Observation of hysteresis-free switching and static negative differential resistance in films of amorphous semiconductors

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It is shown experimentally that switching in films of amorphous semiconductors proceeds in two stages. Even though the switching proceeds along the load line in both cases, hysteresis is observed only after the second switching. The two switching stages are separated by a stable region of current, in which static negative differential resistance can occur.

It is presently universally accepted that in the presence of negative differential resistance of the S-type in amorphous semiconductors, a region of increased current density ("pinch") is produced at the instant of switching.[1–3] In spite of the large number of investigations of amorphous film structures, there is no information on the real current-voltage characteristics (CVC) of the material in the case of a homogeneous sample. The reason is that only pre-threshold and post-threshold sections of the CVC were interpreted so far, and no detailed study was made of the switching region, since it was impossible to fix the position of the switching section.[2]

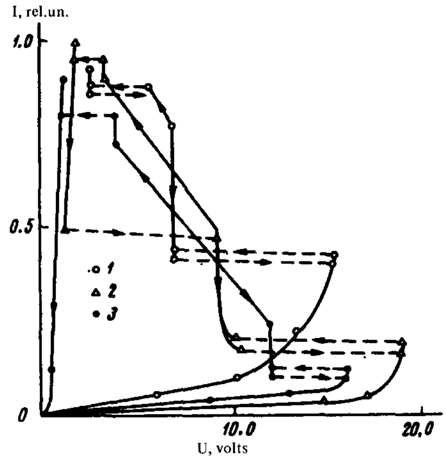
We present here the results of an experimental observation of two-step switching in thin vitreous semiconducting films, and of an investigation of the static negative differential resistance (SNDR). The investigation was carried out in the dc current-generator regime. The samples were Ge-Te, Si-As-Cu-As-Te, Ge-Si-As-Te, and Cu-I-As-Te glass films, of thickness not larger than 10 μ.

The figure shows the CVC of the investigated compositions. We see that two-step switching is typical of all samples. We note the following main features of the CVC:

1. The CVC are symmetrical with respect to reversal of the applied voltage. The two-step character of the switching is observed in all the materials, regardless of whether the sample goes over after the second switching into a state with memory or whether the switching is reversible. The ability to "remember" is determined by the properties of the material.

2. The hysteresis of the CVC after the first switching is quite small and does not depend on either the film composition or the temperature and the current at which the inverse CVC is plotted. At the same time, the hysteresis after the second switching depends on the composition of the film, being much larger and in agreement with the published values.[4]

3. The transition region between the first and second



Typical static CVC for different compositions: 1—Si-As-Te; 2—Ge-Si-As-Te; 3—Ge-Te; Cu-As-Te; Cu-I-As-Te.

switchings is stable and is reproducible in repeated plotting of the CVC.

4. In the range of currents corresponding to the first region, the SNDR has a section whose value of which depends on the composition of the sample and decreases with increasing temperature until single-step switching appears. The behavior of the sample before and after the switching does not differ in this case from the behavior prior to the first and after the second switching in the case of two-step switching.

We indicate that to observe the two-step switching, the measuring circuit and the sample must satisfy a number of requirements.

a) No alteration could be observed in the sample. Our investigations have shown that alteration, i.e., a change in the threshold parameters after application of the first voltage to the sample, is due to the presence and subsequent breakdown of contact barriers, or else barriers on the boundaries of the microinhomogeneities due to the grainy structure of the film.[5] Therefore the use of contacts made of metals such as tungsten or molybdenum leads to appreciable alteration. In this case the switching current increased in the film, so that no two-threshold switching was observed. It appears that analogous changes occur also in the case of large-grain amorphous films, in which alteration is also observed. Therefore the material was sputtered and condensed in a way that ensured production of homogeneous vitreous films (as monitored with an MIM-8 microscope).

b) An important factor when it comes to obtaining two-threshold switching is the area of the contacts, which in our case did not exceed 2×10^{-6} cm^2. An increase in the contact area made it more difficult to observe the two-threshold switching, and apparently increased the probability of the presence of inhomogeneities under the contacts.

c) The samples satisfying conditions "a" and "b" were investigated under current-generator conditions, with the load line crossing the CVC at a single point.

The slight value of the hysteresis in the first switching and its independence of the current suggests that inhomogeneities of the type of current pinches do not occur in the first switching. The CVC in this region reflects either the appearance of weak inhomogeneities such as current layers, or, what is more probable in our opinion, a statistical CVC of the material. To check on this assumption we have investigated the behavior of the reactances of the diode during the course of the plotting of the CVC, by sounding with a microwave signal. We developed for this purpose a microwave set-up that cancelled the active component of the current in the sample and made it possible to measure inductances on the order of several picohenry. It was found that a signal corresponding to the appearance of inductive reactance in the sample was observed only after the second switching. The first switching did not lead to any noticeable changes of the sample inductance.

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