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OPTIMISATION OF THE TECHNOLOGY OF POLISHING OF INPUT WINDOWS MADE OF OPTICAL CERAMICS KO1, KO12 FOR IR SENSORS

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Abstract

OPTIMISATION OF THE TECHNOLOGY OF POLISHING OF INPUT WINDOWS MADE OF OPTICAL CERAMICS KO1, KO12 FOR IR SENSORS

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In this work on the base of elipsometric measurements the technology of machine work of polished details made of optical ceramics KO1, KO12 was optimised. The ellipsometry is a high-performance contactless method of the control of quality of optical surfaces, in which the sharp response of condition of polarisation of the light to the properties and parameters of a surface and surface layers of an investigated reflective system is used. It is shown, that the highly productive technology of a diamond polishing provides achievement of ellipsometric parameters at level of conventional methods of polishing.

Keywords. Ellipsometric control, diamond polishing, optical ceramics.

Анотація

ОПТИМІЗАЦІЯ ТЕХНОЛОГІЇ ПОЛІРУВАННЯ ВХІДНИХ ВІКОН НА ОСНОВІ ОПТИЧНОЇ КЕРАМІКИ КО1, КО12 ДЛЯ ІЧ СЕНСОРІВ

В. П. Маслов, А. З. Сарсембаєва

В даній роботі на основі еліпсометричних вимірів було оптимізовано технологію механічної обробки полірованих деталей з оптичної кераміки КО1 та КО12. Еліпсометрія — високоефективний безконтактний метод контролю якості оптичних поверхонь, в якому використовують залежність стану поляризації світла від властивостей та параметрів поверхні та поверхневих шарів досліджуваної відбивної системи. Показано, що високопродуктивна технологія алмазного полірування забезпечує досягнення еліпсометричних параметрів на рівні традиційних методів полірування.

Ключові слова. Еліпсометричний контроль, алмазне полірування, оптична кераміка.

Аннотация

ОПТИМИЗАЦИЯ ТЕХНОЛОГИИ ПОЛИРОВАНИЯ ВХОДНЫХ ОКОН НА ОСНОВЕ ОПТИЧЕСКОЙ КЕРАМИКИ КО1, КО12 ДЛЯ ИК СЕНСОРОВ

В. П. Маслов, А. З. Сарсембаева

В данной работе на основе эллипсометрических измерений была оптимизирована технология механической обработки полированных деталей из оптической керамики КО1 и КО12. Эллипсометрия — высокоэффективный бесконтактный метод контроля качества оптических поверхностей, в котором используется зависимость состояния поляризации света от свойств и параметров поверхности и поверхностных слоев исследуемой отражательной системы. Показано, что высокопродуктивная технология алмазной полировки обеспечивает достижение эллипсометрических параметров на уровне традиционных методов полировки.

Ключевые слова. Эллипсометрический контроль, алмазная полировка, оптическая керамика.

Introduction

Optical ceramics KO1, KO12 is the polycrystalline material, transparent in IR region. Optical ceramics, in comparison with single crystals, is optically and mechanically isotropic, there are no planes of cleavages and cracks, and it is heat-resistant. Details made of optical ceramics are well grounded and polished with conventional processing techniques. The optical ceramics is a base material for manufacturing of optical parts of devices, which operate in IR wavelengths' range in conditions of large pressure gradients and temperatures (input windows, domes). One of urgent questions of technology effecting of such parts is the necessity of rising of the manufacturing productivity at quality assurance of optical parts surface.

With the purpose of rising the productivity of manufacturing of parts from optical ceramics KO1, KO12 the technology of productive precision diamond polishing, which has supplied increase of productivity by 2 to 5 times, was designed. The ellipsometric method was used as a method of control of quality of polishing.

Method of ellipsometric investigations

At reflection of an electromagnetic wave from an arbitrary reflecting system (Fig. 1) [2,3], a phase difference appears between components of an electric vector, perpendicular and parallel incidence planes, that generally leads to the elliptical polarisation of this wave.

Reflective indexes R_p and R_s of a system and phase difference Δ are connected by basic equation of ellipsometry:

$$\rho = \frac{R_p}{R_s} = tg\psi e^{i\Delta} \qquad (1)$$

Angles ψ и Δ are called ellipsometric parameters of the system.

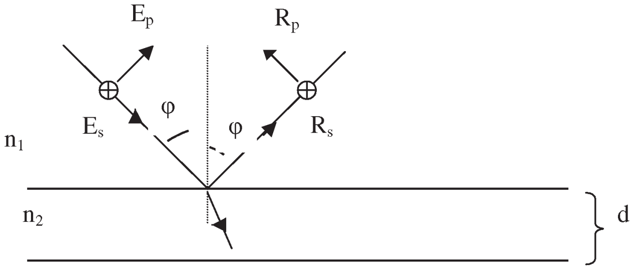

Figure 1. Reflection of flat simple harmonic wave from homogeneous layer (n_1, n_2 — refractive indexes, and d — depth of the sample)

The account of multiple reflections inside a layer on the first and second demarcation resolves to express reflective coefficients of all system, which one enter in the basic ellipsometric equation (1) through the Fresnel reflective indexes on each demarcation r_1, r_2 and depth of a layer. In this case equation (1) gets a view:

$$tg\psi e^{i\Delta} = \frac{r_{1p} + r_{2p}e^{-i\delta}}{1 + r_{1p}e^{-i\delta}} \bullet \frac{1 + r_{1s}r_{2s}e^{-i\delta}}{r_{1s} + r_{2s}e^{-i\delta}} \qquad (2)$$

where $\delta = \frac{4\pi d}{\lambda}\left(n_1^2 - n_2^2 \sin^2\varphi\right)^{1/2}$ — phase difference in a layer.

