Journal of Optoelectronics and Advanced Materials Vol. 4, No. 3, September 2002, p. 793 - 798

PULSED BREAKDOWN OF CHALCOGENIDE GLASSY SEMICONDUCTOR FILMS

E. N. Voronkov

Moscow Power Engineering Institute, 125252 Moscow, Russia

The application of a magnetic field in experiments on breakdown of chalcogenide glassy semiconductor films gives the possibility to investigate a number of fast processes because of the spatial sweep effectuated by the magnetic field. The main phases of the breakdown in long gaps of films have been explained on the basis of generation and reorganization of metastable defects. The obtained results demonstrate the important role of coherent acoustic waves.

(Received 26 June 2002; accepted July 22, 2002)

Keywords: Chalcogenide glass, Amorphous chalcogenides, Breakdown, Solitons

1. Introduction

The worldwide interest to chalcogenide glassy semiconductors (CGS) arosed in the late 1970s and early 1980s from the discovery of the switching effect in them and application of the effect in nonvolatile memory by S. Ovshinsky [1]. We believe that the flagging interest to this phenomenon pursuant to development of silicon memory microcircuits, which have suppressed CGS memory elements, arosed because the switching effect is one of the most efficient techniques for investigation of dynamic processes and nonequilibrium phase transitions in amorphous materials. It should be noted, that a complex nature of the effect hxdas yet to be fully revealed. The effect demonstrates that CGS respond to external excitation not only by changing internal fields and charge distribution, but also by modifications of the structure. In CGS the excitation of the electronic subsystem transforms into the matrix subsystem by generation of metastable defects. This particularity is not typical for semiconductor crystals, and it makes CGS unique medium for investigation of dynamic transformations under external power streams. Thus the optical bistability was observed in CGS [2, 3].

The objective of the present study is to investigate the breakdown dynamics of CGS films and interactions between excited electronic and structure matrix subsystems. This investigation could offer a new approach to the switching effect.

2. Experimental

The films of CGS were deposited on glass substrates by thermal evaporation in vacuum of $\sim 1 \times 10^{-6}$ Torr. The thickness of films was 1-4 micrometer. The experimental results for different compositions were similar. The presented results were obtained in films of As_2SeTe_2.

The experimental arrangements for different electrode configurations are shown schematically in Fig. 1. The gap between electrodes was 1 – 2 mm. Dash lines in Fig. 1 mark regions for which photography are presented in the paper. A sample consisting of substrate with CGS film (1) and metallic electrodes (2) was connected to a generator (3). The pulsed voltage was applied to a sample through a current-limiting resistor (4). The sample was placed in a magnetic field (5). Line 6 shows the breakdown track without the magnetic field. Lines 7, 8 show possible breakdown tracks with magnetic field. The amplitudes of the rectangular pulses applied to the sample were varied in the interval 100 – 1000 V. The pulse durations varied in the interval 10^{-2} – 100 ms. Magnetic induction was 2T. The main experiments were carried out with single pulses. A train of pulses was used to check repeatability of results.

Nonequilibrium phase transitions, as a rule, have a narrow region of controlling parameters. A transition of a control parameter through the border (threshold) of control region brings the system in a new state. As it was difficult to turn out in this region on occasion, a computer simulation was carried out simultaneously with experiments. We used known models of dynamic systems as well as our models for different stages of breakdown. The models used as control parameters: the local temperature, the potential, the concentrations of free and localized charges, and the density of defects. The trend of process depends of initial values of these variables and their derivatives per time and per coordinate. In experiment the breakdown was controlled by amplitude of initial voltage, value of electric current, duration of a pulse, rate of current increase and decrease. The magnetic field gave some additional means for control.

