*JOURNAL OF NANO- AND ELECTRONIC PHYSICS*
Vol. **11** No 2, 02014(7pp) (2019)

*ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ*
Том **11** № 2, 02014(7cc) (2019)

# Regularities of Influence of Electron-beam Technology Modes on the Performance Characteristics of Optical Elements

I.V. Yatsenko[1,*], V.S. Antonyuk[2,†], V.A. Vashchenko[1], O.V. Kyrychenko[3], O.M. Tishchenko[3]

[1] *Cherkasy State Technological University, 460, Shevchenka Blvd, 18030 Cherkasy, Ukraine*
[2] *National Technical University of Ukraine, 37, Peremohy Prosp., 03056 Kyiv, Ukraine*
[3] *Cherkasy Institute of Fire Safety named after Chornobyl Heroes of National University of Civil Protection of Ukraine, 8, Onoprienka St., 18034 Cherkasy, Ukraine*

(Received 09 January 2019; revised manuscript received 04 April 2019; published online 15 April 2019)

Experimental researches and new regularities of influence of electron-beam processing modes on quantitative indexes of quality of surface layers of optical glass and ceramics elements are carried out: purity and smoothness of surface – the surface of optical glass elements is completely free of defects, at the same time, there is an increase of purity class, the reduction of microroughness to 0.4-1.3 nm; thickness of melted layer; structural change and chemical composition; squeezing tension and thickness of strengthened layers – in the optical ceramics elements there appear compression tensions up to 30-70 MPa in strengthened surface layers of 90-210 microns thick. Optimal modes of electron-beam technology are found (thermal impact density $7\cdot10^6$-$8\cdot10^8$ W/m$^2$ of electron beam, travel speed $5\cdot10^{-3}$-$5\cdot10^{-2}$ m/s), which improve the performance characteristics of optical elements: increase of microhardness of the surface and increase of the strength of surface layers, as well as spectral transmission coefficient; increase of elements stability to external thermal and mechanical influences by their exploitation. Herein, there is a temperature increase of surface layers of elements and a rise in their thermal physical properties: volumetric heat capacity, thermal conductivity coefficient, thermal coefficient of linear expansion. The obtained experimental research results and developed on their basis methods of improvement of performance characteristics of optical elements found their practical use and introduction in a wide range of Ukrainian enterprises, which allowed to increase the accuracy and broaden measurement ranges of impulsive range finders for 7-15 %; to increase the probability of flawless performance of optical fairings of infrared guidance and observation devices and fiber-optic beam guides of laser medical devices while performing at 10-20 %.

**Keywords**: Optical-electronic devices, Optical glass, Optical ceramics, Electron beam, Performance characteristics.

DOI: 10.21272/jnep.11(2).02014 PACS numbers: 42.79. Bh

## 1. INTRODUCTION

The modern level of the development of optical-electronic instrument making demands the increased requirements to the performance characteristics of their optical elements: surface microhardness; spectral transmission coefficient; resistance to external thermal and mechanical shocks, etc., that affect the technical and operational characteristics of the devices (impulse laser devices of sighting complexes, laser medical devices, infrared devices of self-guidance, etc.) [1-3].

Wide use of traditional methods of preparation and processing of surfaces of optical elements (mechanical, chemical, chemical-mechanical, etc.) showed that it is impossible to get simultaneously clean and flawless surface, and also flawless surface layers, that leads to deterioration of the performance characteristics of optical elements.

Fundamental and applicable researches, conducted in the field of development of new high intensive technologies of processing of different materials, including optical materials, showed that the most promising sources of energy for such technologies are the focused streams of charged elements (electrons, ions), laser radiation, etc. However, the application, for example, of ionic and laser surface treatment of elements has revealed a number of obstacles that restrict the possibility of their wide use in the optical electronic instrument building: the violation of microgeometry of the surface; formation of local high-temperature zones with large temperature gradients, that lead to the emergence of critical thermostresses in materials and their destruction; complexity of operation (especially scanning laser beam), etc. [4-6].

As the practice has shown, the most convenient, environmentally friendly and easily controllable method of optical element processing is the electron-beam method. There have been shown the application possibilities of the moving electron beam of belt form for polishing optical glass elements and obtaining high purity surfaces with minimal roughness, as well as for strengthening optical ceramics elements and obtaining the surfaces with advanced microhardness and thickness of the strengthened layers of tens of microns. However, the wide use of electron-beam technology in the optical-electronic instrument building is restrained: by the data absence as to the influence regularities of electron-radiation treatment modes on the performance characteristics of optical elements, the operation of which allows to improve technical and performance characteristics of devices, including accuracy and range of measurements, probability of reliable performance in operation, etc.

