Resistance drift in phase change memory devices on a microsecond time scale

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ABSTRACT

The resistance drift effect is studied in phase change memory devices on a microsecond time scale after melt-quenching. By combining the probing voltage signal and the amorphization pulse in one waveform, a fast measurement of the resistance drift effect in the as melt-quenched amorphous phase becomes feasible. The experiments are performed at a custom made electrical tester with fast frequency response, high signal to noise ratio and controlled ambient temperature. The thereby obtained experimental data potentially give new insights in the short term resistance drift behavior.

Key words: resistance drift, melt-quenched amorphous phase, microsecond time scales, phase change memory, phase change materials

While phase change materials have been successfully applied in rewriteable optical data storage, they are also used for novel non-volatile electronic memory devices. The materials have the ability to be switched within nanoseconds between two phases, which show large contrast in electrical resistivity [1]. 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. For this so-called multilevel storage device it is important that the resistance of this device is stable over many orders of magnitude in time. While for the crystalline phase this condition is sufficiently fulfilled, the amorphous phase shows a strong time dependence of the resistance, the so-called resistance drift [2,3].

In literature this effect is often ascribed to relaxation of mechanical stress (due to the contrast in density between the crystalline and amorphous phase) or to a change of electronic defects [2,4,5]. In this work experimental data of the resistance drift are analyzed for a variety of different phase change materials and compared to models reported in literature. Based on a time resolved study on different as-deposited amorphous thin films of phase change material we observed different mechanisms to be responsible for the resistance drift effect (change in activation energy and/or prefactor in the Arrhenius law) [6]. These studies are now extended to investigations of resistance drift on short time scales and to the melt-quenched amorphous phase. This way, potential deviations of the drift behavior from the power law, as reported for $Ge_2Sb_2Te_5$ e.g. by Ielmini et al. [7], can be observed.

In order to measure the time resolved resistance of phase change memory devices, we developed an electrical probing station with a bandwidth ranging from DC up to 1 MHz combined with a huge signal to noise ratio. This is achieved by the use of two operational amplifiers in series, resulting in a 40 dB gain of the measured current signal. The current is measured with the help of a 1 kOhm shunt resistor. All measurements are performed within a controlled ambient temperature.

To investigate the resistance drift effect shortly after applying the amorphization pulse a continuous sine wave probing signal is superimposed with a rectangular pulse for amorphization (Figure 1). The first regime (I) shows the current response of the device in the crystalline state. In this regime the amplitude of the current sine wave and therefore the resistance is constant. During the applied pulse for amorphization (regime II) the device resistance is changed by several orders of magnitude, which indicates the successful transition to the melt-quenched amorphous phase. Shortly after amorphization (regime III) the resistance drift effect can directly be observed in the decay of the envelope of the current sine wave signal over time. Limited by the RC time constant of the setup and device we choose a probing frequency of 20 kHz, which results in a resolution in time of 100 µs (integration over two periods). By using an AC probing signal a lock-in method becomes feasible, which benefits from a huge increase in signal to noise ratio in comparison to common DC probing techniques (since only noise at the probing frequency can disturb the result).

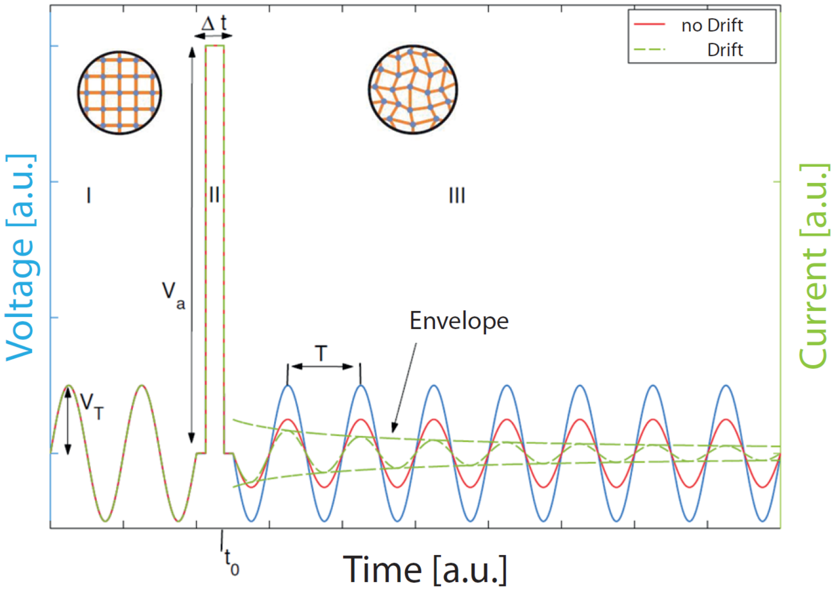

Figure 1: Principle of fast resistance drift measurements. A sine wave signal is superimposed with an amorphization pulse at the time t_0. For times before t_0 a constant current amplitude (due to the crystalline phase) is visible, whereas for $t>t_0$ (probing the melt-quenched amorphous material) a continuous decrease in conductivity can be observed. Modified from [8].

In comparison to previous works the presented new technique facilitates a significant increase in data density and quality. This can be used as a solid basis for characterizations of the relaxation behavior in as melt-quenched chalcogenide glasses. In conclusion, the resistance drift behavior in memory devices containing different phase change materials are compared for a set of different ambient temperatures.

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Biographies

Martin Wimmer received his diploma in physics at RWTH Aachen University in 2010. For his diploma thesis he worked for 12 months on the transient switching behaviour in phase-change memory devices. In January 2011 he started working as a Ph.D. student at RWTH Aachen University expanding his investigations of fast electrical switching in phase-change memories and nanolithography. Since July 2011 he is a doctoral researcher of the collaborative research center "Nanoswitches".

Matthias Kaes received his masters 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.

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.