

Random switching in amorphous gallium antimonide

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Large current pulses cause transitions between states with different electrical conductivities on bulk samples of amorphous GaSb. This switching is of a stochastic nature, possibly because of particular features of the random potential and an interaction with phonons.

1. In the physics of disordered systems, a random potential which determines the random microscopic dynamics of the electrons and ions is usually manifested at the macroscopic level in a regular way, since the contribution of disordering is found through an appropriate averaging procedure. The hopping conductivity caused by random electron transitions, for example, is determined by the state-density function near the Fermi level, not by the particular shape of the random potential. At the same time, it is not possible to rule out in principle situations in which a macroscopic characteristic of a disordered system will depend on an external agent in an irregular way. Of primary interest from this standpoint are amorphous solids in which the excitation and relaxation of a metastable noncrystalline matrix may result in a re-grouping of atoms which in turn causes a random behavior of macroscopic characteristics. In this case, however, there has been essentially no study, to the best of our knowledge, of the possible realization of a random dynamics of a macroscopic quantity.

2. We have studied the effect of large current pulses on the electrical conductivity of bulk samples of amorphous gallium antimonide synthesized by quenching a melt at high pressure.¹ The test samples have comparatively low resistivities, $\rho \sim 10^{-2} - 10^{-1} \Omega \cdot \text{cm}$, and are a mixture of amorphous and crystalline phases.² The relative concentration of the amorphous phase, $x = 0.2 - 0.3$, corresponds to the case in which the electron wave functions are still delocalized.² Measurements of the current-voltage characteristics by a pulse method reveal that for pulse lengths $t_p = 10 - 1000 \mu\text{s}$ a region appears at currents $j = (1 - 6) \times 10^2 \text{ A/cm}^2$ on the ohmic part of the characteristic in which the voltage across the sample depends in an irregular way on the external parameters. To determine the reason for this behavior, we carried out an experiment in which current pulses were passed through a sample with an equilibrium temperature T_0 regulated within 10^{-3} ; after the attainment of T_0 after each pulse, we measured the value of ρ at $j \sim 0.3 \text{ A/cm}^2$. The state of the sample was characterized by a point in the ρ - n plane, where n is the order of the pulse (see the inset in Fig. 1). In the course of the experiment we varied the parameter t_p at a fixed amplitude j_0 .

3. Systematically connecting the points, we find the line $\rho(n)$ (Fig. 1), which is the response of the system to the external agent. Even a monotonic change of t_p leads

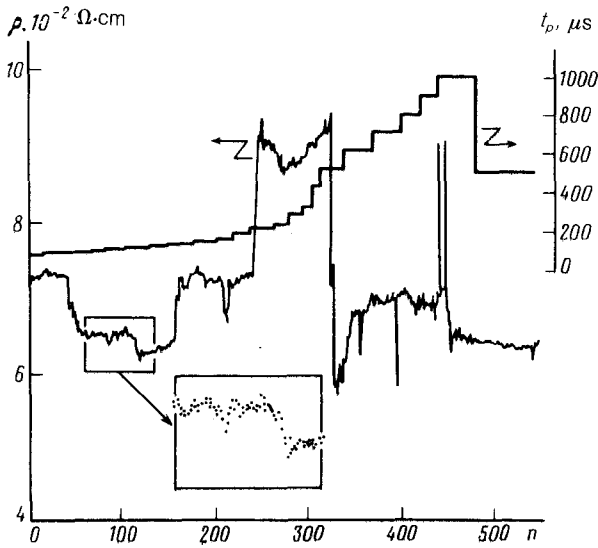


FIG. 1. Curve of $\rho(n)$ for $T_0 = 273$ K and $j_0 = 3 \times 10^2$ A/cm². The scales for the inset are twice as large, along both axes.

to jumps in $\rho(n)$, which separate regions in which ρ varies comparatively smoothly. The experimental error is $\Delta\rho \leq 4 \times 10^{-3}$ and does not exceed the size of the points in the inset in Fig. 1. In the arrangement of jumps, there is no direct relationship with the changes in the pulse lengths; a jump may occur either under the condition $t_p(n) = \text{const}$ or upon a change in t_p (Fig. 2). The random nature of the process is confirmed by the complex zigzag trajectory $\rho(n)$ (Fig. 2), which varies from jump to jump in an irregular way.

