Journal of Non-Crystalline Solids 81 (1986) 255–259
North-Holland, Amsterdam

Letter to the Editor

COMMENTS ON THE FORMATION PROCESS AND THE ELECTRICAL NATURE OF LOCK-ON FILAMENT IN $Ge_{09}As_{20}Te_{71}$ GLASS

M. HARO, E. MÁRQUEZ, L. ESQUIVIAS and R. JIMÉNEZ-GARAY

Departamento de Fisica fundamental, Facultad de Ciencias, Universidad de Cádiz, Apartado 40, Puerto Real, Cádiz, España

Received 18 April 1985

Some characteristics of the switching effect in bulk $Ge_{09}As_{20}Te_{71}$ glassy alloy have been shown in an earlier paper [1]. A study on the lock-on process has been carried out by Tanaka et al. [2], where a general review of the principal characteristics of the memory phenomenon is made. As is well-known, a molten path (switch-on path) is formed between the electrodes, as a result of Joule heating, when a voltage above a threshold voltage is applied. By maintaining the current after the switch-on, a narrow filament grows in the molten region. Once the filament growth process is complete, the sample reaches the memory state [1–6]. We report the filament characteristics and their influence on the formation of a new filament in an experiment carried out under conditions different from a previous experiment [7]. The outstanding difference is that in this case, as opposed to the earlier superficial conduction experiment, the current flows through the sample [8]. Variations in standard deviation of measured values of the delay time have also been observed as a function of the overvoltage (i.e., difference between applied and threshold voltage).

The samples were obtained and prepared after the procedure described in ref. [1]. The electrical device used in the experiment [9] consisted of a tungsten point, used as top electrode, to which a spring was joined guaranteeing gentle constant pressure against the sample. A copper plate was used as the bottom electrode. Full contact between the sample and the bottom electrode was assumed by means of colloidal silver. Delay times were measured employing an electronic device which supplied increasing voltage above that of the threshold. A memory oscilloscope (TRIO MS-1650B) was used to record the time function response.

The sample is excited with constant amplitude and long duration pulse to switch several times, using in each switching process a virginal zone. Ten delay time measurements have been worked out for each applied voltage value. We obtained, from a linear regression fitting between the applied voltage (V) vs

0022-3093/86/$03.50

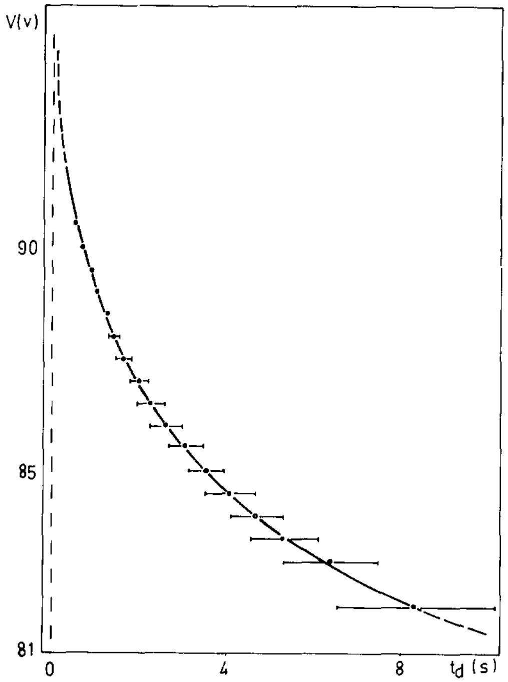

Fig. 1. Statistical distribution of the delay time dispersion.

