ISSN 1027-5495. Functional Materials, 28, No.2 (2021), p. 381-385.
doi:https://doi.org/10.15407/fm28.02.381

Determination of technological process modes for surface formation of substrates for functional components of microoptoelectromechanical systems

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Received January 18, 2021

A method of determining the technological modes for the process of substrates surfaces shaping for the functional components of micro-optoelectromechanical systems is proposed, which allows us to improve the quality of the substrates. A mathematical model is developed to describe the influence degree of the technological process parameters on the roughness during the shaping substrate functional surfaces for the components of micro-optoelectromechanical systems. It allows predicting the parameters of finished optoelectronic products based on these components. The experimental research results for obtaining the dependence of substrate surface quality for micromirrors of optical switches on the processing modes during the grinding and polishing technological operations are presented.

Keywords: functional component, micro-optoelectromechanical systems, technological process, roughness, substrates.

Визначення технологічних режимів формоутворення поверхонь підкладок функціональних компонентів мікрооптоелектромеханічних систем. *І.Ш.Невлюдов, О.О.Чала, І.В.Боцман*

Запропоновано метод визначення технологічних режимів для процесу формоутворення поверхонь підкладок функціональних компонентів мікрооптоелектромеханічних систем, який дозволяє підвищити якість підкладок. Розроблено математичну модель, що описує ступінь впливу параметрів технологічного процесу формоутворення функціональних поверхонь підкладок компонентів мікроптооелектромеханічних систем на їхню шорсткість і дозволяє прогнозувати параметри готових виробів оптоелектроніки на основі цих компонентів. Наведено результати експериментальних досліджень залежності якості поверхні підкладок для мікродзеркал оптичних перемикачів від режимів виконання технологічних операцій їх шліфування та полірування.

Предложен метод определения технологических режимов для процесса формообразования поверхностей подложек функциональных компонентов микрооптоэлектромеханических систем, который позволяет повысить качество подложек. Разработана математическая модель, описывающая степень влияния параметров технологического процесса формообразования функциональных поверхностей подложек компонентов микрооптоэлектромеханических систем на их шероховатость. Она позволяет прогнозировать параметры готовых изделий оптоэлектроники на основе этих компонентов. Приведены результаты экспериментальных исследований зависимости качества поверхности подложек для микрозеркал оптических переключателей от режимов выполнения технологических операций их шлифовки и полировки.

1. Introduction

Micro-optoelectromechanical systems (MOEMS) are evolving rapidly, as electronic devices based on them have many significant advantages, including their size and mass parameters, high functionality and reliability, low power consumption and ease of integration compared to existing traditional telecommunication devices. This primarily applies to MOEMS actuators and switches, which are widely used for the optical network construction [1–3].

The main parameter of the MOEMS switch is the reflection coefficient, i. e. the coefficient of optical power losses in the process of redirection of light fluxes in the optical-glass fiber. The requirements to the quality of these products are only increasing, and the compliance with the specified characteristics and parameters of such components depends on the production technology of their functional components (FC) — mirrors, which consist of a single crystal substrate and applied, as general, metalized layer.

With numerous advantages, there is also a serious problem of ensuring the quality of MOEMS FC and modules based on them, since such products can be exposed to a large number of destabilizing factors at all stages of the life cycle [1–4].

Therefore, the actual task is to further improve the quality of MOEMS components. For this purpose there is a need to use promising implementation variants for the technological processes (TP) and operations of their production and to improve methods of assessing, forecasting and monitoring the characteristics of MOEMS structures at the stages of production and operation of optoelectronic products.

2. Experimental

Functional components of MOEMS are intended for performance of difficult operations with a light beam (reflection, diffraction, modulation, spatial orientation and redirection) [1]. The operational properties of transmission systems based on such components depend on their quality. The necessary quality parameters can be guaranteed with strict compliance with the conditions of the technological process of their production and the use of high-precision equipment for testing and data processing [2–4]; this can be predicted by the results of digital computer modeling.

One of the most important operations in the production process of MOEMS components is the shaping [5]. Finishing operations in such TP are grinding and polishing of the FC substrate surface. The need of grinding and polishing is conditioned by the fact that after almost every stage of fabrication of substrates for MOEMS components, scratches, splits, cracks, swellings, oxidations and other defects remain on their surface. These defects lead to structure heterogeneity of the substrate surface layer and change its physical-technological parameters. Such a layer is called damaged; to remove it, the MOEMS component substrate surface is grinded, etched and polished [5–15].

