CURRENT OSCILLATIONS IN AMORPHOUS SEMICONDUCTORS

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At the present time, research on the electrophysical properties of amorphous substances is being vigorously pursued. This has been stimulated to a considerable degree by the discovery of the switching effect in amorphous semiconductors [1]. In this paper we present some results of an investigation of periodic current oscillations observed under certain conditions together with the switching effect in amorphous chalcogenide semiconductors.

We investigated amorphous films sputtered from the chalcogenide compound (in at.%) $Ge_{10}Si_{12}As_{30}Te_{48}$, and also from GeTe single crystals. The films were sputtered thermally on unheated glass or pyroceram substrates in a vacuum of 10^{-4} mm Hg and had a thickness on the order of 10^{-5} cm. The electron-microscopic and electron-diffraction investigations have shown that the films were amorphous and homogeneous, without inclusions of other phases. Gold or carbon electrodes were sputtered on the investigated films with a gap of 0.1 - 0.5 mm. One of the contacts was also a graphite electrode under pressure; in this case the films were evaporated on a gold layer, which served as the second electrode.

The samples were connected to a sawtooth voltage or a square-wave generator between adjustable ballast resistors R_b rated up to 5×10^4 Ω and a small (18 - 200 Ω) load resistor. The current in the circuit was determined from the voltage drop across the load resistor.

The current-voltage characteristics (CVC) of the investigated materials were plotted by applying to the circuit a linearly-growing sawtooth voltage of frequency from 10 to 10^5 Hz of positive or negative polarity. Figure 1 shows the CVC of the amorphous film $Ge_{10}Si_{12}As_{30}Te_{48}$ in the first quadrant of the coordinate plane. As seen from the figure, the CVC is clearly S-shaped with a section of differential negative conductivity (DNC). The lower inflection point (the start of the DNC region) corresponds to an electric field intensity on the order of 10^5 V/cm in the medium. An analysis of the CVC of this medium has shown that the dependence of the current on the voltage for the branches lying both below and above the DNC section obeys a power law with an exponent 3/2 for the lower branch and 3 for the upper branch. The shape of the CVC was practically independent of the material and construction of the electrodes. The characteristics obtained at positive and negative voltages were symmetrical

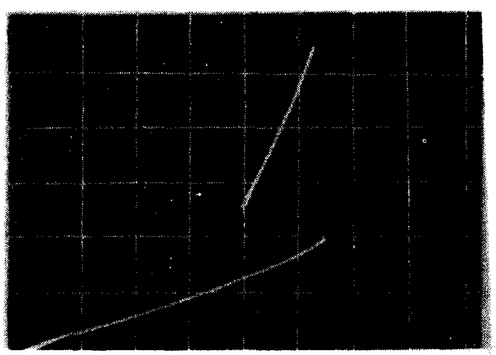

Fig. 1. Current-voltage characteristic: vertical scale - 0.7 mA/division, horizontal - 0.18 V/division.

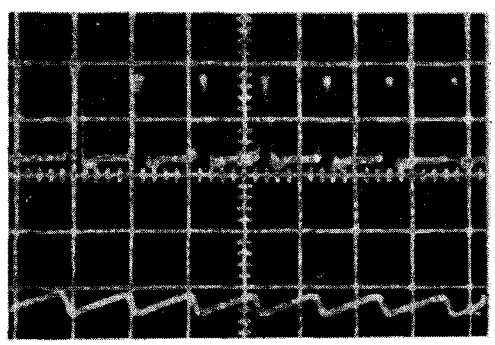

Fig. 2. Oscillogram of the current through the sample (top - 10 mA/div) and of the voltage across the sample (bottom - 1 V/div) during the time of the oscillations. Sweep 1 μsec/div.

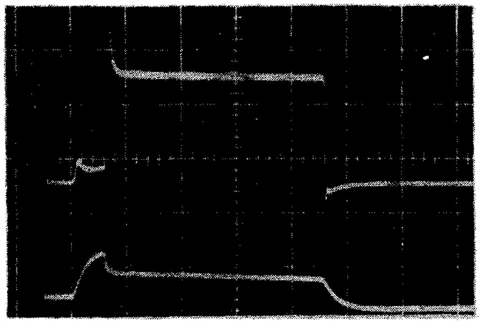

Fig. 3. The same as in Fig. 2, for the switching regime. Sweep 2 μsec/div.

relative to the origin. Their symmetry was conserved also in the case when the contacts were highly asymmetrical (a flat gold electrode and a pointlike graphite electrode). At sawtooth voltage frequencies 10 - 10^5 Hz, the shape of the CVC changed insignificantly. The presence of a DNC section on the CVC suggests the possibile occurrence of spontaneous current oscillations in the circuit of such a sample. Such current oscillations were indeed observed when the circuit was fed with rectangular pulses of duration 10^{-5} - 10^{-6} sec with frequency 10 - 10^4 Hz. They occurred in the case when the voltage on the sample exceeded a certain critical value, corresponding to the lower inflection point of the CVC. The oscillations usually had a regular periodicity; their waveform differed strongly from sinusoidal.

