THE INVESTIGATION OF THE NANORELIEFS OF OPTICAL ELEMENTS OF MEASURING INSTRUMENTS, WHICH MODIFIED BY ELECTRON-BEAM MICROPROCESSING

ДОСЛІДЖЕННЯ МОДИФІКОВАНИХ ЕЛЕКТРОННО-ПРОМЕНЕВОЮ МІКРООБРОБКОЮ НАНОРЕЛЬЄФІВ ОПТИЧНИХ ЕЛЕМЕНТІВ ВИМІРЮВАЛЬНИХ ПРИЛАДІВ

Skoryna E.[1], Medyanyk V.[1], PhD. Bondarenko M.[1], PhD Bondarenko I.[1], PhD Bilokin S.[2], Prof. dr. eng. Antoniuk V.[3]
Faculty of Electronically Technologies[1], Department of Physics[2] – Cherkassy State Technological University, Ukraine
Faculty of instrument-making [3] – National Technical University of Ukraine “KPI”, Ukraine

Abstract: *The results of microprocessing by the ribbon-shaped electron beam of the elements of optical measuring instruments (the material of such elements - K8 glass) with the initial nanorelief of surfaces 15-22 nm after industrial grinding and polishing are presented. Based on the results of studies using a computerized complex control system based on an atomic force microscope, it was established that after electron-beam microprocessing, the nanorelief of optical elements of measuring instruments decreased to 1.5-2.2 nm, satisfying to the requirements put forward to their surfaces.*
KEYWORDS: ELECTRON-BEAM MICROPROCESSING, OPTICAL GLASS, COMPLEX CONTROL, COMPUTERIZED SYSTEM, ATOMIC-FORCE MICROSCOPY

1. Introduction

For the manufacture of optical elements of measuring devices and the formation of their microprofile of the necessary size and shape on them, over the last decades all known materials of amorphous, crystalline, polycrystalline structure have been tested, and for their processing various methods were used, including: industrial deep grinding and polishing methods, grinding and polishing, and the etc.

As research has shown, modern ukrainian optical production is not guaranteed to receive surfaces on an optical glass that would satisfy the requirements imposed on such optical elements. Herewith, the nanorelief in industrially manufactured products exceeds the value of 5 nm, which limits their further use as precision optical elements of optical measuring systems.

At the same time, the impact on the surface of the optical material of abrasive, washing and pickling solutions in the grinding and polishing stages inevitably leads to the formation of chemically heterogeneous defect and fractured layers, the total depth of which can exceed tenths of micrometers. This, in many cases, limits the use of electronic lithography and photolithography technologies.

The problem of compliance withthe necessary level of nanorelief of the surface layer of optical materials in the manufacture of elements of a new generation, increasing the productivity of their manufacture is one of the most relevant in the technology and technology of processing optical materials.

One of the ways to overcome this problem is to attract new tools for the energy microprocessing of optical surfaces, including concentrated electron fluxes.

The efficiency of processing optical glass by a ribbon-based electron beam was first shown in the works V.M. Lisochenka [1].

In papers [2, 3], is shown the possibility of flexible control of the process of electron-beam processing of optical glass and optical ceramics by melting the surface to a depth of up to 200 μm. The authors [4-6] confirmed the efficiency of the use of a ribbon-based electron beam for surface treatment of both optical and technical glass.

At the same time, the question of the qualitative changes in the nanorelief and the defective layer of the optical glass of the silicate group from the action of the low-energy electron beam ($E \leq 6$ keV) has not been studied sufficiently and the relationship between these changes and the parameters of electron-beam microprocessing.

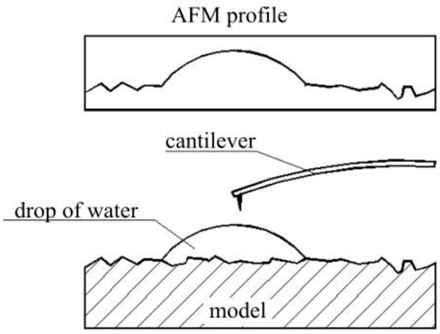
The aim of this work is to determine the changes in nanorelief of the surface of elements from optical glass under the influence of a low-energy electron beam and to establish the relationship between the size of the modified nanorelief and the parameters of electron-beam microprocessing.

2. Experimental method

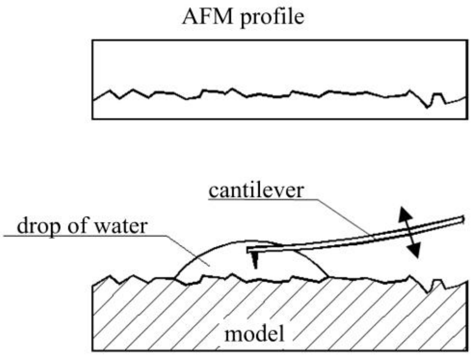
Objects that are treated with an electron beam: plane-parallel round plates (diameter 20 mm, thickness 2, 4, 6 mm) from glass of optical colorless grade K8 (GOST 3514-76) with silver metal coatings applied to their surface. Such objects are widely used in measuring devices as optoelectronic sensors (pressure, capacitance, density of medium, etc.).).

