ELECTRIC FIELD EFFECT ON THERMALLY STIMULATED CONDUCTIVITY IN TRIAGONAL SELENIUM

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The experimental conditions related to the appearance of the fluctuant TSC curve observed earlier in polycrystalline trigonal selenium were investigated. It was found that there exsists a threshold field strength above which the fluctuations of the TSC curve appear at about 120 Vcm^{-1}. This value corresponds to the non-linear part of the current-voltage characteristic of the sample. For the fluctuant TSC to appear, the threshold voltage has to be applied during the recording of the TSC curves, independently from the voltage applied during the illumination and decay periods. No significant changes in the shape of the fluctuant TSC were observed for different heating rates.

Several mechanisms are suggested by which the electric field can, in principle, cause the fluctuant character of a TSC curve.

Introduction

Several papers have been published in recent years on the study of thermally stimulated conductivity (TSC) of traps in selenium. From the TSC curves two [1] or three [2—4] trapping levels were derived and the depth and concentration of the traps were determined. The effect of the duration of illumination on the shape of the TSC curves in amorphous selenium was also investigated [5].

The shape of TSC curves measured in polycrystalline samples of trigonal selenium depends on the applied voltage, and, at a certain voltage, a fluctuant TSC curve appears [6]. In this paper further information concerning the influence of the electric fied on the TSC measured in the same samples is presented.

Experimental

The material used was selenium of 99.996% purity. Rectangular samples of 12 mm×5 mm×0.8 mm were prepared from amorphous selenium by compressing and sintering, crystallized by heat treatment (at 200 °C for 30 minutes), machine polished using an Al_2O_3 grit (<0.1 micron grain size), and etched with sodium sulphite solution. Evaporated gold was used for current contacts to the sample.

Electrical and structural data, obtained at room temperature are found in Table I. Calculating the least Se—Se distances from the X-ray diffraction patterns by the computer method described in [7], good agreement was found with data for selenium single crystals published in the literature [8]. The polycrystalline structure

Table I

ELECTRIC DATA

Electric conductivity	Thermo-electric power	Hole concentration	Mobility of holes
$4.5 \cdot 10^{-5} \Omega^{-1} cm^{-1}$	870 μV/K	$0.8 \cdot 10^{16} cm^{-3}$	$3.44 \cdot 10^{-2} cm^2/Vs$

X-RAY DIFFRACTION DATA

Degree of crystallization:	100%
Size of the crystallites:	540 Å

LEAST Se—Se DISTANCES IN THE LATTICE

In the sample studied:	2.379 Å	3.431 Å	3.720 Å
In Se single crystals [8]:	2.373 Å	3.436 Å	3.716 Å

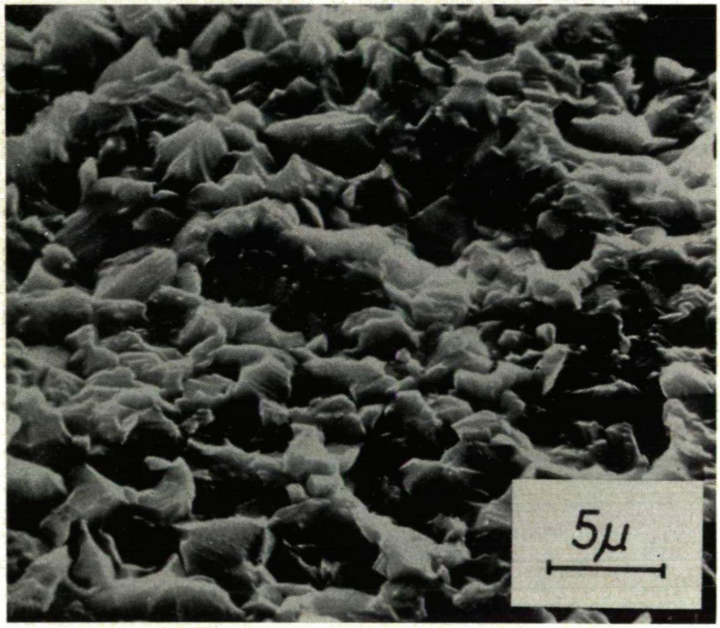

Fig. 1. Scanning electron micrograph of a sample etched with Na_2S solution

and the arrangement of the crystallites can be seen in Fig. 1, which shows a scanning electron micrograph of a sample examined here. Well differentiated crystallites and concretions of the latter are visible. The formation of the concretions may be connected with residual impurities in the sample.

