НАУКОВІ ТА ПРАКТИЧНІ ПРОБЛЕМИ ВИРОБНИЦТВА ПРИЛАДІВ ТА СИСТЕМ

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IMPROVEMENT OF METROLOGICAL SPECIFICATIONS OF IMPULSE LASER RANGEFINDERS BY FINISHING ELECTRON RAY PROCESSING OF THEIR OPTICAL ELEMENTS

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To prevent the negative impact of external thermal actions on metrological characteristics (precision, measurement ranges, etc.) of impulse laser rangefinders of sighting systems the practical importance is finishing electron-ray surface processing of optical elements, which prevents defects on the elements surface (cracks, delaminations, chips, flows etc.), leading to a sharp deterioration of devices and their failures during operation.

The aim is to improve the metrological characteristics of impulse laser rangefinders when operating under conditions of external thermal impact.

The experimental research is conducted and it established the critical values of external thermal impact (heat flow and time of its action), the excess of which leads to the formation on the elements surface the negative defects that lead to their destruction.

The optimal ranges of changes of parameters of the electron ray (thermal action density $F_n = 7\,10^6 \ldots 8\,10^8 W/m^2$ *and the speed of movement* $V = 5\,10^{-3} \ldots 5\,10^{-2}$ *m/s), within which there is maximum improvement of properties of the surface layers of the optical elements.*

There is no formation of negative defects on their surfaces, it increases the transmittance coefficient of infrared radiation elements in 1,4...1,6 times, that lets to increase the accuracy and to expand the ranges of distance measurement by impulse laser rangefinders in 1,2 ... 1,5 times.

Keywords: *precision instrument making, impulse laser rangefinders, electron ray, optical glass, metrological characteristics.*

Introduction

The modern impulse laser rangefinders of sighting systems with optical windows of transmitting and receiving channels in terms of exploitation are subjected to intense external thermal impacts (higher heating temperature and external pressures, etc.) [1 - 4].

On the surface and in the surface layers of the optical elements it is formed various negative defects (cracks, bumps, hollows, flows, etc.). The result is an increase in residual microirregularities; a decrease of the melted layer thickness, which is uneven along the entire surface, which leads to the violation of its flatness and changing the geometric shape of the optical element, which significantly reduces the transmittance coefficient of infrared radiation [9 - 14].

It significantly reduces the metrological characteristics (decrease of accuracy, reducing of measurement ranges, etc.) of impulse laser rangefinders in their. This significantly reduces the metrological characteristics (decrease accuracy, reducing measurement ranges, etc.) of impulse laser rangefinders in their operation.

The causes of negative defects on the surface of optical elements in terms of an external thermal impact that lead to their destruction and reduction of metrological characteristics of impulse laser rangefinders are not studied enough.

That's why, the great importance acquires the improvement of the metrological characteristics of instruments in operation, based on electron ray methods of finishing processing of optical components and let influence on the metrological characteristics of the devices during their operation by improving the physical and mechanical properties of the surface layers [5 - 8].

The research as for the use of electron ray methods of finishing processing for optical components of impulse laser rangefinders is not held enough: not set optimal ranges of electron ray parameters within which it improves the physical and mechanical properties of the surface layers of the elements that affect their metrological characteristics.

The aim to improve the metrological characteristics of impulse laser rangefinders when operating in conditions of external thermal impacts.

Methods and Installations for Research

The evaluation of metrological characteristics of impulse laser rangefinders with optical windows after their finishing electron ray processing was performed by a standard method using impulse laser radiation to measure the distance to moving and stationary objects [3, 4].

To study the influence of parameters of the electron ray on the physical and mechanical properties of the surface layers of the optical elements of glass (K8, K108, BK10, TF110) used flat plates of a size2 $10^{-2} \times 6\ 10^{-2} \times 6\ 10^{-3}$ m, discs of a diameter $3\ 10^{-2} \ldots 5\ 10^{-2}$m and of a thickness $4\ 10^{-3} \ldots 6\ 10^{-3}$ m [5, 8, 15].

