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Improvement of Performance Characteristics of Optical Elements by Using Finishing Electron Beam Treatment

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Abstract
The optimal parameters of the electron beam ranges are found (heat density $F_n = 7 \cdot 10^6 ... 8 \cdot 10^8$ Wt/m^2 and travel speed $V = 5 \cdot 10^{-3} ... 5 \cdot 10^{-2}$ m/s), within which there is improvement of performance characteristics of optical elements: the area occupied by negative defects reduces in 1,8…2,7 times and its purity increases, the flatness remains; residual microroughnesses decrease from 30…40 nm to 0,5…1,2 nm on it; its microhardness increases in в 1,3…1,7 times and the hardened layers 210…230 μm thick are formed; there comes the change of layers structure and their homogenization, silicon-oxygen grid becomes closer to quartz glass, the light scattering coefficient reduces by 10…30 %, and coefficient of infrared radiation transmittance increases up to 2…5 %; the resistance of the elements to the external thermal and mechanical effects is increased.

Keywords: Optical electronic devices, optical glass, optical ceramics, electron beam, performance characteristics

Introduction
The use of modern optical electronic devices, which are constantly expanding, arise an acute problem of increasing of their effectiveness under extreme conditions.
The optical parts of the instruments under these conditions are subjected to intensive thermal and mechanical effects (elevated heating temperatures, external pressures, shock thermal actions under the conditions of supersonic airflow and axisymmetric rotation, etc.).
These external influences result in the formation of cracks, chipsing, wavinesses on the surface of the optical parts and their surface layers, which violate their flatness, and the appearance of other negative defects. At the same time, the performance characteristics of optical elements get worse, that affect the accuracy and measurement ranges of optical-electronic devices during their exploitation under the conditions of external thermal actions [1-6].
Existing methods of improving of the performance characteristics of the optical-electronic devices (laser rangefinders the target complexes, laser medical devices, infrared devices of homing and tracking, space and aerospace mirrors, etc.) do not always provide their normative values, especially under extreme performance conditions.
New possibilities for improving the performance of optical elements of appliances are being opened by a deliberate modification of the physical and mechanical properties of their surface layers by modifying them. One of the efficient methods of surface processing of optical materials is a moving electron beam, which allows the modification of surface layers of optical elements by altering their performance, accuracy and ranges of measurements of devices [7-13].
Phenomena related to the influence of the technological parameters of the formation and performance of the optical elements of devices are not fully studied or systematized.
This makes it relevant to develop methods of managing the properties of the work surfaces of the optical elements of devices through the use of electron beam finishing methods that improve their performance, as well as to increase accuracy, expand ranges of measurement and improve the reliability of appliance performance in the context of intensive external

thermal actions.

Thus the purpose of this work is to improve the performance of the elements of the optic-electronic devices by their finishing electron beam treatment.

Materials and methods

For the investigation of influence of the electron beam parameters on the performance characteristics of elements from optical glasses (K8, K208, BK10) and ceramics (KO1, KO2, KO3, KO5, KO12) they used discs with diameter $3\cdot10^{-2}…5\cdot10^{-2}$ m and thickness $4\cdot10^{-3}…6\cdot10^{-3}$ m [8, 14].

For experimental studies modern methods of physico-chemical analysis were used [14 - 16]: methods of scanning electron microscopy (SEM) and transemission electron microscopy (TEM) to study surface structure and surface layers of optical elements, as well as to determine the thickness of melted layers; methods of atomic force microscopy (AFM) and micro identification by Vickers for the measurement of the residual voids on the surface of optical elements, as well as its microhardness; shooting techniques in x-rays of diffractometers DRONE 2.0 and DRONE 3.0 for measurements of thermal stresses in the surface layers of optical elements; wave dispersion techniques to analyze the elemental composition of surface layers of parts; spectrophotometric methods to measure the coefficients of diffusion and transmission of infrared waves of details.

For finish electron beam processing of surface layers of optical elements aiming to improve performance characteristics advanced installation was used in the part of developed tooling for automated measurement and control of temperature of the processed surface, as well as sensing the electron beam, which is protected by patents of Ukraine (№ 57551, № 91523) (fig. 1).

In the result of the research on sensing of the electron beam by the known method of rotary probe the following empirical dependencies on density of thermal influence in its center from managed parameters of electron beam installation (relative accuracy of 5…8%) were found out:

$$F_n(I_л, V_л, l) = \sqrt{\frac{k_0(I_л, l)}{\pi}} \cdot \frac{I_л \cdot V_y}{B \cdot erf\left[b(I_л, l) \cdot \sqrt{k_0(I_л, l)}\right]} \quad (1)$$

$$k_0(I_л, l) = 1{,}237\cdot10^{7} - 6{,}587\cdot10^{5} l - 3{,}725\cdot10^{4} I_л + 1{,}518\cdot10^{2} I_л l, \quad (2)$$

$$b(I_л, l) \frac{1{,}75}{\sqrt{k_0(I_л, l)}}, \quad (3)$$

where k_0, $2b$ is concentration ratio (severity of the thermal pulse) and the thickness of the electron beam, m; $I_л$ – beam current, mA; V_y – external voltage, kV; l – the distance from the processed surface of the optical element, m.

It is determined that for working change ranges of stated installation parameters ($I_л$ = 50…300 mA, V_y = 6...8 kV;, l = 0,04...0,08 m) the following change ranges of energetic characteristics of electron beam are realized: k_0 = $(0{,}5…5)\cdot10^{7}$ m^{-2}; $2b$ = $(0{,}5…1{,}5)\cdot10^{-3}$ m; F_n = $10^{6}…10^{9}$ Wt/m^2. At that travel speed of the beam was changed within ranges V = 0…0,1 m/s.