The TSC curves were measured and recorded in the usual way. The samples were illuminated up to saturation by a stabilized 100 W tungsten lamp at 100 °K. The heating rate was 0.1 °K sec^{-1}.

Results and discussion

Current-voltage characteristics of the samples were measured to obtain information on the character of the gold contacts.

Mesurements in the dark at room temperature showed the characteristic to be

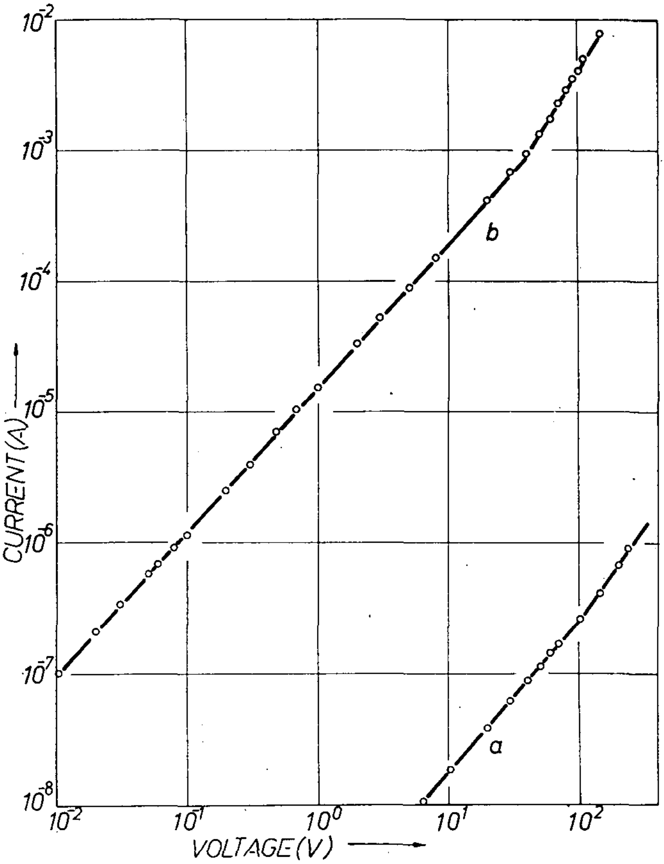

Fig. 2. Current-voltage characteristics obtained at 100 °K; *a*: in a previously not illuminated sample, *b*: after illumination of 5 min, followed by a decay period of further 5 min

linear in the range from $1 \cdot 10^{-4}$ Vcm^{-1} to $5 \cdot 10^{3}$ Vcm^{-1}. The results of I—V measurements made at 100 °K are shown in Fig. 2. Curve *a* shows the I—V characteristic measured in a previously not illuminated sample, curve *b* that after illumination of 5 min., followed by a decay period of further 5 min. It can be seen that curve *a* is linear up to 100 V (*i.e.* 120 Vcm^{-1}) while curve *b* only to 40 V (*i.e.* 50 Vcm^{-1}).

Fig. 3 shows the effects of the electric field on the TSC process. In TSC measurements, generally three periods can be distinguished: those of illumination, decay and heating, respectively. We used two characteristic voltages in our measurements: 10 and 150 V in different combinations during the above periods. Our results were as follows:

1. Applying 10 V during the whole measurement, the result shown in Fig. 3,*a* was obtained. It is to be noted that, on illumination, the conductivity increases by a factor of about 10^4 compared with the dark conductivity, and about 80% of the increased conductivity persists for a long time after the illumination has ceased. In this case the TSC curve has a maximum at 146 °K.

