synchrotron Light Source, Brookhaven National Laboratory, under Contract No. DE-AC02-98CH10886.

## REFERENCES

[1] K. A. Campbell and C. M. Anderson, Microelectron. J., 38, 52 (2007

[2] A. Devasia, F. Bai, S. Gupta, S. Kurinec, M. Davis and K. Campbell, *Thin Solid Films*, vol. 517, pp. 6516-6519, 2009.