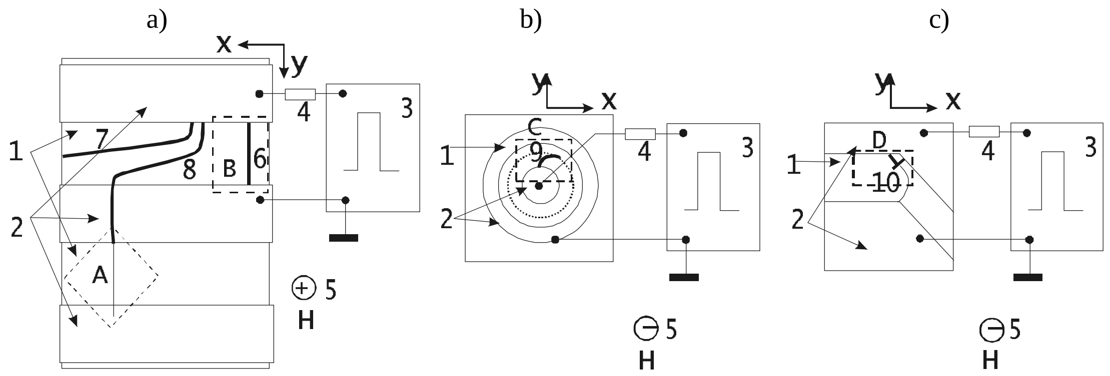

Fig. 1. Schematic diagrams of the experimental arrangements: planar electrodes a), coaxial electrodes b), shaped electrodes c); objects: CGS film (1), electrodes (2), pulsed generator (3), current-limiting resistor (4), magnetic field (5), alternative paths of the observed tracks (6 – 10), regions showed in photo (A, B, C, D).

The magnetic field was used to exclude joule heating of the breakdown channel. Just joule heating burns out all changes of structure matrix, which take place on different stages of breakdown. In magnetic field the current filament moves with high speed along the breakdown gap [4]. The current filament speeded up and then moves with constant velocity, which can exceed to 10^5 cm/s. This velocity is too high to heat the local area by joule heat. That's why the modification of structure after a breakdown in magnetic the field must be caused only by interactions between electronic and matrix subsystems. The magnetic field influences the breakdown mode, but its influence on energy transformations must be negligible.

Magnetic field gives the possibility to estimate the duration of different stages of breakdown with space-time scale. This scale is possible to calculate by measurement of a space displacement of a current track for a certain time of pulse

3. Results

Electric breakdown produces visible track. The investigation of the tracks, formed in different modes, is the main subject of the work.

Fig. 2 shows a photograph of the initial segment of one of the tracks formed in a film after breakdown in a magnetic field (see track 9 region C in Fig. 1b). From Fig. 2 that a hot spot gradually evolves near the anode and, at the same time it moves to the cathode while concurrently moving together with current filament along the substrate ("x"). The current filament is not visible at the photo, because it is cold. The area of speeding up the filament by magnetic field is seen in the photo. The velocity of the filament was saturated (~10^5 cm/s). The track turned almost parallel to the electrode boundary (Fig. 1a track 7), because its velocity in direction of electric field ("y") was 10 – 100 times less than it was in direction x. The photo shows the temperature oscillations of the hot spot. The amplitude and frequency of the oscillations depended of the current amplitude. Fig. 2 demonstrates the advantages of the used experimental method, without magnetic field photo would show only straight burned out channel between electrodes. It is necessary to notice, that hot spot appears only under currents greater than a certain value. It was possible to exclude its development, but in that case the track was invisible.