A sharp change in ρ can be observed at various values of t_p ; comparatively large

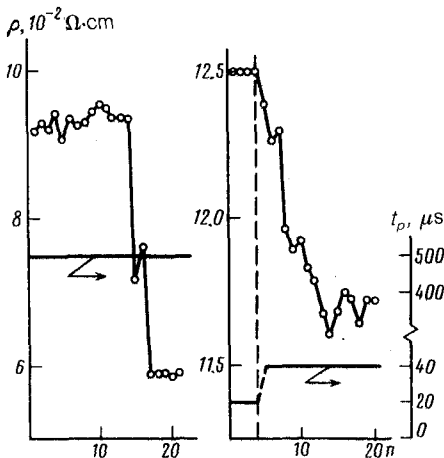


FIG. 2. Switching in amorphous GaSb during pulsed excitation.

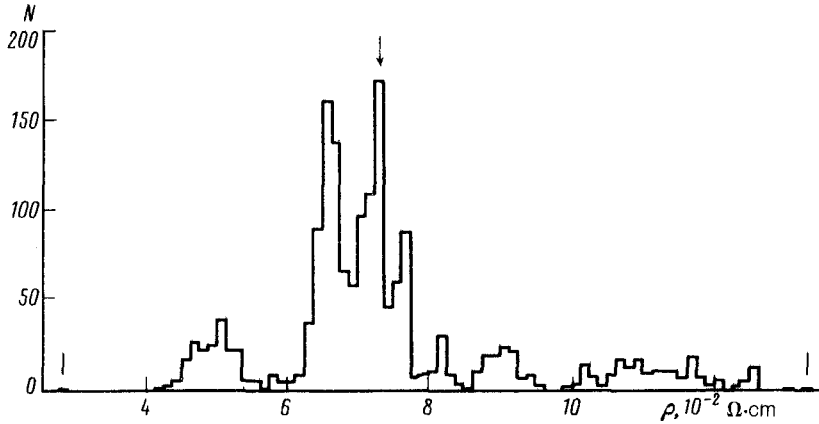


FIG. 3. The distribution function $N(\rho)$. The arrow shows the initial value of ρ , before the beginning of the experiment; the vertical bars show the maximum and minimum values of ρ . The value of $N(\rho)$ in each bin gives the number of values of ρ which fall in this bin during the experiment on $\rho(n)$.

values of t_p correspond to comparatively large changes in ρ ; e.g., at $n > 450$ (Fig. 1) a decrease in t_p from 900–1000 to 500 μs leads to a decrease in the fluctuations in ρ . Under the condition $T_0 = \text{const}$, the value of ρ does not depend on the time in the absence of pulses, while if T_0 is changed sharply immediately after the application of the pulse, one can observe jumps similar to those in Figs. 1 and 2.

Let us examine the distribution function of ρ , i.e., $N(\rho)$, which is dominated by the regions in which $\rho(n)$ varies smoothly (Fig. 3). We see that $N(\rho)$ consists of several maxima, which correspond to the most probable states between which transitions occur. We wish to emphasize that the maximum and minimum values of ρ differ by a factor of five (Fig. 3). This factor is slightly greater than the range which we found for ρ in special measurements involving an isothermal annealing of the amorphous phase from $x = 0.2$ – 0.3 to $x = 0$. In contrast with the irreversible transformation which occurs during annealing, however, the changes in ρ during pulsed excitation are reversible in a statistical sense, since in the course of an experiment the value of $\rho(n)$ of a sample may return to the same value of ρ after several transitions. We might also note that the initial value of ρ (Fig. 3) is at the absolute maximum of $N(\rho)$.

4. In summary, the instability of the I–V characteristic which is observed in *a*-GaSb stems from the presence of several relatively stable states corresponding to different values of ρ . An external agent (current pulses or a change in thermal conditions) initiates a random switching between members of this set of states. To explain the nature of the macroscopic random process, we need to take account of the circumstance that the sample was heated at least several tens of degrees above T_0 during the pulse in our experiments. Since the actual sample is inhomogeneous (a mixture of amorphous and crystalline phases²), the heating of the disordered regions with a relatively low electrical conductivity will be relatively great. The interaction of the electrons with the lattice may thus ultimately lead to a regrouping of the atoms in the

disordered matrix, by analogy with the photostructural changes that occur in chalcogenide glasses, where again the dynamics of this process is quite complex.³ If it is assumed that the most probable values of ρ (Fig. 3) correspond to atomic configurations which are slightly stabler than the rest, and which provide the minima of the potential-energy surface in configuration space, $U(\mathbf{q})$, then the random dynamics of $\rho(n)$ reflects both the complex structure of $U(\mathbf{q})$ and the interaction with phonons. Upon excitation, a transition occurs from one configuration to another: $\mathbf{q}_n \rightarrow \mathbf{q}_{n+1}$. Such transitions may influence the value of ρ , e.g., through the state density, as in the Staebler-Wronski effect.⁴ We cannot rule out the possibility that the derivation of a corresponding theory will make it possible to utilize the phenomenon observed here to study the structure of the $U(\mathbf{q})$ surface.

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