2. Illuminating at 150 V (see Fig. 3,*b*), the intensity of the photocurrent increases in comparison with the former case, and saturation is reached in a shorter time. The decay, measured again at 10 V, is somewhat stronger than in the former case, therefore the TSC curve starts from a lower current intensity. The maximum of the curve is now at 166 °K, *i.e.* it has shifted to higher temperatures.

3. If the decay is measured at the same voltage of 150 V as the illumination was made (Fig. 3, *c*), then the decay is very rapid and very strong; the photocurrent decreases by a factor of about 2 orders of magnitude. The intensity of the TSC curve, measured with 10 V applied voltage also in this case shows a further decrease compared with curves *a* and *b* of Fig. 3 and a simultaneous shift of the maximum to 212 °K.

4. Applying 150 V during the whole measurement of the TSC curve, fluctuations in the TSC curve appeared (Fig. 3,*d*).

5. Similarly, a fluctuant TSC curve (Fig. 3,*e*) was obtained by heating the sample with 150 V applied voltage, while the voltage during the illumination and decay was 10 V. It should be mentioned that in this case 150 V was applied already after 4 min. decay time, with the result that the intensity of the current suddenly increased, then, after reaching a maximum, it decreased nearly to the value of the dark current. This value was lower than that obtained in the former case (Fig. 3,*d*), therefore the fluctuation of the TSC began at a higher temperature.

On the basis of the measurements described, it can be seen that, for the fluctuation of the TSC curve to appear, the voltage of 150 V has to be applied during the recording of the TSC curves, independently from the voltage applied during the illumination and decay periods.

The development of the pattern of fluctuations in the TSC curve as a function of the applied voltage can be seen from Fig. 4. In this case the same voltage was applied during the whole TSC measurement. It can be observed that the threshold voltage for the fluctuations of the current is about 100 V, which value coincides with the break-point on the curve *a* of Fig. 2. With increasing voltage, the fluctuations appear at higher temperatures and a very marked increase in the amplitudes of the curves is to be seen.

No significant changes in the shape of the fluctuant TSC were observed for

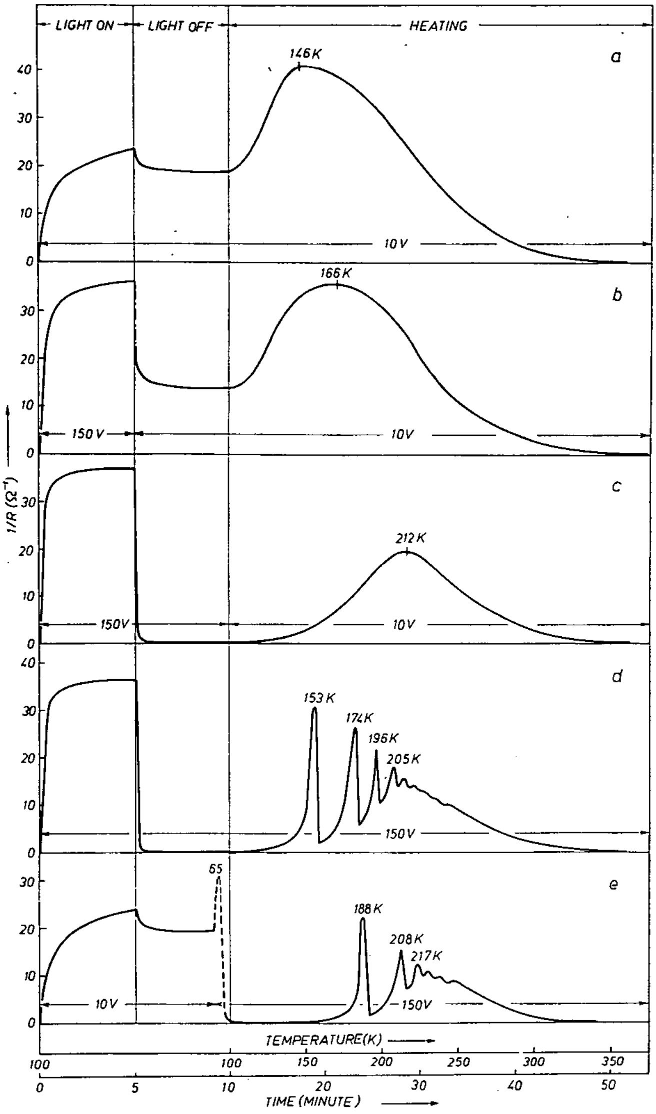

Fig. 3. Effect of the electric field on the TSC curves

different heating rates, but by increasing the heating rate, the maxima shifted to higher temperatures, as usual in the TSC curves.