As a result of transformations from (2) the angle dependencies for the phase difference Δ and angle ψ could be obtained:

$$tg\left(\Delta-\bar{\Delta}\right)=\frac{4\pi d\left(n_1^2-1\right)\left(n_2^2-n_1^2\right)n_2^2\sin\varphi tg\varphi}{\lambda n_1^2\left(n_2^2-1\right)\left(tg^2\varphi-n_2^2\right)}$$

$$tg\psi=tg\bar{\psi}\left[1+\frac{4\pi d\left(n_1^2-1\right)\left(n_2^2-n_1^2\right)n_2^2\sin\varphi tg\varphi}{\lambda n_1^2\left(n_2^2-1\right)\left(tg^2\varphi-n_2^2\right)}\right] \quad (3)$$

where $\bar{\psi}$ и $\bar{\Delta}$ — ellipsometric angles for substrate.

At a Brewster angle ($tg\varphi_{Br}=n_2/n_1$) from the second equation of a system (3) the formula for minimum value of ellipticity follows:

$$tg\psi=\frac{\pi d\left(n_1^2-1\right)\left(n_2^2-n_1^2\right)}{\lambda n_1^2\left(n_2^2-1\right)}\left(n_2^2+1\right)^{1/2} \quad (4)$$

Relation of Fresnel reflective indexes of p- and s-components of electric vector, tgρ and phase difference between them can be counted by usage of a metal-optic method. Photoelectric method of Beattie and Conn is the most suitable among them. The modification of this method, which resolves to apply it to transparent dielectrics, was used in this work [4].

The values directly measured are intensities of reflected from a sample radiation I_0, I_{45}, I_{90}, measured at three azimuths of an analyser α_a (equal accordingly 0°, 45°, 90°) concerning incidence plane and fixed azimuth of polariser ß=45°. Ellipsometric parameters are calculated by the formulas:

$$tg\rho=tg\psi\sqrt{\frac{I_0}{I_{90}}}$$

$$\cos\Delta=\frac{2I_{45}-I_0-I_{90}}{2\sqrt{I_0I_{90}}} \quad (5)$$

As the measurements of ellipsometric parameters are carried out within the limits of a Brewster angle, where cosД passes through zero point, the error of phase difference is minimum, and the next condition is realised:

$$tg\rho=tg\psi \quad (6)$$

Polishing by a diamond tool

The development of technology of a diamond polishing of details made of optical ceramics KO1, KO12 was conducted by results of ellipsometric researches of tgρ and $\Delta\varphi=\varphi_M-\varphi_B$, values of which change after grinding with increase of polishing depth, approximating to those values of these parameters, which characterize an undamaged layer. The requirements on deviation from the shape of optical parts were no more than 1 micron on details up to 80 mm in diameter.

The laser null-ellipsometer LEF-3M-1 (λ=6328Å) was used for the investigations of quality of polished optical ceramics KO1, KO12.

The analyses of influencing of a sample flatness and measurements quantity on the accuracy of ellipsometric parameters measurements were previously conducted. It was established, that deviation from flatness of a sample in limits N=±0,5÷5 has no essential influence on the error of measurements at beam of 1÷2 mm in diameter. With the purpose of obtaining reliable results it was conducted not less than 6 measurements on each sample. Under these conditions the relative error was no more than 10 %.

The changes of a main angle and ellipticity with the polishing depth are conditioned by both changes with depth of physicochemical properties of the damaged layer formed by grinding, and by those changes, which are introduced during polishing and form the polished surface layer.

The depth of a polished layer, at which minimum value of tgρ and minimum value of φ_M is reached, is adopted for depth of the damaged layer for investigated processing. It was established, that after diamond processing the depth of the damaged layer was 1,2÷1,5 times less, than at processing by a free abrasive of the same stippling. On the base of these results limits on over-measure size for technological process were established. The influence of polisher and abrasive materials on roughness and ellipsometric parameters of polished samples of optical ceramics KO1, KO12 is presented in the Table 1.

Table 1

Results of measurement of ellipsometric parameters

Polisher	An abrasive	Roughness R_Z, microns	$tg\rho\cdot10^3$	Φ_M, degrees
Diamond polisher on organic base and diamonds with size 5/3	Diamonds with size 5/3 in organic base	0,015÷0,02	15,5	54°32′
Colophon-pitch resin	Chrome oxide	0,025÷0,03	13,0	54°35′
The cloth	Chrome oxide	Corrugated frame appears	19,0	54°30′

The features of the diamond polishing on the organic base have exhibited in minor increase of ellipsometric parameters, that is conditioned by presence of considerable tangential efforts, and at directional intensive polishing on cloth (V=800 rotation per minute) ellipsometric parameters have even more increased, and a corrugated texture, connected with increase of concentration of structural defects in a direction of processing, have appeared on a surface.

On the base of ellipsometric method of control the technology of a diamond polishing on organic flow bundle, which has allowed increasing productivity of processing in 2÷5 times, was designed.

Conclusions

Offered ellipsometric method of control has allowed optimisation of the technological process of diamond grinding and polishing of optical ceramics KO1, KO12. It was established, that after diamond processing the depth of the damaged layer was 1,2÷1,5 times less, than at processing by a free abrasive of the same stippling. The features of the diamond polishing on the organic base were exhibited in minor increase of ellipsometric parameters, which is conditioned by presence of considerable tangential efforts from the tool.

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