Consequently, the establishment of influence regularities of electron-beam technology on the performance

---

[*] irina.yatsenko.79@ukr.net
[†] victor.antoniuk@gmail.com

characteristics of optical elements, determination of operation modes, within which they are improved, resulting in the decrease of technical and operational characteristics of the optical electronic devices is an important and acute scientific and technical problem. Thus, this work aims to create scientifically grounded bases of the improved performance characteristics of optical elements by establishing influence regularities on them by modes of electron-beam technology.

## 2. OPTICAL ELEMENT CHARACTERISTICS AND METHODS OF THEIR INVESTIGATION

The samples of optical elements of optical electronic devices were used for experimental research: flat-parallel plates, rectangular elements, cylindrical and spherical elements from optical glass (K8, BK10, TF10) and optical ceramics (KO1, KO2, KO5) [1]. For electron-beam processing of surface layers of optical elements the developed technological equipment was used, which differs from the existing electron-beam installations by the technological facilities for automated measuring and temperature control of the processed surface, as well as electron beam sensing, which is protected by the patents of Ukraine.

As a result of researches of the electron beam sensing by the known method of the rotating probe [1] there were determined empirical dependencies of thermal influence density in its center $F_n$ (W/m$^2$) on the controlled technological parameters of the electron beam installation: electron beam current $I_n$, mA; accelerating cranking voltage $V_y$, kV; distances to the processed surface of the optical element $l$, m. It is determined that for the working change ranges of the specified settings ($I_n = 50\text{-}300$ mA, $V_y = 6\text{-}8$ kV, $l = 0.04\text{-}0.08$ m) the following change range is realized: $F_n = 10^6\text{-}10^9$ W/m$^2$. Therefore, the beam travel speed varies within $V = 0\text{-}0.1$ m/s.

For modeling of external influences on optical elements under normal conditions ($P = 10^5$ Pa, $T = 293$ K) controlled IR heating by quartz lamps of the type KGM-220-1000-1 (КГМ-220-1000-1) was used with application of thermosensors RIF-101 (РИФ-101) to control temperatures on the surface of elements in the range of 300-1900 K and external heat flows in the range of $1.5\cdot10^5\text{-}2.3\cdot10^6$ W/m$^2$.

Simulation of the influence of elevated heating temperature (up to 1500 K) and external pressure (up to $10^7$ Pa), as well as the supersonic airflow (up to $2\cdot10^3$ m/s) and angular velocity of rotation (up to $4\cdot10^3$ rad/s) on optical elements (exploitation conditions of the supersonic equipment) were conducted on the standard test installations within the framework of compatible state budget and public contracting research works of Cherkassy State technological University with the Plant Arsenal (Kyiv) and State Enterprise Research and Production Complex "Fotoprylad"(Cherkassy).

Modern methods of physical and chemical analysis were used for experimental researches: methods of raster electron microscopy (REM) and transmission electron microscopy (TEM) for research of surface structure and surface layers of optical elements, as well as the determination of the melted layer thickness; methods of atomic-force microscopy (AFM) and Vickers microsensing for measuring microroughness on the surface of optical elements, as well as its microhardness; methods of micro x-ray spectral analysis (MXSA) for the chemical analysis; the methods of shooting in X-rays on the diffractometers DRON-2,0 and DRON-3.0 to measure the quantities of thermal stresses in the surface layers of optical elements; Central Ring Bend method (CRB) for determining critical values of thermoelastic thermal stresses in optical elements for heating temperatures of 300-1200 K; spectrophotometric methods of determining spectral transmission coefficient of optical elements; critical height determination method, from which steel ball with a diameter of $4\cdot10^{-3}\text{-}5\cdot10^{-3}$ m, which is freely falling, destroys the surface of the element (results in cracks, chips and other negative defects) for the study of mechanical stability of optical elements to shock external loads; contact methods (chromel-alumel thermocouple convertors, temperature measurement range up to 1600 K) and contactless methods (photo resistor FUO-613 (ФУО-613), the range of temperature measuring up to 1500 K) to measure the surface of optical elements; slieren-photographic methods using shadow instrument the IAB-451 (ІАБ-451) for investigation of the structure of air flow, which wraps the optical fairings under conditions supersonic equipment exploitation.