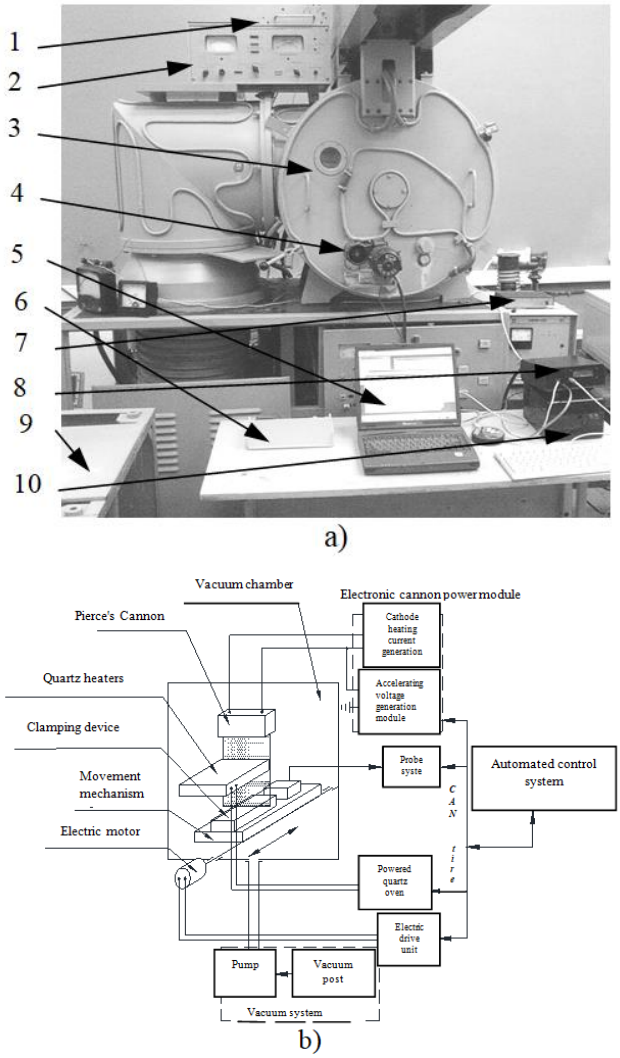


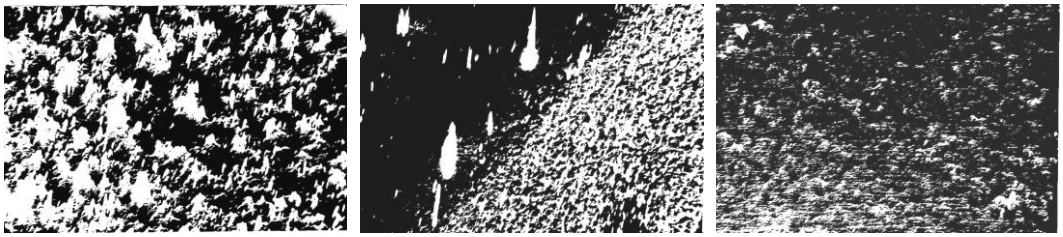
Fig. 1: Appearance (a) and schema (b) of installation for the finishing electron-beam processing of optical elements, which improves their performance: 1 – vacuum gauge magnetic locking VMB-8 (ВМБ-8) ; 2 – gauge ionized-thermocouple VIT-3(ВИТ-3); 3 – vacuum chamber; 4 - electric mechanism of transfer of optical elements; 5 – PC control of installation; 6 – modules of temperature measurement in the treatment area and sensing electronic flow; 7 – thermal management system of optical elements based on device RIF-101 (РИФ-101); 8 – central unit of automatic control system; 9 – power supply and control system of electronic Pierce's cannon; 10 – electric motor control.

Results & Discussion

Electron-microscopic studies of surfaces of optical glass elements showed that the number of negative defects (cracks, scratches, bubbles etc.) decreases in 2…4 times, and the area occupied by them – in 1,8…2,7 times (fig. 2, 3).

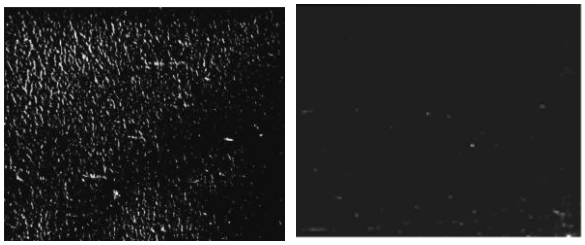
Study of the skanogramms of grinding surfaces from elements' chipping before and after electron beam processing, show that in the first case the height of microroughnesses is 30 ...40 nm, and in the second it is reduced to 0,5...1,2 nm.

The influence of parameters of electron beam on the height of residual microroughnesses is determined: increase of the thickness of thermal action of electron beam F_n from 10^{7} Wt/m^2 to $8{,}5\cdot10^{7}$ Wt/m^2 for the speed of its travel V = $8\cdot10^{-3}$...$5\cdot10^{-2}$ m/s leads to the reduce of the height of residual microroughnesses from 3...5 nm до 1,0...1,5 nm (fig. 4 at V = $5\cdot10^{-2}$ m/s (1); V = $8\cdot10^{-3}$ m/s (2)).



a) b) c)

Fig. 2: Scans of the detail surface made of optical glass K208: a) K208 glass surface before electron-beam treatment, Y-modulation × 610; b) K208 glass surface at impact border electron-beam treatment, Y-modulation × 122; c) K208 glass surface after electron-beam treatment, Y-modulation × 610.



a) b)

Fig. 3: Topogram of elements surface from optical glass BK-10 (БК-10): a) BK-10 glass surface after mechanical polishing, × 2500; b) BK-10 glass surface after treatment by electron flow, × 2500.

