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INFLUENCE OF NEUTRON RADIATION ON THERMAL PARAMETERS OF AMORPHOUSE SEMICONDUCTORS

PAVEL MACKO*, VLASTA MACKOVÁ*, Bratislava

In this paper the results of measurements of the changes of the thermal conductivity λ, the temperature conductivity k, and the specific heat c of amorphous systems $GeS_{1,1}$ and $GeS_{1,35}$ on the integral neutron flux of 10^{20}—10^{23} neutrons m^{-2} were reviewed. The authors try to interpret the obtained dependences by using the mutual connection between the radiation defects and the gradual compensation of unsaturated bonds in the studied systems.

I. INTRODUCTION

Suppositions as regards the insensibility of physical parameters of amorphous semiconductors to various kinds of radioactive irradiation were refuted by the works of L. Hench [1, 2]. The amorphous systems seem to respond with a varying sensibility to radioactive irradiation, even if the limit sensibility is substantially higher then for crystal, resp. alloyed materials. Those facts have led us to study the dependence of some thermal parameter changes of the GeS_x system on the integral neutron flux. Detailed studies of conditions under which glasses are formed from Ge and S (the glass forming regions) were published in [3] and [4]. With regard to the fact that the glass of the first forming region differed from the glass of the second also by its structural arrangement, we have been interested in both kinds of glasses.

II. THERMAL CONDUCTIVITY AND INFLUENCE OF NEUTRON RADIATION

Solving theoretic problems connected with the transport of heat in amorphous materials is very difficult. In the extensive work [5] the problems of thermal conductivity of amorphous materials were solved by a similar method as that for liquids and it is evident that the experimentalist has the possibility to use not only the same apparatus but also the same methods of measurements as those for solid materials. The studied material has been tabled by the classification of materials [5] GeS_x in the group $C_2[\sigma = (1 \times 10^{-2}$—$1 \times 10^{-12})\ \Omega^{-1}\ cm^{-1}]$ and in accordance with the mentioned work the thermal conductivity can be expressed in the form:

$$\lambda = \lambda_E + \lambda_{bp} + \lambda_M \tag{1}$$

λ_E — the component of thermal conductivity due to free carriers of charge; λ_{bp} — the bipolar component of thermal conductivity; λ_M — the molecular (lattice) component of thermal conductivity.

With regard to the high value of the specific resistance of GeS_x the whole thermal conductivity is being reduced to the molecular component only, so that:

$$\lambda \doteq \lambda_M \, . \tag{2}$$

In [6] the problem of the dependence of λ_M on the integral neutron flux was solved. Bombarding fast neutrons form the complex of defects in the system, the influence of which on the thermal conductivity can be expressed by the relation:

$$\lambda = f(1/\Phi) = f'(1/N_D) \tag{3}$$

Φ — the integral neutron flux; N_D — the concentration of defects formed by neutrons.

The pronounced structural inhomogeneity of glasses does not permit to search theoretical relations which could describe the dependence of the changes of the tested parameters on the integral neutron flux. A similar conclusion was arrived at also by the authors in [7]. By their experiments the lower limit of the sensibility of some materials from the integral neutron flux was specified: $\Phi = 5 \times 10^{20}\ nm^{-2}$.

III. EXPERIMENTAL RESULTS

The impulse measuring method has been used for our measurements [8, 9]. The surface source of heat was a copper furnace and the maximal temperature indicators on the surface of the sample were three thermocouples switched on in series. In this way the sensibility of measurements increased, and simultaneously by this arrangement of thermocouples the mean value of the maximal temperature was specified as well as the mean value of the parameters k and λ of the measured samples. The arrangement of the measurements is evident form Fig. 1.
Our measurements started from measurements of the thermal conductivity λ and the temperature conductivity k. The value of the specific heat c was calculated from the relation:

$$\lambda = kc\varrho \, . \tag{4}$$

It was assumed that the specific mass did not change due to irradiation.

For our experiments the following glass types were available: 1. from the first glass forming region $GeS_{1,1}$. 2. from the second glass forming region $GeS_{1,35}$.

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* Department of Physics, Slovak Technical University, Gottwaldovo nám. 19, 880 19 BRATISLAVA, Czechoslovakia.