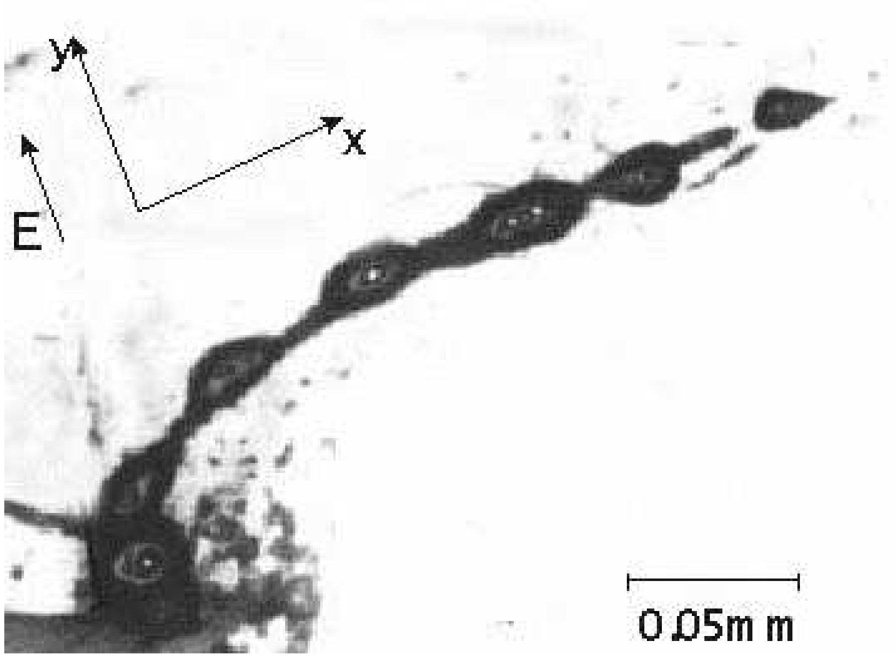

Fig. 2. Photograph of initial part of a track after breakdown in a magnetic field (Fig. 1b, region C, track 9), E – electric field.

In order to register the moment, when a hot spot would reach the anode, a capacity discharge was used. As soon as the value of discharge current vanished, the movement of the filament in X direction ceased and the spot reached the grounded cathode (Fig. 1a, track 8).

When the hot spot actually attained the cathode, the electrode burned up and, what is particularly interesting, a track in the form of a crystallized filament propagated in a zone, where the electric field was zero (track 8, region B of Fig. 1a). A relevant photo, showing the directional propagation of the excitation over a great distance after the grounded electrode, is given in Fig. 3. Most likely the energy in this zone is transported by a deformation wave.

The experiment with special configuration of electrodes was carried out in order to verify a possibility of generation of a deformation wave [5]. A dog-leg shape of electrodes is shown in Fig. 1 c. The change of the direction of a gap line must not influence the propagation of the deformation wave, but must redirect the current filament. In the experiment the current amplitude was not enough to a evolve hot spot. Fig. 4 shows the photograph of a film section near the electrode bend, after a breakdown in the magnetic field (region D in Fig. 1c).

As seen from Fig. 4 the electrode bend ceases propagation of the deformation wave and the current filament. Almost instant disappearance of the current filament and cease of energy pumping had accompanied by extracting of a big amount of energy stored in the structure matrix of CGS.

The calculations performed in Ref. 5 revealed, that propagation of an excitation in a system of partly movable ions could result in an acoustic soliton. Thus Fig. 4 demonstrates a soliton decay (the excitation propagated from the left to right). Splashes of material are observed in front of the crest of the leading edge. This indicates that this front propagated with substantial release of energy.

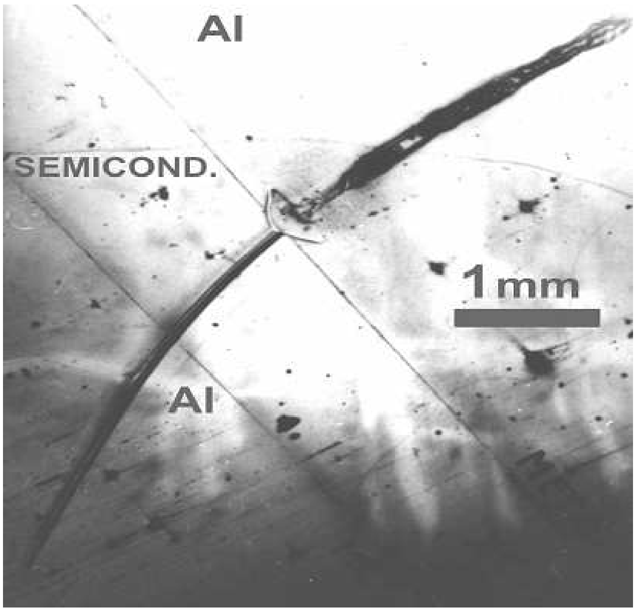

Fig. 3. Photograph of the final part of a track after breakdown in a magnetic field (track 8, region B, Fig. 1 a).

The results of numerical simulation of soliton dynamics in bistable media explain the appearance of two fronts. Fig. 4 b displays the simulation results showing the decay of a topological soliton [6]. The comparison between the experimental and the computational results is interesting. A characteristic feature of the experiment with respect to the calculations is that in our case (calculation) the propagation of the stationary wave was associated not with the system bistability but with rather a constant inflow of energy. When the inflow of energy ceases, the soliton decays.