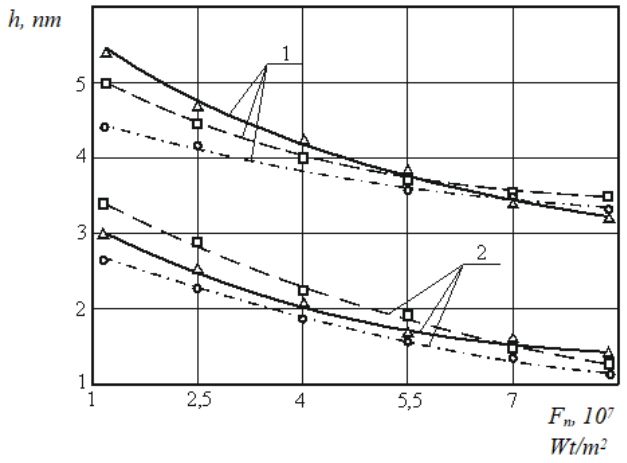


Fig. 4: Height dependence of residual microroughnesses on the surface of elements of optical glass K8 (——), TF110 (ТФ110) (– – –) and BK10 (БК10) (– · – ·) from the density of heat effect of electron beam for its different travel speeds: $V = 5 \cdot 10^{-2}$ m/s (1); $V = 8 \cdot 10^{-3}$ m/s (2) (Δ, ○, □ – experimental data).

It has been established that the maximum thickness of melted layer h_m can reach values 250 ... 300 μm, that may exceed the maximum allowable quantities h^* = 150...200 μm, which leads to violation of flatness and geometric shape of the optical element (fig. 5 for elements from optical glass BK10 (БК10) (1) and (2) TF110 (ТФ110) at heat density values $F_n = 5 \cdot 10^8$ Wt/m^2 and $F_n = 3 \cdot 10^8$ Wt/m^2)).

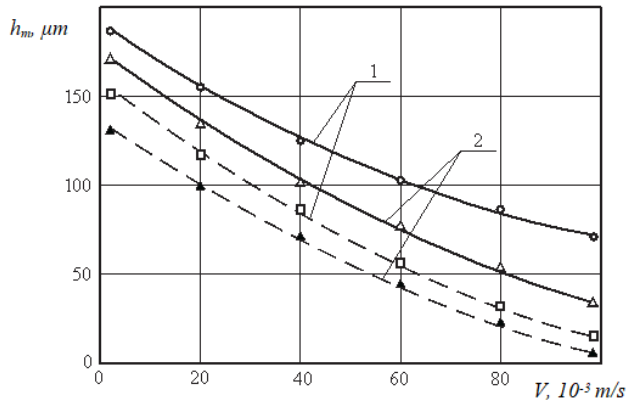


Fig. 5: The dependence of maximum thickness of melted layer in elements of optical glass BK10 (БК10) (1) and TF110 (ТФ110) (2) at $F_n = 5 \cdot 10^8$ Wt/m^2 (——) and $F_n = 3 \cdot 10^8$ Wt/m^2 (– – –) from travelling speed of electron stream (Δ, ○, □, ▲ – experimental data).

In this case, the value h_m significantly depends on the F_n and its travel speed V: increase of F_n from $7 \cdot 10^6$ Wt/m^2 to $8 \cdot 10^8$ Wt/m^2 leads to an increase in the thickness of melted layer from 25 μm up to 230 μm; increase in running speed of the electron beam from 10^{-3} m/s до 10^{-2} m/s leads already to reduction of the depth of melting from 200 μm to 30 μm.

It is found out that the electron beam generated surface layers of elements from optical glass have chemically changed structure. Thus, the analysis of the change of elemental composition of detail surface layers (up to 20…40 μm thick) made of glasses K8, K108, K208, which was lead with the help of wave dispersion spectrometer, showed the reduced concentration of Na and O, decrease of Si concentration and the stability of K concentration (fig. 6, 7). At the same time, the X-ray analysis method shows, in the case of the raw elements from glass BK10 and processed by electronic beam, that there isn't observed any appreciable quantitative change in

the chemical composition of layers, but it can be concluded that the homogeneity of the distribution of elements in the microvolumes of the surface layers of elements is improved after electronic treatment (fig. 8, 9).

It is also established that the electron beam treatment of elements from the optical glass by welding results not only in the homogenization of the surface, but also in the oriented restructuring of the surface of the silicon-oxygen grid of glass close to the structure of the quartz glass. This is mainly due to the removal of the K ions, as well as other elements-modifiers at the simultaneous effects of high temperatures on the surface up to 1300 ... 1600 K.

Electron microscopic analysis of the images of surfaces and cross thin sections of elements from optical ceramics before and after electron beam treatment (fig. 10, 11) shows that there is a noticeable change in structure at the depth of the element (up to 200 … 250 μm). In this case, the gross relief of deformed origin with elements of "viscous" destruction is evident, indicating the ability of the material to resist destruction under mechanical influence.

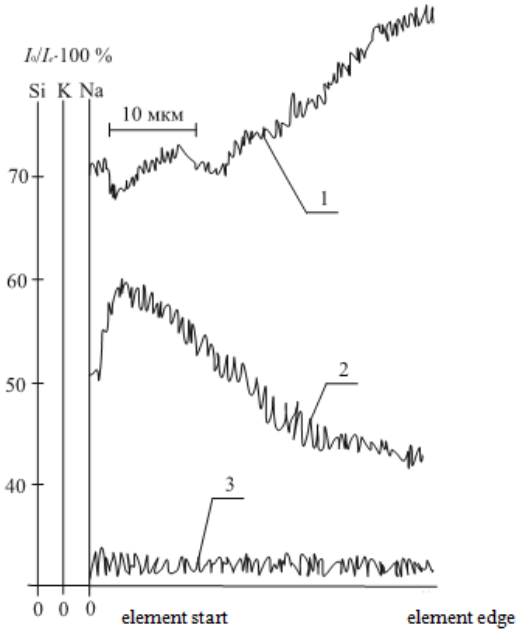
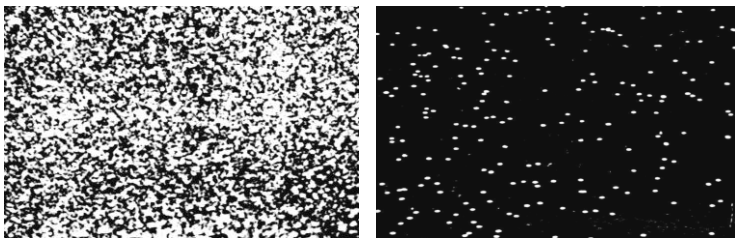


Fig. 6: Concentration distributions of elements on the surface of elements from the optical glass K108 after electronic treatment: 1 – Si·10^4, imp/sec; 2 – Na·10^3, imp/sec; 3 – K·10^2, imp/sec.



a) b)

Fig. 7: Concentration distribution O_{κ_α} on the surface of elements from the optical glass K108: a) – before electron treatment; b) –after electron treatment.