For conducting this research it was developed specialized electron-ray equipment [8], which allows to realize ribbon electron ray of a width $5\ 10^{-4} \ldots 5\ 10^{-3}$ m, a length $6\ 10^{-2} \ldots 8\ 10^{-2}$ m and density of heat action $F_n = 5\ 10^{6} \ldots 9\ 10^{8}$ W/m^2 and speed of movement $V = 3\ 10^{-3} \ldots 10^{-1}$ m/s.

The simulation of external thermal impact on devices optical elements was carried out under normal conditions ($P = 10^5$ Па, $T = 293$ К), for what it was used a controlled infrared heating quartz lamps KGM-type 220-1000-1 using sensors of control RIF-101 of temperature elements surface in the range 300 ... 1500 K and external heat flow in the range $1{,}5\ 10^{5} \ldots 2{,}3\ 10^{6}$ W/m^2 [8].

The experimental study of structure of surface, surface layers of the optical elements and defining the height of the residual microirregularities on the surface, the maximum thickness of the melted layers was carried out by methods of optical microscopy and microprobe analysis, including raster and scanning microscopy (SEM), transmission electron microscopy (TEM) and atomic force microscopy (AFM) [16, 17]. To measure the transmittance coefficient of infrared radiation by optical elements it was used spectrophotometers of near ($\lambda = 0{,}2 \ldots 2{,}5$ microns) and far ($\lambda = 2{,}5 \ldots 25$ microns) IR (SF-46, IKS-29 and others) [18].

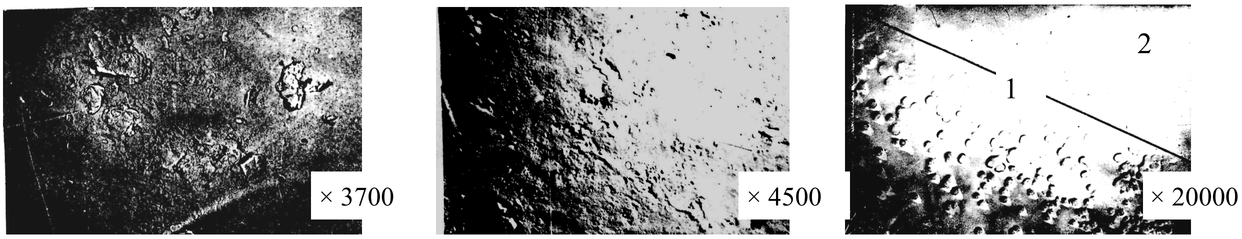
Results and analysis

The electron microscopic study of surfaces of optical elements (optical windows of laser rangefinders, etc.) showed that after standard mechanical processing there is a large number of negative defects (small cracks of depth of 0.1 ... 0.7 microns, thin scratches of length of 2 ... 5 microns, bubbles of size of $10^{-3} \ldots 10^{-2}$ microns, etc.).

It was established that these defects under conditions of intense external thermal impact (higher heating rate 400 K / s, etc.) are further developed, leading to deterioration of the metrological characteristics of devices (accuracy, measurement range, etc.) in the operation .

Defects that remain on the surface of optical parts after mechanical processing are eliminated after electron ray processing under optimal parameter values of an electron ray (density of thermal action $F_n = 7\ 10^{6} \ldots 8\ 10^{8}$ W/m^2 and its movement speed $V = 5\ 10^{-3} \ldots 5\ 10^{-2}$ m/s). The most significantly modified, it is bubble sizes (diameters) on the surface of the optical elements that are reduced in 2...4 times, other microdefects smaller than 1...2 microns are not observed.

That is a result of electron ray processing of the surface of optical elements like "cleared", small defects are eliminated; while the area occupied by these defects are decreased (Fig. 1, 2).