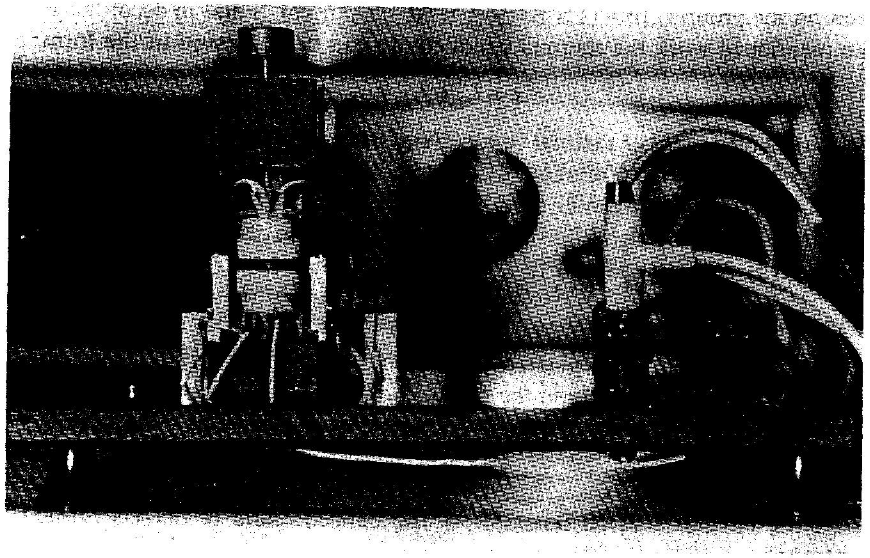

Fig. 1. The preparation for the measurement of the thermal and the temperature conductivities of the studied material.

From both types of glass samples were cut out of a 8 nm diameter and of different thicknesses. Five series of samples with four different thicknesses were prepared from each type. Series N^0 1 — was not irradiated; Serie N^0 2 — was irradiated by an integral neutron flux of 1×10^{20} nm^{-2}; Serie N^0 3 — was irradiated by an integral neutron flux of 1×10^{21} nm^{-2}; Serie N^0 4 — was irradiated by an integral neutron flux of 1×10^{22} nm^{-2}; Serie N^0 5 — was irradiated by an integral neutron flux of 1×10^{23} nm^{-2}. Every sample was measured ten times.

The value of the specific mass before and after irradiation were the following:

$$\varrho \ \mathrm{GeS}_{11} = 2.12 \times 10^3 \ \mathrm{kg\ m^{-3}}$$

$$\varrho \ \mathrm{GeS}_{1.35} = 3.22 \times 10^3 \ \mathrm{kg\ M^{-3}}$$

The values of the measured parameters before irradiation were:

1. for the system GeS_{11}:

$\lambda = 0.837 \times 10^{-1}\ \mathrm{Wm^{-1}K^{-1}}$, $k = 1.025 \times 10^{-7}\ \mathrm{m^2s^{-1}}$,

$c = 386\ \mathrm{Jkg^{-1}K^{-1}}$

2. for the system $\mathrm{GeS}_{1.35}$:

$\lambda = 1.2 \times 10^{-1}\ \mathrm{Wm^{-1}K^{-1}}$, $k = 2.67 \times 10^{-7}\ \mathrm{m^2s^{-1}}$,

$c = 130\ \mathrm{Jkg^{-1}K^{-1}}$.

The values of the parameters λ, k and c after irradiation with individual integral neutron fluxes are plotted in Fig. 2 for the system GeS_{11}, and in Fig. 3 for the system $\mathrm{GeS}_{1.35}$.

The error of measurement of the relative changes of thermal and temperature conductivities was within the range of 5—8 %.

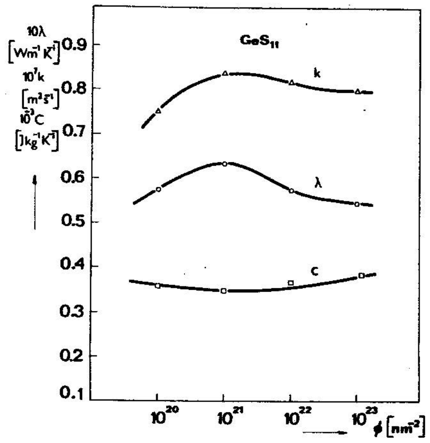

Fig. 2. Dependence of the parameters λ, k and c on the integral neutron flux for the system GeS_{11}.