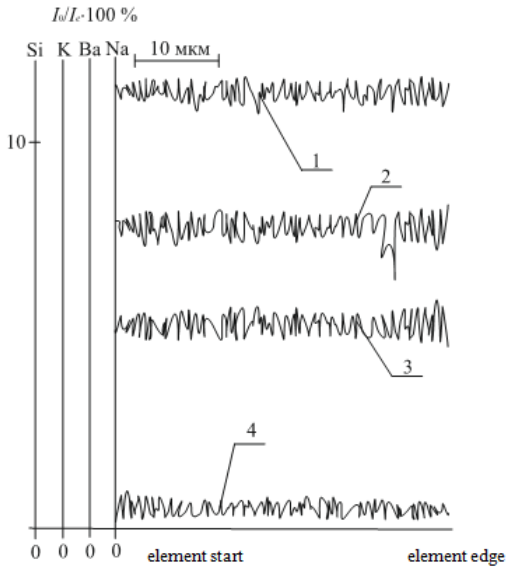


Fig. 8: Concentration distribution of elements on the surface of elements from optical glass ВК10 (БК10) before electron treatment: 1 – Si, imp/sec; 2 – K·10^3, imp/sec; 3 – Ba·10^3, imp/sec; 4 – Na·10^2, imp/sec.

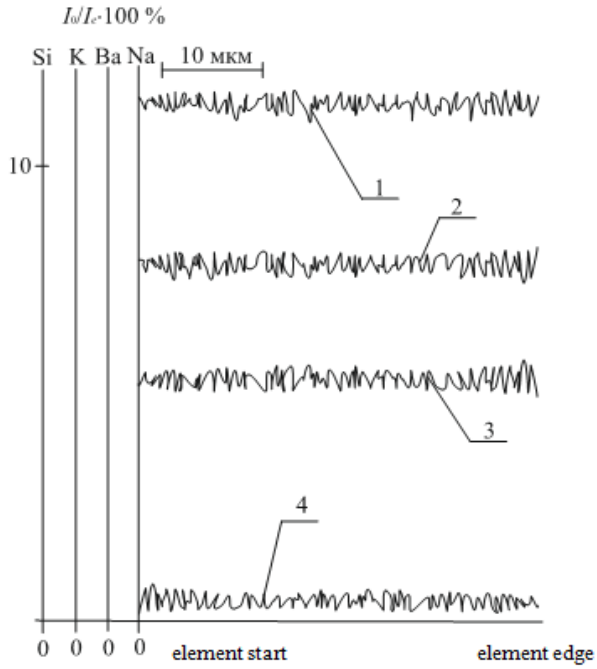
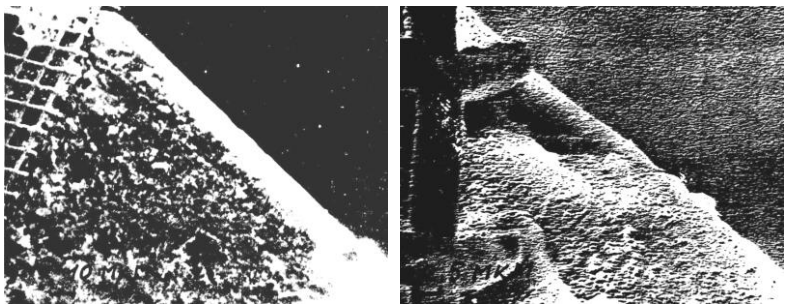


Fig. 9: Concentration distribution of elements on the surface of elements from optical glass ВК10 (БК10) after electron treatment: 1 – Si, imp/sec; 2 – K·10^3, imp/sec; 3 – Ba·10^3, imp/sec; 4 – Na·10^2, imp/sec.



a) b)

Fig. 10: Images of failure pattern of elements from optical ceramics KO1 in secondary electrons after electron treatment: a) – area of electron beam effect, × 400; b) area of electron beam effect, × 2800, Y-modulation.

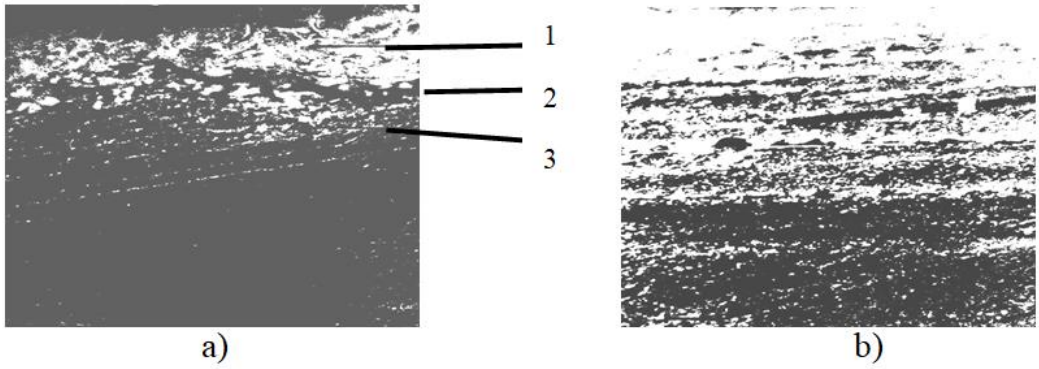


Fig. 11: Microstructure of etched section of chip of elements from optical ceramics KO2 after electron treatment: a – area of electron beam effect, × 130 (1 – plastic, 2 – space, 3 – affected area); b - area of electron beam effect, ×350.