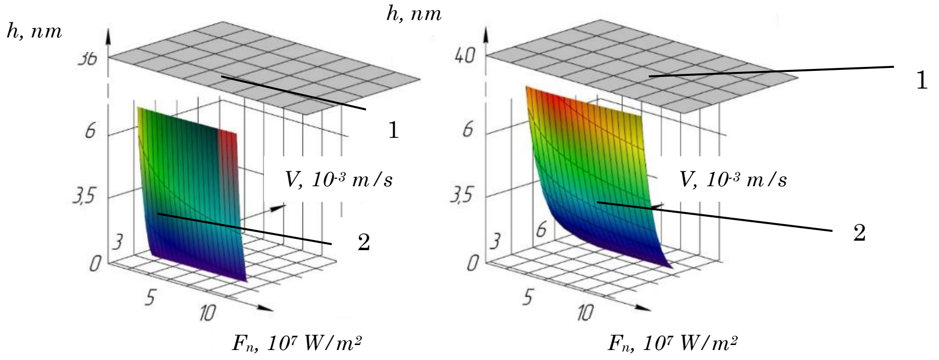
The relative error did not exceed 5-10 % in the studies of the determination of the above-mentioned characteristics of optical elements.

## 3. INVESTIGATION RESULTS AND THEIR ANALYSIS

It is found that after standard processing the most characteristic is the presence of microdeffects, such as cracks up to 0.1-0.7 microns deep, scratches of 2-5 microns long, as well as blisters of $10^{-3}\text{-}10^{-2}$ microns in. After electron-beam processing the size of blisters (diameters) on the surface of elements decreases 2-4 times, with other microdefects less than 1-2 microns are not observed, that is, as a result of processing of the electron beam the surfaces of elements become "cleared", small defects are eliminated. At the same time, with the increase of $F_{\text{п}}$ to $7\cdot10^7$ W/m$^2$, the area of the mentioned defects decreases 1.8-2.7 times. Study of topology of surfaces of elements before and after electron-beam processing shows that in the first case the magnitude of microroughness is 30-40 nm, and in the second case it is reduced to the level of 0.5-1.2 nm.

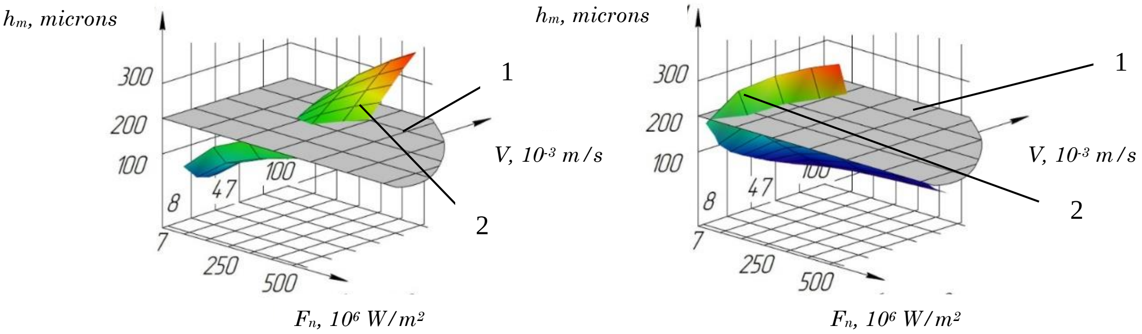
Detailed research of the surface structure of the optical glass elements by AFM methods allowed to determine the following influence of modes of electron-radiation technology on the microroughness size: increase of $F_n$ from $7\cdot10^6$ W/m$^2$ to $8\cdot10^8$ W/m$^2$ and decrease of V from $3\cdot10^{-2}$ m/s to $5\cdot10^{-3}$ m/s leads to reduction of the microroughness magnitude from 5-6 nm to 0.7-1.2 nm (Fig. 1).