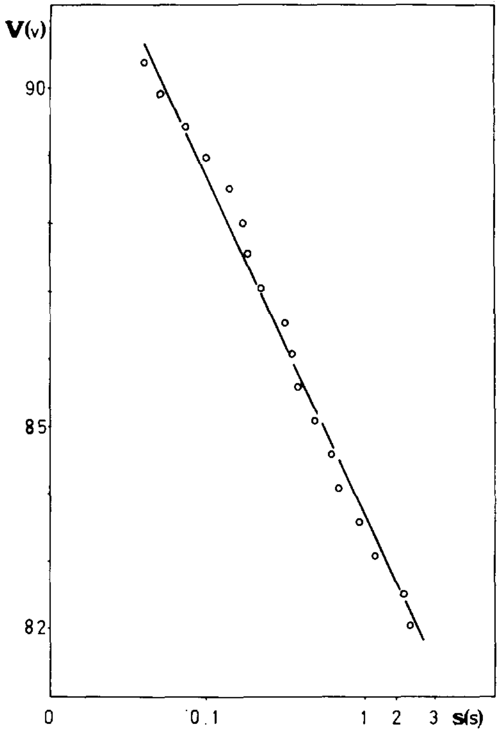

Fig. 2. Representation of the applied voltage versus the logarithm of the standard deviation.

the inverse square root of the delay time (t_d), the following Owen equation [10]:

$$t_d = \frac{1355.7}{(V - 42.7)^2}$$

We have observed that at the same time as the overvoltage increases the delay time dispersion decreases. Figure 1 accounts for the statistical distribution of the delay time dispersion. The delay time standard deviations as a function of the applied voltage tend asymptotically towards infinite for voltage values above 82 V (threshold voltage 80 V), whereas when the voltage is higher than 90 V, it tends asymptotically toward zero. A representation of the applied voltages vs ln s, s being the standard deviation, is seen in fig. 2. The equation

$$s = 3.81 \cdot 10^{74}\ \mathrm{V}^{-38.07}$$

is deduced from the linear regression fitting of both magnitudes. A decrease in the standard deviation may be observed when the overvoltage increases.

As has been shown in previous experiments, the presence of a filament near the electrodes offers a low resistance zone that makes the formation of a new

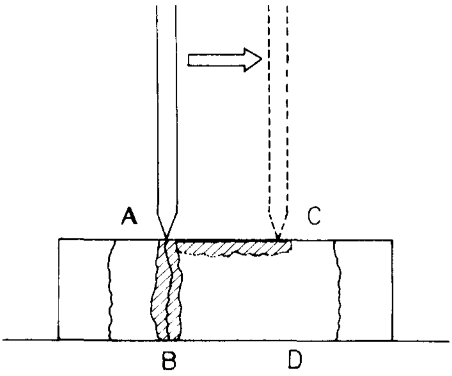

Fig. 3. Outline of the filament formation.

filament easier. It proves that the threshold voltage for a determined electrode configuration, depends mainly on the sample history. In the present case, with an electrode on either side of the sample, a phenomenon of similar characteristics is seen. We have observed that by placing the tip of the top electrode on point A (fig. 3) and applying an electrical stimulation of enough amplitude and duration in order to set the memory state, a filament (BA) is formed between the electrodes. If the top electrode is moved to a new position C and an electrical stimulation with the same characteristics as the former is applied, a new filament appears. This filament, as opposed to the first one, has a superficial piece linking the C and A points. In short, this filament is composed of two parts, one through the sample, the AB piece, that existed previously as a result of the first stimulation, and the second one, the AC piece, that is formed superficially.

From a detailed observation of the photomicrograph shown in fig. 4, we could deduce that, in effect when the switching occurs, the filament appears in a preferential zone of the sample [3,11]. Naturally the carriers would look for a minimal resistance path. Before the switching comes on, the structure of the material is completely amorphous. During switching, a fusion in the interelectrodic zone takes place. Stopping the electrical stimulation produces rapid cooling and a filament constituted by both crystalline and amorphous domains is formed. This filament may connect microregions with a high number of tellurium-rich crystalline domains [11].

In the photomicrograph of fig. 5 an extreme of a superficial filament, similar to that schematically outlined in fig. 3, is shown. As can be noticed, a switch-on path boundary appears. The early stage of filament formation, as a consequence of partial crystallization, can also be seen.