It is determined that electron beam action on the elements from optical ceramics (F_n = 10^6...$2{\cdot}10^7$ Wt/m^2, V = 10^{-3}...$2{\cdot}10^{-2}$ m/s) leads to the increase of microhardness of its surface depending on electron beam parameters: increase of F_n of 10^6 Wt/m^2 to $1{,}5{\cdot}10^7$ Wt/m^2 leads to the increase of surface microhardness of ceramics in 1,5...1,7 times and decrease of V from $1{,}5{\cdot}10^{-2}$ m/s до 10^{-3} m/s leads to the increase of surface microhardness of ceramics in 1,3…1,4 times (fig. 12).

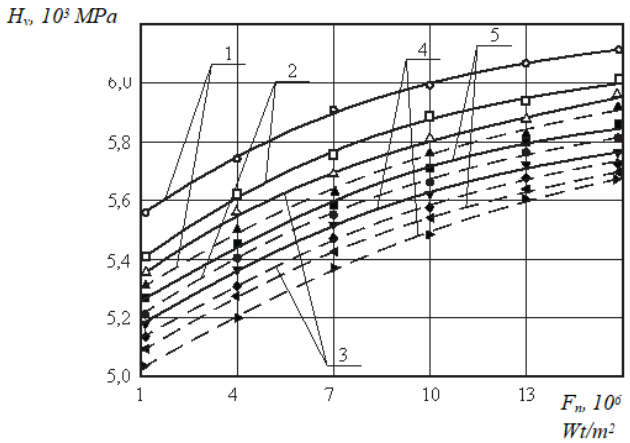


Fig. 12: Dependence of microhardness of elemental surface from optical ceramics KO12 (1), KO2 (2), KO1 (3), KO5 (4) и KO3 (5) at $V = 7{\cdot}10^{-3}$ m/s (———) and $V = 1{,}5{\cdot}10^{-2}$ m/s (– – –) from the density of thermal action of electron beam (Δ, ○, □, ▲, ■, ♦, ▼, ●, ►, ◄ – experimental data).

It is determined that the thickness of hardened layer (Δ), where there are major structural changes, and the microhardness of the processed material increases, changes in the ranges from 70...90 μm to 210...230 μm at the thickness of processed units $4...6{\cdot}10^{-3}$ m (fig.13).

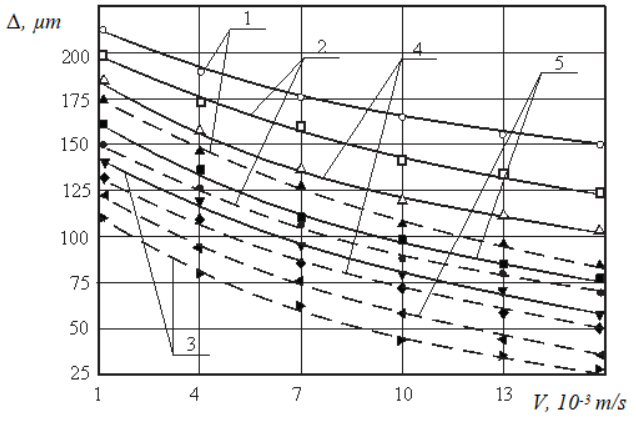


Fig. 13: Dependence of hardened layers of elements from optical ceramics KO12 (1), KO2 (2), KO1 (3), KO3 (4) and KO5 (5) at F_n = $1{,}5{\cdot}10^7$ Wt/m^2 (———) and $F_n = 2{\cdot}10^6$ Wt/m^2 (– – –) from travel speed of electron beam (Δ, ○, □, ▲, ■, ♦, ▼, ●, ►, ◄ – experimental data).

Value Δ depends on the parameters of electron beam: increase of F_n from 10^6 Wt/m^2 to $2{\cdot}10^7$ Wt/m^2 leads to an increase of the thickness of hardened layer in 1,8...2,6 times, and the increase of beam travel speed from $1{,}5{\cdot}10^{-3}$ m/s to $2{\cdot}10^{-2}$ m/s leads to the reduction of the thickness of the hardened layer in 1,7...2,5 times.

It is shown, that irrespective of the ceramics nature (KO1, KO2, KO3, KO12, KO5) in the surface layers of elements, that are processed by electron beam, for the observed ranges of change of the thickness of thermal action (to $1{,}5{\cdot}10^7$ Wt/m^2) and travel speed (to $2{\cdot}10^{-2}$ m/s) noticeable

phase changes are not observed, but the increase in the size of crystalline granules takes place. With relative extension of the lines in X-ray patterns it is established that, almost independently of the crystallographic directions in the crystalline lattices of the ceramics after electron beam treatment there appears a noticeable change of micro-distortions and sizes of the mosaic blocks (table 1).

Data of table 1 shows that the impact of an electron beam on the surface of elements from optical ceramics results in an increase of mosaic blocks in 3,3 ... 7,7 times and decrease of micro-distortions crystalline lattices in 3,7 ... 5.9 times.

Table 1: The results of processing of experimental data on the extension of lines on radiographs, mosaic block sizes (D) and change in the settings of a crystalline lattice ($F_n = 3 \cdot 10^6$ Wt/m^2, $V = 3 \cdot 10^{-3}$ m/s)

Parameters	**Element before treatment**			
	Physical expansion of the two lines		Block size D, $\dot{A}$	Change in the settings of a crystalline lattice $\frac{\Delta d}{d} \cdot 10^{-4}$
Ceramics	$\beta_1 \cdot 10^{-3}$, rad	$\beta_2 \cdot 10^{-3}$, rad		
KO1	1,472	1,734	1150	3,421
KO2	1,283	1,452	980	1,643
KO12	1,514	1,812	1240	3,810
KO3	1,120	1,320	890	1,225
KO5	1,132	1,289	760	1,117
Element after treatment				
KO1	0,687	0,231	4430	0,873
KO2	0,321	0,108	5250	0,291
KO12	0,746	0,254	4110	0,992
KO3	0,224	0,986	4210	0,193
KO5	0,589	0,637	5850	0,987

It has been established that, regardless of the technological treatment regimens of the elements from optical ceramics, there is always an increase in the size of the mosaic blocks and a reduction of micro-distortions of their crystalline lattices, that means that electronic treatment produces more coarse-grained surface layers with compressive stresses in the crystalline lattices.