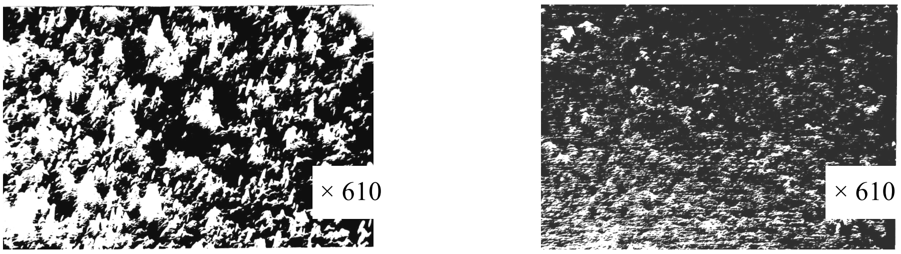


а) б) в)

Fig. 1. Electron microscopic images of the surface of the element of the optical glass K8 - surface after mechanical processing (a); surface after electron ray processing (b); optical glass K-108 (c) - after mechanical polishing (1) and after electron ray processing (2)

The study of scanngrams of grinding surface of the chips elements before and after electron ray processing showed that after mechanical processing the microirregularities height is 30 ... 40 nm, but in the case of electron ray processing it reduces to the level of 0,5...1,2 nm (Fig. 2).

It is set the influence of the parameters of the electron ray on microscopic residual height: increasing the density of heat exposure of electron ray F_n from 10^7 W/m^2 to $8{,}5\ 10^7$ W/m^2 for its movement speed $V = 8\ 10^{-3} \ldots 5\ 10^{-2}$ m/s, causes to reducing the residual microscopic height from 3...5 nm to 1.0...1.5 nm (Fig. 3).



а) б)

Fig. 2. Scanngrams of surface of optical glass element BK10after processing (a) and after electron ray processing (b), Y-modulation

Maximum thickness of the melted layer $h_{пл}$ can reach values 250 ... 300 microns, which can exceed the maximum allowable size of microirregularities $h^* = 150…200$ microns [8], which leads to disruption of the flatness and geometric shape of the optical element (Fig. 4).

The value $h_{пл}$ essentially depends on the ray density F_n and the movement speed V: increasing the density F_n from $7\ 10^6$ W/m^2 to $8\ 10^8$ W/m^2 leads to increasing the thickness of melted layer from 25 microns to 230 microns, and increasing the speed movement of the electron ray from 10^{-3} m/s to 10^{-2} m/s causes reducing the melting depth from 200 microns to 30 microns.

In addition, it was found that after finishing electron-ray processing of optical elements it increases the transmittance coefficient of infrared radiation $k_{\lambda}(\lambda)$, which significantly affects the basic metrological characteristics of impulse laser rangefinders (accuracy, measurement range, etc.).

The relative coefficient of transmittance of infrared radiation by optical elements of optical glass K8 and BK10 from the wavelength is determined by the formula:

$$\bar{k}_{\lambda} = \frac{k_{\lambda}^{обр}}{k_{\lambda 0}},$$

where $k_{\lambda 0}$, $k_{\lambda}^{обр}$ – coefficient value before and after electron ray processing (density of thermal action $F_n = 8\ 10^8$ W/m^2, movement speed $V = 5\ 10^{-3}$ m/s).

For experiments the samples of K8 and BK10 optical glass with thickness $H = 6\ 10^{-3}$ m were used.

Figure 5 shows the dependence of the relative coefficient of transmittance of infrared radiation by optical elements of optical glass K8 (1) and BK10 (2) after electron ray processing from the wavelength.

As the experimental studies showed the coefficient of transmittance of infrared radiation k_{λ} increases.

Thus, for the elements of optical glass K8 and BK10 the strongest increase of the coefficient k_{λ} (50...60%) is observed for ranges of changes $\lambda = 0{,}3…2$ microns and $\lambda = 3…4$ microns.

As a result of the experiments it was found that electron ray processing leads to improving physical and mechanical properties of the surface layers of the optical elements of the devices.

