Semiconductor Physics, Quantum Electronics & Optoelectronics. 2004. V. 7, N 2. P. 199-201.

PACS: 81.05.Je

Ellipsometric control of quality of polished MgF_2 optical ceramics

V.P. Maslov, A.Z. Sarsembaeva, F.F. Sizov
V. Lashkaryov Institute of Semiconductor Physics, National Academy of Sciences of Ukraine
41, prospect Nauky, 03028 Kyiv, Ukraine
Phone/fax: +380 (44) 265 0555, E-mail: maslov@isp.kiev.ua, sizov@isp.kiev.ua

Abstract. In this work, ellipsometric measurements were used to optimise the technology of machine working the polished parts made of MgF_2 optical ceramics. The ellipsometry is a high-performance contactless method to control quality of optical surfaces, which is used here due to a sharp response of light polarisation conditions to the properties and parameters of surface and subsurface layers in investigated reflective systems. It is shown that the highly productive technology of diamond polishing provides achievement of ellipsometric parameters at a level of conventional methods of polishing.

Keywords: ellipsometric control, diamond polishing, optical ceramics.

Paper received 16.12.03; accepted for publication 17.06.04.

1. Introduction

Optical ceramics based on MgF_2 are polycrystalline materials transparent in IR spectral range. Optical ceramics in comparison with single crystals are optically and mechanically isotropic, there are no planes of cleavages and cracks, and they are heat-resistant. Parts made of optical ceramics are well grounded and polished with conventional processing techniques. The optical ceramics are base materials for manufacturing optical parts of devices, which operate in IR wavelengths range in conditions of large pressure gradients and temperatures (input windows, domes). One of the urgent questions to process such parts is the necessity of rising the productivity of manufacturing high-quality surface in these optical parts.

With this purpose, the technology of effective precise diamond polishing that provides the increase of productivity by 2 to 5 times was designed. The ellipsometric method was used as a method to control quality of polishing [1].

2. Method of ellipsometric investigations

When electromagnetic wave is reflected from an arbitrary reflecting system (Fig. 1) [2,3], a phase difference appears between components of an electric vector that are perpendicular and parallel to the plane of incidence, which, in general, results in the elliptical polarisation of this wave. Reflection coefficient R_p and R_s of a system and phase difference Δ are related by the basic equation of ellipsometry:

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

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

The account of multiple reflections inside a layer at the first and second optical boundaries allows to express reflection coefficients of all the system, which enter into the basic ellipsometric equation (1) through the Fresnel reflection coefficients at each boundary r_1, r_2 and the depth of the layer. In this case, Eq. (1) gets the following form:

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

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 transforming Eq. (2), the angle dependencies for the phase difference Δ and angle ψ could be obtained:

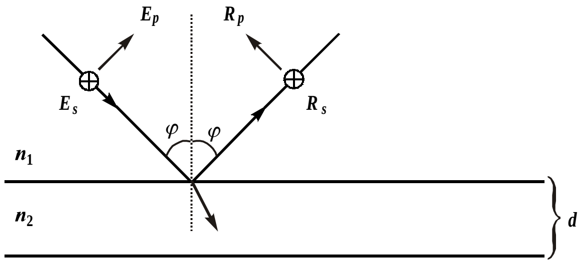

Fig. 1. Reflection of flat simple harmonic wave from homogeneous layer (n_1, n_2 – refractiion indexes, and d – thickness of the layer).

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

where $\bar{\psi}$ and $\bar{\Delta}$ – ellipsometric angles for substrate.

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

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

Relation of Fresnel reflection coefficient for p- and s-components of the electric vector, $tg\rho$ and phase difference between them can be counted by usage of metal-optics methods. The photoelectric method by Beattie and Conn is the most suitable among them. The modification of this method [4,5] allowing to apply it to transparent dielectrics was used in this work.