The study of the surface layer structure of optical glass elements before and after electron-beam processing showed that the maximum depth of the zone of the main thermal layer or the thickness of the melted $h_m$ layer is essentially dependent on $F_n$ and $V$ (Fig. 2) and can achieve magnitude of 300-350 microns, which exceeds the maximum allowable value of $h_m^* = 100\text{-}150$ microns with some critical values of $F_{ni}^*$ and $V_{ni}^*$ ($i = 1$, 2, …), which leads to the formation of the influxes and wavelike sites on the surface of elements that results in violation of its flatness and, ultimately, to the geometric shapes violation.



a b

**Fig. 1** – Dependencies $h(F_n, V)$ for the optical glass elements TF10 (a) and BK10 (b): 1 – element not processed by electron beam; 2 – element processed by electron beam



a b

**Fig. 2** – Dependencies $h(F_n, V)$ for the optical glass elements BK10 (a) and K8 (b): 1 – maximum allowable value of $h^*$; 2 – values of $h_m$ obtained by electron beam processing

It is found, that the layers on the surface of optical glass elements modified by electron beam have changed in different degrees the chemical composition. Thus, the analysis of change of element composition of layers 10...20 microns thick on the surface of optical glass elements K8 showed reduction of Na and O concentrations, increase of Si concentration and constant K concentration. At the same time, on the example of raw and processed by electron beam optical glass elements BK10 it is shown that the noticeable quantity of changes in the chemical composition of layers on their surface is not observed, but it is possible to make a conclusion about improvement of distribution uniformity of elements in the microvolumes of surface layers after electron processing.

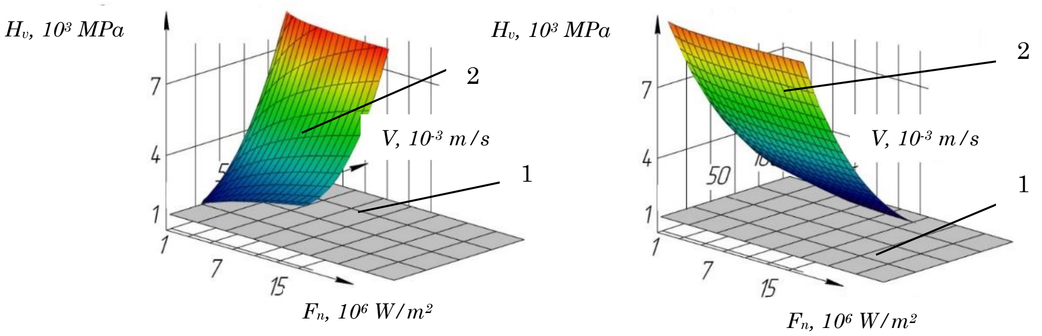
It is also determined that electron-beam processing of optical glass elements by melting leads not only to homogenization of layers, but also to the oriented adjustment near the surface of the silicon oxygen glass lattice, which becomes close to the structure of the quartz glass. This is due, mainly, to extraction of K ions, as well as other elements – modifiers at the simultaneous influence of high temperatures on the surface (up to 1200-1300 K), which leads to improvement of the stability of optical elements to the external thermal and mechanical influences.

As a result of the studies, it was shown that irrespectively of the ceramics nature (KO1, KO2, KO5) in the surface layers of elements that are processed by electron beam, with the increase of $F_n$ to $1.5 \cdot 10^7$ W/m² and of V to $2 \cdot 10^{-2}$ m/s the noticeable phase changes are not observed, but there is an increase in mosaic blocks by 3.1-7.8 times and decrease of the microdistortions of the crystalline lattice by 1.2-6.3 times. Analysis of the obtained changes in the parameters of crystalline lattices after electron-beam processing showed the presence of compressive stresses in thin surface layers of elements at the depth of 40-60 microns for the central part of the treated areas (area size $4 \cdot 10^{-2}$-$5 \cdot 10^{-2}$ m) in the considered ranges of changes in the parameters of electron beam: for optical ceramics elements KO2 up to 30-40 MPa; for optical ceramics elements KO1 up to 60-70 MPa; for optical ceramics elements KO5 up to 55-65 MPa.

The influence of modes of electron-beam technology on the microhardness $H_v$ of the surface of optical ceramics elements is determined: the increase of $F_n$ to $1.5 \cdot 10^7$ W/m² and of $V$ to $1.5 \cdot 10^{-2}$ m/s increases $H_v$ from $1.21 \cdot 10^3$-$2.86 \cdot 10^3$ MPa to $4.84 \cdot 10^3$-$7.15 \cdot 10^3$ MPa (Fig. 3).