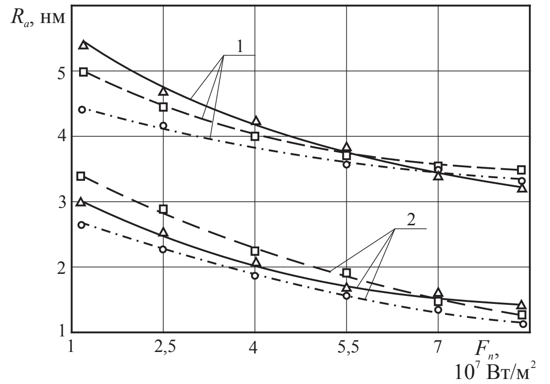


Fig. 3. The dependence of height of residual microirregularities on the surface of the optical glass elements K8 (-----) TF110 (- - -) and BK10 (--- - --) from the density of thermal influence of the electron ray for different speeds of its movement: $V = 5\ 10^{-2}$ m/s (1); $V = 8\ 10^{-3}$ m/s (2) (Δ, ○, □ - experimental data)

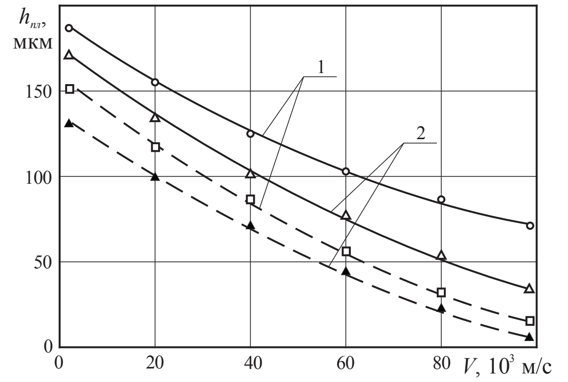


Fig. 4. The dependence of maximum thickness of melting layer of optical glass elements BK10 (1) and TF110 (2) at $F_n = 5\ 10^8$ W/m^2 (-----) and $F_n = 3\ 10^8$ W/m^2 (- - -) from the speed of the electron ray ((, ○, □, ▲ - experimental data)

Improvement of the accuracy and extension of the distance measurement ranges by impulse laser rangefinders of the sighting systems by finishing electron ray processing of the surfaces of their optical windows.

To assess the impact of electron ray processing on the working surfaces of devices optical components the research of metrological characteristics of impulse laser rangefinders was carried [4].

For experimental studies the sighting system device with an operating wavelength of the laser radiation $\lambda = 1{,}06$ microns was used.

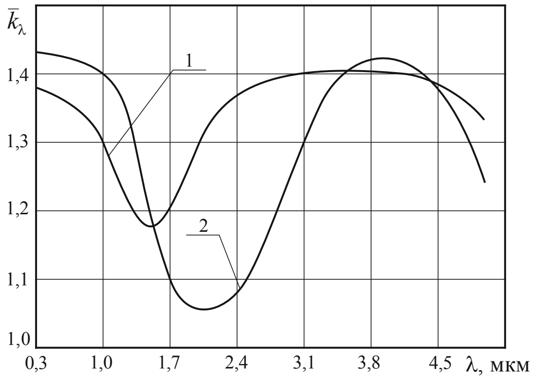


Fig. 5. The dependence of relative coefficient of transmittance of infrared radiation of optical elements of optical glass K8 (1) and BK10 (2) from the wavelength

Fig. 6 shows a general view of the sighting system device (Fig. 6 a) and the simplified diagrams of transmitting (Fig. 6 b) and receiving channels (Fig. 6 c) of the impulse laser rangefinder equipped with output and input windows made of optical glass K8 and BK10 with the diameters d_1, $d_2 = 3\ 10^{-2} \ldots 5\ 10^{-2}$ m and thickness, $H_2 = 4\ 10^{-3} \ldots 6\ 10^{-3}$ m accordingly.

The relative measurement error of distance $\overline{\Delta L}$ was defined by the formula:

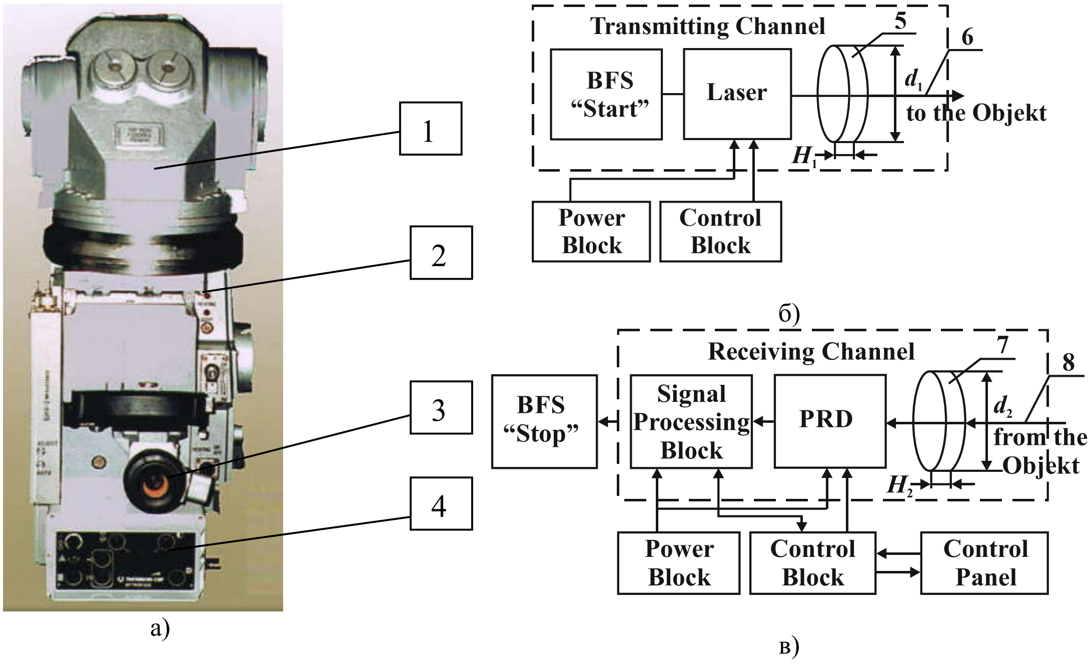
$$\overline{\Delta L} = \frac{\Delta L^{\text{обр}}}{\Delta L_0},$$

where ΔL_0, $\Delta L^{\text{обр}}$ - measurement error of the distance before and after electron-ray processing of the windows, accordingly (error $\Delta L_0 = 10$ m at the distance $L = 10^3$ m).

As a result of experimental studies of measuring the distance to moving and stationary objects (targets) using impulse laser radiation it was revealed that finishing electron-ray processing of surfaces of the optical windows of transmitting and receiving channels at optimal values of the ray parameters $F_n = 8\ 10^8$ W/m^2 and $V = 5\ 10^{-3}$ m/s let to increase the transmittance coefficient of infrared radiation in 1,3...1,4 times and thereby to improve measurement accuracy of the distance in 1.4...1.5 times.

Fig. 7 shows the dependence of the relative error of measurement of the distance from the coefficient of transmittance of infrared radiation by optical windows of optical glass K8 (1) and BK10 (2).

<u>The extension of measurement ranges of the distance</u>. To determine the effect of the coefficient k_λ on the value of maximum distance a transcendental equation was used [4]:



а)

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Fig. 6. The general view of the sighting device complex (a) and simplified diagrams of transmitting (b) and receiving (c) channels of the impulse laser rangefinder 1 - optical head with a laser rangefinder; 2 - opto-mechanical block; 3 - eyepiece device; 4 – control panel of the thermal imaging camera gunner; 5 - output optical window of the rangefinder transmitting channel; 6 - stream of infrared radiation directed to the object; 7 - input optical window of the rangefinder receiving channel; 8 - stream of infrared radiation, which is diffused by the object and enters the input window; BFS - block of formation of signal; PRD - photoreceiver device; d_1, H_1, d_2, H_2 - diameters and thicknesses of the output and input windows accordingly.

$$\overline{L}^2 = \overline{k}_\lambda \cdot e^{-2\cdot\alpha_a\cdot L_0\cdot\left(\overline{L}-1\right)}, \quad (1)$$

where $\overline{L} = \dfrac{L^{обр}}{L_0}$ - relative distance of the impulse laser rangefinder; α_a - coefficient of damping of laser radiation in the atmosphere, м$^{-1}$; L_0 - the initial distance м; $L^{обр}$ - measured distance after electron-ray processing of the optical windows due to increasing the transmittance coefficient of infrared radiation k_λ.