In order to prevent the appearance of these defects during the technological process, it is necessary to identify the factors that affect the substrate quality and analyze the mechanisms of defect formation. This will allow us to improve the existing methods of assessment, testing and forecasting of the surface characteristics of the FC substrates at the stages of their design, production operation, as well and as to develop technological support for their quality.

A full factorial experiment was performed to analyze the parameters of the technological process of shaping silicon substrates for the MOEMS functional components during polishing and grinding using different types of diamond grinding pastes (ACM 2/1, ACM1 4/10, ACM 0/28).

The most significant input factors of finishing technological operations of substrate shaping, which meet all the factorial experiment requirements, are the test sample processing time — t (min), the spindle rotation speed of the grinding-polishing machine — v (rpm) and the grains size of paste for surface polishing and grinding — z (μm) [4]. In all conducted experiments, the pressure was constant.

The ranges of changing the factors were as follows: the maximum material processing time x_1 = 10...20 min, the disk rotation speed x_2 varied from 30 to 40 rpm, the minimum grain size of the paste x_3 was 2 μm, and the maximum — 32 μm.

Based on the results of a full factorial experiment and verification of the regression significance of the coefficients according to Student's criterion, the following regression equation was obtained in coded form:

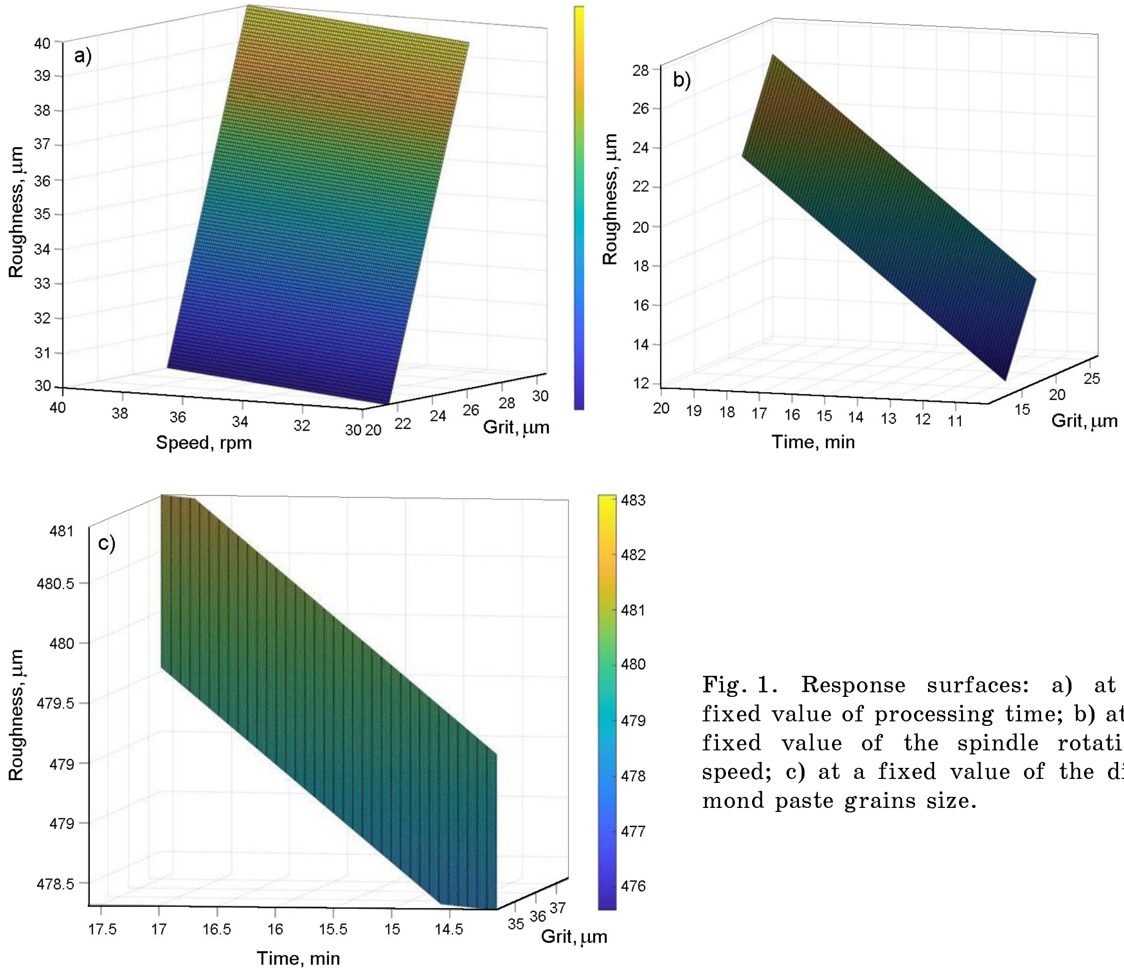

