DS 39: Focus Session: Resistive Switching by Redox and Phase Change Phenomena VI (Kinetics and Transport in PC materials)

Time: Thursday 9:30–11:15 Location: CHE 89

Invited Talk DS 39.1 Thu 9:30 CHE 89

Switching kinetics in phase change materials — •Martin Salinga — RWTH Aachen, Sommerfeldstrasse 14, 52074 Aachen, Germany

Phase change materials are essential ingredients for next-generation electronic memory devices and reconfigurable electronics for their ability to be switched between states with very different resistivity within nanoseconds upon electrical excitation, while being stable over many years otherwise. It is these materials' characteristic combination of electronic excitability of their amorphous phase and their unconventional structural transformations that makes this seeming contradiction possible. Thorough experimental investigations of both phenomena allowed us to gain deeper insights into the fundamental properties of this family of materials. Recently the crystallization kinetics could be traced back to an extremely high fragility of the undercooled liquid phase. A comprehensive model including the quenching rate dependence of the glass formation and relaxation processes in the glass managed to explain the different experimental observations reported in literature. Our investigations of transient effects in electrical excitation of phase change materials concentrate on the changes around the threshold for resistivity breakdown in the amorphous phase. The results from both studies are discussed to give guidance to experimentalists and theoreticians aiming for a fundamental understanding of the physics of phase change materials.

DS 39.2 Thu 10:00 CHE 89

Growth of GeTe/Sb_2Te_3 Superlattices by Molecular Beam Epitaxy — •Rui Ning Wang[1], Jos Boschker[1], Raffaella Calarco[1], Jamo Momand[2], and Bart Kooi[2] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [2]Zernike Institute for Advanced Materials, Groningen, Netherlands

For their ability to be reversibly switched between a crystalline and a stable amorphous phase, drastically changing their optical and electrical properties, GeTe and GeSbTe alloys (GST) have already been used in optical data storage applications for more than a decade. These materials are also serious candidates in electrical data storage devices because of non-volatility and high scalability. Simpson *et al.* have demonstrated that arranging GeTe and Sb_2Te_3 into a superlattice (SL) structure enables an analogous crystalline ↔ crystalline switching mechanism that greatly reduces the switching energy while improving the cyclability and switching speed [1].

In the work presented here, GeTe/Sb_2Te_3 SLs were grown on Si(111) substrates by molecular beam epitaxy. The epi-structures showed an out-of-plane Si $\langle 111 \rangle \parallel$ SL $\langle 0001 \rangle$ orientation and in-plane Si $\langle 11\bar{2} \rangle \parallel$ SL $\langle 10\bar{1}0 \rangle$ orientation. An effort has been made to reduce the layer thickness of each constituent down to 1 nm for GeTe and to 2 nm for Sb_2Te_3, and improve surface and interface roughness. These state of the art superlattices provide a clear platform for fundamental studies of the switching mechanism in such structures.

[1] R. Simpson *et al.*, Nature nanotechnology, vol. 6, pp. 501-5, 2011.

DS 39.3 Thu 10:15 CHE 89

Phase-Change Materials: Impact of Disorder on Thermal and Electrical Transport — •Karl Simon Siegert[1], Felix Lange[1], and Matthias Wuttig[1,2] — [1]1.Physikalisches Institut (IA), RWTH Aachen University — [2]JARA - Fundamentals of Information Technology, RWTH Aachen University, 52056 Aachen, Germany

Disorder plays a vital role in crystalline phase-change compositions along the pseudo-binary line between GeTe and Sb_2Te_3 (GSTs). Many of these compounds crystallize in a rocksalt-like structure where one sublattice is fully occupied by Te atoms, while a random distribution of Ge, Sb and vacancies populates the second sublattice. This gives rise to pronounced configurational disorder which impacts charge transport by localizing electrons [1].

A thorough investigation of GST stoichiometries and measurements of thermal conductivity by the 3ω method towards low temperatures (50 K) demonstrate that thermal transport is affected by disorder as well. Especially disordered vacancies act as efficient point scattering sources and disrupt phonon heat transport. Hence, thermal and electrical conductivities are affected by the same mechanism, albeit on different scales. This finding opens up a pathway to manipulate electrical and thermal transport properties in GSTs through the degree of disorder. Such transport engineering is not only crucial for future data storage devices based on resistance switching, but should be highly valuable for thermoelectrics as well.

[1] T. Siegrist *et al.*, Nat. Mater. 2011, 10, 202-208.