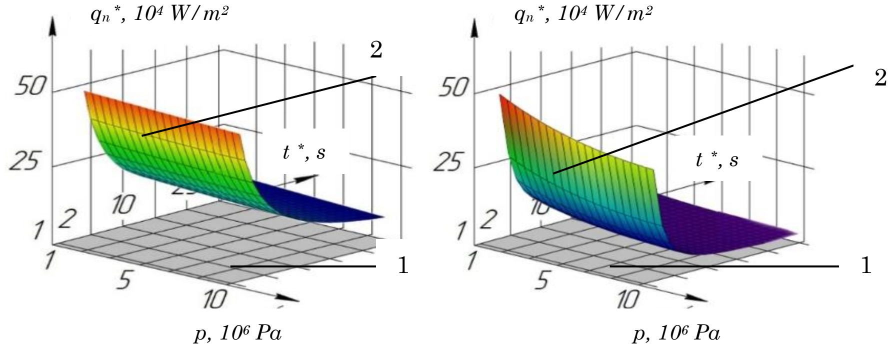
It is established, that after electron-beam processing of optical elements as a result of purity increase and reduction of microroughness of the surface by its melting, change of chemical composition and restructuring of the crystalline structure, formation of strengthened layers with the compressive stresses increase their resistance to external thermal and mechanical influences. So, when $F_{\text{п}}$ increases up to $8 \cdot 10^8$ W/m$^2$ and V up to $5 \cdot 10^{-2}$ m/s, the critical values of external heat flows grow from $0.2 \cdot 10^5$-$4.8 \cdot 10^5$ W/m$^2$ to $0.4 \cdot 10^5$-$8.7 \cdot 10^5$ W/m$^2$ for the time of their impact of 3-20 s (optical glass elements) (Fig. 4), as well as from $5.1 \cdot 10^5$-$2.6 \cdot 10^6$ W/m$^2$ to $0.7 \cdot 10^6$-$5.2 \cdot 10^6$ W/m$^2$ (optical ceramics elements) (Fig. 5).

It is also shown that critical values of thermal elastic stresses $\sigma^*$ at heating temperatures $T = 300$-$1200$ K for optical glass elements increase from 11-62 MPa to 17-115 MPa, and for optical ceramics elements from 75-115 MPa to 148-281 MPa.



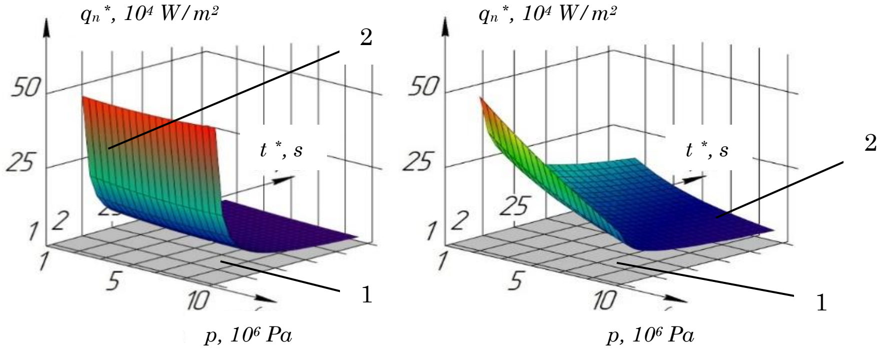
a b

**Fig. 3** – Dependencies $H_v(F_n, V)$ for the optical ceramics elements KO1 (a) and KO5 (b): 1 – element not processed by electron beam; 2 – element processed by electron beam.



a b

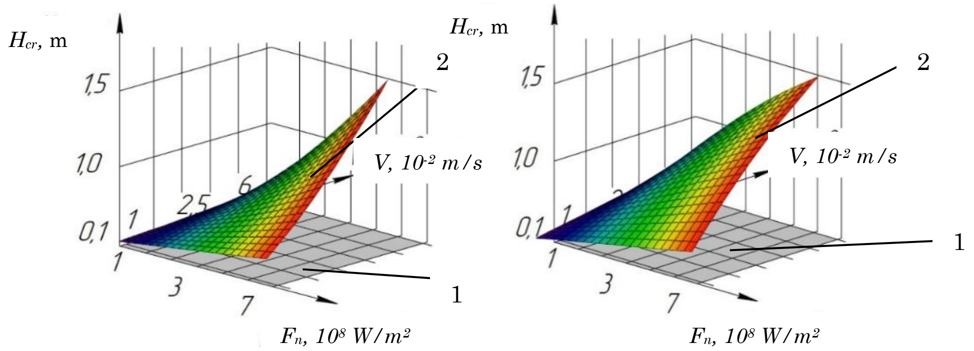
**Fig. 4** – Dependencies $q_n^*(P, t^*)$ for optical glass elements K8 (a) and TF10 (b): 1 – element not processed by electron beam and 2 – element processed by electron beam



a b

**Fig. 5** – Dependencies $q_n^*(P, t^*)$ for optical ceramics elements KO1 (a) and KO5 (b):1 – element not processed by electron beam; 2 – element processed by electron beam