Fig. 1. Response surfaces: a) at a fixed value of processing time; b) at a fixed value of the spindle rotation speed; c) at a fixed value of the diamond paste grains size.

$$y = 20.33 - 5.17x_1 + 2.25x_2 + 9.21x_3 + 1.98(0.05z - 1.13)x_1x_3.$$

After decoding it is the next:

$$y(t,v,z) = 20.33 - 5.17(0.2t - 3) + 2.25(0.2v - 7) + 9.21(0.05z - 1.13) + 1.98(0.2t - 3)(0.05z - 1.13).$$

After performing transformations and reductions, we obtain the equation:

$$y(t,v,z) = 8.7975t + 0.45v + 0.1635z + 0.0198tz - 14.6251.$$

By fixing the values of each of three factors that affect the final value of substrate surface roughness, at their average level (according to the full factorial experiment plan) the following equations are obtained:

$$y_t = 15(v,z) = 0.45v + 0.4605z - 5.8273,$$
$$y_v = 35(t,z) = 0.58652t + 0.1635z + 0.0198tz - 1.1249,$$
$$y_z = 17(t,v) = 0.92312t + 0.45v - 1.1249.$$

Using the obtained equations of the response surfaces, the dependences of the silicon substrate material roughness on the duration of processing with different types of diamond grinding pastes are presented in Fig. 1.

According to the graphs, the influence of each factor (or their combination) of the grinding and polishing technological process on the functional surface shaping parameters of the silicon substrates of MOEMS components was evaluated.

A combination of factors for obtaining the planned value of the prototype roughness was determined and recommendations were formulated to ensure the necessary modes of shaping TP for MOEMS FC.

For example, to obtain the surface roughness of the FC substrate at the level of 15 µm, it is necessary to process the sample with grinding paste ACM 0/28 for 7 min, with paste ACM1 4/10 for 12 min, and by using of paste ACM 2/1 during 17 min.

