XRD/TEM/EELS Studies on Memory Device Structures

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INTRODUCTION

Over the past decade, numerous emerging memory technologies are being considered as contenders to displace either or both NAND flash and DRAM as scaling limitations of these conventional memories are perceived for applications in mobile devices. Some of these include Magnetic and Spin Transfer Torque Random Access Memory (MRAM, STTRAM), Phase Change RAM (PCRAM), Ferroelectric RAM and Resistive RAM memories. These technologies can be classified as relying on one of the movements: atomic, ionic, electron charge or spin in nanoscale thin films comprising of a variety of materials. The literature shows about 50 elements of the periodic table being investigated for these memory applications owing to their unique physical and chemical properties. Engineering memory devices requires nanoscale characterizations of film stacks for their chemical compositions and crystalline nature in addition to electronic properties such as resistance, magnetization and polarization depending upon the principle involved. This paper focuses on how x-ray diffraction (XRD), transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS) techniques have been employed to obtain insight into engineering magnetic tunnel junctions (MTJ) and PCM devices.

EXPERIMENTAL

The MTJ and PCRAM memory cells were fabricated using physical vapor deposition (PVD) of memory layers (MTJ at Veeco, PCRAM at Boise State University and IBM Watson Research Center) and subsequent design and fabrication at the RIT Microelectronic Engineering cleanroom facility. The time-resolved x-ray diffraction (TR XRD) analyses were performed 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. HRTEM and EELS analyses were performed at Micron Technology using Hitachi HD-2300 STEM fitted with a Gatan Enfina PEELS Spectrometer. 2D-XRD was performed at RIT using Bruker Dimension D8 system with GADDS detector.

MAGNETIC TUNNEL JUNCTION (MTJ)

A stack of CoFeB/MgO/CoFeB forms the core of the MRAM memory cell consisting of 10-12 layers comprising of top and bottom electrodes, pinning and barrier layers. For proper functioning of the MTJ, there must be band matching between CoFe and the tunneling barrier MgO which requires crystallization of these nanoscale thin layers. Amorphous CoFeB films are annealed with MgO as the template; however, boron diffusion needs to be investigated. While EELS can provide information on boron diffusion, XRD analysis in this thin film stack is not possible. Therefore, a multi layered (7 bi-layers) structure was designed for obtaining sufficient diffracted X-ray

signal while still maintaining structural resemblance to the single MTJ [1,2]. This enabled us to design suitable annealing conditions for crystallization of CoFeB and quantify boron diffusion in MgO as illustrated in Fig.1.

