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Experimental Studies of Electronic Transport of Chalcogenide Glass Electrical Switches

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Final Report

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14. ABSTRACT

The electrical conductivity, Seebeck coefficient, and Hall coefficient of 3 micron thick films of amorphous $Ge_2Sb_2Te_5$ have been measured as functions of temperature from room temperature down to as low as 200 K. The electrical conductivity manifests an Arrhenius behavior. The Seebeck coefficient is *p*-type with behavior indicative of multi-band transport. The Hall mobility is *n*-type and low (near 0.07 cm^2/V sec at room temperature).

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Chalcogenide alloys have been identified as potential candidates for a variety of reconfigurable applications. They have already been used in rewritable optical and electrical memory However, the mechanism of the phase transition is poorly understood. One of the more controversial issues of the origin of the threshold switching phenonenon, illustrated in Illustration. 1, below.

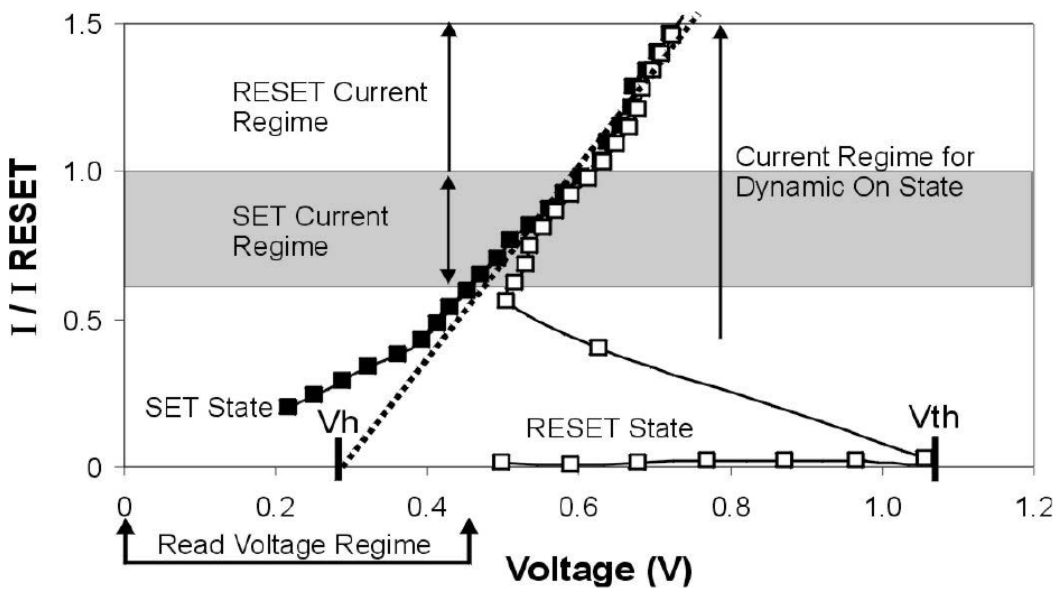

Illustration 1: Threshold switching. Taken from S. Lai, IEDM (2003)

Note that, at a finite threshold voltage the material converts from high to low resistance. This happens without a change in the atomic arrangement. Clearly, the mechanism for this phenomenon will depend crucially on the mechanism for carrier transport in the amorphous state. The valence alternation pair model, where in most free carriers are frozen into lcoalized defect states, leaving a few, high-mobility carriers, has enjoyed wide acceptance. However, in other materials, such as As_2Te_3, we have shown that carrier transport is through a low mobility, hopping motion of a very large number of carriers in small polaron states. Over the past three years, UNM has performed transport studies on samples from University of Utah and from Sandia National Laboratories. UNM measured:

- Temperature-dependent electrical conductivity
- Hall coefficient
- Seebeck Coefficient
- Photo conducitivity

on several amorphous materials systems, including GeTe, Sb_2Te_3, and $Ge_2Sb_2Te_5$.

The important accomplishments during this period were:

1. The establishment of activation energies for hopping conductivity in the three materials listed above.
2. The theoretical study of high-field transport through a model of polaronic transport in on and two dimensional systems.
3. The correlation of activation energies for hopping with oxygen content in GeTe and in $Ge_2Sb_2Te_5$.
4. The measurement of the Seebeck coefficient in all three materials
5. The measurement of the low temperature Hall coefficient
6. The unambiguous interpretation of the transport in Sb_2Te_3 as polaronic.
7. The establishment of the size of mobility in amorphous $Ge_2Sb_2Te_5$, and the observation that, while the transport is ambipolar, so that we could not estalish whether the sign of the Hall was anomalous, the best model for transport in this material is polaronic.

It is important to note that all three of the measurements, Seebeck effect, Hall Effect, and temperature dependent conductivity, are required to assess the viability of the polaron model.

In Sb_2Te_3 the transport is unambiguously a hopping motion of a large number of carriers. They exhibit an anomalous sign for the Hall coefficient, which is easily, though not uniquely, explained by a small polaron model. The carrier density is much larger than the estimated density of coordination defects (from spin resonance), so that even if these defects displayed large electron-lattice coupling constants, their numbers would be insufficient to account for the effect. Thus, we claim that in Sb_2Te_3 the dominant carrier transport mechanism is via small polarons. Transport is extremely sensitive to both oxygen content and to small percentages of crystallanity. In $Ge_2Sb_2Te_5$ the interpretation is not quite as clear. In this case there is not a dominant carrier type for transport, so that the sign of the Hall coefficient cannot be used as a consistent marker. However, it is clear the that transport is activated. Furthermore, it is clear from the density of charge carriers that the transport is not due to relatively few carriers with very high mobility. Rather, the mobility is very low, and the carrier density is roughly $10^{18}cm^{-3}$. The size of the carrier density argues strongly against the idea that this is defect mediated transport. For this to be true, the actual defect density would need to be between one and two orders of magnitude larger, or 10^{19}-10^{20} cm^{-3}. This is clearly non-physical.

In our first model for threshold switching, we argued essentially for a coulomb blockade at sites where the hopping probability is small that would be overwhelmed at high fields. While this model gave encouraging results in one-dimension, at higher dimensions, carriers simply went around the defect, so that the mechanism was ineffectual.

We attach a series o publications that resulted from the work undertaken during this contract.

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