The values directly measured are intensities of radiation reflected from a sample I_0, I_{45}, I_{90} measured at three azimuths of an analyser ψ_α (equal accordingly 0°, 45°, 90°) concerning incidence plane and fixed azimuth of polariser β = 45°. Ellipsometric parameters are calculated using the formulae [6]:

$$tg\psi=tg\beta\sqrt{\frac{I_0}{I_{90}}},$$
$$\cos\Delta=\frac{2I_{45}-I_0-I_{90}}{2\sqrt{I_0 I_{90}}}. \tag{5}$$

As the measurements of ellipsometric parameters are carried out within the limits of the Brewster angle, where $\cos\Delta$ passes through zero point, the error of phase difference is minimum, and the following condition is realized:

$$tg\rho=tg\psi \tag{6}$$

3. Polishing by a diamond tool

The development of technology of a diamond polishing the parts made of MgF_2 optical ceramics was performed using results of ellipsometric researches of tg 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 undisturbed layer. The requirements on deviation from the shape of optical parts were no more than 1 micron on diameters of details up to 80 mm.

The laser null-ellipsometer LEF-3M-1 (λ = 6328Å) was used to investigate quality of polished MgF_2 optical ceramics.

The analyses of the influence of the sample flatness and number of measurements on the accuracy of determining ellipsometric parameters were previously conducted. It was ascertained that deviation from flatness of a sample within limits N = ±0.5…5 has no essential influence on the error of measurements at the light beam diameter 1…2 mm. With the purpose to obtaine reliable results, we carried out not less than 6 measurements on each sample. Under these conditions, the relative error was no more than 10 % [7].

The changes of the 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 by the form of the polished layer surface [8, 9].

The depth of a polished layer, at which the minimum value of $tg\rho$ and minimum value of φ_M are reached, is adopted for the 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 that after processing by a free abrasive of the same grain sizes. On the base of these results, the technological limits on processing were established. Data about the influence of polisher and abrasive materials on roughness and ellipsometric parameters of polished samples are summarized in Table 1.

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

Using the above ellipsometric method, designed was the technology of diamond polishing on organic flow bundle, which has allowed 2 to 5-fold increase in productivity of processing surface of optical parts.

Table 1. Results of measurements of ellipsometric parameters

Polisher	An abrasive	Roughness R_Z, micrometes	$tg\rho \cdot 10^3$	Φ_M,°
Diamond polisher on organic base and diamonds with the size 5/3	Diamonds with the size 5/3 in organic base	0.015…0.02	15.5	54°32′
Colophon-pitch resin	Chromium oxide	0.025…0.03	13.0	54°35′
The cloth	Chromium oxide	Corrugated frame appears	19.0	54°30′

4. Conclusions

The offered ellipsometric method of control has allowed to improve the technological process of diamond grinding and polishing MgF_2 optical ceramics. It was shown that after diamond processing the depth of the damaged layer was 1.2…1.5 times less than that after processing by free abrasives of the same grinding. The features of the diamond polishing on the organic flow bundle were exhibited in minor increase of ellipsometric parameters, which is conditioned by the presence of considerable tangential efforts of the tool.

References

1. T.V. Vladimirova, N.Ya. Gorban, V.P Maslov, T.S. Melnik, V.A. Odarich. The research of the optical proper ties and structure of sitall // *Optiko-mekhanicheskaya promylennost*, №9, p. 31-33 (1979), in Russian.
2. *Fundamentals of an ellipsometry*. Edited by A.V. Rzhanov // Novosibirsk, Nauka, 1979.
3. T.V. Andreeva, V.A. Tolmachev. Methodological aspects of ellipsometric experiments on optical materials // *Optiko-mekhanicheskaya promylennost*, №10, p. 36-39 (1986), in Russian.
4. V.A. Odarich. Measurements of small ellipsometric parameters by a photoelectric method // *Zavodskaya laboratoriya*, №43, p. 1093 (1977), in Russian.
5. Beattie G.R, Conn G.K., Phil. Mag., , 46, p. 222-225 (1955).
6. A.I. Voniurihin, V.P. Gerchanovskaya. *Optoelectronic polarisation devices*, Kiev, Tekhnika, 1984, p. 136-138, in Russian.
7. *The reference book of the technologist – optician*, Ed. by S.M. Kuznezcova, M.A. Okatova, Leningrad, Magnitostroenie, Leningrad department, 1983., 414 pages in Russian.
8. A.I. Belyaeva, A.A. Galuza, T.G. Grebennik, V. Pyuriyev. Optical constants of surface layer on gadolinium gallium garnet: ellipsometric study // *Semiconductor Physics, Quantum Electronics and Optoelectronics*, **2**(4), p. 61-65 (1999).
9. M.J. Riedl, *Optical design fundamentals for infrared systems*, SPIE Optical Eng. Press, Bellingham, USA (1995), p.136.