PCM Materials & Devices: High Speed and Low-dose TEM Imaging

Tripathi, S.[1], Janish, M.[2], Dirisaglik, F.[3], Cywar, A.[3], Zhu, Y.[4], Jungjohann, K.[5], Silva, H.[6] and Carter, C.B.[7]

[1] Electrical & Computer Engineering, University of Connecticut, Storrs, CT 06269, United States, [2] Materials Science & Engineering, University of Connecticut, Storrs, CT 06269, United States, [3] Electrical & Computer Engineering, University of Connecticut, Storrs, CT 06269, United States, [4] IBM Thomas J Watson Research Center, 1101 Kitchawan Road, Yorktown Heights, NY 10598, United States, [5] Center for Integrated Nanotechnologies (CINT), Sandia National Lab, Albuquerque, NM 87123, United States, [6] Electrical & Computer Engineering, United States, [7] Chemical & Biomolecular Engineering, University of Connecticut, Storrs, CT 06269, United States

Phase-change memory (PCM) materials are being developed for faster, non-volatile & high-density memory that can facilitate more efficient computation as well as data storage. The materials used for these PCM devices are usually chalcogenides that can be switched between their amorphous and crystalline phases thus producing orders of magnitude difference in the electrical resistivity [1, 2]. The operation of such devices is limited by elemental segregation and void formation, which occurs as a result of the extensive cycling. After crystallization, the structure gradually transforms from fcc to hexagonal. In the present work, we are studying these different phase changes *in-situ* as they occur in PCM materials basically using TEM imaging. The aim is to correlate device modeling and electrical characterization in order to improve the models and enable accurate, predictive simulations. The thin-film materials and devices can be directly deposited onto Protochips devices, allowing controlled temperature changes while imaging in the TEM. Although the temperature change rate achievable is too slow as compared to the fastest PCM-device operation, these rates can provides valuable insights into the various property changes in the material and phase transformations as well. Both a C_s-image-corrected Titan ETEM and a Tecnai F30 have been used for this study. The ETEM is equipped with a K2 direct electron detector camera allowing high-speed video recording of these PCM materials.

Special features of this project are illustrated in the TEM images below. Figure 1a shows the contrast from the as-deposited film, which is typical of amorphous material. The grains range in size, with some smaller than 10 nm in diameter and others as large as 75 nm. Figure 1b and 1c shows successive images of the as-deposited film before heating. Figure 1b and 1c shows the high-magnification images of the PCM film at room temperature after it had been heated ex-situ to 400°C. The small crystallite have almost similar sizes but vary in orientation. The irradiation by the electron beam in this case, did not apparently change the particles, at room temperature. Comparing specimens that have been heat-treated in the TEM with those treated under typical processing conditions is of critical importance. This nucleation and growth was most likely because of the imaging electron beam itself and exemplifies a well-known challenge in TEM: the electron beam irradiation can change structures and reactions. Therefore, in all the situations, it is important to use low-dose as well as beam-blanking techniques to separate changes that are induced by the electron beam from those that are due to radiation damage, heat or under the influence of electric current [3]. In this presentation, we will present the recent results with the use of high-speed imaging and initial observations using the CINT Discovery Platform wherein the phase changes can be induced by heating, or any other stimuli, such as applying a voltage across the thin film.

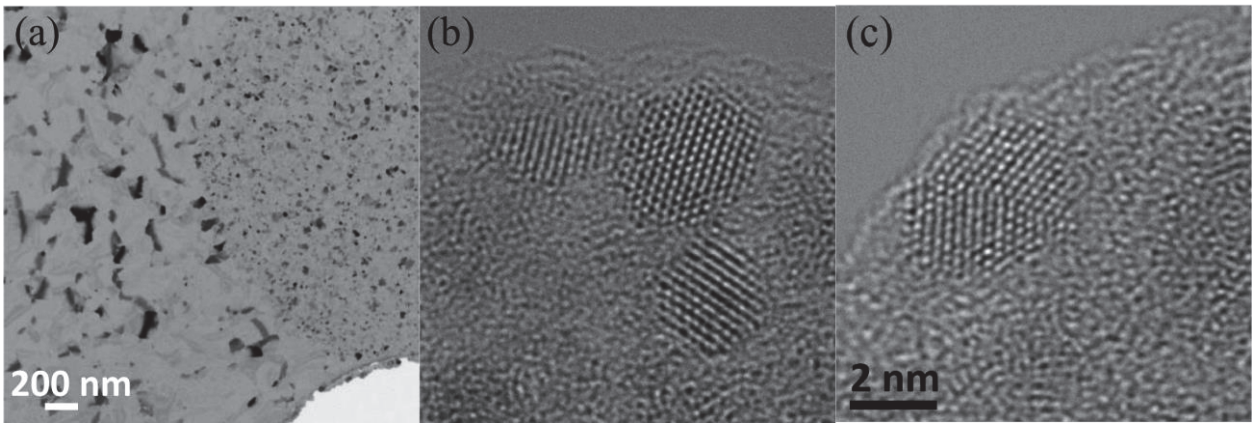

Figure 1: (a) Low-magnification bright- field image of GST thin film showing the electron beam irradiated area with a smaller grain size; (b) & (c) high-resolution TEM images of a GST film after *ex-situ* heating it at 400°C (Cs-image-corrected Titan operating at 300kV). The average grainsize is typically about 3nm in diameter and may contain twin boundaries. No size change was observed during imaging in the TEM.

1. Fong, S., C. Neumann, and H. Wong (2017) IEEE Trans Electron Devices **64**(11): p. 4374-4385. Phase-Change Memory - Towards a Storage-Class Memory.
2. Lencer, D., M. Salinga, and M. Wuttig (2011) Adv Mater **23**(18): p. 2030-58. Design rules for phase-change materials in data storage applications.
3. Bakan, G., et al. (2016) J Appl Phys **120**(16): p. 164504. Extracting the temperature distribution on a phase-change memory cell during crystallization.

Acknowledgment: This work is supported by NSF under grant No. 1710468. TEM analysis was performed at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science by Los Alamos National Laboratory (Contract DE-AC52-06NA25396) and Sandia National Laboratories (Contract DE-NA-0003525).