When the intensity which flows through the sample increases because of a drop in resistance, produced by maintaining the high conduction state for a long time, the number of crystalline domains increases and a decrease of the threshold voltage occurs. In fig. 6 a completely formed switch-on path may be

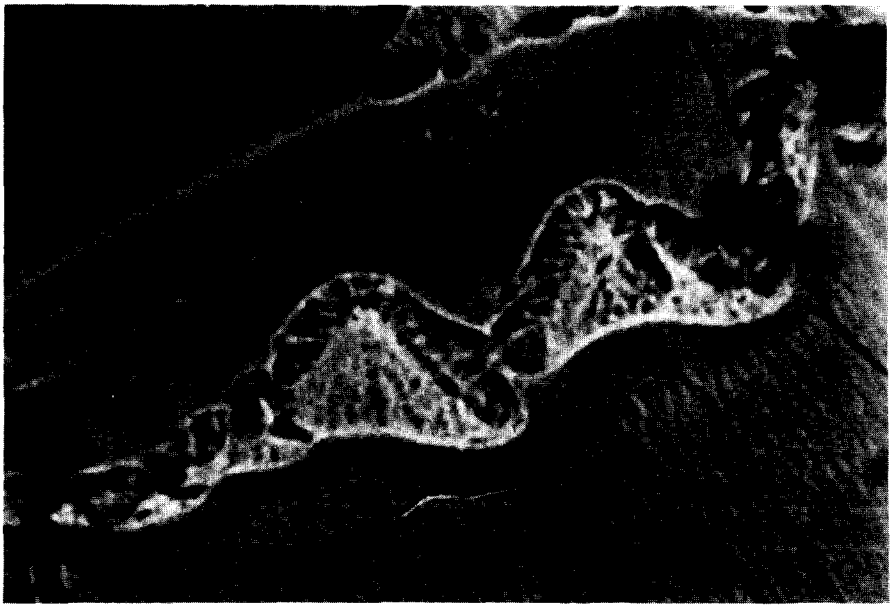

Fig. 4. Photomicrograph (× 140) of both the switch-on path and filament. A lock-on intensity of 30 mA was employed for the formation of this filament, its length and average width being, respectively, 1.3 mm and 50 μm approximately.

Fig. 5. An extreme of a superficial filament (× 140).

Fig. 6. Photomicrograph (×35) of a switch-on path enclosing a partially developed filament.

made out as well as a partially developed filament through the interelectrodic line. The fact that the filament formation was not completed may probably be accounted for by the duration of the intensity, insufficient to produce the memory state.

References

[1] E. Mârquez, P. Villares and R. Jiménez-Garay, J. Non-Cryst. Solids 74 (1985) 195.
[2] K. Tanaka, Y. Okada, M. Sugi, S. Iizima and M. Kikuchi, J. Non-Cryst. Solids 12 (1973) 100.
[3] K. Tanaka, S. Iizima, M. Sugi and M. Kikuchi, Solid State Commun. 8 (1970) 75.
[4] C.H. Sie, M.P. Dugan and S.C. Moss, J. Non-Cryst. Solids 8–10 (1972) 877.
[5] C.H. Sie, J. Non-Cryst. Solids 4 (1970) 548.
[6] R.D. Gould, J. Non-Cryst. Solids 55 (1983) 363.
[7] R. Jalauria and A. Mansingh, J. Non-Cryst. Solids 16 (1974) 321.
[8] M. Saji and K.C. Kao, J. Non-Cryst. Solids 22 (1976) 223.
[9] M. Saji and K.C. Kao, J. Non-Cryst. Solids 18 (1975) 275.
[10] A.E. Owen, J.M. Robertson and C. Main, J. Non-Cryst. Solids 32 (1979) 29.
[11] A.G. Steventon, J. Non-Cryst. Solids 21 (1976) 319.