There are several processes by which the electric field can, in principle, cause the fluctuant character of a TSC curve.

a) Quenching of the conductivity by the field [9] explained by the barrier model for conduction in selenium, as developed by STUKE [10].

b) Negative resistance produced by impurity centres under double injection. This concept was used to explain the spontaneous fluctuations under dc applied voltage in gold-doped Ge at 77 °K [11].

c) Changes in the capture cross section, barrier height, and frequency factor of Coulomb-attractive trapping centres, due to a deformation of the potential around the centre (field-enhanced ionization) [12].

The present results do not enable us to decide between the possible processes given above. Still it seems worth while to point out some observations which may help in understanding the described phenomenon. First of all, the fluctuations on the TSC curve appear if the applied voltage is in the non-linear part of the current-voltage characteristic. Further, from the voltage dependence of the development of the fluctuations (Fig. 4), it seems that the phenomenon is associated with negative resistance. Finally, the areas under the TSC curves of Figs. 3*c* and 3*d* are equal, which shows that the number of thermally freed charge carriers after decay to the same photocurrent intensity is independent from the voltage applied during the heating of the sample.

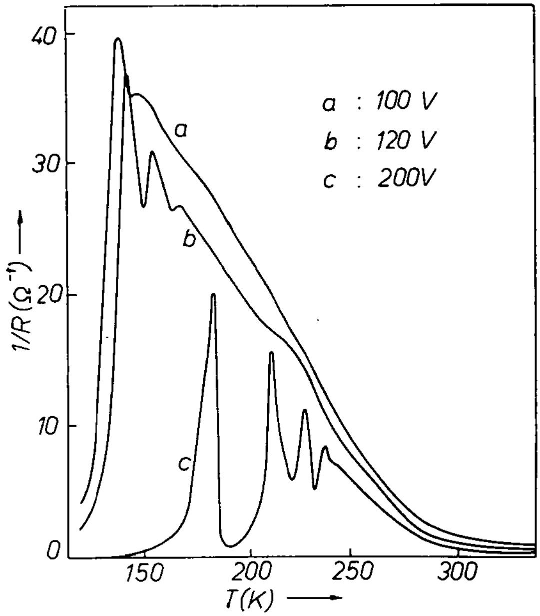

Fig. 4. Development of the pattern of the fluctuant TSC as a function of the voltage applied

It is possible that more than one of the above processes take place simultaneously. Further experiments are needed to state which processes are really involved and to what extent each of them is effective.

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ВЛИЯНИЕ ЭЛЕКТРИЧЕСКОГО ПОЛЯ НА ТЕРМОСТИМУЛИРОВАННУЮ ПРОВОДИМОСТЬ ТРИГОНАЛЬНОГО СЕЛЕНА

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Исследованы экспериментальные условия появления ранее наблюдаемых флюктуаций на кривой термостимулированной проводимости (ТСП) в поликристаллическом тригональном селене. Найдено, что критическое значение поля для появления флюктуаций тока около 120 Vcm^{-1}. Это значение находится в нелинейной части вольтамперной характеристики кристалла. Для появления флюктуаций на кривой ТСП критическое поле должно подаваться на кристалл во время снятия кривой ТСП, независимо от значения поля во время освещения образца и следующего периода затухания фототока. Применение различных скоростей нагрева не привело к заметным изменениям формы и числа флюктуаций кривой ТСП. Предложены механизмы, через которые электрическое поле может, в принципе, вызвать флюктуационный характер кривой ТСП.