UDC 539.67:539.374

THE INFLUENCE OF X-IRRADIATED TO DOSE 1057 R LiF CRYSTALS' TOOLING ON THEIR OPTICAL DESCRIPTIONS

G.O. Petchenko[1], S.M. Boiko[2]
[1]O.M. Beketov Kharkiv National University of Urban Economy, Kharkov, Ukraine
E-mail: gdaeron@ukr.net;
[2]M.Ye. Zhukovskiy Kharkiv National Aerospace University, Kharkov, Ukraine
E-mail: svitlanazagreba7@gmail.com

Here there were investigated the influence of plastic deformation ε on the optical characteristics of X-irradiated to dose 1057 R LiF crystals and the colorimetric characteristics of optical radiation passing through crystals with different ε. It was established that change of strains in the interval 0.155...3.3% leads to reversible changes in the spectral dependences of the transmittance coefficient $\tau_\lambda(\lambda)$, as well as the coordinates of the color and brightness of the radiation, passing through the crystal, but the color of the radiation thus remains constant.

INTRODUCTION

This work is the continuation of a series of papers [1–4], aimed at studying the nature of radiation defects in LiF single crystals with different mechanical stages [5–8]. Works [1–8], in turn, complement works [9–12] and others, where the influence of structural defects on the course of phonon-dislocation interaction processes in other crystals was studied. In works [1–4] an optical absorption method was used, which, unlike acoustic [5–12], allows to carry out quantitative and qualitative analysis of effective centers of radiation origin fastening at dislocations.

It is known that LiF single crystals, besides being model, and, therefore, rather convenient for testing the existing theories, are quite attractive from the practical point of view. They are used in detectors and dosimeters of ionizing radiation, in electrical circuits – for the delay of electrical signals, it is known [8, 13] about their use in laser technology, medicine and radiobiology. In addition, LiF crystals are widely used in optics, particularly in X-ray optics as crystal monochromators [8].

When using LiF crystals in optical devices as functional materials, it is important to know, how external factors will affect their optical characteristics. Papers [1–4] showed that ionizing radiation and plastic deformation significantly affects the transmission capacity of samples in the observed range of wavelength of 220...650 nm.

It is known that one of the key units of an optical device is a radiation receiver. At the design stage, the receiver is selected for spectral sensitivity to perform the specific research tasks. It is assumed that the spectral composition of radiation passing through the optical system of the device remains unchanged, and the receiver response is predictable and effective. With variations in the color of the radiation, due to structural changes in functional materials, a decrease in the efficiency of radiation registration by an optical device can be observed.

The purpose of this work is to determine the effect of deformation and ionizing radiation on the color characteristics of the rays passing through the crystal, which acts as light filter.

MATERIALS AND METHODS OF THE RESEARCH

The investigated crystals are LiF samples with an orientation of <100> and a size of approximately 16×16×30 mm. The purity of the used crystals is 10^{-4}% by weight. To eliminate the internal stresses resulting from mechanical treatment, the test specimens were annealed in a muffle furnace MP-2UM for about 12 hours at a temperature close to the melting point of the crystal $T \sim 0.8\ T_{melt}$ (T_{melt} = 870 °C), followed by slow cooling to room temperature. The preliminary deformation of the samples was carried out on a machine of the type "Instron" at a deformation rate of ~ $10^{-5}\ s^{-1}$ by compression along the crystallographic direction <100>. Control over the achievement of the required value of ε was ensured by accurately recording the moment of the crystal's output to the yield point with a mark on the tape of the recorder KSP-4, and the change in the length of the samples was controlled by the comparator IZA-2 and other means. X-ray irradiation of crystals was carried out on a standart device URS-55 equipped with an X-ray tube with a copper anode and operating parameters U = 40 kW; I = 10 MA. The power of the radiation dose at the location of the crystals, according to the indications of the dosimeter KID-2, was 0.11 R/s. The total sample irradiation time was 160 min, corresponding to the radiation dose of 1057 R. For the optical experiment the spectrophotometer SP-26 was used. The investigated wavelength range was 200...650 nm. As a luminaire, the deuterium lamp DDS-30 was used with measurements in the spectral range 200...350 nm, and the incandescent lamp OP-33-0.3 with measurements in the range 350...650 nm. For the whole range of measurements, an antimony-cesium photocell F-17 was used as a photodetector of radiation. All experiments were carried out at a constant temperature T = 300 K.

RESULTS AND DISCUSSION

Fig. 1 shows the deformation's influence onto dependences' localization $\tau_\lambda(\lambda)$ for various strains ε – 0.4; 0.65; 0.8, and 3.3% [1–4]. It is clearly seen the retrace of the dependences with a strain.

