Impact of DoS changes on resistance drift and threshold switching in amorphous phase change materials

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1. INTRODUCTION

Phase change material based memory (PCM) is a promising versatile memory candidate since it is fast and non-volatile and exhibits a much higher endurance than Flash [1].
One of the main challenges of PCM is the drift of resistance with time in the amorphous phase because it hampers the storage of multiple bits in a single cell which is a common solution to reduce cost. Another main challenge is the transient electrical behavior of the amorphous phase under high electrical fields, called threshold switching, which may limit the latency in high speed applications.
Both of these phenomena occurring in the amorphous phase have been attributed to dynamic behavior and changes in the electronic density of states (DoS), in particular to the band gap and large defect concentrations within the band gap [2]. In this communication, we present results on the resistance drift and threshold switching behavior of GeTe and other phase change materials.

2. EXPERIMENTS

Sheet resistances measurements have been performed using a custom made heated probing station which allows measurement of resistances up to 100 GOhm and a temperature stability of 0.01 K. Each sample was heated up with a ramp rate of 180 K/min to the annealing temperature and held at this temperature for at least 16 hours. Sheet resistance was monitored during the annealing process every 30 s to determine both activation energy at the beginning of the annealing process and the resistance drift exponent during the annealing.
To capture the transient threshold switching effect a custom build high frequency electrical tester was used. The threshold voltage V_t at which the amorphous state becomes high conductive was measured in the amorphous-as-deposited state for bridge devices with different length and different materials [3]. From the linear dependence of V_t on device length, the threshold switching field E_t was calculated.
Optical absorption experiments were performed at room temperature on GeTe thin film samples using photothermal deflection spectroscopy (PDS).

3. RESULTS & DISCUSSION

According to previous publications [4] the drift at a constant temperature can be described by a power law, $R(t) = R_0(t/t_0)^{\nu}$, with $R_0 = R(t_0)$, the resistance at an arbitrary time t_0. As Kim et al. [5] pointed out before, this law needs to be corrected by a time constant t_s, accounting for the thermal history of the device, to describe our data. With $t_0 = t_s$ this yiels: $R(t) = R_s(1+t/t_s)^{\nu}$. Furthermore, we confirmed that ν is anti-proportional to the readout temperature T_r as observed by Boniardi et al. [4] and that a resulting T_r independent variable called drift energy $E_d = k_B T_r \nu$ is linearly dependent on the annealing temperatue T_a. Assuming activated band transport, this leads to $E_a(T_a,t)=E_s+E_d(T_a)\ln(1+t/t_s)$ with $E_d(T_a)=E_0+\kappa T_a$ for the activation energy E_a. Comparing various materials, we find that the drift coefficient at $T_r = T_a = 50$ °C tends to increase with activation energy before drift E_s; a similar trend as the thresholds switching field shows in dependence on the optical band gap. To confirm that an increase of the band gap is responsible for resistance drift, PDS measurements have been performed. The shift of the absorption edge towards higher energies for drifted samples confirms that the band gap is increasing upon drift, while the exponential tail of defect states is not significantly changed.

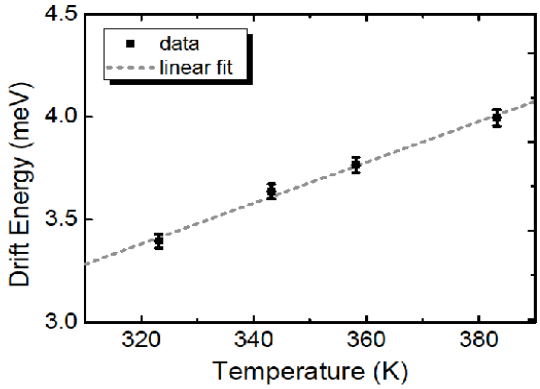

Fig 1: Drift energy of GeTe measured during annealing as a function of annealing temperature.

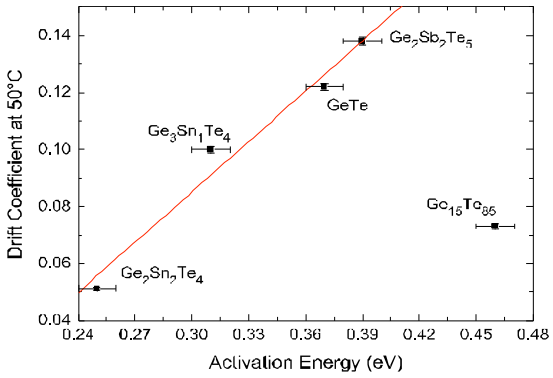

Fig. 2. Drift coefficient of various materials as a function of the activation energy.

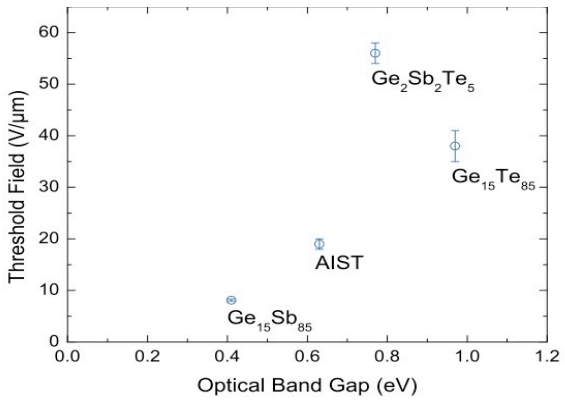

Fig. 3. Threshold switching field of various materials as a function of the optical band gap.

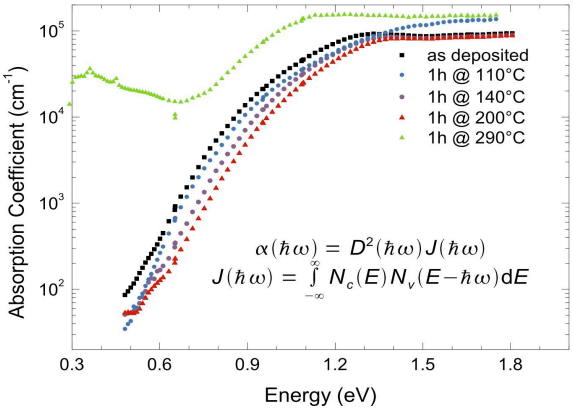

Fig 4: Absorption coefficient of GeTe measured by Photothermal Deflection Spectroscopy.

4. CONCLUSION

A time correction, accounting for the thermal history of the thin film, needs to be incorporated into the power law describing the resistance drift. The drift coefficient is dependent on read and annealing temperature and related to the activation energy of conduction. The drift exponent increases with activation energy before the beginning of the drift for most of the materials. A similar trend was observed for the threshold switching field as a function of the optical band gap. The general behavior is confirmed by photothermal deflection spectroscopy measurements which identify an increase of the band gap to be responsible for drift.

The results demonstrate that measurements of the DoS can serve as a guide to predict the resistance drift and threshold switching behavior. However, further studies need to investigate the impact of defect states within the band gap since they might provide an explanation for deviations from the observed trend.

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