Figure 2 shows an oscillogram of the voltage in the $Ge_{10}Si_{12}As_{30}Te_{48}$ sample and of the current through it during the time of such oscillations. The frequency and waveform of the oscillations depended on the sample voltage S_n (and also to a certain degree on R_b), increasing with increasing V_n. The oscillation frequency could vary as a result of these factors from 5×10^5 to 5×10^7 Hz, and their amplitude remained practically constant. The polarity of the applied voltage, the material and the construction of the electrons, and the repetition frequency of the pulses feeding the circuit have practically no influence on the characerr of the oscillations. Similar oscillations were observed also in amorphous GeTe films under analogous conditions.

When V_n increased above a certain value fixed for each sample, the oscillations stopped. The voltage interval at which they took place decreased with decreasing R_b. When R_b dropped below a certain value on the order of 10^3 - 10^4 Ω, no oscillations were produced at any V_n. After the oscillations were interrupted (by increasing V_n or by decreasing R_b), the sample operated in the switching mode (Fig. 3). In this case the switching delay time (τ_d) corresponded to the period of the preceding oscillations, and the switching amplitude corresponded to the amplitude of the latter. The dependence of τ_d on V_n agreed qualitatively with the dependence of the period of the oscillations on V_n. The current buildup and decay times were equal to the minimum buildup and decay times of the current pulse observed in the same sample in the self-oscillation regime. The already noted correspondence between a large number of parameters characterizing the current-oscillation and current-switching regimes, and also the possibility of transition from one regime to another by varying V_n or R_b, is quite characteristic. This correspondence gives grounds for regarding both phenomena as different manifestations, in the investigated materials, of current instability due to the presence of a DNC on their CVC. The case of self-oscillations is, from this point of view, an oscillating spontaneous switching into a state of unstable equilibrium. The S-shaped CVC with a DNC section indicates the possible occurrence in such materials of electric instability accompanied by violation of the homogeneity of the current distribution over the cross section of the sample and by formation of "current pinches" [2], which leads to an increase of the conductivity of the sample - switching [1]. In the case when the resistance of the external circuit (R_b)

is so large that the current after the switching turns out to be insufficient to maintain the highly-conducting state, the latter is violated. After a definite time, which depends on the electric parameters of the semiconductor, and also on V_n and R_b, the conducting state arises again and the cycle of the reversible switching thus repeats periodically. The oscillations considered here differ from purely relaxation oscillations [3] due to the presence of two discrete values of the sample resistance and to the switching voltages between them, in that their time parameters are determined by the kinetics of the electronic processes in the sample, and not by the reactive parameters of the passive circuit elements.

[1] S.R. Ovshinsky, Phys. Rev. Lett. 21, 1450 (1968).
[2] B.K. Ridley, Proc. Phys. Soc. 81, 966 (1963).
[3] A.I. Andronov, A.A. Vitt, and S.E. Khaikin, Teoriya kolebanii (Theory of Oscillations), Fizmatgiz, 1959.

SELF-TRAPPING OF POWERFUL ELECTROMAGNETIC WAVES IN A DENSE PLASMA

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It is well known from linear wave theory that an isotropic plasma is opaque to electromagnetic waves at a frequency below the plasma frequency, $\omega < \omega_p$. However, if the intensity of the electromagnetic wave is sufficiently large, it produces a redistribution of the density of the charged particles and formation of a waveguide channel in a "transcritical" plasma is possible [1 - 4]. In the present article we describe direct observations of the passage of intense electromagnetic waves through a dense plasma. We show that the results are in agreement with the theoretical estimates.

1. The experimental setup consisted of an evacuated cylinder (80 cm diameter and 220 cm long), evacuated to a pressure 0.1 Torr. With the aid of a coaxial plasma source located on the end wall of the cylinder, this volume was filled with a plasma with low degree of ionization. The maximum electron density was $N_e \approx 10^{13}$ cm^{-3} and was attained within ~0.5 msec after the start of the discharge in the injector, after which a plasma decay set in with a characteristic time ~10 msec. The microwave generator was a pulsed magnetron for the 10-cm band, delivering up to 300 mW. The radiator was a horn antenna and the receiver the open end of a waveguide; the distance between the antenna and the waveguide ranged from 40 to 60 cm. The internal surface of the vacuum chamber, on the side of the receiving waveguide, was covered with an absorber to decrease the reflection of the waves from the walls. The magnetron was triggered with different delays relative to the start of the discharge, making it possible to investigate the interaction in a wide range of concentrations. The plasma concentration was determined from the cutoff of two weak probing signals with wavelengths $\lambda = 3$ cm and $\lambda = 12$ cm, under the assumption that the plasma decay is exponential. A system of resonant filters was used to decouple the weak signal from the powerful pulse.

2. The extensive experimental material accumulated as a result of the measurement[1)] makes it possible to regard as established the penetration of

1)At each value of the pulse delay (electron concentration) and of the incident power, some 30 - 40 measurements were made. Although the effect of bleaching of the plasma was registered in each experiment, the measurement results were averaged to obtain the quantitative characteristics.