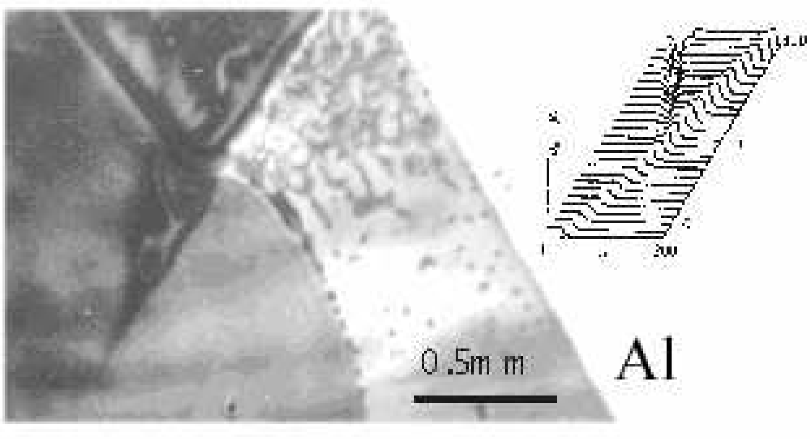

Fig. 4. Photograph of a section of the film with traces of soliton decay, where the excitation propagated from left to right (a) and results of simulation of soliton decay (b).

The computer calculations and a few experiments were performed in order to prove that oscillations of the hot spot were possible without the magnetic field. The model for computer simulation supposed that the injected charge propagates to the anode with a constant velocity and respectively, all the energy pumped in the matrix by recombination is expended for heating of the injection spot. Rising of the spot temperature is accompanied by lowering of injection and, respectively, lowering of recombination rates. The result of the simulation shows the influence of the breakdown regime on the way of the development of process, and that in some cases the oscillation mode is possible [7].

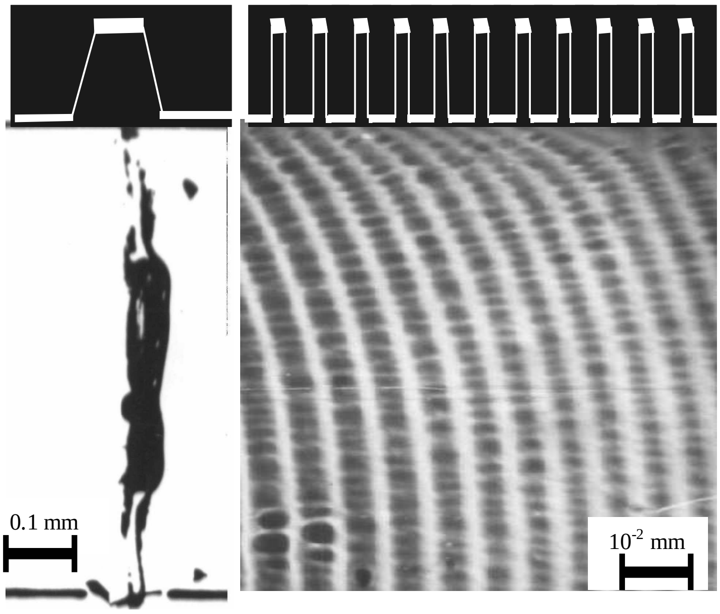

Fig. 4. Photographs of tracks after breakdown without magnetic field: single long pulse (a), a chain of shot pulses.

Experiments were preformed according the scheme Fig. 1 a (track 5, region B). Fig. 5 shows two modes of breakdown. The tracks of Fig. 5b were obtained in the breakdown by a chain of shot pulses. The estimated frequency of the hot spot oscillations was ~ 10^7 Hz. The photo shows bending of the tracks. One of a reason for it may be in the modification of the film structure by the previous acoustic wave. Thus the bent front line of the modified CGS film is seen in Fig. 4.