The study of processing objects was carried out using a computerized system of complex control, manufactured on the basis of an atomic force microscope (AFM) “NT-206V” (the manufacturer of “Microtestmashines”, Gomel, Belarus). For visualization of the object of investigation at a magnification of 100 times, used optical chamber "Logitech", whose viewing field is $1\times0{,}75$ mm^2.

The schemes for determining the surface nanorelief using a computerized integrated control system for non-contact (a) and contact (b) AFM schemes are shown in Fig.1.



a



b

Fig. 1. Obtained surface profiles for noncontact (a) and contact (b) operation schemes of a computerized integrated control system based on the atomic force microscopy method

The sensitive element of the microscope is the cantilever, the deflection of which, when in contact with the surface, is determined by means of a laser beam. The positioning of the surface to be measured under the cantilever is carried out by means of high-precision stepping motors (in the X-Y plane with a pitch of 2.5 µm, along the Z axis with a step of 200 nm).

The profile of the surface to be examined is determined by scanning the cantilever in the X-Y plane in a 13 × 13 µm section using a piezoceramic scanner in steps of up to 1 nm. The displacement of the cantilever along the vertical axis is carried out by a piezotube with a pitch of 0.02 nm in the range 3 µm. The image of the microrelief of the optical surface was obtained by applying the following operating modes of the AFM: static (contact), Fig. 1a, and dynamic (noncontact), Fig. 1 b..

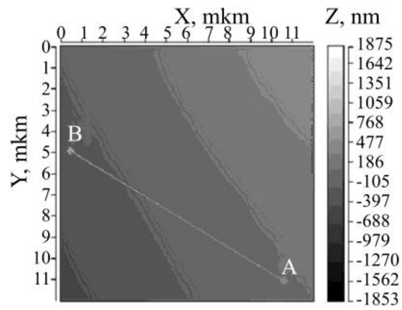
In dynamic mode, the cantilever is superimposed on the vertical axis with a frequency of 10 Hz to 400 kHz. The main advantages of this mode are the significantly increased sensitivity of the measuring system (it is theoretically possible to achieve an atomic resolution of the device) and to ensure the mechanical integrity of the probe and sample.

The positioning of the cantilever above the surface of the optical glass and the further settings of the "laser beam-cantilever" system occurs in manual mode using the long-focusing camera "Logitech" built into the AFM device with a 150-fold increase in the image on the PC display. As can be seen from Fig. 2, the correct positioning of the cantilever, which provides the most complete and accurate information retrieval by the sensitive AFM system on the topology of the surface, is achieved by focusing the laser of the photo detecting device on the upper edge of the cantilever.

The scanning process is completed automatically, after which the computer monitor received a surface image. For processing and analysis of data from the microrelief, the programm Surface v.6.2 was used, which provides such types of information: three-dimensional visualization of the surface; surface profiling in the required section; distribution of surface heights; angular histogram.

The average time to prepare for work and scan one sample is 10 ... 12 minutes.

The use of the atomic force microscopy method, it was possible to investigate the surface modified by the electron beam and the surface layer of the K8 glass product (Fig. 2).



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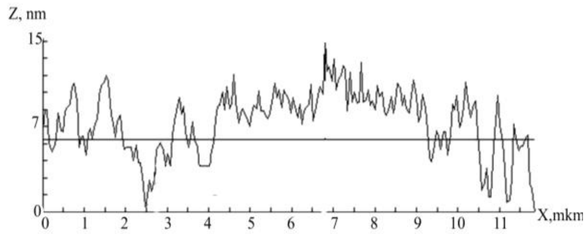


b

Fig. 2. Appearance (a) and nanorelief along the AB (b) line of the surface area (12×12 µm) of the fragment of the plate of the optoelectronic capacitance sensor from K8 glass with a metallic thin silver film fused in its surface by an electron beam (film thickness 350 nm).

