Hall mobility in amorphous phase change materials

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ABSTRACT

Measurements of the Hall mobility in thin films of as deposited amorphous phase change material are shown. By employing a sinusoidal variation of both the externally applied sample voltage and magnetic field at different frequencies the microvolt Hall signal can be very accurately detected with a lock-in method. The temperature dependence of the Hall mobility as well as aging effects are studied. The implications on steady state transport in amorphous phase-change materials are presented by including thermopower measurements.

Key words: hall mobility measurements, as deposited amorphous phase, phase change materials, small polarons, resistance drift

While phase change materials (PCM) have been successfully applied in rewriteable optical data storage, they are also used for novel non-volatile electronic memory devices. The material has the ability to be switched within nanoseconds between two phases, which show large contrast in electrical resistivity [1]. Although the electrically induced rapid switch from the amorphous semiconducting to the crystalline metallic state is known to be an electronic effect [2], no coherent picture of this transition has been experimentally verified.

In literature, threshold switching is related to such diverse mechanisms as generation and recombination [3], field induced nucleation [4] and small polaron avalanches [5]. As the various models also differ in their description of the steady state transport in amorphous PCM, measurements of conductivity, thermopower and Hall mobility can provide insight into the applicability of the various models. In this work, experimental data for the Hall mobility and its temperature dependence are presented for several PCMs including $Ge_2Sb_2Te_5$.

In order to accurately measure the temperature dependence of the Hall mobility of PCM thin films (2 µm), a custom built setup (temperature range 4-370 K) is employed. Sinusoidal modulation of both the magnetic field B (200 mT at f_B = 2Hz) and the sample voltage U (120 V at f_U = 3 Hz) is used to spectrally separate the Hall signal U_H(25 µV) from unwanted contributions such as induction voltages (50 mV) and the offset voltage due to the misalignment of the two Hall contacts (1 V). The Hall signal oscillates at the frequencies f_U +- f_B (as $U_H \propto U*B$) and its amplitude and phase are detected with a lock-in amplifier. The sign of the Hall voltage is extracted from the phase of the detected signal. By calibrating the absolute phase against a sample of known charge carrier type (p-type crystalline $Ge_1Sb_2Te_4$), the sign of the Hall effect can be determined.

By employing this measurement technique the room temperature Hall mobility of amorphous $Ge_2Sb_2Te_5$ (annealed at 120°C for 3h to prevent drift during the measurement) a room temperature Hall mobility of μ_H = (0.062+-0.002) cm^2/Vs is determined. The measured phase corresponds to an n-type Hall effect. Thermopower measurements indicate that the amorphous samples are p-type, whereas the sign of the Hall effect is negative – an observation common for amorphous materials and often referred to as the sign anomaly.

Figure 1 shows an exemplary temperature dependence (290 – 340 K) of the measured Hall mobility as well as the conductivity of the aforementioned sample. While the Hall mobility increases only weakly (30%) the conductivity increases by an order of magnitude which corresponds to activation energies of E_μ = 0.05 eV and E_a= 0.4 eV.

Previous studies [7] have indicated that resistance drift in amorphous phase change materials can be related to either a drift in the activation energy E_a ($Ge_2Sb_2Te_5$) or the prefactor $R*$ ($Ag_4In_3Sb_{67}Te_{24}$). Therefore, a study of the change of the temperature dependent Hall mobility upon annealing for different materials can provide more insight into the conduction and relaxation mechanisms of amorphous phase change materials.

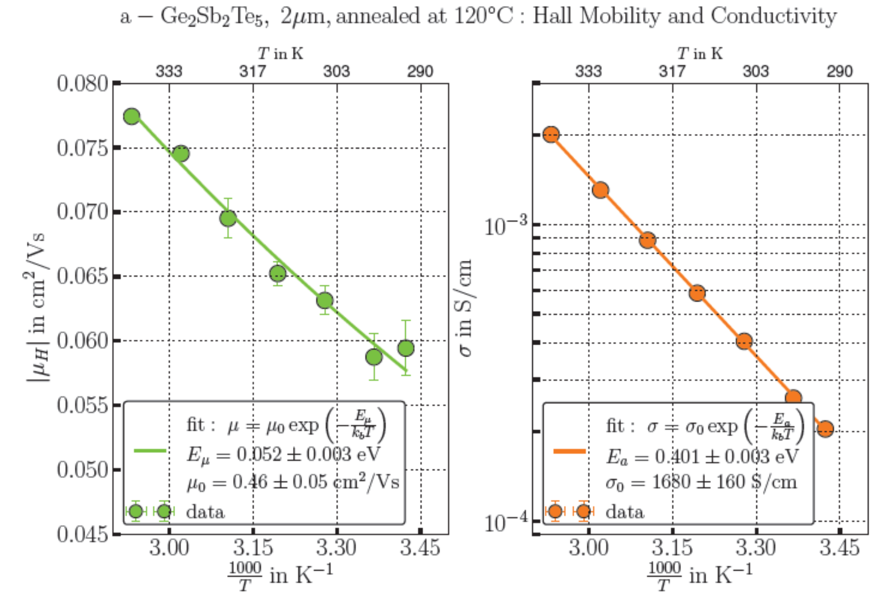

Figure 2: Hall mobility (left) and conductivity measurements (right) of an amorphous as-deposited $Ge_2Sb_2Te_5$ sample taken in a temperature range from 290 – 340 K. The Hall mobility increases weakly with temperature, whereas the conductivity increases by an order of magnitude. These increases correspond to activation energies of $E_\mu = 0.05$ eV and $E_a= 0.4$ eV, respectively.

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Biographies

Matthias Kaes received his master's degree in physics at RWTH Aachen University in 2012. In his thesis work he established a technique to accurately measure the Hall mobility of amorphous chalcogenide thin films. In February 2012 he started working as a Ph.D. student at RWTH Aachen University within the collaborative research center SFB 917 "Nanoswitches". His studies focus on electrical and electronic relaxation of amorphous phase change materials as well as the fabrication and compositional analysis of phase change line cells.

Alexander Mantz is currently working towards his master's degree in physics at RWTH Aachen University. His thesis work focuses on measuring the time evolution of the Hall mobility during resistance drift in various amorphous phase change thin films.

Hanno Volker received his diploma in physics from RWTH Aachen University in 2008. His thesis elucidates the electrical transport properties of amorphous phase-change materials, focusing on resistance drift, threshold switching and field-effect mobility. Since then, he has worked as a graduate student at RWTH Aachen University. His field of research includes Hall-effect measurements on amorphous phase-change materials as well as the effects of structural disorder on the transport properties of crystalline phase-change materials.

Martin Salinga is an academic staff member of the department of physics at RWTH Aachen University, Germany. He obtained his diploma in 2004 and his Ph.D. degree in 2008, both in physics, from RWTH Aachen. For his diploma thesis on crystallization kinetics of phase-change materials used in optical data storage, he performed his research both at RWTH Aachen and at Harvard University. From February 2005 until September 2006, he was on assignment at the IBM Almaden Research Center, investigating both crystallization kinetics and electronic properties of phase-change materials. Back at RWTH Aachen, Martin Salinga continues his studies on phase-change materials while also teaching. Since July 2011 he is principal investigator and member of the steering committee of the collaborative research center "Nanoswitches", a long-term research project funded by the German science foundation to study resistively switching chalcogenides for future electronics.