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THE MODELING OF PROGRESS OF PRODUCTION DEFECTS IN SURFACE LAYERS OF FUNCTIONAL OPTICAL COMPONENTS OF MOEMS

Nevliudov I., Omarov M., Chala O.

The subject *of this research is modeling the process of development of manufacturing defects in the surface layer of functional optical components of micropotoelectronic systems (MOEMS).* ***The aim is*** *to visualize the processes of development of manufacturing defects; increase the accuracy and reliability of the information received; reducing the labor intensity of developing a technological process for manufacturing functional optical components MOEMS, by creating special software****. The task is:*** *analysis of the physical and technological features of the production of MOEMS functional optical components substrates, previously developed mathematical models, the choice of an operating system and programming language, an integrated development environment for modeling the development of manufacturing defects of the surface layer of MOEMS functional optical components based on the developed software****. The methods*** *used are: computer data processing methods using the Linux operating system (UBUNTU), the Python 3.8 programming language, the PyCharm integrated development environment. The following* ***results*** *were obtained: it is proposed to use a developed software product to simulate the development of manufacturing defects in the surface layer of MOEMS functional optical components that allows you to visualize the process of degradation processes in the development of manufacturing defects in the surface layer of MOEMS functional optical components, improve the accuracy and reliability of the information received; and reduce the complexity of developing technological processes for manufacturing such components. This software product has a residual high accuracy due to the use of modern methods of computer data processing and a high-level programming language, the ability to choose both existing manufacturing processes, using the features of the source materials, and adjusting physical and technological parameters and creating corrected manufacturing processes for a given object, to obtain two-dimensional visualization of processes in time and prediction of degradation processes, due to the use of developed mathematical models.* ***Conclusions. Scientific novelty of the results*** *A mathematical model of the development of manufacturing defects of the surface layer of functional optical components MOEMS has been developed, which differs from the known ones in that it takes into account the occurrence of a random variable of a component of the model with the possibility of prediction, which allows, on*

the basis of the developed software, to visualize the process of development of manufacturing defects, to increase the accuracy, reliability of the received information; to reduce the complexity of the technological process of manufacturing functional optical components MOEMS.

Introduction

The scientific field of low-dimensional semiconductor structures is a rapidly developing part of the science of materials, which has significant technological applications [1-6]. At the moment, the scientific world is studying silicon - as the main material for substrates in electronic devices, MEMS and MOEMS.

This is especially important for three reasons. First, because silicon is not capable of emitting visible light, even at cryogenic temperatures. Second, light-emitting nanostructures can be easily fabricated without the help of any expensive lithographic or epitaxial technique, which is a common approach for producing nano-sized structures. Third, silicon is the most technologically important material known to mankind and dominant in microelectronics. [7-9].

If we consider the field of technology, equipment and production of electronic equipment, then silicon is the basis for substrates of electronic products, functional components of microelectromechanical (MEMS) and microoptoelectromechanical systems (MOEMS). Such systems are now widely used in a variety of devices, ranging from special space applications to consumer electronics.

Such components are the main functional elements of the above systems, and the accuracy and adequacy of the device as a whole depend on their correct, laid down initial parameters.

Control and test operations that are part of the structure of modern technological processes cannot give a complete guarantee of the absence of defects in the production of this type of components and their behavior over time, taking into account the operating conditions [9-10].

Most of the defects arise precisely because of defectiveness and (or) the presence of impurities in the initial materials of substrates or substrates of substrates of functional optical components of MOEMS and during the process of their manufacture [9-12].

Therefore, we decided to consider the defects of the substrates of the layers and sublayers of the functional optical component of the MOEMS, as the main and primary source of defectiveness of the component of the MOEMS.

The problem is that at the stage of production of starting materials it is unlikely that it is possible to trace the defectiveness of structures and the dependence of physical and technological parameters that directly affect the quality and conformity of the output characteristics of MOEMS components; the factor of kinetics of degradation processes in materials, which manifests itself in time and, partially, depends on the operating conditions of the product.

In this regard, scientific and practical problems are now relevant and timely, which are associated with the prediction, prediction and management of defect formation of layers and sublayers of functional components of the MOEMS, which are solved by monitoring parameters, the development of defects inherent in production, which in turn do not always worsen parameters of microsystems [9-12], on the contrary, over time, can even improve with the right approaches in design and production and certain operating conditions [13-18].