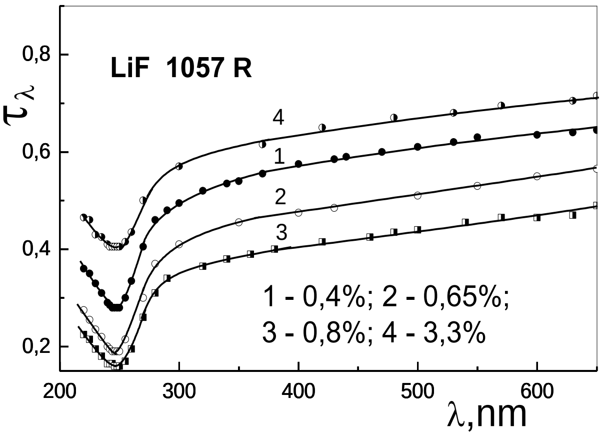

Fig. 1. The retrace effect of the curves $\tau_\lambda(\lambda)$ of the strain in LiF

In the Fig. 2 data on characteristics are given $\tau_\lambda(\lambda)$ for all investigated in [1–4] lithium fluoride crystals. This figure clearly shows how in the range 0.155…0.8% transmittance of the samples decreased monotonously and as further deformations of the samples in the range of deformations of 0.8…3.3%, returned to the crystals their "transparency" as for the passage of optical radiation in the range 220...650 nm. That is, as we see, with a slight deformations of lithium fluoride crystals, their transmittance decreased, but further deformation allowed reproducing the initial optical characteristics for this crystals.

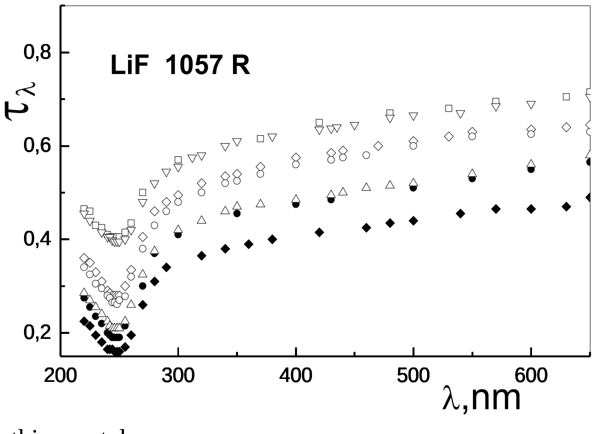

Fig. 2. The effect of transmittance returning to samples plastically deformed by irradiation to a dose of 1057 R. The samples are LiF crystals with strains: ∇ – 0.155%, ◊ – 0.4%; • – 0.65%; ♦ – 0.8%; Δ – 1.2 %; o – 1.5%; □ – 3.3%

The specified feature may be useful for applied physics in terms of improving the service characteristics of the equipment based on the use of ionic crystals and in particular LiF as functional materials for physical elements, devices and systems based on them. One can imagine the situation in which one of these elements lost its optical characteristics due to, for example, mechanical external action. Artificial supplementary "uploading" of this element can facilitate the return of the required working parameters to the original state.

After it turned out that the deformation can be a tool for returning the transmittance of crystals to the initial state, it makes sense to go over to the colorimetric task of studying the colority of the radiation on LiF samples in the range of degrees of previous deformation of 0.155…3.3%.

It is known that in the presence of dependences $\tau_\lambda(\lambda)$ and the known spectral density of the radiation flux from the source of radiation we can make the equation of radiation colority [14]:

$$D = x' \cdot X + y' \cdot Y + z' \cdot Z, \qquad (1)$$

where *X*, *Y*, *Z* – the main colors of the colorimetric system and x', y', z' – the color's coordinates; $x' + y' + z' = m$ – color's module. Colority coordinates x, y, z can be by the formulas:

$$x = \frac{x'}{m},\ y = \frac{y'}{m},\ z = \frac{z'}{m}. \qquad (2)$$

Apparently, that to form the equation of color, that penetrates through the crystal (1) and in order to calculate its colority (2) it is necessary to know the coordinates of the color.

Them, in their turn, one can define with he help of spectrophotometric method [15] by the formulas [14]:

$$x' = \Delta\lambda \cdot \sum_{i=\lambda_1}^{\lambda_n} \varphi_{e\lambda i} \cdot \tau_{\lambda i} \cdot \bar{x}_{\lambda i}; \qquad (3)$$

$$y' = \Delta\lambda \cdot \sum_{i=\lambda_1}^{\lambda_n} \varphi_{e\lambda i} \cdot \tau_{\lambda i} \cdot \bar{y}_{\lambda i}; \qquad (4)$$

$$z' = \Delta\lambda \cdot \sum_{i=\lambda_1}^{\lambda_n} \varphi_{e\lambda i} \cdot \tau_{\lambda i} \cdot \bar{z}_{\lambda i}, \qquad (5)$$

where $\bar{x}_{\lambda i}$, $\bar{y}_{\lambda i}$, $\bar{z}_{\lambda i}$ – the specific tristimulus values; $\varphi_{e\lambda i}$ – spectral radiation flux density of the source; $\Delta\lambda$ – calculation phase, that for most cases provides sufficient precision when $\Delta\lambda$ = 10 nm.