In addition, test analysis of optical ceramics elements, which are strengthened with electron beam by standard technique (finding the boundary values of the critical height $H_{cr}$, from which the steel ball ($d = 4 \cdot 10^{-3}$-$5 \cdot 10^{-3}$ m) falls free, destroys the top of the item (immersion of cracks, chips) showed that at the beam parameters $F_n = 10^8$-$5.5 \cdot 10^8$ W/m$^2$ and $V = 10^{-2}$-$5 \cdot 10^{-2}$ m/s, the critical height, from which the steel ball drops, which destroys the surface of the element, is: for raw elements $H_{cr} = 0.18$-$1.1$ m, and for processed – $H_{cr} = 0.37$-$1.35$ m, that is, for the elements, which are processed by electron beam, the value of the $H_{cr}$ 1.4-3 times exceed the value for raw elements (Fig. 6).



a b

**Fig. 6** – Dependencies $H_{cr}$ ($F_n$, $V$) for optical ceramics elements KO1 (a) and KO2 (b): 1 – element not processed by electron beam; 2 – element processed by electron beam

The influence of electron-beam technology modes on the spectral coefficient of optical elements $k_\lambda$ ($\lambda$ – wavelength) is determined as follows: with the increase of $F_n$ to $8 \cdot 10^8$ W/m$^2$ and the decrease of V to $5 \cdot 10^{-3}$ m/s there is an increase of $k_\lambda$ of 4-6 % for optical glass elements (the IR-transparency range from 0.76 microns to 2.25 microns) and by 5-7 % – for optical ceramics elements (the IR-transparency range from 0.76 microns to 12.5 microns).

The analysis of the experimental researches allowed to establish the following modes of the electron beam technology, within which there is an improvement of the considered performance characteristics of optical elements (surface microhardness $H_v$, spectral transmission coefficient $k_\lambda$, resistance to external thermal and mechanical influences): $F_n = 7 \cdot 10^6$-$8 \cdot 10^8$ W/m$^2$, $V = 5 \cdot 10^{-3}$-$5 \cdot 10^{-2}$ m/s.

It is determined (Table 1) that after finishing electron beam processing of surfaces of optical elements of the devices for parameters of the beam by determined optimal ranges of their application, geometric form deviation from the established ones corresponds to those accepted in instrument making. In this case, the surface purity of optical elements in P class after electron beam treatment rises by one purity class (for example, for aerial photoshooting lenses from the VI to V class; for mirrors – from IV to III, etc.).

It is determined that the increase of $F_n$ to $8 \cdot 10^8$ W/m$^2$ and reduction of V to $5 \cdot 10^{-3}$ m/s leads to the rise in temperature of surface layers of optical elements to 1200-1300 K, which results in the increase of volume heat capacity $C_V(T)$ by 1.8-2.5 times, coefficient of heat conduction $\lambda(T)$ by 1.9-2.7 times and thermal coefficient of linear expansion $\alpha_T(T)$ by 1.1-1.2 times (Table 2).

**Table 1** – The values of tolerances on the quality indices of optical elements, which are raw and processed by electron beam ($F_n = 5 \cdot 10^7$ W/m$^2$, $V = 7 \cdot 10^{-3}$ м/c)

| Tolerances on the surface of elements by<br>Elements of opto-electronic devices | | Flexure $N_0$, $N^{processed}$ | | Form $\Delta N_0$, $\Delta N^{processed}$ | | Purity class $P_0$, $P^{processed}$ | |
|---|---|---|---|---|---|---|---|
| | | $N_0$ | $N^{proc}$ | $\Delta N_0$ | $\Delta N^{proc}$ | $P_0$ | $P^{proc}$ |
| Lenses | colmators and astronomy | 1-3 | 3 | 0.2-0.3 | 0.2 | VIII | VII |
| | airophotoshooting | 1-3 | 3 | 0.1-0.5 | 0.5 | VI | V |
| | photographic | 3-5 | 5 | 0.3-0.5 | 0.3 | VI | V |
| Glasses, magnifiers | | 3-5 | 3 | 0.5-0.1 | 0.5 | V | IV |
| Prisms | displaying | 0.5-1 | 0.5 | 0.1-0.3 | 0.1 | III | II |
| | refracting | 2-4 | 2 | 0.5-1 | 0.5 | IV | III |
| Filters opposite and behind glasses | | 5-10 | 5 | 0.8-2 | 0.8 | III | II |

Note. The following designations are adopted: $N_0$, $\Delta N_0$, $P_0$, $N^{proc}$, $\Delta N^{proc}$ and $P^{proc}$ that are the values of the quality indices of raw and processed by electron beam optical elements, respectively.

