

RESEARCH OF A MICROPLASMA BREAKDOWN IN THIN FILMS OF GLASSY SEMICONDUCTORS

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Experiments were carried out to detect presence of a microplasma in thin films of glassy chalcogenide semiconductors. Films of As_2Se_3 and As_2SeTe_2 were investigated. In the regime of a "soft" breakdown time series of current and voltage of the samples based on As_2Se_3 were measured and then processed by spectral analysis. Films of As_2SeTe_2 were used for experiment with long discharge space. This experiment resulted in observation of oscillating streamer discharge. A model was suggested to explain the phenomenon.

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1. Introduction

Investigation of electronic processes occurring at high electrical fields in thin films of vitreous semiconductors is of great interest both for theory of carrier multiplication in amorphous semiconductors [1], and for practical application of this material for pulse generation of acoustic and optical radiation [2]. At high current concentration density of free charge carriers become so large that electron subsystem have to be considered as a plasma media or, speaking other words, a microplasma, because these regions are localized in solid state. The main feature of a microplasma by analogy with gaseous plasma is collective behavior of involved charge carriers. This effect results in the presence of nonlinear processes in microplasma media. Such processes can have the resonant or oscillatory nature depending on different conditions.

In the given work the results of experimental investigation of an electrical instability arising in a mode of "soft" and irreversible breakdown of thin films of vitreous semiconductors are presented. Films of As_2Se_3 and As_2SeTe_2 were under study. Experimental procedure with the samples based on As_2Se_3 included dynamic measurement of I-V (current-voltage characteristics) and pulse measurements of sample's current and voltage series for constant voltage of the generator. Films of As_2SeTe_2 were used for registration of the spatial distribution of the energy, developing in the sample at an irreversible streamer breakdown.

2. Experimental

Samples with films of As_2Se_3 presented sandwich-like structure Au-Vitreous semiconductor- In_2O_3 -Glass substrate. One contact to the amorphous film was In_2O_3 layer, and the other one was pinch gold contact with an area of $2.5 \cdot 10^5 \mu m^2$. The thickness of films for different samples was made varying from 0.2 to 1 μm . Samples with As_2SeTe_2 film had rather different structure and thickness of the chalcogenide film. The structure consisted of a glass substrate with chalcogenide film deposited upon it and planar metallic electrode strips with the distance between them 0.2 mm deposited on the surface of the semiconductor film. The thickness of the chalcogenide films was 1 – 5 μm . All the chalcogenide films were produced by vacuum evaporation.

Investigation of samples based on As_2Se_3 was conducted as follows. At first, single saw teeth-like pulse of voltage was applied to the sample during 5 ms. Measurement of current and voltage of the sample started simultaneously with the beginning of the pulse. After the I-V characteristic is defined, several square voltage impulses of different amplitude with high duration were applied to the sample. The pulse must be long enough to measure sufficient amount of current and voltage data for statistical processing. Amplitude of the pulses covered all voltage range of the earlier measured I-V characteristic. The length of the measured time series was 5000 values. One should mention that in this case the voltage applied not exceeded breakdown threshold. The aim was to measure time series near the breakdown threshold, which was defined by strong noise on the I-V characteristic. Time se-

ries were subjected to spectral analysis. Above-mentioned experiment was carried out in such conditions, when amorphous material was not subjected to irreversible changes. Other extreme case was the experiment on observation of a streamer breakdown in lengthy interelectrode gap. For this experiment a samples based on As_2SeTe_2 were used. At the beginning of the experiment the pulse of voltage, with leading edge less than duration of all characteristic processes in structure, was applied to the structure. The duration of the pulse must be large for the completion of the streamer process [3]. The track pattern was influenced by parameters of electric impulse: amplitude, the rate of voltage increasing, impulse duration and resistance of the generator.

3. Results and discussion

Processing of series for the several As_2Se_3 samples showed that there was special threshold on the I-V characteristic at the forward bias (when potential on the In_2O_3 electrode was positive). If the amplitude of the square pulse was greater than threshold then spectral analysis showed low frequency chaotic oscillations for voltage series. Presented in this work results concerned the film of As_2Se_3 with thickness of $0.3 \mu\text{m}$. I-V characteristic for the sample is shown on Fig. 1. Investigation had shown that the threshold of oscillations approximately equaled to 1 V while the irreversible breakdown began approximately at 1.5 V. The curves of spectral analysis for the current and voltage series before oscillation threshold looked like curves shown on Fig. 2 for voltage 0.8V at the forward bias. Fig.3. shows curves of spectral analysis for forward voltage 1.1V. All the curves for reverse bias had shape of white noise with a rise at low frequencies.