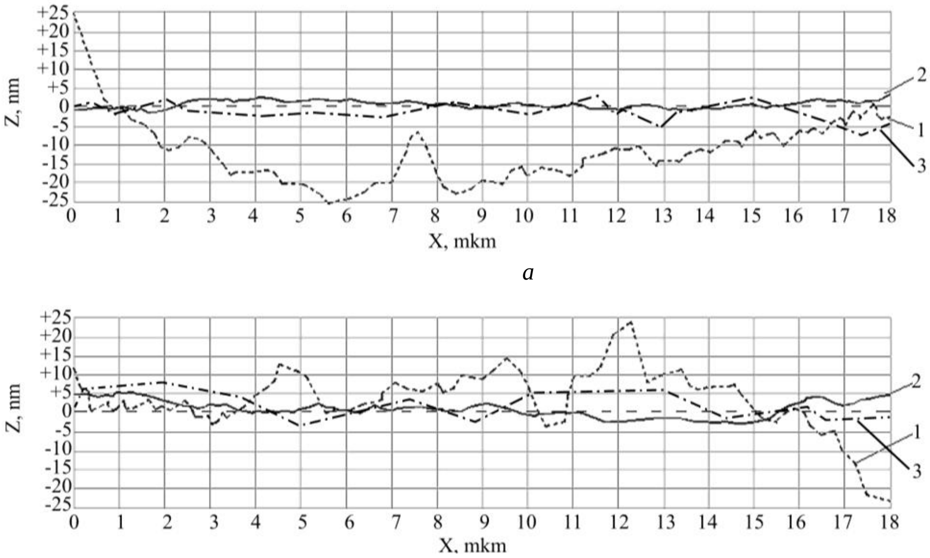
3. *Results and discussion*

The results of the investigation and comparison of the nanorelief of the element surface from the optical glass K8 after machining, laser and electron beam microprocessing with applying a modern computerized complex control system for nanometric studies have shown the promise of this method in metrology, in integral optics at the manufacture and use as elements of measuring devices of micro- and nano-optical elements [7].

According to the profiles shown in Fig. 3, it can be concluded that both after mechanical (deep grinding-polishing) (profile 1, Fig.3.a) and after laser microprocessing (profile 3, Fig.3.b), the surface of the plate from optical glass has a characteristic nanorelief, which is much higher than the allowable value of the arithmetic average of the nanoscale, which is 5 nm.

This indicates the inability to use these methods of surface microprocessing in the manufacture of optical elements of measuring systems of modern instrumentation.

At the same time, the nanorelief of the surface obtained after electron-beam microprocessing (profile 2, Fig. 3a, b) indicates high accuracy and uniformity of the surface created, and the use of this method allows obtaining high-quality surfaces with guaranteed levels of purity and microroughness, whose value does not exceed 5 nm.



a

b

Fig. 3. The characteristic nanorelief of the surface of optical elements from K8 glass after mechanical (1), electron beam (2), and laser (3) processing. NT-206V

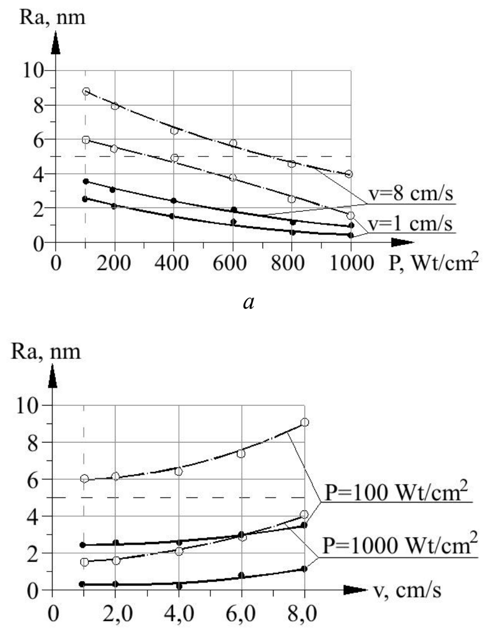


Fig. 4. Dependence of the average arithmetic roughness of the nanorelief Ra on the specific power of the electron beam $P_{пит}$ (*a*) and the speed of electron-beam micromachining $V_{пот}$ (*б*): ○ – by the works [8, 9]; ● – by the advanced technology; -- -- -- the maximum permissible values of the nanorelief on surfaces for optical elements

Further studies of the nanorelief of the surface of elements (on the example of circular plates with a diameter of 20 mm and a thickness of 2 mm, optical glass K8) made it possible to establish the dependence of the arithmetic average roughness Ra on the specific power of the electron beam P_{num} (*a*) and on the speed of the electron beam V_{nom} (*б*), Fig.4.

As can be seen from the dependences shown in Fig. 4 (a) and (b), according to the technological regimes described in Refs. [8 and 9], an increase in the specific power of the electron beam at 300 W/cm^2 for electron flow velocities of the order of 1 cm/s sec to 750 W/cm^2 for electron flow velocities of 8 cm/s leads to a decrease in the arithmetic average of the surface roughness below the permissible value of 5 nm. Herewith, according to the technological regimes obtained for improved technology for electron flow rates of 1-8 cm/s, the average arithmetic nanovelities for the entire range of specific power (100-1000 W/cm^2) is 2.2-1.5 nm.

4. Conclusion

In the process of performing scientific research, changes in the nanorelief of the surface of optical elements from glass for measuring system devices from the action of low energy electron flux have been determined, and the relationship between the size of the modified nanorelief and the parameters of electron-beam microprocessing.

It is established that as a result of electron-beam microprocessing the nanorelief of the surfaces of products from optical glass K8 decreases from 4-9 nm to 1.5-2.2 nm. Это достигается путем управлением скоростью и удельной мощностью электронного потока.

The obtained surfaces of optical elements made of K8 glass with a nanorelief of 1.5-2.2 nm satisfy the requirements imposed by modern production of metrological measuring means for such optical elements.

5. Literature

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