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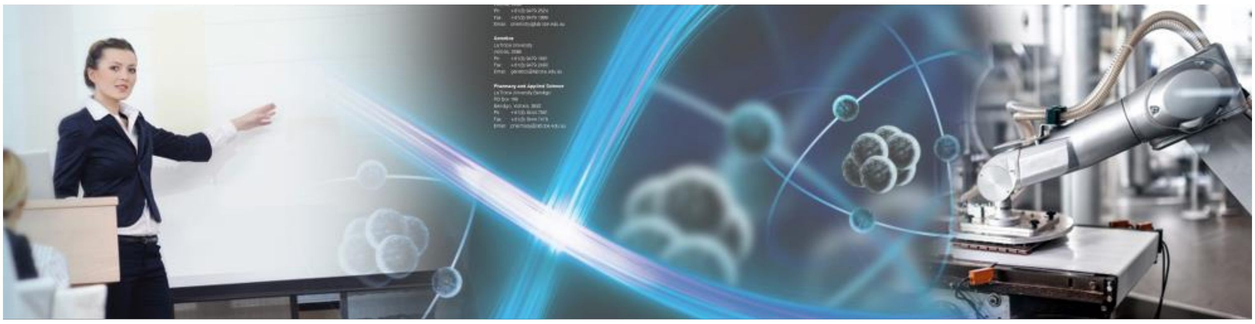

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MANUFACTURING & MECHATRONIC SYSTEMS 2021

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Manufacturing & Mechatronic Systems 2021: Proceedings of Vst International Conference, Kharkiv, October 21-22, 2021: Thesises of Reports / [Ed. I.Sh. Nevlyudov (chief editor).] .- Kharkiv .: [electronic version], 2021. – 180 p.

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ВИРОБНИЦТВО & МЕХАТРОННІ СИСТЕМИ 2021

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Mathematical Model of Substrates Formation for Functional Components of Microoptoelectromechanical Sensors

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Abstract: A method of technological modes determining for the process of substrates surfaces shaping for the functional components of microoptoelectromechanical systems is proposed, which allows to improve the quality of the substrates. A mathematical model is developed that describes the parameters influence degree of the technological process of the substrates functional surfaces shaping for the microoptoelectromechanical systems components on their roughness and allows to predict the parameters of finished optoelectronic products based on these components. The experimental researches results for obtaining the dependence of substrates surface quality for micromirrors of optical switches on processing modes during the grinding and polishing technological operations are presented.

Keywords**:** functional component, microoptoelectromechanical systems, technological process, roughness, substrates.

I. Introduction

Microoptoelectromechanical 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 networks construction [1-6].

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 of these products quality are only increasing, and 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, as such products can be exposed to a large number of destabilizing factors at all stages of the life cycle [2].

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 optoelectronic products production and operation.

II. Experimental Details

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 only if strict adherence to the technological process conditions of their production and the use of high-precision equipment for testing and data processing [2-4], which can be predicted by the results of digital computer modeling.

One of the most important operations in the process of MOEMS components production 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 MOEMS components substrates fabrication on their surface remain scratches, splits, cracks, swellings, oxidations and other defects. They lead to structure heterogeneity of the substrates surface layer and changes in its physical-technological parameters. Such layer is called damaged and to remove it the MOEMS component substrate surface is grinded, etched and polished [3].

In order to prevent the appearance of these defects during the technological process of MOEMS switches FC manufacturing, it is necessary to identify the factors that affect the substrates quality and analyze the defect formation mechanisms in them. This will allow to improve the existing methods of assessment, testing and forecasting of the surfaces 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 technological process parameters of silicon substrates shaping 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 value was constant.

The ranges of factors change were as follows: the maximum material processing time $x_1 = 10\ldots 20$ *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.*

According to the experiment results the regression equation was obtained in coded form:

$$y = 20{,}33 - 5{,}17x_1 + 2{,}25x_2 + 9{,}21x_3 + 1{,}98x_1 x_3.$$

After decoding it is the next:

$$y(t,v,z) = 20{,}33 + 5{,}17(0{,}2t - 3) +$$
$$+2{,}25(0{,}2v - 7) + 9{,}21(0{,}05z - 1{,}13) +$$
$$+1{,}98(0{,}2t - 3)(0{,}005z - 1{,}13).$$

After performing transformations and reductions, we obtain the equation:

$$y(t,v,z) = 8{,}7975t + 0{,}45v + 0{,}1635z + 0{,}0198tz - 14{,}6251\,.$$

$$y_{t=15}(v,z) = 0{,}45v + 0{,}4605z - 5{,}8273\,.$$

$$y_{v=35}(t,z) = \ 0{,}58652\,t + 0{,}1635\,z + 0{,}0198\,tz + 1{,}1249\,.$$

$$y_{z=17}(t,v) = \ 0{,}92312t + 0{,}45v - 1{,}1249\,.$$

Using the obtained equations of the response surfaces, the dependences of the silicon substrate material roughness on the duration of processing by different types of diamond grinding pastes are plotted, the results are presented in Fig. 1. According to the graphs, the influence of each factor (or factors combination) of the grinding and polishing technological process on the functional surfaces shaping parameters of the MOEMS components silicon substrates 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.