Prediction and control of defect formation served as the basis for the development of a promising scientific direction in technologies for the production of semiconductors, materials and electronic devices and was named defect engineering [19-20].

We have developed a mathematical model for the development of manufacturing defects in the surface layer of substrates of functional components MOEMS [20].

A mathematical model based on these basic manufacturing defects that arise in the surface layer of substrates of functional optical components of MOEMS, in the technological processes of their production, taking into account dynamic processes.

The developed mathematical model takes into account the emergence of a random component of the model with its predictive ability [20].

The results obtained must be taken into account [20] when developing technological processes for the production of electronic devices, in particular, microsystems based on MOEMS components.

We continued our research. On the basis of a mathematical model developed by us [20], in order to reduce the complexity of solving the problem of data analysis, it was decided to simulate the development of manufacturing defects in the surface layer of optical functional components, and create our own software product for this purpose.

The use of such a software product will allow not only to visualize a part of the technological process of manufacturing the substrate of the functional component of MOEMS (in terms of predicting and predicting defect formation), but also will improve the accuracy; the reliability of the information received; and will reduce the labor intensity and cost of developing a technological process for the manufacture of such objects as a whole.

Substantiation of physical and technological processes of the technological process for the production of optical surfaces of functional components of MOEMS, which affect defect formation

A typical MOEMS manufacturing process consists of several manufacturing processes, which, as a rule, are independent from each other and separated in space and time.

Figure 1 shows a typical manufacturing process for a MEMS optical switch. The manufacturing processes for the manufacture of microelectromechanical switches consists of eight main groups or stages.

Their differences are due to the functional, design and technological features of the components. In turn, the composition of the component base of information transmission systems is characterized by a significant variety both in terms of the principles of operation, design, and in the technological processes of their production used [21-25]. Such technological processes are diverse; we will focus on this typical version.

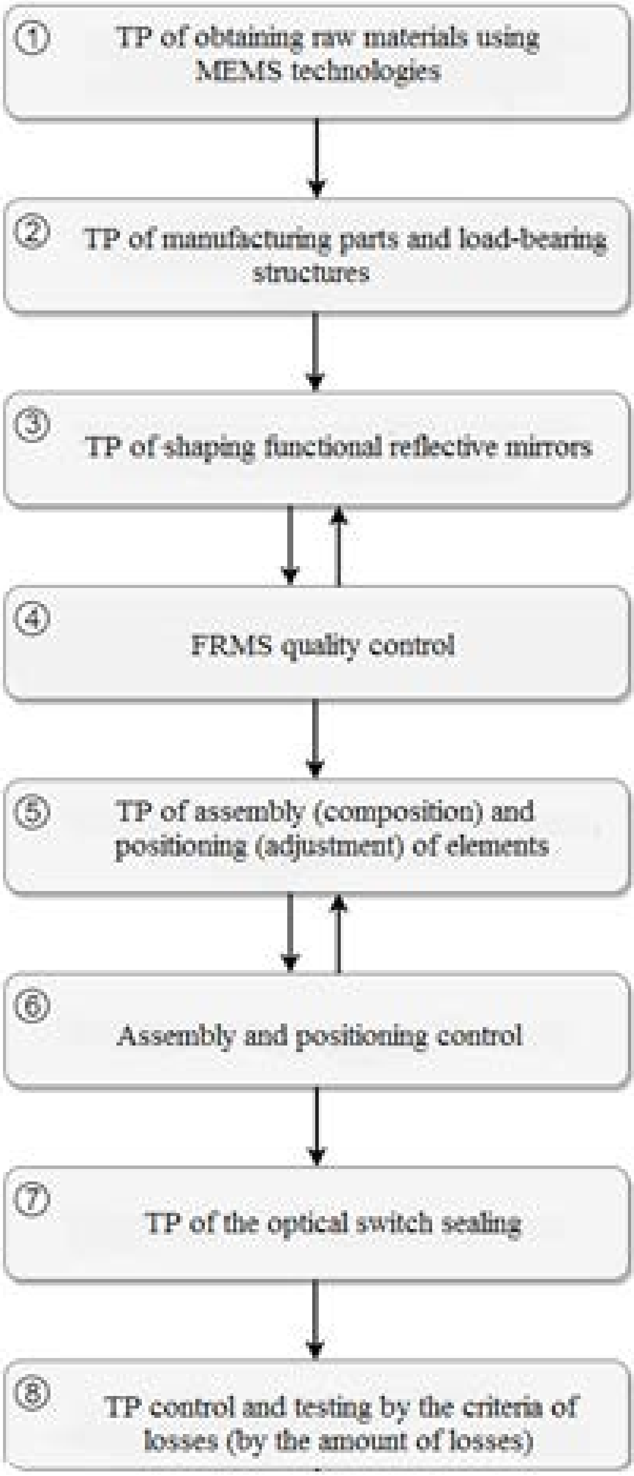

Fig. 1. Typical manufacturing process for a MOEMS switch

Of greatest interest to us is the first stage of the optical switch manufacturing process.