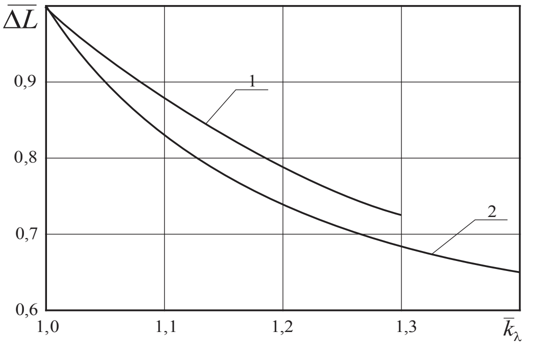

Fig. 7. The dependence of relative error of distance measurement by impulse laser rangefinders with windows of optical glass K8 (1) and BK10 (2) from transmittance coefficient of infrared radiation

The calculation results in equation (1) were obtained for the case of meteorological distance of visibility $S_м > 10L_0$ (there is no air haze at the object and it is clearly perceived the object and its parts, it was taken: initial distance – $L_0 = 10^3$m; – $S_м = 2\ 10^4$ m; attenuation coefficient of laser radiation in the atmosphere – $\alpha_a = 0{,}082$) [4].

Fig. 8 shows the dependence of the relative distance of the impulse laser rangefinder with windows of optical glass K8 (1) and BK10 (2) from transmittance coefficient of infrared radiation. The windows with a thickness $H = 4\ 10^{-3}$ m and a diameter $d = 3\ 10^{-2}$ m processed by electron ray with thermal impact density $F_n = 2{,}5\ 10^7$ W/m^2 and its movement speed $V = 5\ 10^{-2}$ m/s.

As shown in Fig. 8 by increasing the transmittance coefficient of infrared radiation k_λ in 1.4 times (for glass K8), distance value L increases in 1.3 times, while by increasing k_λ in 1.3 times (for glass BK10) - L increases in 1,2 times.

The results of research were used by State Concern Research and Production Complex “Photoprylad”, in the production process to improve impulse laser rangefinder of sighting systems, which are produced as well as to develop new devices to expand the ranges of distance measurement and to reduce measurement error in their operation, taking into account the external thermoimpact (confirmed by act of implementation 16.05.2016).

Conclusions

1. It is established the optimum ranges of parameters changes of electron ray (density of thermal impact $F_n = 7\ 10^6 ... 8\ 10^8$ W/m^2 and the movement speed $V = 5\ 10^{-3} ... 5\ 10^{-2}$ m/s) within which it is observed the improvement of physical and mechanical properties of the surface layers of the elements of optical glass (K8, K108, BK10, TF110):

– the surface is cleaned of defects (scratches, bubbles, small cracks, etc.) that remain after standard mechanical processing;

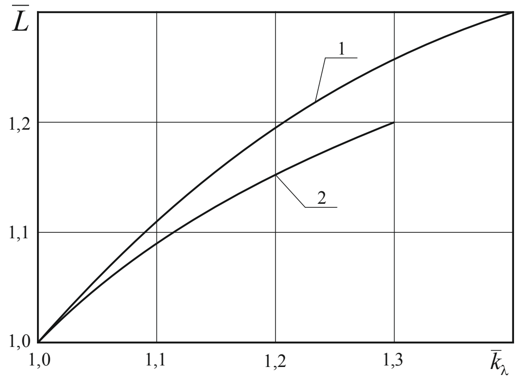

Fig. 8. The dependence of relative distance of impulse laser rangefinder with windows optical glass K8 (1) and BK10 (2) from transmittance coefficient of infrared radiation

– the height of residual microirregularities decreases in 3..5 times;

– the thickness of the melted layer increases in 2 ... 3 times, while not exceeding the maximum permissible values;

– the transmittance coefficient of infrared radiation k_λ for elements of optical glass K8 and BK10 in 1.5 ... 1.6 times increases.

2. It was established that finishing electron ray processing of surfaces optical windows of impulse laser rangefinders leads to expanding the range of distance measurement in 1.2 ... 1.3 times and reducing a measurement error in 1.4 ... 1.5 times.

