

# Experimental Studies of Electronic Transport of Chalcogenide Glass Electrical Switches

Dave Emin and Arthur Edwards

University of New Mexico  
Department of Physics and Astronomy  
Albuquerque, NM 87131

1 October 2006

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.



**AIR FORCE RESEARCH LABORATORY**  
**Space Vehicles Directorate**  
**3550 Aberdeen Ave SE**  
**AIR FORCE MATERIEL COMMAND**  
**KIRTLAND AIR FORCE BASE, NM 87117-5776**

## NOTICE AND SIGNATURE PAGE

Using Government drawings, specifications, or other data included in this document for any purpose other than Government procurement does not in any way obligate the U.S. Government. The fact that the Government formulated or supplied the drawings, specifications, or other data does not license the holder or any other person or corporation; or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

This report was cleared for public release by the Air Force Research Laboratory/VS Public Affairs Office and is available to the general public, including foreign nationals. Copies may be obtained from the Defense Technical Information Center (DTIC) (<http://www.dtic.mil>).

AFRL-VS-PS-TR-2007-1017 HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION IN ACCORDANCE WITH ASSIGNED DISTRIBUTION STATEMENT.

//signed//

---

ARTHUR EDWARDS  
Program Manager

//signed//

---

JOHN P. BEAUCHEMIN, Lt Col, USAF  
Deputy Chief, Spacecraft Technology Division  
Space Vehicles Directorate

This report is published in the interest of scientific and technical information exchange, and its publication does not constitute the Government's approval or disapproval of its ideas or findings.

# REPORT DOCUMENTATION PAGE

*Form Approved*  
*OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 01/10/2006		<b>2. REPORT TYPE</b> Final Report		<b>3. DATES COVERED (From - To)</b> 29/06/2004 to 01/10/2006	
<b>4. TITLE AND SUBTITLE</b> Experimental Studies of Electronic Transport of Chalcogenide Glass Electrical Switches				<b>5a. CONTRACT NUMBER</b> FA9453-04-1-0370	
				<b>5b. GRANT NUMBER</b>	
				<b>5c. PROGRAM ELEMENT NUMBER</b> 61102F	
<b>6. AUTHOR(S)</b> Dave Emin and Arthur Edwards				<b>5d. PROJECT NUMBER</b> 2305	
				<b>5e. TASK NUMBER</b> RP	
				<b>5f. WORK UNIT NUMBER</b> AA	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> University of New Mexico Department of Physics and Astronomy Albuquerque, NM 87131				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Air Force Research Laboratory Space Vehicles Directorate 3550 Aberdeen Ave., SE Kirtland AFB, NM 87117-5776				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> AFRL/V SSE	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b> AFRL-VS-PS-TR-2007-1017	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited. (Clearance #VS07-0120)					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b>  The electrical conductivity, Seebeck coefficient, and Hall coefficient of 3 micron thick films of amorphous Ge <sub>2</sub> Sb <sub>2</sub> Te <sub>5</sub> 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 <i>p</i> -type with behavior indicative of multi-band transport. The Hall mobility is <i>n</i> -type and low (near 0.07 cm <sup>2</sup> /V sec at room temperature).					
<b>15. SUBJECT TERMS</b> Seebeck coefficient, Hall coefficient, Ge <sub>2</sub> Sb <sub>2</sub> Te <sub>5</sub>					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>
<b>a. REPORT</b> Unclassified	<b>b. ABSTRACT</b> Unclassified	<b>c. THIS PAGE</b> Unclassified			Arthur Edwards
			Unlimited	8	<b>19b. TELEPHONE NUMBER (include area code)</b> (505) 846-9600



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 phenomenon, illustrated in Illustration 1, below.

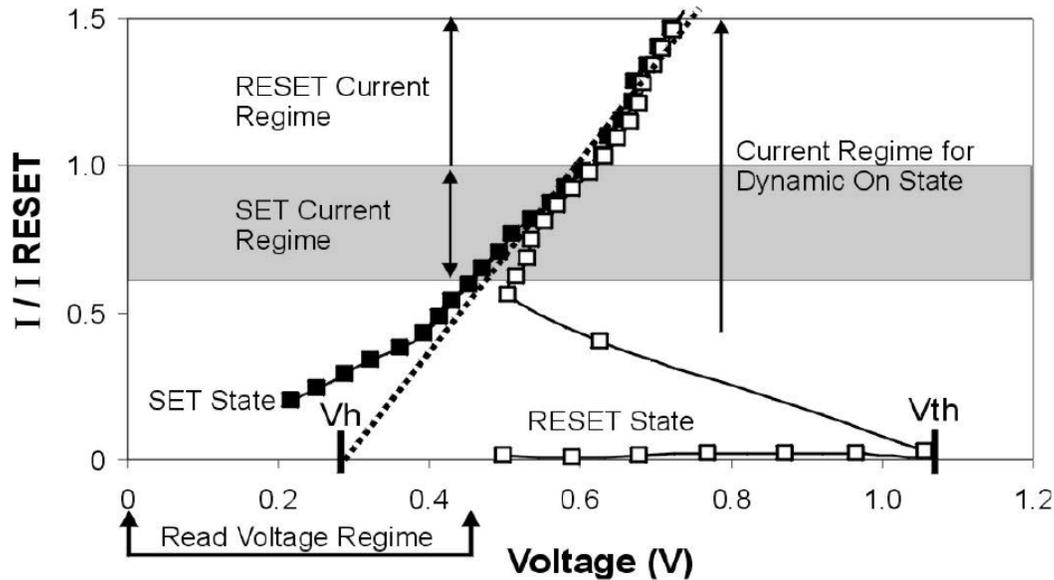


Illustration 1: Threshold switching. Taken from S. Lai, IEDM (2003)

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 localized defect states, leaving a few, high-mobility carriers, has enjoyed wide acceptance. However, in other materials, such as  $\text{As}_2\text{Te}_3$ , 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 conductivity

on several amorphous materials systems, including  $\text{GeTe}$ ,  $\text{Sb}_2\text{Te}_3$ , and  $\text{Ge}_2\text{Sb}_2\text{Te}_5$ .

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 one and two dimensional systems.
3. The correlation of activation energies for hopping with oxygen content in GeTe and in  $\text{Ge}_2\text{Sb}_2\text{Te}_5$ .
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  $\text{Sb}_2\text{Te}_3$  as polaronic.
7. The establishment of the size of mobility in amorphous  $\text{Ge}_2\text{Sb}_2\text{Te}_5$ , and the observation that, while the transport is ambipolar, so that we could not establish 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  $\text{Sb}_2\text{Te}_3$  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  $\text{Sb}_2\text{Te}_3$  the dominant carrier transport mechanism is via small polarons.

Transport is extremely sensitive to both oxygen content and to small percentages of crystallinity. In  $\text{Ge}_2\text{Sb}_2\text{Te}_5$  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 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  $10^{18}\text{cm}^{-3}$ . 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  $10^{19}\text{-}10^{20}\text{cm}^{-3}$ . 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 of publications that resulted from the work undertaken during this contract.

## DISTRIBUTION LIST

DTIC/OCP 8725 John J. Kingman Rd, Suite 0944 Ft Belvoir, VA 22060-6218	1 cy
AFRL/VSIL Kirtland AFB, NM 87117-5776	2 cys
AFRL/VSIH Kirtland AFB, NM 87117-5776	1 cy
Official Record Copy AFRL/VSSE, Arthur Edwards	1 cy