Taking into account that in the spectral measurements in the interval 350...650 nm as a luminaire in the spectrophotometer SP-26 used the incandescent lamp OP-33-0.3, which can be considered as a source of type A, using standart table values [16], which specify the behavior characteristics $\varphi_{e\lambda i}$, $\bar{x}_{\lambda i}$, $\bar{y}_{\lambda i}$, $\bar{z}_{\lambda i}$ in visible spectrum. The calculation was made for spectral range 380…650 nm in the Excel program for the curves $\tau_\lambda(\lambda)$ in Fig. 2, occupying the uppermost position (ε = 0.155 and 3.3%) and the extreme lower position (ε = 0.8%).

As a result of complex calculation of optical and lighting parameters we can note the following. Reduction of τ_λ approximately by one and a half times at transition from values of previous deformations of crystals ε = 0.8 to ε = 0.155 and 3.3% causes a decrease of color coordinates in the same value x', y', z' and brightness of a basic color of radiation $L = 683 \cdot y'$, passing through the investigated medium by a similar magnitude of coordinates and it is described by the equation (1) [14]. As to the color characteristics of the radiation passing through the investigated crystals with different mechanical state, they remain unchanged – $x \approx$ 0.44; $y \approx$ 0.41; which holds on a constant level such characteristics as $\lambda^* \sim 570$ nm (dominant wavelength) and $P \sim 5\%$ (color purity).

Thus, it can be verified that the plastic deformation of the LiF samples in the deformation range 0.155...0.8% leads to a significant decrease (~ 1.5 times) of the sample transmittance, and, in the same proportion, to reduce the colorimetric and lighting characteristics x', y', z', L, and a further increase in deformation in the interval of 0.8...3.3% causes the return of these characteristics to the starting positions. In this case, the structural changes of the studied crystals in no way reflected in the change in color (spectral composition) of radiation passing through the crystal. This interesting, in our opinion, experimental result suggests that the radiation detector chosen for this design of an optical device will not loose its effectiveness in the unpredictable deformations of the functional material, the role of which plays a crystal. At the same time, the issue of influencing the above characteristics of the dose of ionizing radiation remains unresolved. From our works [1–4] it is known that the increase of this dose to ~ 400 R doesn't cause the appearance of absorption bands of optical radiation in the investigated crystals. Thus the family of curves $\tau_\lambda(\lambda)$ behaves similar to the deformation – namely, curves $\tau_\lambda(\lambda)$ are shifted down approximately parallel to the original curve. But, starting with the limit values ~ 400…600 R (which are different for the crystals with different ε) in dependences $\tau_\lambda(\lambda)$ revealed the absorption bands caused by the appearance in the crystals of the color centers that, in our opinion, can completely change the color radiation passing through the investigated crystal. This subject requires careful study and will be considered by us in further work.

CONCLUSIONS

For the first time it has been found that with increasing of residual deformation in X-irradiated to dose 1057 R LiF samples, the spectral curves $\tau_\lambda(\lambda)$, and characteristics x', y', z', L, as well change nonmonotonously. In the deformation interval 0.155...0.8%, increase in deformation leads to the reduction of these parameters for about 1.5 times, but after passing the critical point of 0.8% (transition from primary to secondary sliding planes when moving dislocations [7]), the situation changes to the opposite – increasing deformations to 3.3% returns the specified characteristics to the original level. At the same time, the change in ε in the interval 0.155...0.8% does not affect the color of the radiation passing through the crystal. The indicated effect of the reversible displacement of the quantitative optical characteristics of radiation with the invariability of qualitative ones, it's may appear to be of interest for applied optics (lighting engineering, colorimetry, photometry) and physics of devices, elements and systems.

REFERENCES

1. G.A. Petchenko. Investigation of the radiation defect nature in irradiated LiF crystals // *Bulletin of V.N. Karazin Kharkiv National University*. 2013, N 1075, issue 18, p. 50-54.

2. G.A. Petchenko, A.M. Petchenko. Optical absorption in irradiated LiF crystals // *Bulletin of V.N. Karazin Kharkiv National University*. 2013, N 1076, issue 19, p. 35-38.

3. G.A. Petchenko, S.S. Ovchinnikov. Effect of the preliminary deformation and irradiation on the optical absorption in LiF crystals // *Problems of Atomic Science and Technology. Series "Physics of Radiation Effect and Radiation Materials Science".* 2014, N 2(90), p. 29-33.