In conclusion, it is necessary to note, that the obtained experimental research results and developed on their basis methods of improvement of performance characteristics of optical elements have found a practical application and introduction in a wide range of Ukrainian enterprises (Special instrument-making enterprise "Arsenal", V.E. Lashkaryov Institute of Semiconductor Physics of NAS of Ukraine (Kyiv), PJSC "Avikos" (Lviv), State Enterprise Research and Production Complex "Photoprylad" and SPPB "Fotonika Plus" (Cherkassy), which allowed to increase the accuracy and broaden measurement ranges of impulsive range finders for 7-15 %; to increase the probability of flawless performance of optical fairings of infrared guidance and observation devices and fiber-optic beam guides of laser medical devices while performing at 10-20 %.

**Table 2** – Change ranges of thermal physical characteristics of optical elements on heating temperatures $T = 300$-$1300$ K influenced by electron beam

| Optical material / Thermal and physical characteristics | K8 | BK10 | TF10 | KO1 | KO2 | KO5 |
|---|---|---|---|---|---|---|
| $C_V \cdot 10^{-6}$, J/m$^3$·K | 1.71-3.37 | 1.77-3.65 | 1.80-3.91 | 0.73-1.52 | 2.1-4.8 | 1.44-3.89 |
| $\lambda$, Wt/m·K | 1.05-2.03 | 1.15-2.39 | 0.67-1.13 | 15.1-31.5 | 17.1-42.5 | 44.3-93.1 |
| $\alpha_T \cdot 10^6$, K$^{-1}$ | 7.6-9.1 | 6.8-8.5 | 7.8-10.2 | 11.7-17.3 | 9.7-13.6 | 10.8-14.1 |

## 4. CONCLUSIONS

1. New influence regularities of modes of electron-beam processing on quantitative displays of surface layers quality of optical glass and ceramics elements are established:

– the surface of optical glass elements is completely cleared of defects (cracks, scratches, etc.), which were obtained at their mechanical polishing; at the same time, there is an increase of purity class, the reduction of microroughness to 0.4-1.3 nm;

– in the optical glass elements there is a surface melting at the depth of up to 130-220 microns, while the flatness is not violated; homogenization of the chemical composition of hydrolysis products is realized, as well as approximate restructuring near the surface of the silicon-oxygen lattice of the glass, which becomes close to the structure of quartz glass;

– in the optical ceramics elements there appear compression tensions up to 30-70 MPa in strengthened surface layers of 90-210 microns thick.

2. For the first time modes of electron-beam technology are found (thermal impact density $F_n = 7 \cdot 10^6$-$8 \cdot 10^8$ W/m$^2$, travel speed of electron beam $V = 5 \cdot 10^{-3}$-$5 \cdot 10^{-2}$ m/s), within which there is an improvement of the performance characteristics of optical elements:

– increase of microhardness of the surface of optical ceramics elements from $1.21 \cdot 10^3$-$2.86 \cdot 10^3$ MPa to $4.84 \cdot 10^3$-$7.15 \cdot 10^3$ MPa and increase of the spectral coefficient of IR-radiation by 4-6 % for optical glass elements and by 5-7 % – for optical ceramics elements;

– there is an increase in critical values of external heat flow, which leads to the destruction of elements by 1.5-2 times, while the increase of external pressure to $10^7$ Pa reduces the specified critical values by 1.3-1.5 times; critical values of thermoelastic stresses in optical elements at heating temperatures 300-1200 K increase by 1.5-2.5 times, indicating the increase of resistance to thermal impacts and elevated external pressure of optical elements processed by electron beam;

– the values of the critical heights of the fall of steel balls on their surface, leading to the destruction of elements, increase from 0.18-1.1 m to 0.37-1.35 m, i.e. increases their resistance to mechanical shocks.

3. For the first time it is determined that the increase of $F_n$ to $8 \cdot 10^8$ W/m$^2$ and reduction of V to $5 \cdot 10^{-3}$ m/s leads to the temperature increase of surface layers of optical elements to 1200-1300 K, which results in the increase of volume heat capacity $C_V(T)$ by 1.8-2.5 times, thermal conductivity coefficient $\lambda(T)$ by 1.9-2.7 times, and thermal coefficient of linear expansion $\alpha_T(T)$ by 1.1-1.2 times.

