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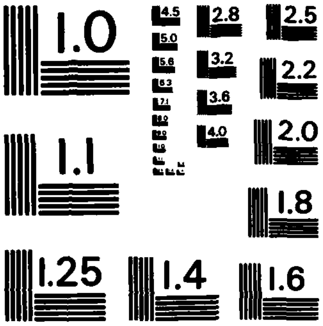

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HOT-ELECTRON INJECTION INTO GaAs AND RELATED MATERIALS

FINAL REPORT

DAVID ADLER

OCTOBER 5, 1982

U. S. ARMY RESEARCH OFFICE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

We have investigated a wide array of phenomena involving chalcogenide glasses, amorphous silicon alloys, and III-V semiconductors. We began with a study of chalcogenide-glass/GaAs heterojunctions, finding an accumulation region near the anode of the GaAs which pins the field below threshold in forward bias; in reverse bias, a depletion region is induced near the cathode of the GaAs. Similar results were found for InP heterojunctions. A model was developed for threshold switching in chalcogenides, including the mechanism for the switching and recovery events and the nature of the ON-state. A narrow-band electroluminescence was detected [over]

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at room temperature during the pulsed ON-state, and evidence for its coherence was found. Thin-film transistors were fabricated using a chalcogenide glass as the active material resulted in a μf product of approximately 2 cm^2/V-s, more than a factor of 10^6 greater than those previously reported. The field effect was found to be transient and a detailed model was developed. The effect is controlled by a potential barrier which retards neutral defect interconversion. Similar results were invoked to explain the Staebler-Wronski effect in amorphous silicon alloys and fatigue in MNOS transistors. Finally, switching in amorphous silicon alloys was investigated in detail.

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Table of Contents

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Theses

"Transient Effects in Chalcogenide Glasses and Related Materials", Robert C. Frye

"Switching in Sputtered Hydrogenated Amorphous Silicon, M. Christina Gabriel

SUMMARY OF RESEARCH FINDINGS

1.0 Threshold Switching in Chalcogenide Glasses

1.1 Mechanism for Threshold Switching

A critical-field electrothermal model for both threshold and memory switching was solved for both transient and steady-state conditions, and shown to provide good agreement with experimentally determined parameters. This agreement reinforces the validity of our electronic model for initiation and maintenance of the on state. An isothermal electronic model was analyzed for filamentary on-state solutions via a set of phenomenological kinetic equations. The predictions of the model agree with a variety of experimental results. The origin of the instability is the appearance of the critical electric field near the anode. Field-induced carrier generation then causes the charged traps in the bulk to neutralize. When all the traps are filled, carriers can transit the sample with an enhanced drift mobility, and the generation rate required to sustain the on state is greatly reduced from its threshold value.

1.2 The On State

A detailed, isothermal model of the on state of amorphous chalcogenide threshold switches was developed. Steady-state carrier generation and recombination processes were estimated, and the carrier distributions in the radial direction of the conducting filament was calculated under the assumption that there are no axial variations. Simulations of dynamic decay of the filament after the sustaining voltage is removed were used to calculate both the maximum interruption time before reswitching is necessary and the time dependence of the device resistance during decay as functions of the on-state operating point. Good agreement with experiment was obtained. The model predicts a rapid increase of device resistance in the vicinity of the maximum interruption time, and this has been confirmed by subsequent measurements. Since the rise time of the device resistance in this region is limited by the measuring circuitry and essentially independent of the on-state operating point up to at least 100 mA, the electronic nature of both the on-state and the recovery process is convincingly confirmed.

2.0 Electroluminescence from the On State of a Chalcogenide Glass

A narrow-band emission was detected at room temperature during the pulsed on state of a well-characterized threshold switching material, amorphous $Te_{39}As_{36}Si_{17}Ge_{7}P_{1}$. The luminescence peak is centered around (0.55 ± 0.03) eV, very close to half of the optical band gap of this material, 1.1 eV. This ratio of luminescence peak to optical band gap is similar to that obtained for the photoluminescence of a large class of chalcogenide glasses in their off states, strongly suggesting that the origins of the on-state electroluminescence and off-state photoluminescence are the same. The electroluminescence exhibits a threshold behavior, appearing only for on-state currents in excess of 4 mA. The output follows a lambertian law for solid angles up to about 0.7 steradians, and slowly deviates below the lambertian law at larger solid angles. The width of the luminescence line is less than 0.1 eV, indicating that its origin cannot be black-body radiation. This provides another confirmation of the electronic nature of threshold switching.

