Application of electron beam lithography to the study of the scalability of phase change memory devices

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Phase change materials hold great promise as the basis for future non-volatile memory devices. The scalability of phase change technology is a critical issue for its development. We have addressed this issue by examining the scaling behavior of these materials both as nanoparticle arrays and as devices.

We have fabricated large area (2mmx5mm) arrays of phase change nanoparticles using electron-beam lithography, with sizes of the particles between 20 and 80 nm and spacings of 80 and 100 nm. Arrays were made from the phase change materials Ge2Sb2Te5, nitrogen-doped Ge2Sb2Te5, Ge15Sb85, Sb2Te, and Sb2Te doped with Ag and In. Care was taken during fabrication to keep the sample temperatures well below the crystallization temperatures of these materials, so that the as-fabricated nanoparticles were in the amorphous phase. The crystallization behavior of the nanoparticle arrays was studied using time-resolved X-ray diffraction at beamline X20C of the National Synchrotron Light Source at Brookhaven National Laboratory. It was found that all nanoparticle arrays show an amorphous-crystalline phase transition. The crystallization temperatures of the nanoparticles arrays were found to be close to those of their corresponding blanket film crystallization temperatures. Most nanoparticle arrays show a difference in crystallographic texture compared to thick films.

In complementary studies, we have fabricated bridge memory cells, using a doped GeSb alloy. We were able to make bridges of this material from very thin films, just 3nm thick, and with widths as small as 20nm wide. The bridges were fabricated by first depositing a film of doped GeSb over the bottom electrode structures, together with a thin oxide cap layer. Next a resist hard mask was formed across the narrow gaps between the electrodes using electron beam lithography and a negative resist (HSQ). The film was then milled away by Argon ion milling while rotating the sample, leaving a phase change material bridge, which was encapsulated without breaking vacuum. We were able to make bridges with lengths as short as 40nm and up to several hundred nm long. We find that even the smallest devices can be cycled repeatedly, and with RESET currents as low as 100 microamperes. Our findings are in relatively good agreement with detailed simulations.

The crystallization of such small nanoparticles and the successful switching of such small bridge devices indicate that memory technology based on phase change memory elements can indeed scale to dimensions of the order of 10nm.