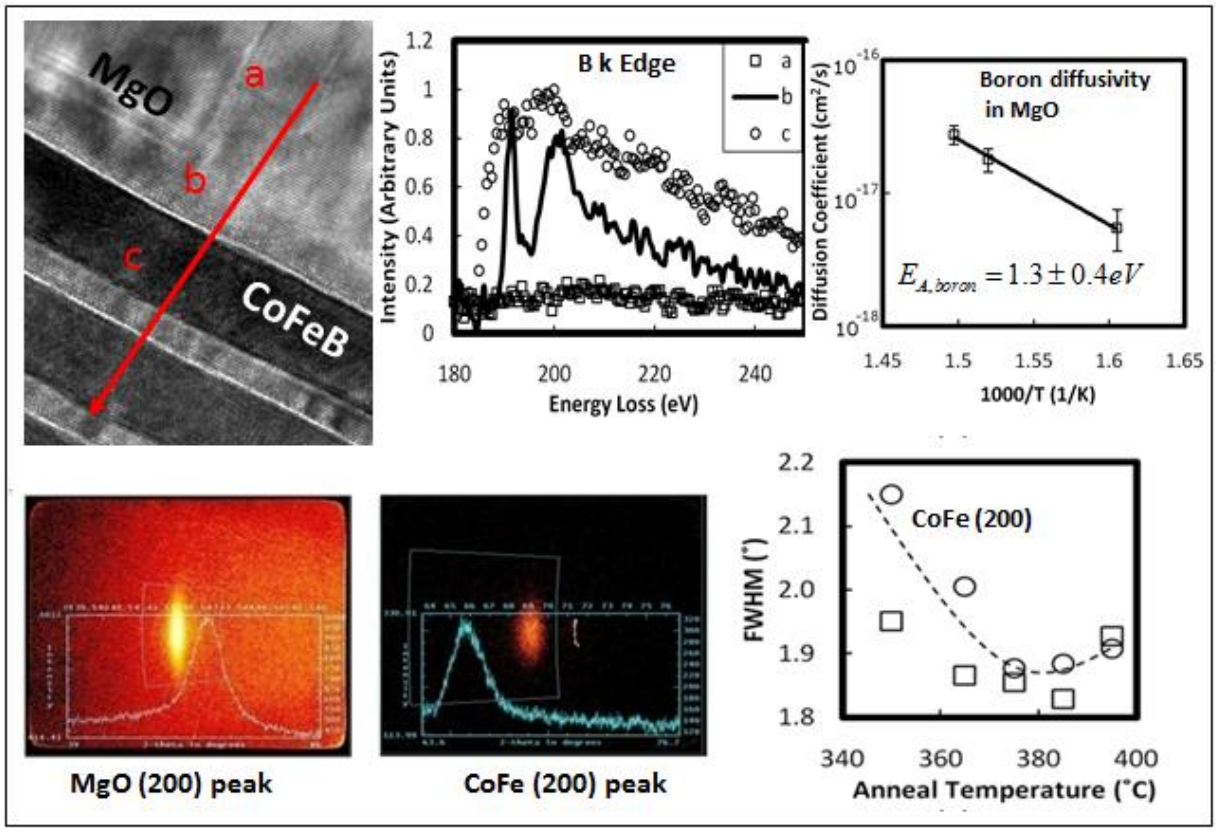

FIGURE 1. Top row: Boron EELS data acquired as a function of annealing at different locations to extract its diffusion coefficient in MgO; Bottom row: 2D-XRD of MgO and CoFe peaks to study crystallization and grain growth with annealing.

PHASE CHANGE MEMORY STRUCTURES

The phase change materials $Ge_2Sb_2Te_5$ (GST) and GeTe have been studied extensively for their application in re-writable optical storage and in PCRAM. Various configurations of GST and GeTe (bilayers and doped) have been investigated to designe suitable memory cells for highly scaled devices. Bilayer chalcogenides composed of GeTe or Ge_2Se_3 and SnTe or SnSe are explored for these applications. Using TRXRD 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 HRTEM and PEELS. The study reveals the temperature limitations for each stack. 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 [3]. Learning from the bilayer stacks, doped GST and GeTe, were investigated for the influence of various dopants on the crystallization behavior and electrical switching properties of GST and GeTe. The dopants included nitrogen, silicon, titanium, and aluminum oxide. TRXRD show that all GST samples (undoped and doped) first crystallized into the rocksalt crystal structure, and at higher temperature into the hexagonal phase [4]. The crystallization temperature increased with doping, and also the transition temperature from the rocksalt to the hexagonal crystal structure. For doped GeTe the crystal structure after heating was rhombohedral, similar to undoped GeTe, with slightly changed lattice constants. For GST nitrogen doping was most efficient in terms of increased crystallization temperature. Ti-doped GeTe material had the highest crystallization temperature of around 350 ºC. The crystallization temperatures measured by XRD corresponded with the resistivity versus temperature measurements. It was observed that the doping can be used to tune the threshold field of the phase change material. In particular doping with aluminum oxide for GST and nitrogen doping for GeTe leads to a substantial increase in threshold field which is desirable for ultra-scaled

PCRAM devices. This work is being continued to study other RAM structures including ferroelectric tunnel junctions that will be presented at the conference.