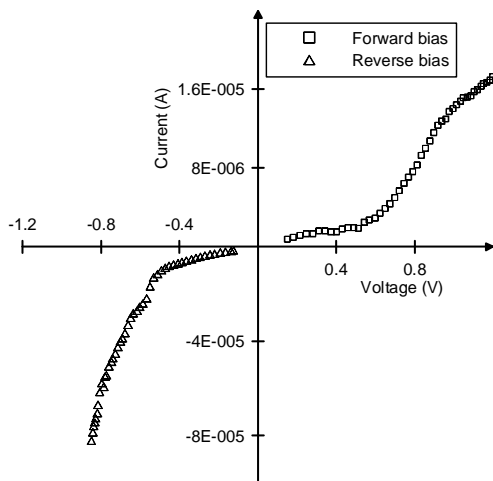


Fig. 1. The I-V characteristic for As_2Se_3 sample, measured before studying time series.

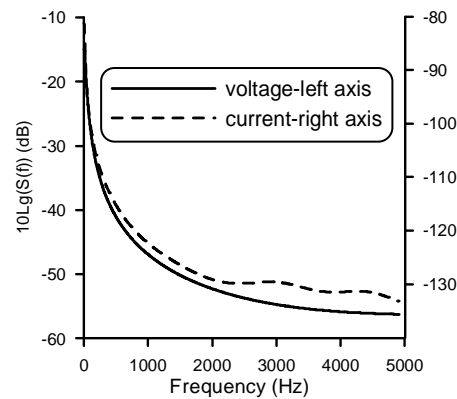


Fig. 2. Curves of spectral analysis for time series of current and voltage at the mean forward voltage of 0.8V.

Figures with results of spectral analysis show distribution of spectral density $S(f)$ for the time series of current and voltage, expressed in decibels. Dependence of the spectral density on frequency is defined by the expression:

$$S(f_k) = \frac{\Delta}{n} \left| \sum_{t=1}^n x_t \cdot \exp(-2\pi i f_k t) \right|^2 \quad (1)$$

Where n is length of the series, $k=0,1,2,\dots,n/2$, f_k are the discrete Fourier frequencies, x_t – time series of current or voltage.

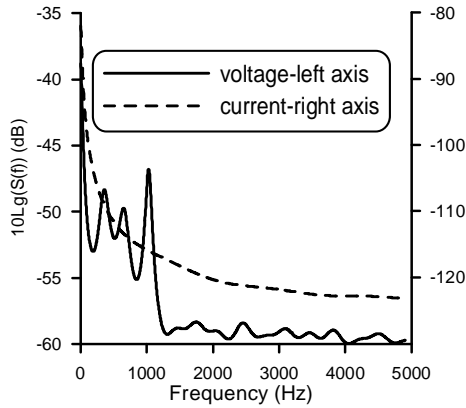


Fig. 3. Curves of spectral analysis for time series of current and voltage at the mean forward voltage of 1.1V.

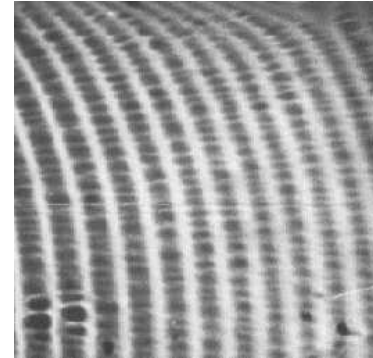


Fig. 4. Traces left in the material by pulsating head of a streamer.

Presence of close several peaks on spectral curves (Fig. 3) points to at least three periodic processes in volume of the structure. These oscillations are supposed to be due to microplasma generation and damping. The generation of a microplasma region leads to a local rising of carriers. As the pulse generator in that case acted as current source so changes in carriers had resulted in detected potential oscillations.

Results obtained with As_2SeTe_2 samples enabled us to recognize microplasma generation by traces in the chalcogenide film. The energy dissipation during impulse breakdown was registered visually by the view of the melted material track. To demonstrate reproducibility of that mode, the breakdown was executed by sequence of similar pulses, so Fig. 4 shows a number of parallel channels.

In order to explain this effect we proposed that two concurrent processes take place in the streamer head: the electron-hole generation and the heating, which reduces generation.