We also measured the optical properties of thin-film light-emitting diodes of $Si_{18}Te_{45}As_{28}Ge_{9}$. We determined the wavelength dependence of the refractive index of the deposited glass, the passive external interference mode structure of the fabricated devices with reflecting lower contacts and semi-transparent upper contacts and the corrected infrared emission spectrum on the same devices. At currents just above the optical threshold in the on-state the emission is narrow band, at a wavelength consistent with earlier experiments, while at higher currents the emission shows the narrow component with a broad component which follows the shape of the passive external transmittance. The optical threshold current of these types of devices increases with increased thickness of the transparent upper contact indicating the optical feedback requirement of this emission. The various results we have obtained reinforce the presumption that the emission is stimulated.

3.0 Properties of Chalcogenide-Glass/GaAs Heterojunctions

Heterojunctions of threshold-type chalcogenide glasses deposited onto crystalline n-GaAs with several different values of of carrier concentration were fabricated and investigated. Once the glass is switched into the on state, very asymmetric behavior was observed. Under forward bias, the devices exhibit low resistance, but strong current saturation was obtained under reverse bias. No microwave gains or losses were detected. These results were explained by a consideration of the expected results when an N-type negative-differential-resistance device is placed in series with an S-type negative-differential-resistance device. A band diagram for the heterojunctions was determined. In forward bias, the filamentary nature of the on state of the glass is the dominant feature. Outside the filament, the glass in the off state is a poor conductor, resulting in the appearance of an accumulation region in the GaAs near the interface. Within the filament, the glass in its on state has a large field near its cathode. The resulting excess positive charge builds up an image charge in the GaAs, again giving an accumulation region. Because of this omnipresent accumulation region, the current density in the GaAs is reduced, and the saturation current density in the glass is not reached in the GaAs throughout the range of GaAs carrier concentrations investigated. Thus, the heterojunctions act just like a glass between two metallic contacts. On the other hand, in reverse bias, the observed current saturation indicates that a large depletion region exists in the GaAs. This must be due to the presence of a large anode field in the on state of the glass, a new and important result. This conclusion could not have been reached from our previous studies of glass/Si heterojunctions because of the absence of negative differential mobility in the Si.

4.0 Properties of Chalcogenide-Glass/InP Heterojunctions

Our model for the electronic properties of chalcogenide-glass/GaAs heterojunctions discussed in the previous section predicts that glass/InP heterojunctions should exhibit qualitatively similar behavior. Several such heterojunctions were fabricated, and indeed the same behavior has been observed in each case.

5.0 Chalcogenide-Glass Thin-Film Transistors

We fabricated thin-film transistors using a multicomponent chalcogenide glass as the active material. Under ordinary preparation conditions, no field effect was observed. However, when the glass was reactively sputtered in hydrogen/argon mixtures, reproducible data were obtained. Transconductance measurements indicate that the μf produce is 1.6 cm^2/V-sec for the p-type films. From the observed hysteresis, we estimated $\mu \approx 2$ cm^2/V=sec and thus the fraction of the induced charge that is mobile, f, is about 0.7. The large-signal transconductance of 4.6×10^{-3} Ω^{-1} implies strong electron-phonon coupling. A quantitative interpretation of the results suggested that the trap-emptying times are in excess of 1 hour while the trap-filling times are less than 10 msec. Our observed values for the μf produce were greater than those previously reported by a factor in excess of 10^6.

6.0 Transient Effects in Amorphous Semiconductors

6.1 Electronic Structure of Chalcogenide Glasses

Although field effects are generally unobservable in Se-As glasses, there have been several reports of relatively large responses in Te-As glasses. Since valence alternation pairs (VAPs) characterized by a negative effective correlation energy are expected to be as important in Te-As glasses as in Se-As glasses, these results are surprising. A second difficulty is the inconsistency in temperature variation of the field effect observed in amorphous $Te_{39}As_{36}Si_{17}Ge_7P_1$. The results indicate that the observed effects are dominated by very slow transients which can take as long as several hours to decay at room temperature. Once the transients disappear, the steady-state field effect is consistent with the existence of a large density of VAPs in these glasses.

Under the assumption of the presence of charged defects with a negative effective correlation energy, a first-order kinetic model for carrier trapping was developed. The model predicts the observed transient response provided a barrier exists between the two neutral defects obtained when the positive center traps an electron and the negative center traps a hole. It is the interconversion between these neutral defects which pins the Fermi energy and concommitantly suppresses the field effect. The barrier explains the long-time transient at room temperature. Measurements at elevated temperatures confirmed this model and led to the identification of the trap densities and energies. In addition, it was possible to identify the origin of the apparent discrepancies in temperature behavior between previously reported measurements. We concluded that the effective density of states in chalcogenide glasses observed by non-equilibrium measurements such as photoconductivity or field effect can be a function of time. The time scale is controlled by the barrier between the two neutral defects, small in Se-As glasses but much larger (about 0.7 eV) in Te-As glasses.