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ПОЛІПШЕННЯ МЕТРОЛОГІЧНИХ ХАРАКТЕРСТИК ІМПУЛЬСНИХ ЛАЗЕРНИХ ДАЛЕКОМІРІВ ФІНІШНОЮ ЕЛЕКТРОННО-ПРОМЕНЕВОЮ ОБРОБКОЮ ЇХ ОПТИЧНИХ ДЕТАЛЕЙ

Для попередження негативного впливу зовнішніх термічних дій на метрологічні характеристики (точність, діапазони вимірювання та ін.) імпульсних лазерних далекомірів прицільних комплексів практичне значення має фінішна електронно-променева обробка поверхонь їх оптичних елементів, яка запобігає виникненню дефектів на поверхні елементів (тріщин, відшарувань, сколів, напливів та ін.), що призводять до різкого погіршення характеристик приладів та їх відмов при експлуатації.

Метою роботи є покращення метрологічних характеристик імпульсних лазерних далекомірів при експлуатації в умовах зовнішнього термовпливу. Проведено експериментальні дослідження та встановлено критичні значення параметрів зовнішніх термодій (теплового потоку та часу його дії), перевищення яких призводить до утворення на поверхні елементів негативних дефектів, що призводять до їх руйнування.

Встановлено оптимальні діапазони зміни параметрів електронного променю (густини теплової дії F_n = $7\ 10^6 \ldots 8\ 10^8$ Вт/м^2 та швидкості переміщення $V = 5\ 10^{-3} \ldots 5\ 10^{-2}$ м/с), в межах яких спостерігається максимальне покращення властивостей поверхневих шарів оптичних елементів.

При цьому не відбувається утворення негативних дефектів на їх поверхнях, збільшується коефіцієнт пропускання ІЧ-випромінювання елементами у 1,4…1,6 рази, що дозволяє збільшити точність та розширити діапазони вимірювання дальності імпульсними лазерними далекомірами у 1,2…1,5 разу.

Ключові слова: точне приладобудування, імпульсні лазерні далекоміри, електронний промінь, оптичне скло, метрологічні характеристики.

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УЛУЧШЕНИЕ МЕТРОЛОГИЧЕСКИХ ХАРАКТЕРИСТИК ИМПУЛЬСНЫХ ЛАЗЕРНЫХ ДАЛЬНОМЕРОВ ПУТЕМ ФИНИШНОЙ ЭЛЕКТРОННО-ЛУЧЕВОЙ ОБРАБОТКИ ИХ ОПТИЧЕСКИХ ДЕТАЛЕЙ

Для предотвращения негативного влияния внешних термических воздействий на метрологические характеристики (точность, диапазоны измерения и др.) импульсных лазерных дальномеров прицельных комплексов практическое значение имеет финишная электронно-лучевая обработка поверхностей их оптических элементов, которая предотвращает возникновение дефектов на поверхности элементов (трещин, отслоений, сколов, наплывов и др.), приводящих к резкому ухудшению характеристик приборов и их отказам при эксплуатации.

Целью работы является улучшение метрологических характеристик импульсных лазерных дальномеров при эксплуатации в условиях внешних термовоздействий. Проведены экспериментальные исследования и установлены критические значения параметров внешних термовоздействий (теплового потока и времени его воздействия), превышение которых приводит к образованию на поверхности элементов негативных дефектов, приводящих к их разрушению.

Установлены оптимальные диапазоны изменения параметров электронного луча (густини теплової дії F_n = $7\ 10^6 \ldots 8\ 10^8$ Вт/м^2 та швидкості переміщення $V = 5\ 10^{-3} \ldots 5\ 10^{-2}$ м/с), в пределах которых наблюдается максимальное улучшение свойств поверхностных слоев оптических элементов.

При этом не происходит образование негативных дефектов на их поверхностях, увеличивается коэффициент пропускания ИК-излучения элементами в 1,4...1,6 раза, что позволяет увеличить точность и расширить диапазон измерения дальности импульсными лазерными дальномерами в 1,2...1,5 раза.

Ключевые слова: точное приборостроение, импульсные лазерные дальномеры, электронный луч, оптическое стекло, метрологические характеристики.

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