Measurement of crystallization kinetics in phase change materials using multiple microscopic techniques


1. Center for Integrated Nanotechnologies, Sandia National Laboratories, Albuquerque, NM, USA
2. School of Mechanical, Industrial, and Manufacturing Engineering, Oregon State University, Corvallis, OR, USA
3. Materials Science Division, Lawrence Livermore National Laboratory, Livermore, CA, USA
4. Department of Physics, Oregon State University, Corvallis, OR, USA
5. Integrated Dynamic Electron Solutions, Inc., Pleasanton, CA, USA
* Corresponding author: melissa.santala@oregonstate.edu

Phase change materials (PCMs) are materials with distinct optical and electrical properties in the amorphous and crystalline phases that make them useful for memory applications [1]. In memory devices, amorphous bits are crystallized in nanoseconds by either laser or Joule heating, but the amorphous phase must also be stable against crystallization for long-term data retention. Crystal growth rates relevant to memory devices span orders of magnitude and fundamental questions regarding PCM crystallization mechanisms remain open, partly due to the difficulty in measuring crystallization kinetics in certain temperature regimes. Only a small set of materials satisfy the requirements of adequate contrast in properties, amorphous stability at low temperatures, and rapid crystallization. Ag- and In-doped Sb-Te alloys have been widely used in optical solid-state memory devices [2] and could be used for resistivity-based devices.

In this work, multiple imaging techniques are used to measure crystal growth in a PCM with a nominal composition of Ag₃In₄Sb₇₆Te₁₇ (AIST) over a broad range of temperatures. At low temperatures, crystal growth was imaged under isothermal conditions using optical microscopy with a hot stage. At intermediate temperatures, a transmission electron microscopy (TEM) heating holder was used with conventional image capture using a TVIPS camera. To access higher temperatures and higher crystal growth rates in situ laser heating was used. The highest growth rates were measured with dynamic TEM, a photo-emission TEM technique with nanosecond-scale time resolution. To bridge the gap between conventional image capture and DTEM experiments, the IDES Relativity® system was used to sub-frame single camera exposures [2]. An example of a sub-framed image of laser-induced crystal growth in AIST is shown in Figure 1, where each sub-frame is a 1 millisecond exposure. The use of complementary experimental techniques allow the crystal growth rates to be mapped over a large temperature range and can give insights into the crystallization kinetics of PCMs and other marginal glass formers. The growth rates observed from the different techniques span from ~10⁻⁹ to 10 m/s. Challenges associated with integrating results from different techniques will be discussed [3,4,5].

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Figure 1. Bright field TEM during amorphous-to-crystalline phase transformation in an AIST thin film induced by in situ laser heating. Each sub-framed image has a temporal resolution of 1 ms. The final frame in the lower right is used for image alignment and appears overexposed because the brightness and contrast has been adjusted to best display the microstructural features in the 15 imaging frames.