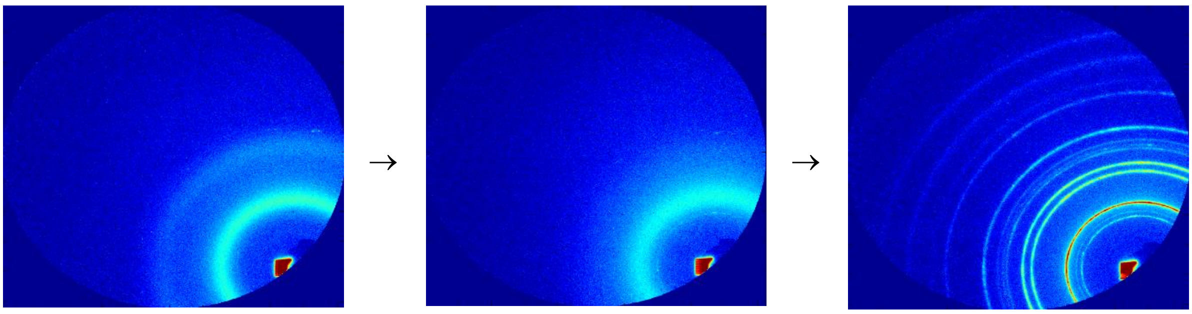
Ultrafast X-ray diffraction resolves transient structures upon crystallization of Phase-Change Memory Materials

P. Zalden[2,3,14] F. Quirin[1] J. Siegel[6] M. Trigo[4] P. Andreasson[7] H. Enquist[8] M. Shu[9] T. Pardini[10] M. Chollet[11] D. Zhu[11] H. Lemke[11] J. Larsson[7] A. M. Lindenberg[4,12] S. Hau-Riege[10] D. A. Reis[4] M. Wuttig[13] C. Bressler[2,14] W. Gawelda[2] and K. Sokolowski-Tinten[1]

The demand for information storage is ever increasing. Phase-change memory is an emerging technology that offers high storage density (less than 3 nm active volume) and energy efficient operation due to its non-volatile nature. It is based on the property contrast of an active material between its glassy and crystalline states. The performance of such memory devices relies mostly on the properties of the glass-forming material. It is essential for a memory technology to offer long-term data retention at ambient conditions, while enabling fast switching upon excitation. This means that the glass needs to be stable for >10 years at ambient conditions, but crystallize rapidly on the nanosecond timescale at elevated temperatures. These seemingly contradicting design goals are met by the unique kinetic properties of the materials employed: The high fragility of their supercooled liquids leads to a remarkably strong temperature-dependence of viscosity at low temperatures and a wide temperature window of low viscosity at elevated temperature. Recent experiments at the x-ray free electron laser (XFEL) LCLS at SLAC, USA have enabled us to probe the atomic structure of the transient supercooled liquid states before they crystallize. The resulting data reveal the microscopic changes that accompany the highly temperature-dependent kinetic properties.

In this talk I will introduce the working principle of phase-change memory with special attention to the underlying materials' properties. Discussing basic glass formation, I will outline the unique kinetics of phase-change materials and explain how XFELs can be used to study glass formation and crystallization dynamics in unprecedented detail.



initial amorphous | transient (after 10 ps) | final crystalline

Fig. 1: Diffraction patterns of 60 nm $Ge_{15}Sb_{85}$ on 150 nm thick membranes of SiN. Depending on the time delay, the ultrafast x-ray diffraction reveals the transient liquid and supercooled liquid states.

1 Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Lotharstrasse 1, 47048 Duisburg, Germany.
2 European XFEL, Albert-Einstein-Ring 17, 22761 Hamburg, Germany
3 Stanford Institute for Materials and Energy Sciences, SLAC National Accelerator Laboratory, 2575 Sand Hill Rd., CA 94025 Menlo Park, USA.
4 Stanford PULSE Institute, SLAC National Accelerator Laboratory, 2575 Sand Hill Rd., CA 94025 Menlo Park, USA.
5 Institut für Physik und Astronomie, Universit¨ at Potsdam, Karl-Liebknecht-Strasse 24-25, 14476 Potsdam, Germany.
6 Instituto de Optica, CSIC, C/Serrano 121, 28006 Madrid, Spain.
7 Department of Physics, Lund University, Professorsgatan 1, 223 62 Lund, Sweden.
8 MAX IV Laboratory, Lund University, Ole R¨ omers v¨ ag 1, 223 63 Lund, Sweden.
9 Department of Applied Physics, Stanford University, CA 94305 Stanford, USA.
10 Lawrence Livermore National Laboratory, Livermore, CA, USA.
11 Linac Coherent Light Source, SLAC National Accelerator Laboratory, 2575 Sand Hill Rd., CA 94025 Menlo Park, USA.
12 Department of Materials Science and Engineering, Stanford University, CA 94305 Stanford, USA.
13 I. Physikalisches Institut and JARA-FIT, RWTH Aachen, Sommerfeldstrasse 14, 52074 Aachen, Germany.
14 Hamburg Centre for Ultrafast Imaging (CUI), Cluser of excellence at University of Hamburg, Germany.