6.2 Electronic Structure of Amorphous Silicon Alloys

Tight-binding estimates of the energies of the various charge configurations for dangling bonds in amorphous silicon alloys suggest that the effective correlation energy is negative in this case. Nevertheless, unpaired spins are routinely observed in these materials, an apparent inconcistency. Another problem with a-Si:H alloys is the so-called Staebler-Wronski effect, in which the dark conductivity and photoconductivity of the material are reduced considerably at room temperature after exposure to light. This has been attributed to photogeneration of defects or to band bending near the contacts. We used a first-order kinetic model with negatively correlated defects to analyze the transient photoconductivity and find that we can explain the Staebler-Wronski effect without any additional assumptions. The barrier between the two neutral defects in a-Si appears to be about 1.3 eV, sufficiently large that the transient persists for centuries at room temperature. This explains the apparent stability of both states.

7.0 Fatigue in MNOS Transistors

An extension of our model for transient effects in chalcogenide glasses can explain the fatigue problem which plagues MNOS transistors. In this model, charge storage is due to the creation of positively charged defects on nitrogen sites, N_4^+. At long times, negative correlation energy effects lead to an effective pinning of the Fermi level, and this in turn causes the observed fatigue. The time scale for the fatigue is controlled by the potential barrier retarding the extra bond formation and subsequent relaxation necessary to convert a Si_3^o dangling bond into a N_4^o over-coordinated center.

8.0 Switching in Sputtered Hydrogenated Amorphous Silicon

Several different types of hydrogenated amorphous silicon films prepared by rf-sputtering techniques were investigated for potential threshold and memory switching applications. In no case was true reversible switching observed, as is routinely found in a wide array of chalcogenide-glass films prepared with similar device geometries and deposition procedures. We concluded that the presence of large concentrations of positively and negatively charged defect centers is essential for useful switching devices, in accordance with a recent model. Non-ohmic effects in the highest-quality a-Si:H films were investigated, and the Schottky-barrier height at the Mo-Si interface was determined to be (0.7±0.13) eV.

PUBLICATIONS

1. "The Mechanism of Threshold Switching in Amorphous Alloys", David Adler, Heinz K. Henisch, and Sir Nevill F. Mott, Reviews of Modern Physics 50, 209-220 (1978).
2. "Electroluminescence from the On State of a Thin-Film Chalcogenide Glass", Peter J. Walsh, Sachio Ishioka, and David Adler, Applied Physics Letters 33, 593-595 (1978).
3. "A Model for the On State of Amorphous Chalcogenide Threshold Switches", Kurt E. Petersen and David Adler, Journal of Applied Physics 50, 5065-5072 (1979).
4. "Properties of Chalcogenide-Glass/n-GaAs Heterojunctions", Robert C. Frye, David Adler, and Melvin P. Shaw, Journal of Applied Physics 50, 4866-

4871 (1979).

5. "Fabrication and Characterization of Heterojunctions between Chalcogenide Glasses and III-V Crystals", Robert C. Frye, David Adler, and Melvin P. Shaw, Journal of Non-Crystalline Solids 35/36, 1099-1104 (1980).

6. "Threshold Switching in Chalcogenide-Glass Thin Films", David Adler, Mischa S. Shur, Marvin Silver, and Stanford R. Ovshinsky, Journal of Applied Physics 51, 3289-3309 (1980).

7. "Transients Effects in Chalcogenide Glasses", Robert C. Frye and David Adler, Physical Review Letters 46, 1027-3030 (1981).

8. "Photoconductivity and Negatively Correlated Defects", Robert C. Frye and David Adler, Physical Review B24, 5485-5496 (1981).

9. "Field Effect in Chalcogenide Glasses", Robert C. Frye and David Adler, Physical Review B24, 5812-5834 (1981).

10. "Active and Passive Studies of Amorphous Chalcogenide IR Emitters", Peter J. Walsh, A. Jaefer, Malcolm J. Thompson, and David Adler, Journal de Physique 42, Colloque C4, Supplement 10, 317-322 (1981).

11. "Switching in Hydrogenated Amorphous Silicon", M. Christina Gabriel and David Adler, Journal of Non-Crystalline Solids 48, 297-305 (1982).