In the result of conducted studies it has been established (fig.14, 15) that in the case of electron beam treatment of optical elements the increase of such an important characteristic as IR transmission coefficient k_λ *(λ)* takes place (λ – wave length, error not more than $5 \cdot 10^{-3}$) for all the ranges of IR transparency of details (table 2).

Thus, values k_λ increase in 2 …3% for the elements from optical glass K8 and BK10 (БК10), and for the details of elements from optical ceramics БК10 in 4…5 %; at the same time values k_λ for the elements from optical ceramics KO3 и KO12 do not change.

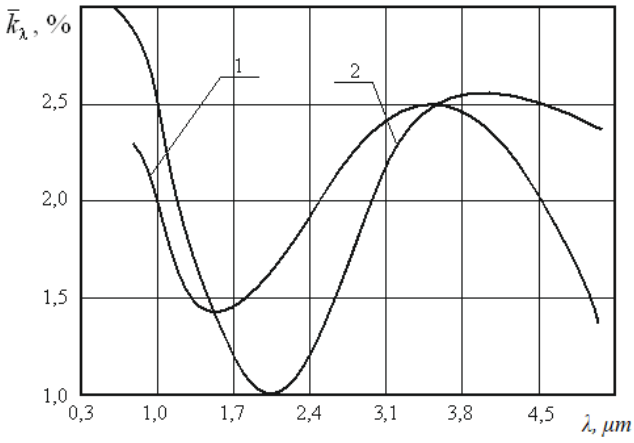


Fig. 14: Dependence of relative coefficient of IR-radiation transmission of optical elements from glasses K8 (1) and BK10 (2) (thickness of the flat layer of element $H = 4 \cdot 10^{-3}$ *m*; $T_0 = 300$ *K*; $F_n = 1{,}5 \cdot 10^7$ *Wt/m*^{2}, $V = 7 \cdot 10^{-3}$ *m/s*) from wave length.

$\bar{k}_\lambda = \frac{k_\lambda^{обр}}{k_{\lambda 0}}$, where $k_\lambda^{обр}$ – coefficient meaning k_λ after electron beam treatment; $k_{\lambda 0}$ – its meaning before electron beam treatment; $F_n = 1{,}5 \cdot 10^7$ *Wt/m*^{2}, $V = 7 \cdot 10^{-3}$ *m/s*) from wave length.

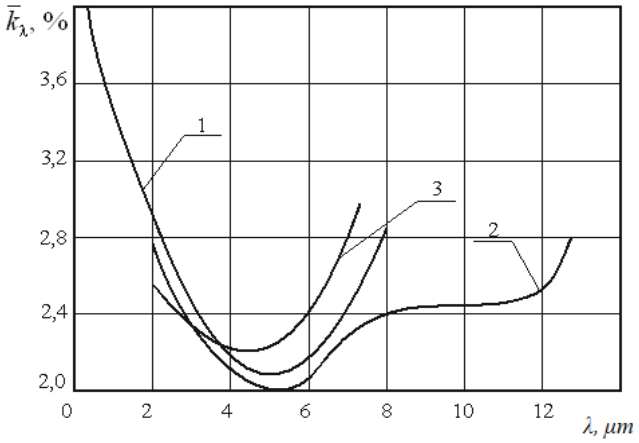


Fig.15: Dependence of relative coefficient of IR-radiation transmission of optical elements from ceramics KO5 (1), KO2 (2) и KO1 (3) (thickness of the flat layer of element $H = 10^{-2}$ *m*; $T_0 = 300$ *K*; $F_n = 1{,}5 \cdot 10^7$ *Wt/m*^{2}, $V = 7 \cdot 10^{-3}$ *m/s*) from wave length.

The increase of IR transmission coefficient for elements from optical glass is due to the reduction in the number and size of negative defects on the surface and in the surface layers (scratches, cracks, pimples, bubbles, depression, etc.) when they are melted under the influence of the electron beam.

In the result there is reduction of the residual microroughnesses of h (nm) on their surfaces and to increase of the depth of the melting h_m (μm) to the maximum allowable h^* values. Therefore, there is a one-to-one correspondence between the k_λ coefficient and such important performance characteristics of the surface layers of elements as h and h_m, which are presented in Fig. 16.

Table 2: IR transparencies areas of optical elements $\Delta\lambda = \lambda_2 - \lambda_1$ (at $H = 4 \cdot 10^{-3}$ m – for optical glass and $H = 10^{-2}$ m – for optical ceramics)

Element material / $\Delta\lambda$, μm	К8,ВК10	КО1	КО2	КО5
$\Delta\lambda = \lambda_2 - \lambda_1$, μm	5 – 0,76	7 – 2	12,5 – 2	8 – 0,76

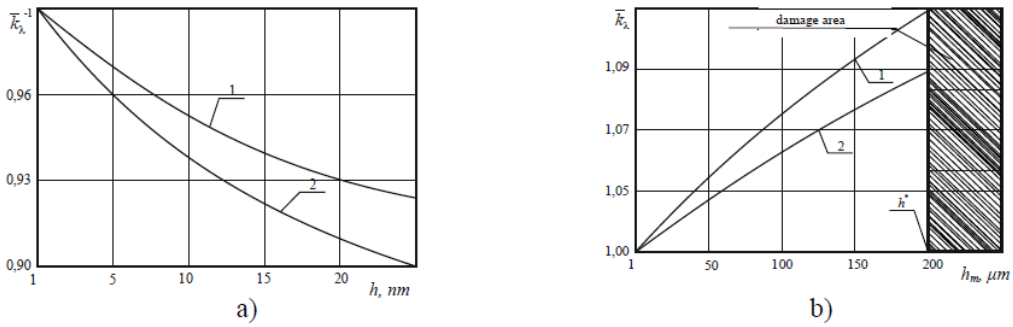


Fig. 16: Influence of residual microroughnesses h (a) and the thickness of melted layer h_m (b) on the value $\bar{k}_\lambda$ for the elements from optical glass BK10 (1) and K8 (2) (λ = 1,06 μm).

