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RADIOACTIVE CONDUCTIVITY OF FULLERITE C_{60} STIMULATED BY LOW DOSES OF β-IRRADIATION

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Introduction

Fullerenes find the increasing practical application (nanoelectronics, nanolithography [1], phototransformers of energy [2], etc.). In this connection research of electrical properties fullerenes are considerably dilated.

For today one of directions in research electrical properties of fullerenes is studying influence of the radioactive irradiation on these properties. The most of papers is devoted to studying of influence of middle and high fluences F> 10^{11} cm^{-1} on C_{60} fullerenes electrical properties [3]. Effects, connecting with influence of low dose of the ionizing irradiation while are insufficiently investigated.

The purpose of the present work was to reveal and study the effect of low dose (F< 10^{10} cm^{-2}) irradiation on the electrical conductivity of the C_{60} single crystal.

Results and discussion

The experiments were performed with C_{60} single crystals of high purity (99.95% C_{60}). The crystals were grown at the Institute of Solid-State Physics, Russian Academy of Sciences. The electric current flowing through indium contacts served as a measure of conductivity. The contacts were fixed on one of the faces of the sample with silver paste. The voltage U applied to the contacts was equal to 50–70 V. The samples were exposed to β-irradiation with the use of a radioactive source ^{90}Sr +^{90}Y. The mean energy of electrons <E> was equal to 0.536 MeV. All measurements were carried out at room temperature.

Figure 1 shows dependences of low dose of the β-irradiation current ΔI_R increase versus exposure time. Times of saturation are incremented with the increase of radiation intensity from 5 up to 20 min. Relaxation times remain is constant ~1 h in all cases too. The linear growth of dependence of C_{60} single crystal conductivity from intensity (fig. 2) is revealed.

Research of C_{60} single crystal beta conductivity in an interval 230 <T <320 K has shown, that it has termoactivated character in a fcc-phase. Obtained value of activation energy E_{fcc}=0.17 eV is close to an activation energy of photoconductivity E=0.2 eV [4].

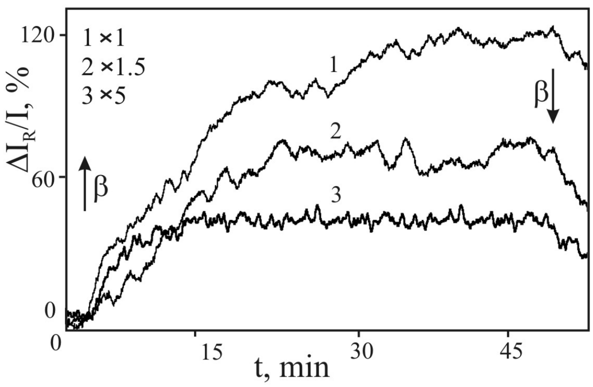

Fig. 1. Change of an increase of C_{60} single crystal conductivity versus different electron dose rate of β irradiation К: 1 – К=1,7·10^6 $cm^{-2}s^{-1}$, 2 – К=0,9·10^6 $cm^{-2}s^{-1}$, 3 –К=0,09·10^6 $cm^{-2}s^{-1}$. Arrows indicate the instants of onset and termination of β irradiation.

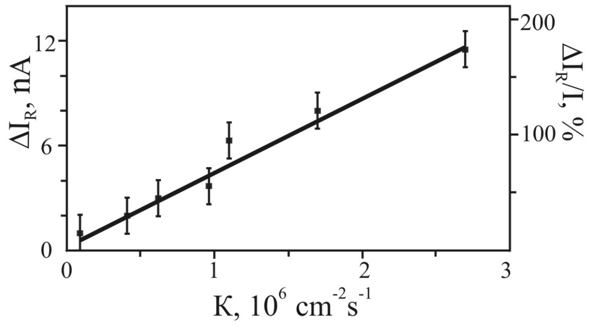

Fig. 2. Dependence of increase of a current ΔI_R from electron dose rate of the ionizing irradiation.

At temperature lower than fcc-sc phase transition (T <260-255 К) decrease of an activation energy up to E_{sc}=0.09 eV was observed.