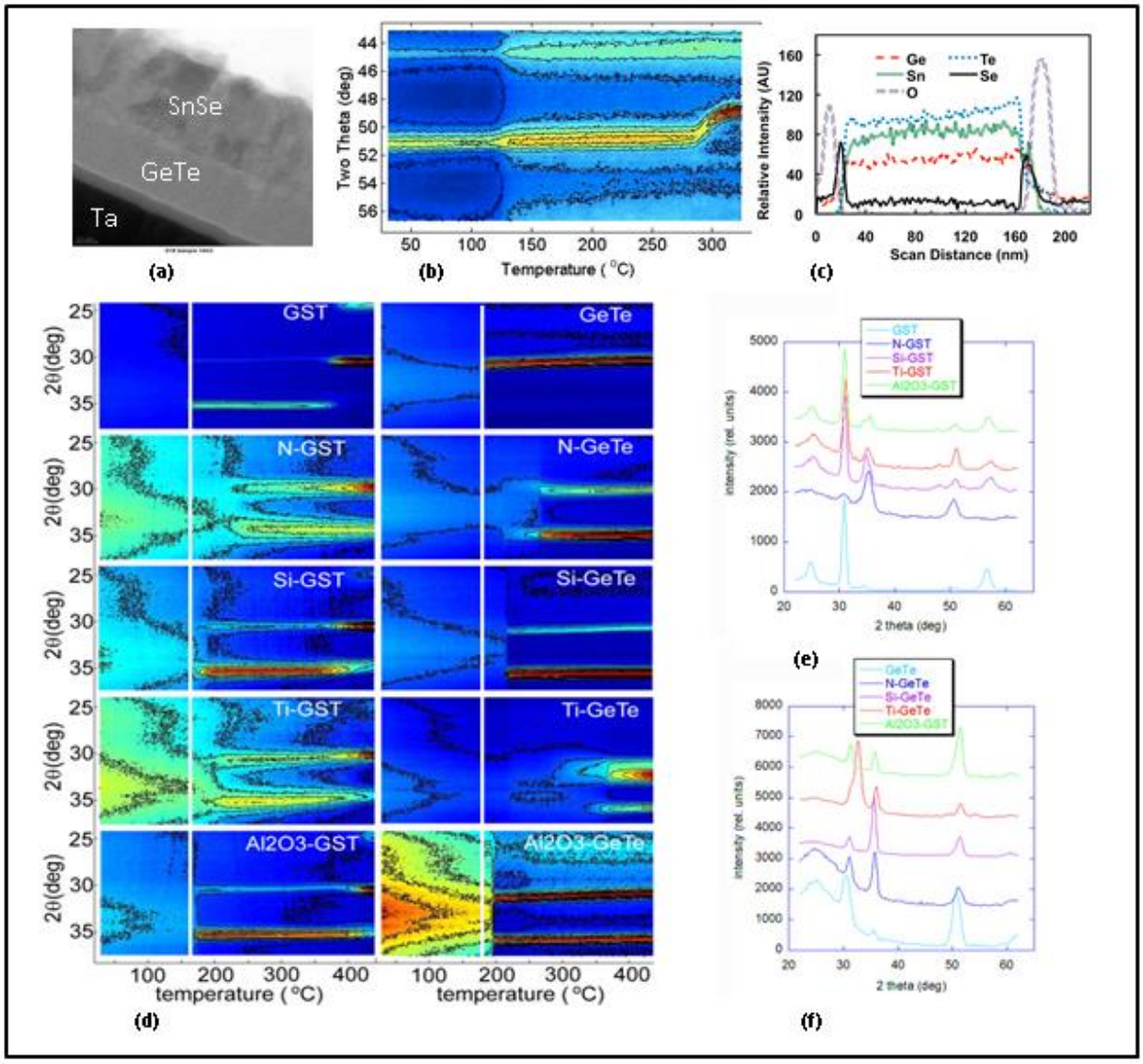

FIGURE 2. GeTe/SnSe stack (a) showing phase transition from rhombohedral to cubic structure of GeTe(Sn) phase ~ 300C (b); (c,) PEEL elemental area scans for GeTe/SnSe sample as deposited and annealed to 340C; (d) TRXRD measurements on undoped and doped GST (left) and undoped and doped GeTe (right). Plotted is the intensity of diffracted XRD peaks as a function of temperature; (e, f) The θ–2θ scans of undoped and doped GST and GeTe after a ramp to 450 ºC [4].

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KEYWORDS

Time Resolved X-Ray Diffraction, Electron Energy Loss Spectroscopy, Magnetic Tunnel Junction, Phase Change Memory