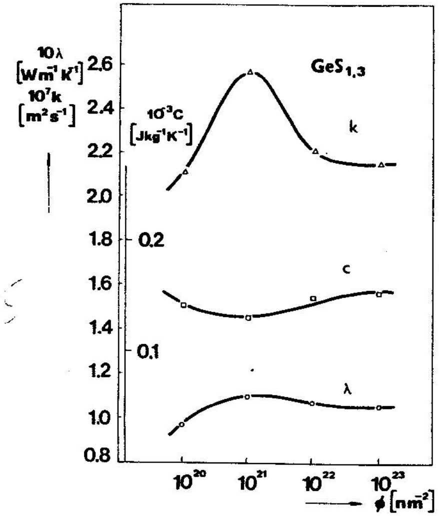

Fig. 3. Dependence of the parameters λ,k and c on the integral neutron flux for the system $\mathrm{GeS}_{1.35}$.

IV. INTERPRETATION OF THE MEASURED RESULTS

The structure of the GeS glasses from the first glass forming region, formed from the sulfide chains with a k-valency Ge-ion in the chain, is open, with many interstitial unsaturated bounds.

Similarly to the second glass forming region, where the glass is stabilized by ion-bonds there is a great concentration of unsaturated bonds. The situation which can be derived from our results is analogical to that described by the authors of [10, 11]. About 10^{25}—10^{26} unsaturated bonds in one m^3 were been found in an amorphous semiconductor (after it had been technologically processed). After annealing closely below the recrystallisation temperature, uncompensated spins were compensated and the amorphous state even though disordered conditions of the system remained became "maximally ordered" one.

The results of our experiments show that up to a certain limit, represented by the density of the neutron flux $\Phi_0 \sim 10^{18}$ nm^{-2}, there occurs an increase of the scattering processes and a decrease of the parameters k and λ. If the integral neutron flux increases over Φ_0, the continuous increase of the radiation defects begins to influence the compensation of the unsaturated bonds (active defects) of the mentioned structures. Bombarding neutrons of the integral flux Φ_{max} begin to cause in the material the concentration defects $N_D = k\Phi_{max}$, where the constant k is of the value [12] $k = 2 \times 10^4\ n^{-1}\ m^{-1}$. At $\Phi_{max} \sim 10^{21}\ nm^{-2}$ the concentration of the radiation defects in the sample is $N_{D max} \approx 10^{25}\ m^{-3}$. These defects compensate the active defects from the unsaturated bonds in the system. The limit density of the neutron flux Φ_{max} defines according to our measurements the maximal compensation of unsaturated bonds in the system related to the minimal values of the scattering processes during the transport. These values correspond to the maximal values of the λ and k curves.

The changes of the specific heat c influenced by the integral neutron flux are characterized by the minimal value of c in maximally ordered system.

V. CONCLUSION

According to the measured values of changes the thermal parameters it can be proved that changes in the scattering processes in amorphous systems occured owing to mechanical-radial changes which are strongly influenced by these effects. Because of this, the studied parameters became also sensitive to the primary effect — to the integral neutron flux.

REFERENCES

[1] Hench L. L., Daughenbaugh G. A., J. Nucl. Mater., *25* (1968), 58.
[2] Hench L. L., Non Cryst. Sol. *2* (1970), 250.
[3] Kawamoto Y., Tsuchihashi S., J. Amer. Ceram. Soc., *52* (1969), 711.
[4] Kawamoto Y., Tsuchihashi S., J. Amer. Ceram. Soc., *54* (1971), 131.
[5] Regel A. R., Smirnov I. A., Shadrichev E. V., Phys. Stat. Sol., *5* (1971), 13.
[6] Macko P., J. Phys. Chem. Sol. *32* (1971), 1181.
[7] Hench L. L., Clark A. E., Schaake H. F., J. Non Cryst. Sol., *8—10* (1972), 837.
[8] Krempaský J., Czech. J. Phys., *B 14* (1964), 533.
[9] Barta Š., Cesnak L., Krempaský J., Kubičár L., Czech. J. Phys., *B 23* (1973), 703.
[10] Moss S. C., Graczyk J. F., Phys. Rev. Lett., *23* (1969), 1167.
[11] Moss S. C., Graczyk J. F., *Proc. Tent. Int. Conf. Phys. Semicond.* Cambridge Mass 1970.
[12] Cleleand J. W., Crawford J. H., Pigg J. C., Phys. Rev., *98* (1955), 1535.

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