TEMPERATURE DEPENDENCE OF STIMULATED AND UNSTIMULATED CURRENT IN POLYCRYSTALLINE CdSe AT 77-273° K

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Abstract

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TEMPERATURE DEPENDENCE OF STIMULATED AND UNSTIMULATED CURRENT IN POLYCRYSTALLINE CdSe AT 77-273° K

1. In polycrystalline powder photoresistors made of cadmium selenide FS-D0 and FS-D1, we have found a stimulation effect of the same order of magnitude as that described for special CdS single crystals studied in the works of Barschauer, Litton, and Reynolds ([1]-[3]), which prompted a number of further studies to elucidate the nature of this effect ([4]-[7]). All these studies were carried out either on the same crystals as those used by the first investigators or on similar "top" crystals.

We measured, for FS-D0 tablets ([10]) at a temperature of 155° K, the ratio of the stimulated current to the unstimulated current, equal to 10^8, and a considerable increase of this ratio with further lowering of the temperature. Such a large enhancement of the current under stimulation is achieved exclusively through a decrease in the unstimulated ordinary current as the temperature is lowered. The stimulated current proved, in the temperature interval from 77 to 273° K, to be independent of temperature.

2. Cadmium selenide at one and the same temperature may be in one of two states: in a state with low conductivity, strongly dependent on temperature, for example proportional to T^{21}, where T is the absolute temperature, or else in a state with high conductivity (greater than the former by several orders of magnitude), not dependent on temperature, at least in the interval 77-270° K. The cell is transferred from the state with low conductivity to the state with high conductivity by stimulation, namely by the preliminary action of an electric voltage or of light. To transfer the sample from the state with high conductivity to the state with low conductivity, it is sufficient to heat the cell to 120° C and then cool it in the dark to the initial temperature.

Of the two types of conductivity that a semiconductor may possess, the state with low conductivity is naturally to be regarded as ordinary semiconductor conductivity, in the present case as electronic conductivity in the conduction band. The second conductivity, independent of temperature, is conductivity of a special kind. This conductivity is distinguished by the fact that: a) it arises in the process of stimulation, b) it does not depend on temperature (from 77 to 273° K), and c) it is destroyed upon heating to a temperature, for example, of 120° C.

It has been shown ([8]) that stimulation can be created in an ordinary semiconductor by introducing a considerable concentration (of the order of 10^8 particles/cm^3) of appropriate impurities.

The role of a considerable impurity content in the formation of stimulation, and the indication given by Mott and Twose that in impurity semiconductors an increase in impurity concentration leads to a decrease and then to the disappearance of the activation energy of impurity conductivity, after which the specific resistance becomes independent of temperature down to the lowest temperatures ([9]), compel one to suppose that the stimulation process,

at least in some cases, consists in switching the semiconductor from ordinary conductivity to conductivity in the impurity band.

An analogous conclusion regarding stimulation in cadmium sulfide single crystals is very thoroughly substantiated in work (5). Assuming the presence, in cadmium selenide after stimulation, of conductivity in the impurity band, we find an explanation for the independence of the conductivity from temperature in the assumption of a negligible activation energy.

Reducing the stimulation effect to switching from ordinary conductivity to conductivity in the impurity band opens the way to mastering this effect and putting it to use.

3. For the measurements, FS-DO tablets (10) were taken; the organic film was removed with dichloroethane, and the tablet was clamped between glasses with a conducting coating. Such a sandwich-type cell was placed in a cryostat with reliable light insulation and with a heating device. The temperature on the surface of the cell was controlled

Fig. 1 Fig. 2

Fig. 1. Current-voltage characteristics of polycrystalline CdSe in logarithmic coordinates at temperatures: A_1B_1CD 77°, A_2B_2CD 155°, A_3B_3CD 186°, A_4B_4CD 237°, A_5B_5CD 273°K

Fig. 2. Dependence of $\log I$ of unstimulated currents on T^{-1} in polycrystalline CdSe

by means of a thermocouple. The voltage was taken from a stabilized DC voltage source. The cell was protected from breakdown by an additional resistance, which in the series of measurements given below was equal to 150 kΩ.

The experiment began with heating the cell at 120°C for 20 min in order to return the cell to its initial state. Then the cell was cooled in the dark to the desired temperature.

The experiments consisted of measurements, at definite temperatures, of the current-voltage characteristic of the cell; moreover, the measurement was carried out by gradually increasing the voltage on the cell, starting from small values and reaching the critical voltage (about 300 V), at which stimulation began; namely, the current began to increase at constant, and then also at decreasing, voltage on the cell (11). The growth of the stimulation process

at first accelerated, reaching a limiting speed, then slowed down and, finally, stopped (12), after which a new stable current-voltage characteristic of the stimulated current was measured.

4. Figure 1 presents, on a logarithmic scale, the characteristics measured at 77, 155, 186, 237, and 273°K, denoted respectively by A_1B_1CD, A_2B_2CD, A_3B_3CD, A_4B_4CD, and A_5B_5CD.

In the region < 100 V, the logarithmic curves for the unstimulated currents have an approximately linear form, i.e., the current is in a power-law dependence on the voltage, and this exponent increases as the temperature is lowered: at 273°K $b = 1.92$; at 237°K $b = 2.5$; at 186°K $b = 4$; at 155°K $b = 4.8$.

At point C, all characteristics join the common characteristic of the stimulated current (10). The straight line in the graph (Fig. 1) is the result of superposing six graphs (to those indicated above, the graph at 255°K was also added), with the scatter of values being very small: out of 37 measurements, in only three did the deviation from the mean exceed 10%. We give the obtained mean values of the stimulated current:

U, V	10	20	30	40	50	60	70
I, mA	0.22	0.80	1.7	3.2	5.0	7.4	10.0

These values are satisfactorily covered by the expression

$$I = 2 \cdot 10^{-6} U^2.$$

For other specimens the exponent of U was 3.0; 2.87. The characteristic of the stimulated current shows no hysteresis; for the forward and reverse voltage runs the current values are the same. We give an example of such measurements:

U, V	10	20	30	40	50	60	70
I, mA	0.275	0.82	1.70	3.25	5.10	–	–
I, mA	0.275	0.84	1.70	3.20	5.10	7.60	10.4

The latter current values given here are close to the values at which progressive heating of the specimen occurs, followed by its destruction. Values up to 5 mA were quite reproducible. The conductivity at 77° reached values of 10^{-4} $\Omega \cdot \text{cm}^{-1}$.

5. For unstimulated currents at voltages sufficiently far from the critical value, one may consider the dependence on T^{-1} (Fig. 2). The current values were taken at $U = 80$ V. For temperatures from 250°K to lower values, the graph is a straight line, from whose slope the dissociation energy of the impurity determining the initial conductivity is calculated. Starting from the expression $I = I_0 e^{-W/kT}$, we obtain $W = 0.32$ eV. The same data can be represented by the empirical formula $\log I = 37.7 + 21.5 \log T$ (for $U = 80$ V).

6. Powder preparations of cadmium selenide were investigated under the action of electric fields by Nicol (13) and Bube (14). They observed at room temperature an increase in conductivity after excitation by the critical voltage; when the applied voltage was decreased, the cell returned to its initial state. Bube considered the effects he obtained as a special kind of breakdown. We repeated these experiments with powdered cadmium selenide "for phosphors" and with an ethylcellulose binder, and reproduced the results described by them.

With CdSe powders without binder, at 77°K we obtained effects analogous to those described in the present work, though not as strong.

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Note: Figure translations are in progress. See original paper for figures.