## REFERENCES

1. V.A. Vashchenko, I.V. Yatsenko, Y.G. Lega, O.V. Kirichenko, *Osnovy elektronnoi pbrobky vyrobiv z optychnych materialiv [The basics of electronic processing of optical materials]* (Kiev: Naukova Dumka: 2011) [In Russian].
2. A.R. Glushchenko, V.I. Gordienko, A.V. Burak, Y.A. Denisenko, *Tankovye nochnye sistemy i pribory nabludeniya [Tank night systems and surveillance devices]* (Kiyv: Photoprylad: 2007) [In Ukrainian].
3. I.V. Yatsenko, V.S. Antonyuk, V.A. Vashchenko, V.V. Tsybulin, *J. Nano- Electron. Phys.* **8**(1), 01027 (2016),
4. V. Yatsenko, V.S. Antonyuk, V.I. Gordienko, V.A. Vashchenko, O.V. Kirichenko *J. Nano- Electron. Phys.* **9**(1), 01010 (2017).
5. I.V. Yatsenko, *Journal of Multidisciplinary Engineering Science Studies (JMESS)* **3**(5), 1764 (2017).
6. I.V. Yatsenko, V.S. Antonyuk, V.I. Gordienko, V.A. Vashchenko, O.V. Kirichenko *J. Nano- Electron. Phys.* **10**(4), 04028 (2018).

# Закономірності впливу режимів електронно-променевої технології на експлуатаційні характеристики оптичних елементів

І.В. Яценко[1], В.С. Антонюк[2], В.А. Ващенко[1], О.В. Кириченко[3], О.М. Тищенко[3]

[1] *Черкаський державний технологічний університет, бул. Шевченка, 460, 18030, Черкаси, Україна*
[2] *Національний технічний університет «Київський політехнічний інститут імені Ігоря Сікорського», проспект Перемоги, 37, 03056, Київ, Україна*
[3] *Черкаський інститут пожежної безпеки ім. Героїв Чорнобиля Національного університету цивільного захисту України, вул. Оноприєнка, 8, 18034, Черкаси, Україна*

Проведено експериментальні дослідження та встановлено нові закономірності впливу режимів електронно-променевої обробки на кількісні показники якості поверхневих шарів елементів з оптичного скла та кераміки: чистоту та гладкість поверхні – поверхня елементів з оптичного скла повністю очищується від дефектів, при цьому відбувається підвищення класу чистоти, зменшення мікрошорсткості до 0.4-1.3 нм; товщину оплавленого шару; зміну структури та хімічного складу; стискаючі напруження та товщину зміцнених шарів – у елементах з оптичної кераміки виникають стискаючі напруження до 30-70 МПа у зміцнених поверхневих шарах товщиною 90-210 мкм. Знайдено оптимальні режими електронно-променевої технології (густини теплового впливу $7 \cdot 10^6$-$8 \cdot 10^8$ Вт/м$^2$ електронного променю, швидкості його переміщення $5 \cdot 10^{-3}$-$5 \cdot 10^{-2}$ м/с), які покращують експлуатаційні характеристики оптичних елементів: збільшення мікротвердості поверхні та підвищення міцності поверхневих шарів, а також спектрального коефіцієнта пропускання; підвищення стійкості елементів до зовнішніх термічних та механічних впливів при їх експлуатації. При цьому відбувається збільшення температури поверхневих шарів елементів та підвищення їх теплофізичних властивостей: об'ємної теплоємності, коефіцієнта теплопровідності, термічного коефіцієнта лінійного розширення. Отримані результати експериментальних досліджень, а також розроблені на їх основі методи покращення експлуатаційних характеристик оптичних елементів, знайшли практичне використанням та впровадження на цілому ряді підприємств України, що дозволило підвищити точність та розширити діапазони вимірювання дальності імпульсних лазерних далекомірів на 7-15 %; збільшити ймовірність безвідмовної роботи оптичних обтічників ІЧ-приладів наведення і спостереження та волоконно-оптичних світловодів лазерних медичних приладів при експлуатації на 10-20 %.

**Ключові слова**: Оптико-електронні прилади, Оптичне скло, Оптична кераміка, Електронний промінь, Експлуатаційні характеристики.