DS 39.4 Thu 10:30 CHE 89

Drift of the voltage dependence of resistance in melt-quenched phase change memory cells — •Martin Wimmer, Matthias Kaes, and Martin Salinga — 1. Physikalisches Institut (IA), RWTH Aachen

Phase change materials are the essential ingredients for promising novel non-volatile electronic memory devices. The materials have the ability to be switched upon electrical excitations within nanoseconds between two otherwise stable phases, which show large contrast in electrical resistivity. One approach to improve the information density of such a phase change memory device is to store several logic bits in one physical cell by distinguishing between different states of partial crystallization (multilevel storage). For such a device it is important that the resistance is stable over many orders of magnitude in time. While for the crystalline phase this requirement is sufficiently fulfilled, the amorphous phase shows a strong time dependence of the resistance, the so-called resistance drift. In literature this effect is often ascribed to structural relaxation effects, which, as a consequence, lead to changes of electronic defect states and thereby altering the electronic properties, e.g. the conductivity, of the material. In this work, we study the effect of drift on the voltage dependence of the resistance in phase change memory devices on a time scale starting only microseconds after melt-quenching. Our experimental findings are interpreted within the common drift theories, e.g. the Poole-Frenkel model for conduction in the sub-threshold regime.

DS 39.5 Thu 10:45 CHE 89

Structure and Transport Properties of Pseudo Ternary SnTe, GeTe, Sb_2Te_3 Chalcogenides — •Felix R. L. Lange[1], Stefan Jakobs[1], Tim Labohm[1], Jan Kirchhof[1], Tobias Schäfer[1], K. Simon Siegert[1], and Matthias Wuttig[1,2] — [1]I. Physikalisches Institut (IA), RWTH Aachen University, 52056 Aachen, Germany — [2]JARA - Fundamentals of Information Technology, RWTH Aachen University, 52056 Aachen, Germany

Ternary chalcogenides along the line between GeTe and Sb_2Te_3 have caught interest due to their high degree of disorder in the crystalline phase. Only recently Siegrist *et al.* reported an insulator-to-metal transition in the crystalline phase [1]. Depending on the annealing temperature of the thin films the electrical resistivity is either thermally activated or develops metallic at elevated temperatures. While little change is noticed on the carrier concentration the electrical resistance spans over six orders of magnitude at room temperature. Based on DFT calculations Zhang *et al.* identified clusters of vacancies to localize the wave functions responsible for charge transport in the early meta-stable cubic phase [2]. Dissolution of these clusters upon annealing then leads to a delocalization of the corresponding wave functions concomitant with the transition to the metallic state. Here we explore pseudo ternary alloys of SnTe, GeTe and Sb_2Te_3 in order to utilize both, stoichiometry and annealing condition to adjust the degree of disorder concomitant with tailored transport properties.

[1] T. Siegrist *et al.*, Nat. Mater. **10**, 202-208 (2011)
[2] W. Zhang *et al.*, Nat. Mater. **11**, 952-956 (2012)

DS 39.6 Thu 11:00 CHE 89

Disorder Induced Localization in Crystalline Phase Change Materials: $Sn_1Sb_2Te_4$ as a Model System — •Tobias Schäfer[1], Hanno Volker[1], Felix vom Bruch[1], Artur Romanov[1], Stefan Jakobs[1], Felix Lange[1], and Matthias Wuttig[1,2] — [1]I. Physikalisches Institut (IA), RWTH Aachen University, 52056 Aachen, Germany — [2]JARA FIT, RWTH Aachen University

The electrical resistivity of the crystalline phase of many phase-change materials (PCMs) can be reduced by several orders of magnitude via annealing. This annealing effect can be attributed to the reduction of

disorder in the material, which is initially exceptionally high in most PCMs and therefore dominating the transport. Disorder-dominated transport is a key feature of most PCMs due to their low electron correlation, while most other semiconductors and semimetals feature both disorder and correlation effects (Mott-Anderson-physics).

While previous studies on disorder-dominated transport in PCMs have been mostly conducted on $Ge_1Sb_2Te_4$ and other materials on the pseudobinary line between GeTe and Sb_2Te_3 [1,2], this study focuses on the isoelectronically replaced $Sn_1Sb_2Te_4$ to emphasize the universality of disorder-dominated transport in PCMs. Low-temperature transport and magneto-transport measurements are utilized to analyze the influence of disorder in PCMs.

[1] T. Siegrist et al., Nat. Mater. 10, 202 (2011)
[2] N.P. Breznay et al., Phys. Rev. B 86, 205302 (2012)