It was found that β-conductivity of C_{60} single crystal sensitive to magnetic field (MF) with B< 1 T. The increase in β-conductivity up to 3.5 % was observed in MF. The dependency of β-conductivity on B is saturation reached at 0.2 T (Fig. 3). Influence of a magnetic field on the conductivity σ cannot be connected with change of free charge carriers' mobility in MF. Indeed, the relative change of conductivity in organic crystals, connecting with a deformation of a motion trajectory of the free charge carriers in MF B~0.1-1 T, with typical for C_{60} carriers mobility u ~10^{-2} $cm^2/V{\cdot}s$, is $\Delta\sigma/\sigma$~10^{-10} while the experimental values exceeded $3 \cdot 10^{-2}$. Dependence of orientation of MF and direction of a current was absent, that should be typical for galvanomagnetic effects.

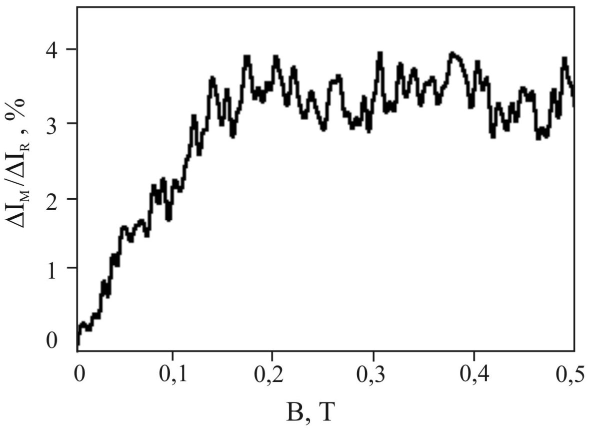

Fig. 3 Dependence of an increase of β- current $\Delta I_M/\Delta I_R$ on induction static magnetic field B.

The basic effect due to interaction of fast electrons with the material is determined by the ionization of molecules and the formation of point defects. An increase in the electrical conductivity can be associated with multistage collision ionization of molecules in the lattice of the C_{60} crystal by relativistic electrons due to external excitation. Under these conditions, the energy of a conduction electron produced in the initial ionizing event is sufficiently high for subsequent ionization of C_{60} molecules. The increment of the electric current in this case is estimated as $\Delta I_R = K \cdot e \cdot S \cdot \langle E \rangle / E_0 \sim 10^{-8}$-$10^{-9}$ A in this case, where $e = 1.6 \cdot 10^{-19}$ C is the elementary charge, E_0 ~20 eV is an energy exceeding the ionization energy of the fullerene molecule, $\langle E \rangle = 0.536$ MeV – average energy of electrons of irradiation, and S – sample area. It can be seen that the calculated increase of the electric current is within the range of experimental values $\Delta I_R = 10^{-8}$–10^{-9} A. Suggested mechanism is confirmed by C_{60} single crystal conductivity on irradiation intensity results. However, the long times of rise and relaxation of the radiation-induced current cast some doubt on the fact that the observed increase in the electrical conductivity is caused only by multistage collision ionization of C_{60} molecules. Proper allowance must be made both for already existing deep-level trapping centers of free charge carriers and for new defects arising under β-irradiation and also serving as traps for free charge carriers. It should be noted that, at the beginning of β-irradiation, the trapping centers are generated and filled simultaneously. After β-irradiation is ceased, the traps undergothermal depletion. The determination of the energy location of deep-lying levels and elucidation of the nature of radiation-induced defects in C_{60} single crystal call for further investigation.

One of principal causes of increase of β-conductivity in MF can be a magnetosensitive non-equilibrium processes connected with charges carriers transport or change of intensity of capture (release) by traps of electrons and holes. High times of increase and decrease of β-conductivity confirm the given assumption, indicating the contribution of defect structure to β-conductivity of C_{60} single crystal in MF.

Conclusions

Thus, in this work is shown, that conductivity of C_{60} single crystal is sensitive to of low dose to the ionizing irradiation.

Acknowledgements

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