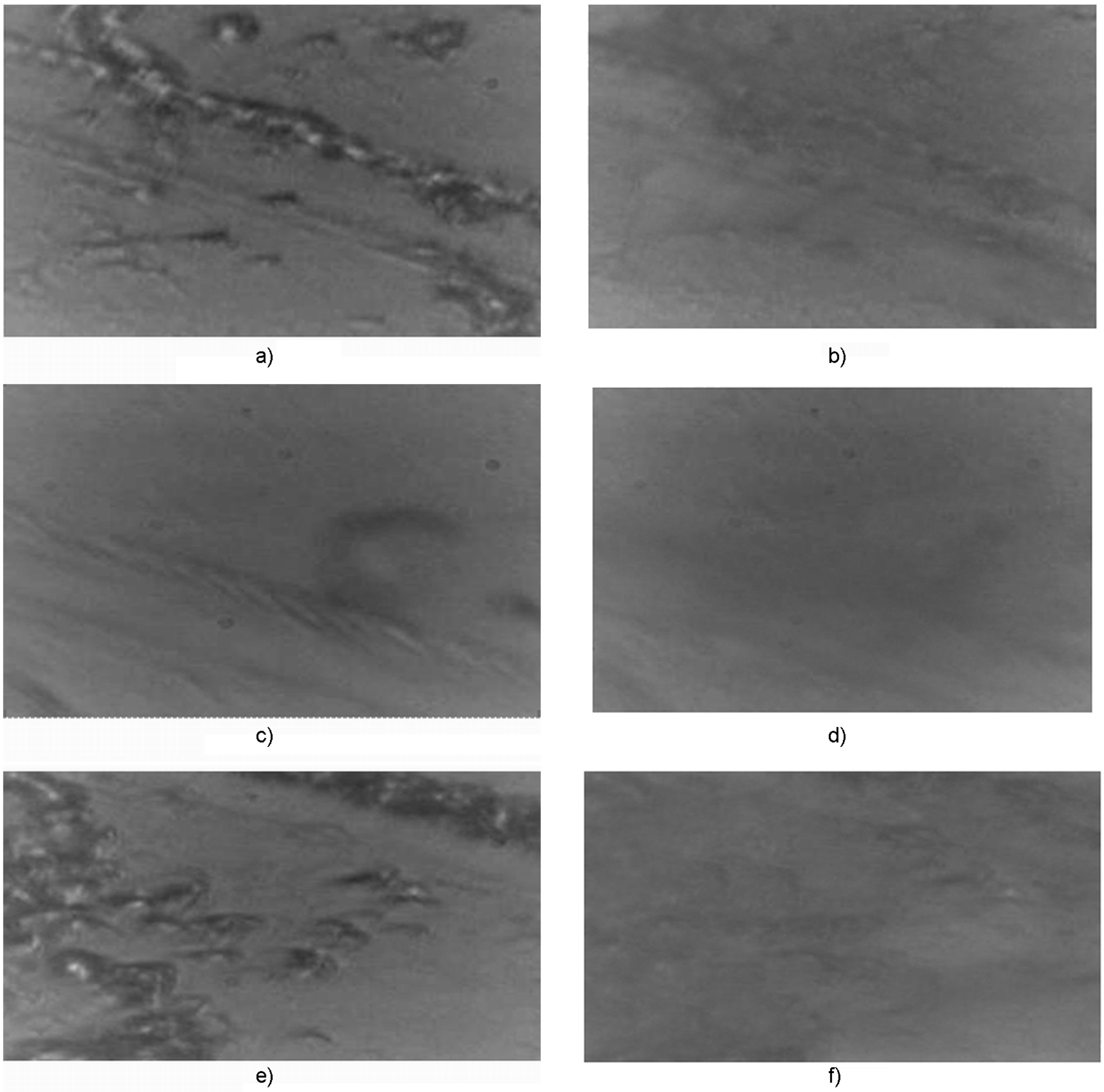

Fig. 2. Surfaces of silicon substrates for MOEMS switches mirrors: a, c, e — before processing; b, d, f — after processing.

3. Results and discussion

At the next stage of the research, on the basis of the received response surfaces (Fig. 1), the corresponding modes for surface shaping were chosen for MOEMS FC substrates and the experimental silicon substrate samples were fabricated.

An experiment on practical approval of the obtained theoretical results was conducted on the basis of Research and production enterprise "Ukrintech" in an accredited testing laboratory. Processing of silicon FC substrates for optical actuators was performed on the FTP-1M grinding-polishing machine of the PreciPolish series.

In Fig. 2 the photographs of substrates for micro-mirrors of optical switches are presented. The samples before processing are shown in images *a*, *c* and *e*; images *b*, *d* and *f* show the substrates after processing in accordance with the technological modes determined on the basis of computer simulation results (Fig. 1a, b, c, respectively) to obtain a roughness value of 15 μm.

As can be seen from Fig. 2, after processing, the number and sizes of defects decreased in the micromirror substrate structure, namely, cracks, splits, scratches, shells, spots and pores. Thus, at the chosen processing modes the planned roughness value was obtained, which was inspected by the non-destructive testing method developed by the authors [16].

Thus, the performed researches make it possible to substantiate the values of TP shaping parameters for the silicon substrates of MOEMS micromirrors, which, in turn, will reduce the number of dislocations and sizes of defective micronucleus in the substrates before the deposition of a reflective metallization layer.

4. Conclusion

According to the obtained results, a method is proposed for determining the influence degree of technological factors on the surface shape of substrates for functional components of micro-optoelectromechanical systems in the technological process of their shaping.

The dependences between the roughness value of MOEMS FC substrates and the parameters of shaping process technological modes are obtained; in particular, the effects of spindle rotation speed, processing time, grain size of polishing paste and their combined action are analyzed, that makes it possible to assess the surface shape parameters of MOEMS FC substrates and to improve their quality.

The obtained results should be used in the development and preparation of technological processes for fabrication of the substrates for functional components of micro-optoelectromechanical systems.

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