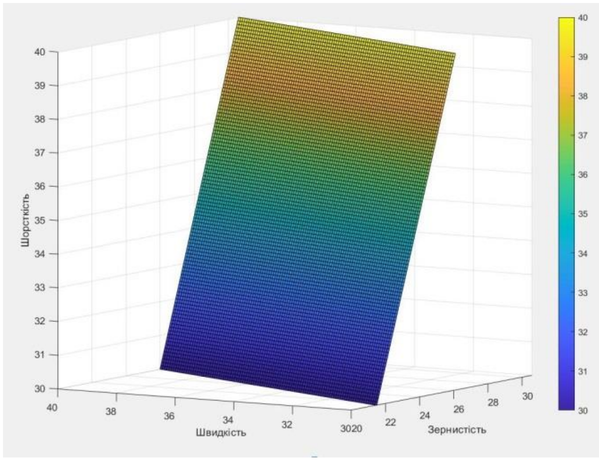
For example, to obtain the surface roughness of the FC substrate at the level of *15 µm*, it is necessary to process the sample with grinding paste ACM 0/28 for *7 min*, with paste ACM1 4/10 for *12 min*, and by using of paste ACM 2/1 during *17 min.*

III. Results and Discussion

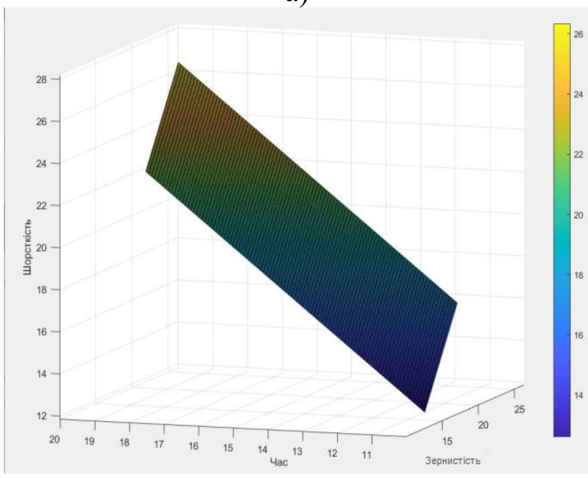
At the next researches stage on the basis of computer modeling results for shaping of MOEMS FC substrates surfaces the experimental silicon substrates samples were fabricated.

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 samples for optical actuators was performed on the FTP-1M grinding-polishing machine of the PreciPolish series.

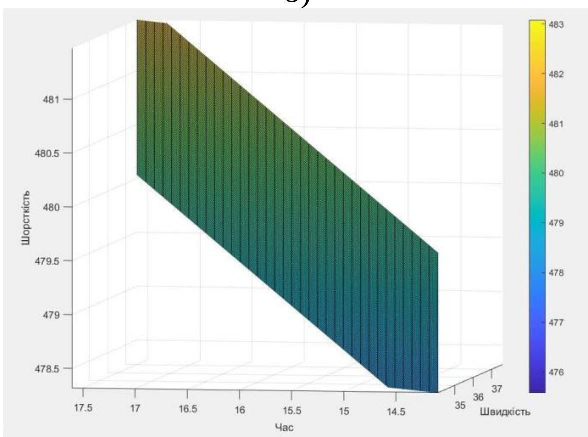
In Fig. 2 the photographs of substrates samples for micro-mirrors of optical switches are presented. There are the substrates samples before processing on images *a*, *c* and *e*; images *b*, *d* and *f* show the substrates samples after processing in accordance with the technological modes determined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



a)



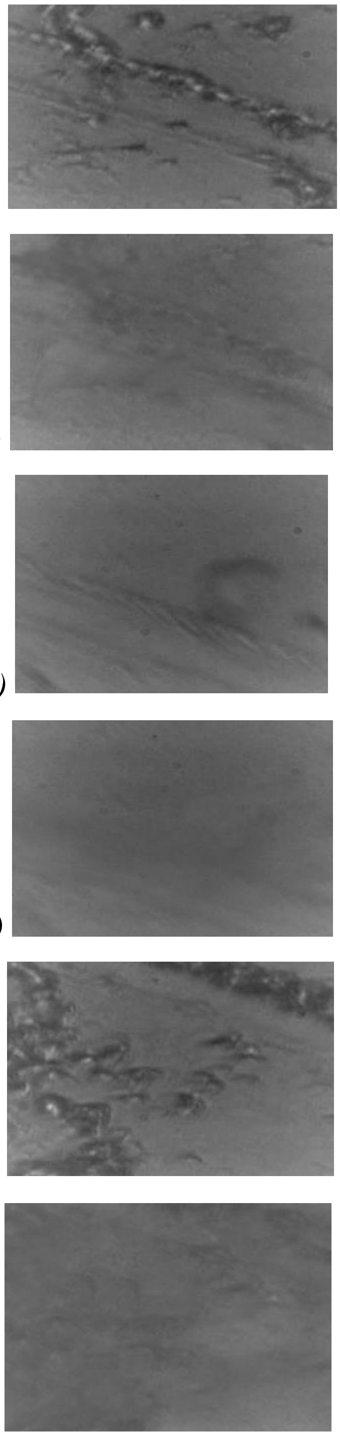
b)



c)

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

As can be seen from Fig. 2, after processing in the micromirror substrate structure the number and sizes of defects were decreased: e.g. of 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].



a) b) c) d) e) f)

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

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

The dependences between the roughness value of MOEMS FC substrates and the parameters of shaping process technological modes are obtained, in particular influence of spindle rotation speed, processing time, grains size of polishing paste and their combined action are analyzed, that allows 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 the substrates of microoptoelectromechanical systems functional components.

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