Streamer breakdown is rather complicated process and has some consequence steps. We considered the some main stages. During delay time τ_d the forming of the cathode streamer head takes place, after that the wave of plasma generation spreads from cathode to anode and forms a current channel. As a result of this process the potential jump and the high field region occurs near anode. At the next stage double injection of hot carriers into depletion region takes place from the anode and the channel. The level of injection is so high, that impact Auger recombination becomes dominated. The current through channel enlarges at several orders. The head of anode streamer generates plasma and moves toward the cathode. The recombination process in the anode streamer head is accompanied by phonon generation [2] and the hot spot becomes powerful source of phonon stream modulated by periodic oscillation

This process is similar to leader breakdown of gases. This stage of breakdown used to call spark breakdown because the temperature of the leader head is so high that it emits light.

In the discussion of possible nature of oscillations we exclude the initial and final stages of anode blazing up and cathode blazing down. We consider only the period, when the leader head (hot spot) moves to cathode with a constant velocity. In that case it is possible to use stationary approximation, because the average energy dissipated by the hot spot is equal to the energy of supply. The equation of the charge balance is standard:

$$\frac{dQ}{dt} = G - U - \text{div}(J), \quad (2)$$

Q – charge of carriers, G – generation part, U – recombination part, J – current density.

In order to calculate the concentration of carriers in the head we assume that the volume of the head is constant. After integration and differentiation we shall get:

$$\frac{d^2 N}{dt^2} = \frac{dG}{dt} - \frac{dU}{dt} \quad (3)$$

Where N - concentration of electrons in the head of the leader. As we can see the balance of generation and recombination rates determines the change of carriers. If we take into consideration heating and temperature dependence of Auger recombination we can write non-linear system:

$$\begin{aligned} y_1' &= y_2 \\ y_2' &= -ay_1^2 - by_1 + c \end{aligned} \quad (4)$$

Where y_1 - normalized concentration, y_2 - rate of concentration variation, constants "a", "b" and "c" are determined by material properties. The numeric decisions of equation were determined under different conditions. The phase diagram for one of variants is at the Fig. 5. It shows the possibility of existence not only divergent but also periodic solutions in accordance with different initial conditions. We marked (A, B, C) three different possible cases, demarcated by phase lines, which from our point of view are similar to some of our experimental results.

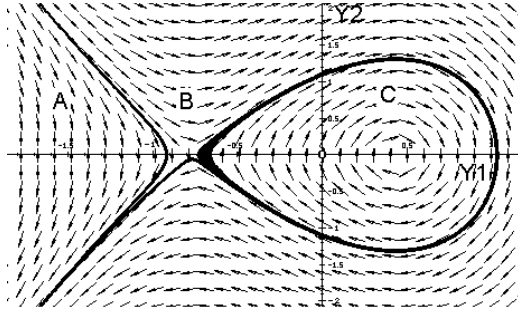


Fig. 5. The phase diagram of numeric solutions.

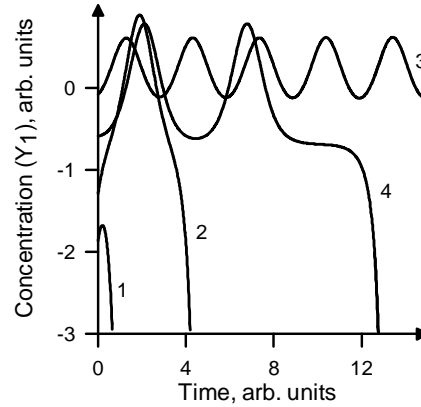


Fig. 6. The solutions, which demonstrate the existence of not only divergent (1,2,4), but periodic (3) solutions.

The four different solutions, which are corresponded to the marks on phase diagram, are represented at Fig. 6.

Solution "1" corresponds to region A (Fig.), solution "2" to B, solution "3" to C and solution "4" to the border between B and C. Cases "1" and "2" could be correlated with well-known solid trace of melted material during spark breakdown. Solution "4" could explain breakdown channel with two (or other discrete number) hot spots. The most interesting case is "3", which, from our point of view, causes tracks of fig.4. The picture demonstrates that the periodic oscillatory breakdown is rather reproducible. But we must pay attention that the range of initial conditions that produces periodic oscillations is rather narrow, as possible to notice at Fig. 5.

4. Conclusion

The performed investigation confirms the existence of electrical instabilities at high electric fields. In our case, the study of time series of current and voltage revealed low frequency chaotic oscillations, which can be explained by generation and damping of several microplasma regions.

Another experiment on observation an irreversible spark breakdown in long discharge gaps demonstrated that, depending on initial conditions, breakdown in chalcogenides has an oscillating character, which must be accompanied by powerful periodically modulated stream of phonons. According to the suggested model this never known before effect is explained by competition between processes of carrier's generation and recombination, resulting in periodical generation of a microplasma in streamer's head.

Acknowledgement

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