For items from optical ceramics the increase of $\bar{k}_\lambda$ occurs as a result of the structural changes of the surface layers (increasing sizes of mosaic blocks, layers become more compact, etc.), resulting in an increase of microhardness of their surfaces H_v and the formation of hardened layers having thickness Δ.

Therefore, there is also a one-to-one correspondence between the coefficient $\bar{k}_\lambda$ and parameters and H_v and Δ, dependencies between which are presented in Fig. 17.

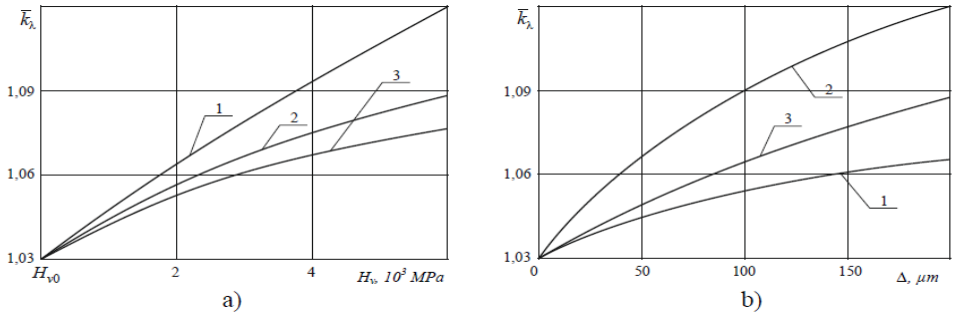


Fig. 17: Influence of microharness of the surface H_v (a) and thickness of hardened layers Δ (b) on the value $\bar{k}_\lambda$ for the elements from optical ceramics KO5 (1), KO2 (2) и KO1 (3) (λ = 2 μm).

As a result of electron-beam processing of optical elements without reflow there occurs homogenization of chemical composition of the chemical composition of hydrolysis products (dissolution of K_2O и Na_2O at depth effects of the electron beam up to 2...4 μm), which fill the defective surface layer, that remains after the standard mechanical processing, which leads to an improvement of the performance characteristics of the surface

layers of the elements, namely to the reduction of their surface light scattering coefficient (wave length λ = 632,8 nm) (fig. 18).

In the result of the studies, it was found that, in the case of electronic beam treatment of optical elements, the value of light scattering coefficient k_c is reduced by 10 ... 30 %.

The analysis of the results of the pilot studies showed that the identified improvements in the performance of optical elements are observed for the following optimal ranges of change of electron beam parameters: $F_n = 7 \cdot 10^6 \ldots 8 \cdot 10^8$ Wt/m^2, $V = 5 \cdot 10^{-3} \ldots 5 \cdot 10^{-2}$ m/s.

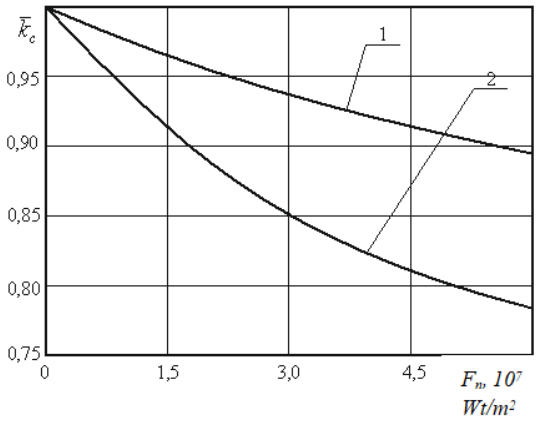


Fig. 18: Dependence of relative light scattering coefficient of working surfaces of optical elements from glasses K108 (1) and BK10 (2) from the thickness of thermal action of electron beam for different travel speeds (thickness of elemental flat layer $H = 4 \cdot 10^{-3}$ m; $T_0 = 300$ K; $\bar{k}_c = \dfrac{k_c^{обр}}{k_{c0}}$, where $k_c^{обр}$ – value k_c after electron beam treatment; k_{c0} – its value before electron beam treatment; V = $5 \cdot 10^{-3}$ m/s).

Thus, in the light of modern technologies used in optic-electronic tool engineering, electron beam treatment of optical elements is defined as potentially able to improve performance characteristics of elements of optoelectronic devices as well as getting on the surface functional micro-profiles using electronic beams which can be used as the element base in microoptics, fiberoptics and integrated optics, optoelectronics, functional electronics etc. In addition, the undeniable advantage of electron-beam technology is its environmental friendliness and ability to obtain the microparts with improved performance characteristics on a common board from optical material in a single technological cycle, the use of which in optical-electronic devices contributes to increased reliability in extreme operating conditions.

Conclusions

It is established that for optimal ranges of change of electron beam parameters (thickness of thermal action F_n = $7 \cdot 10^6 ... 8 \cdot 10^8$ Wt/m^2 and travel speed $V = 5 \cdot 10^{-3} ... 5 \cdot 10^{-2}$ m/s) improvement of performance characteristics of optical elements is observed:

- the quantity of negative defects reduces on the surface of optical elements (scratches, cracks, pimples etc.) as well as the area occupied by them in 1,8…2,7 times;
- the height of residual micro microroughnesses on the surface of elements reduces from 30…40 nm to 0,5…1,2 nm, and maximum thickness of melted layers reaches 250…300 μm;
- microhardness of the surface of elements increases in 1,3…1,7 times, hardened layers are formed to 210..230 μm thick;
- change of layer structure and their homogenization takes place, silicon-oxygen grid becomes close to the quartz glass on the depth to 20…40 μm;
- noticeable change of the structure to 200…250 μm for the elements from optical ceramics takes place, the gross relief of deformed origin with elements of "viscous" destruction is evident, mosaic in 3,3 …7,7 times and micro distortions of crystalline grids reduce in 3,7 …5,9 times;
- coefficient of light scattering reduces by 10…30% and IR radiation transmittance coefficient increases by 2..5%.