4. Discussion

The breakdown of CGS films is a multistep route. At each phase of it some process dominate over others. The developments of dominatnt process at each phase is determined by energy supply and by the resulting state of the system at the previous stage. It is possible to determine three main phases of breakdown:

1. First phase (time of delay) begins just after the moment of the voltage switching on. The voltage must be higher than some threshold value. As a rule, at this stage the notable changes of the current are absent. The delay time as longer as the voltage are closer to the threshold value. During this phase the supplied energy transforms into the energy of charged metastable defects. The current density is small and the injected charge is negligible. At the same time the electric field is high enough to stimulate an electron emission from defects with low ionization energies in favor of defects with higher energies. Configurations of interacted defects and a set of their properties are rather broad [8]. The models of involving positively (D^+) and negatively (D^-) charged defects are commonly used in models of structure transformations. The models of interactions and forming of regions with metastable structure are under construction now [9,10]. The space distribution of defects involves redistribution of electric field, redistribution of strain energy, and charge transport. The first phase comes over when the local region with modified structure matrix (prechannel) is formed. The prechannel accumulates a part of energy supported by external source.

2. The second phase starts when main part of supported energy begins to dissipate in the modified region. The concentration of supplied energy speeds up processes of forming localized region and changing its properties. At this stage prechannel transforms to the current channel. At the end of the second phase the region of high field appears near anode, and holes from anode inject in the channel and transform it to a high conductivity state. There are several ways of process at this stage. One of them carefully is considered in Ref. 11. One of the main features is the type of the channel conductivity. From our point of view the channel has electron conductivity. This conclusion is supported by the formation of high field region near anode.
3. It is possible that the third phase is typical only for long channels. For this stage the movement of the high energy dissipation region (hot spot) from the anode takes place along the channel. Holes injected from anode displace the double charged layer (DCL) to the cathode and thus the anode p type area starts to grow at the cathode. Electrons and holes injected through the DCL recombine in the neighbor regions and heat the DCL. The heating of the DCL reduces the injection and, accordingly, the recombination rates. These effects create the necessary basis for oscillations.

5. Conclusions

The application of the magnetic field in experiments on breakdown of CGS films gives the possibility not only to increase substantially the current density without destroying the sample but also to investigate the fast processes due to spatial sweep effectuated by the magnetic field.

Experiments show that in breakdown of long gap in CGS film the DCL layer is formed near the anode. As a result of recombination of injected charges the supplied energy dissipates in the region of the DCL and forms a hot spot. The hot spot moves to the cathode. The temperature of hot spot oscillates with the frequency ~ 10^7 Hz.

The results obtained made it possible to demonstrate the important role of coherent acoustic waves, which in experiments on breakdown of solids is usually masked by delayed action of thermal effects.

The main phases of breakdown in CGS films is possible to be explained on the basis of generation of metastable defects.

References

[1] S. R. Ovshinsky, Pat., USA, cl. 307-885, No. 3281591 (1963).
[2] J. Haito, G. Zantai, I. Kosa Samogyi, Sol. St. Commun. **23**, 401 (1977).
[3] V. M. Lyubin, V. K. Tikhomirov, JETP Lett. **52**, 80 (1992).
[4] S. V. Kurokhtin, E .N. Voronkov, Materials Sci. Trans., Russia, No. 6-7, 39 (1997)
[5] E. N. Voronkov, JETP Lett. **70**, 72 (1999).
[6] L. L. Manevich, A. V. Savin, V. V. Smirnov, S. N. Volkov, Usp. Fiz. Nauk **164**, 937 (1999).
[7] E. N. Voronkov, Bulletin of the V. Tarasov Center of Chemotronics of Glass. No. 1, 115, Ed. Mendeleev Unversity of Chemical Technology, Moscow (2000).
[8] S. A. Dembovsky, A. S. Zyubin, F. V. Grigoriev, Fiz. Teckh. Poluprrovodn. **32,** 843 (1988).
[9] M. Popescu, J. of Optoelectronics and Adv. Mater. **3**, 279, (2001).
[10] M. Popescu, H. Bradaczeck, J. of Optoelectronics and Adv. Mater. **3**, 249, (2001).
[11] D. Adler, M. S. Shur, M. Silver, S. R. Ovshinsky, J. Appl. Phys. **51**, 3289 (1980).