4. G.A. Petchenko, A.M. Petchenko. Dependence of electronic color center concentration on the state of irradiated LiF crystal dislocation structure // *Problems of Atomic Science and Technology. Series "Physics of Radiation Effect and Radiation Materials Science"*. 2015, N 2(96), p. 25-28.

5. G.A. Petchenko, A.M. Petchenko. The study of the dislocation resonance in LiF crystals under the influence of the low-dose X-irradiation // *Functional Materials*. 2010, v. 17, N 4, p. 421-424.

6. G.O. Petchenko. Acoustic studies of the effect of X-ray irradiation on the dynamic drag of dislocations in LiF crystals // *Ukrainian Journal of Physics*. 2011, v. 56, N 4, p. 339-343.

7. A.M. Petchenko, G.A. Petchenko. The characteristics ultrasonic absorption in LiF at dislocation density variation // *Bulletin of V.N. Karazin Kharkiv National University. Series "Physics"*. 2009, issue 12, N 865, p. 39-44.

8. G.A. Petchenko. The study of dynamic and structural characteristics in irradiated crystals LiF // *Problems of Atomic Science and Technology. Series "Physics of Radiation Effect and Radiation Materials Science"*. 2013, N 2(84), p. 55-59.

9. A.M. Petchenko, G.A. Petchenko. Dynamic damping of dislocations with phonons in KBr single crystals // *Functional Materials*. 2006, v. 13, N 3, p. 403-405.

10. A.M. Petchenko, G.A. Petchenko. Effect of crystal pre-straining on phonon damping of dislocations // *Functional Materials*. 2008, v. 15, N 4, p. 481-486.

11. A.M. Petchenko, V.I. Mozgovoi, A.A. Urusovskaya. The viscous drag of dislocations in singlecrystals NaCl in temperatures 77-300 K // *FTT*. 1988, v. 30, N 10, p. 2992-2995.

12. V.M. Andronov, A.M. Petchenko, V.I. Startsev. Temperature dependence of a drag coefficient of dislo-

cations in potassium chloride in temperatures 77-413 K // *Acoustical Journal*. 1975, v. XXI, issue 4, p. 502-507.

13. I.M. Nekludov, A.K. Malik, A.A. Parkhomenko, A.V. Rudnitskiy. Ionization mechanisms of radiation-induced defects' generation in LiF crystals irradiated with high-energy electrons // *Problems of Atomic Science and Technology. Series "Physics of Radiation Effect and Radiation Materials Science"*. 2009, N 2(93), p. 52-56.

14. V.V. Meshkov. *The basics of lightning engineering*. M.: "Energiya", 1979, 368 p.

15. M.M. Gurevich. *Photometry (Theory, methods and devices)*. L.: "Ehnergoatomizdat", 1983, 272 p.

16. State Standart "GOST" 7721-89. *The illuminants for color measuring. Types. Specifications. Designation.* M.: "Standarts publishing house", 1989.

Article received 22.12.2017

ВЛИЯНИЕ МЕХАНИЧЕСКОЙ ОБРАБОТКИ ОБЛУЧЕННЫХ ДО ДОЗЫ 1057 Р КРИСТАЛЛОВ LiF НА ИХ ОПТИЧЕСКИЕ ХАРАКТЕРИСТИКИ

Г.А. Петченко, С.Н. Бойко

Исследованы влияния пластической деформации ε на оптические характеристики облученных до дозы 1057 Р кристаллов LiF и колориметрические характеристики оптического излучения, проходящего через кристаллы с разными ε. Определено, что изменение деформации в интервале 0,155…3,3% приводит к обратимым изменениям спектральных зависимостей коэффициента пропускания $\tau_\lambda(\lambda)$, а также координат цвета и яркости излучения, проходящего через кристалл, но цветность излучения при этом остается на постоянном уровне.

ВПЛИВ МЕХАНІЧНОЇ ОБРОБКИ ОПРОМІНЕНИХ ДО ДОЗИ 1057 Р КРИСТАЛІВ LiF НА ЇХ ОПТИЧНІ ХАРАКТЕРИСТИКИ

Г.О. Петченко, С.М. Бойко

Досліджено вплив пластичної деформації ε на оптичні характеристики опромінених до дози 1057 Р кристалів LiF і колориметричні характеристики оптичного випромінювання, що проходить через кристали з різними ε. Встановлено, що зміна деформації в інтервалі 0,155…3,3% призводить до оборотних змін спектральних залежностей коефіцієнта пропускання $\tau_\lambda(\lambda)$, а також координат кольору і яскравості випромінювання, що проходить через кристал, але колірність випромінювання при цьому залишається на сталому рівні.

.