References

1. Yatsenko I. V. Influence patterns of the finishing electron beam treatment of the surface of optical parts on their physical-mechanical properties / Yatsenko I. V. // Journal of Multidisciplinary Engineering Science Studies (JMESS), ISSN: 2458-925X ,Vol. 3 Issue 5, May – 2017, Berlin, Germany. – P. 1764-1770.
2. Yatsenko I.V., Antoniuk V.S, Vashchenko V.A., Tsybulin V.V.(20016) Poperedzhennya mozhluvuh ryinyvan optuchnuh elementiv tochnogo pruladobydyvannja v ymovah zovnishnih termodij [Advance of possible destructions of optical elements of precise engineering under he conditions of external thermal actions]. Jurnal nano- ta elektronnoi fizuku, vol. 8, no. 1, pp. 01027–01032.
3. Maslov V.P. Fiziko-tehnologicheskie problem obespechenia rabototsposobnosti optoelektronnuh snsornuh priborov pri ekstremalnuh yslovijah [Physical and technological problems in ensuring the performance of optoelectronic sensors under extreme conditions]. Sensorna elektronika I mikrosustemni tehnologii, no. 1, pp 57-62.
4. V. Maslov Development of technology for joining glass-ceramics parts with zero thermal expansions // OE. – 47(2), 023401, (February 2008). – P.023401-1 – 023401-4/
5. V. Maslov Effect of the state of the surface layers on the strength of materials for optoelectronic and sensors devices // International Scientific Journal Semiconductor Physics, quantum Electronics and Optoelectronics - 2008 – V.11, No 3– P. 286 – 291.
6. Maslov V.P., Chumachkova M. M. (2008) Fizuchna model formyvannja porushenogo mehanichnoju obrobkoju poverhnevogo shary materialiv optuko elektronnuh i sensornuh pruladiv [Physical model of formation distorted by mechanical processing surface layer of the material of opto-electronic and sensor devices]. Ukrajinskij fizuchnuj zhurnal [Ukrainian physical journal], no. 10, pp 980-984.
7. Yatsenko I.V., Antoniuk V.S, Vashchenko V.A., Tsybulin V.V. (2017) Vuznachennja krutuchnuh znachen parametriv ekektronnogo promenju pru poverhnevomy oplavlenni optuchnuh elementiv tochnogo pruladobuduvannja [Determination of the critical values of parameters of electronic beam in the surface machining of optical elements in precision engineering]. Jurnal nano- ta elektronnoi fizuku, vol. 9, no. 1, pp. 01010(5).
8. Vashchenko V.A., Yatsenko I.V., Lega J.G., Kiritchenko O,V. Osnovu elektronnoji obrobku vurobiv z optuchnuh materialiv. [Basics of electron treatment of devices from optical materials]. K.: Naykova dumka, 562 p.
9. I. V. Yatsenko, “Experimental and statistical models of impact determination of the electron beam parameters on surface layers properties of optical elements in precision instruments building”, Pratsi. Odes’kyi politechnichnyi universytet, Issue 1(48), 2016, pp. 63–69.
10. I. Yatsenko, V. Antoniuk, M. Bondarenko, V. Vashchenko, “Influence of parameters by electronic ray on properties of superficial layers of optical elements of exact instrument-making”, International journal for science and innovations for the industry “Innovations in discrete productions”, ISSN 114-8907, YEAR III, ISSUE 1/2015, Sofia, pp. 13–15.
11. I. Yatsenko, V. Antoniuk, O. Kiritchenko, V. Vashchenko, “Improvement of technical and operational characteristics of devices with optical elements by preliminary electron beam treatment of their surface”, International journal for science and innovations for the industry “Machines. Technologies. Materials”, ISSN 1313-0226, YEAR X, ISSUE 6/2016, Bulgaria, pp. 47–50.
12. I. Yatsenko, V. Antoniuk, O. Kiritchenko, V. Vashchenko, V. Tsybulin, “Increasing the resistance of precision instrument-making elements from optical glass to external thermo-influences by preliminary electron-beam processing of surfaces”, International journal for science and innovations for the industry “Innovations in discrete productions” ISSN 1314-8907, YEAR IX, ISSUE 1/2016, Bulgaria, pp. 9–12.

13. I. Yatsenko, V. Antoniuk, O. Kiritchenko, V. Vashchenko, V. Tsybulin, “Improving the reliability instruments of measuring and thermal control of objects of different physical nature by the finish of electron beam processing surfaces of optical elements”, International journal for science and innovations for the industry “Innovations in discrete productions” ISSN 1314-8907, YEAR X, ISSUE 2/2016, Bulgaria, pp. 11–14.
14. Okatov M.A., Antonov E.A., Baigojin A.B. Spravochnik optika-tekhnologa [Optics-Technologist Guide]. SPb.: Politekhnika, 679 p.
15. Zverev V.A., Krivopustova E.V., Tochlina T.V. Opticheskie materialu. Ychebnoe posobie dlya konstryktorov opticheskih systemi priborov. [Optical materials. Training Guidebook for designers of optical systems and devices]. Spb.: Izdatelstvo SP NIYITMO, 243 p.
16. Viljchinskaya S.S., Lisitsun V.M. Opticheskie materialu i tekhnologii. [Optical materials and technogies]. Tomsk: Izd. Tomskogo politekhnicheskogo yniversiteta, 107 p.