Inhomogeneous change of temperature of ionic crystals under the action of a pulsed electron beam

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Abstract. This paper presents the results of mathematical modeling of temperature change in ionic crystals in an area of dissipation of energy of an electron beam. Fluence is varied from 0.1 to 1.2 J/cm$^2$. Electron beam pulse duration was 24 ns, and the maximum electron energy of 280 KeV. The initial temperature of the crystals varied from 20 to 400 K. The calculation is performed considering the inhibitory effect of electrons in the field of space charge formed by a vacuum gap 1000 micron before the irradiated surface.

1. Introduction
Using pulsed electron beams allows generating short-lived defect concentration sufficient for detection and research of the mechanisms of defect formation in solids. However, the impact on ionic crystals pulsed electron beams has some specific features compared with low-intensive sources of radiation. In an area of energy dissipation of pulsed electron beam is formed strong electric field and the temperature rises along with the generation of non-equilibrium electron-hole pairs, which affects the efficiency of formation and decay of an electron-hole excitation and also on the postradiation processes [1]. Effect of temperature increase in an area of energy dissipation is not enough studied, making it difficult to correct account of this factor in the analysis of research results.

2. Method of calculating
In the calculations used spectrum of a pulsed electron beam [2], which was determined experimentally by attenuation in thin foils, as described in [3]. To calculate the distribution of thermalized electrons in the sample and the absorbed energy density applied a variation "enlarged" collisions of Monte Carlo method using the angular distribution of Moliere-Bethe [2]. Ionization losses are determined by the formula Bethe-Bloch and the average ionization potential is defined by the formula Sternheimer [4]. Distributions of charge density are determined by the algorithm presented in [2]. To estimate the cooling time of the heated region can use the relation given in [5]:

$t_b < \frac{D}{\chi} < \frac{D^2}{\chi}$

where $\chi$ – coefficient of thermal diffusivity of the target material; $D$ – the characteristic size of the heated region; $t_b$ – heating time. Variable $\frac{D^2}{\chi}$ it makes sense characteristic cooling time of the heated region. Condition means that during pulsed electron beam (PEB) irradiation, the temperature field varies weakly and determined by the distribution of the radiation energy.
3. Results of calculation

Simulation of the temperature distribution over the thickness of the irradiated material (Z) was performed for ionic crystals LiF, CaF$_2$, NaCl and KBr. Results of calculations shown in figure 1.

From the results of calculations that at low initial temperature of the crystal at the end of irradiation the greatest temperature increase of the crystal ($\Delta T$) takes place in the subsurface layer and then decreases monotonically with increasing distance from the irradiated surface. The magnitude of such a large temperature change is due, firstly, the low specific heat capacity of the material at low initial temperatures. Secondly, with increasing fluence PEB increased influence of field of space charge in the vacuum gap, which leads to large energy in the subsurface layer of the crystal and thus to greater heating of his. [6]. The totality of these processes leads to the fact that the form $\Delta T(Z)$ is different from the form of energy release $W(Z)$. These regularities are common to all of the crystals.

For a detailed consideration of the time variation of the temperature and energy release in the layers of crystal with increasing distance from the irradiated surface was performed calculations with allowance the spectral-temporal parameters of PEB, leading to spatiotemporal dependence energy release in the sample. Results of calculations shown in figure 2. It is seen that with increasing distance from the irradiated surface total time of energy release in the layer is reduced. Spatiotemporal function of energy release defines complicated dependence of change of temperature in the layers with the irradiation time. With increasing distance from the irradiated surface is characteristic reduction of heating time of layer. But the form of $\Delta T(Z)$ becomes almost constant though $W(Z)$ is continuously growing. This effect is characteristic throughout the irradiated volume of the crystal (i.e. for all layers). After some time (for CaF$_2$ after 14 ns and KBr after 12 ns) been a sharp rise $W(Z)$ and synchronous growth $\Delta T(Z)$ in subsurface layers (figure 2, layer «0 μm»), due to the inhibitory effect of the field of space charge in the vacuum gap [6].

Figure 1. Calculated forms of energy release ($W$, dashed curves) and change of temperature of crystal ($\Delta T$) at the end of PEB in crystals CaF$_2$ (a) and KBr (b) at initial temperature of the crystal ($T_M$) 20 K.
From the results it follows that $\Delta T_z$ are maximized for subsurface region of the crystal. In Figure 3 shows the calculated dependence of $\Delta T$ of subsurface layers from $T_M$ in crystals CaF$_2$, KBr, NaCl and LiF at the end of irradiation PEB. In these layers (up to 75 microns from the irradiated surface) energy release is almost 50 percent of a total energy release throughout the irradiated volume of the crystal (figure 1). On a plot of dependency $\Delta T(T_M)$ where $T_M < 80$ K the determining factor of high heating for all of the crystals is a low specific heat capacity of materials. With an increase of $T_M$ more than 80 K values of $\Delta T(T_M)$ are practically constant. In this area the high temperature is mainly due to high energy release in the subsurface region of the crystal due to presence a field of space charge in the vacuum gap. So at a fluence of PEB equal to 0.58 in KBr temperature reaches an average of 35 K, in NaCl $\Delta T$ – an average of 20 K, in CaF$_2$ $\Delta T$ – an average of 18 K, in LiF $\Delta T$ – an average of 10 K.
Figure 3. Calculated dependence \( \Delta T \) of the maximum of energy release from \( T_M \) in crystals CaF\(_2\) (a), KBr (b), NaCl (c), LiF (d) at the end of PEB

4. Conclusion

Studying the temperature dependences of the spectra of pulsed cathodoluminescence, values of decay component, as well as the temperature dependence of the yield of products of irradiation, an important factor is the temperature of the material in which the measurements are carried out. Consequently, as shown in this paper, the presence of spatiotemporal inhomogeneity of temperature of the crystal, as well as a significant heating of the material during irradiation PEB, even at low fluence, will make a significant distortion in the measurement results. This effect of inhomogeneous change of a temperature must be taken into account in the research of the temperature dependence of the yield of products of irradiation and kinetic processes postradiational.

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