The first group is made up of TPs for the production of starting materials for substrates of optical functional elements MOEMS. It is at this stage that the component substrate is formed and, as a rule, coatings are applied to its base, usually metallized.

These technological processes are characterized by high complexity, but at the same time group execution and mass production, thoroughness of finishing and typing, underdeveloped nomenclature, high level of manufacturability and automation of production, high reliability and constantly decreasing cost [7-8].

But it should be noted that the further development of the component base and initial materials is in the direction of synthesis and convergence, the use of new materials, stricter requirements for their parameters, reduction of defects in substrates and forming layers, stabilization and improvement of the accuracy of the technological process, automation of production using machine control on all production processes.

It is at this first stage that it becomes possible to predict and predict defects in the structures of substrates, their layers and sublayers.

Defectiveness, that is, the layer of the reacted substance of the sublayer of the substrate (μm), appears with time (t) and does not always lead to a deterioration of the parameters laid down by the technological process.

If we consider the control parameter of the reflectivity of the functional mirror, the coefficient of loss for reflection-re-reflection of the optical signal, then this parameter changes with time towards a decrease, under certain conditions of manufacture and operation.

Let us consider the list of manufacturing defects of substrates of functional optical components of micropotoelectronic systems on which the mathematical apparatus of the model [20] was built, the considered processes will be entered in table 1. It should be noted that we have considered only truly significant technological processes.

Table 1

List of manufacturing defects of substrates of MOEMS functional components

[7-8, 20, 11-12, 26-28]

No.	Technological process	Defects	The cause of the defect	Failure mechanisms
1	Fabrication of the substrate and epitaxial layer, including the evaporation rate of the material	Crack propagation and migration	Cracks	Partial separation of sublayers
		Inhomogeneities	Mechanical stress	Changing the aspect ratio. Ratio of the maximum size to the minimum size no more than 2)
		Impurities	Concentration of elements in the base area	Partial separation of sublayers
		Scratches	Careless attitude	Violation of diffuse profiles
		"Dome-shaped" or bulging dome	Contamination of the substrate with impurities	Punctures
3	Diffusion	Diffusion emissions	Diffusion over existing dislocations, local fusion of the master alloy with impurities	Changing structure parameters
		Areas of excessive diffusion	Dislocations at the edges of diffusion regions	Reducing structure stress, deformation
4	Oxidation (as a special case of diffusion)	Cracks	Etching oxide	Regions of parasitic diffusion
		Parasitic diffusion	Oxide defects	Cracks, holes

To control the occurrence of such defects, there is a fairly wide variety of non-destructive testing methods [29, 30]. To control the surfaces of the functional components of microtototoelectronic systems, we proposed a tested method [31].

Description of the software product

Using the data in Table 1 and [20], it was decided to develop a specialized software product for predicting the development of manufacturing defects in optical functional components of the MOEMS.

The software product was developed based on the Linux operating system (UBUNTU).

Linux kernel, includes one or another set of utilities and programs of the GNU project, and possibly the use of other components.

In favor of this choice was the fact that, like the Linux kernel, systems based on it are usually created and distributed in accordance with the development model of free and open source software. Linux systems are distributed mostly free of charge in the form of various distributions - in a form that is ready for installation and convenient for maintenance and updates - and that have their own set of system and application components, both free and, possibly, proprietary. In our case, the choice fell on Linux (UBUNTU).

Not unimportant is that Linux runs on many processors of various architectures such as x86, x86-64, PowerPC, ARM, Alpha AXP, SPARC, Motorola 680x0, SuperH, IBM System / 390, MIPS, PA-RISC, AXIS CRIS, Renesas M32R, Atmel AVR32, Renesas H8 / 300, NEC V850, Tensilica Xtensa, many others [32].

Among the variety of programming languages, we chose the high-level general-purpose programming language Python 3.8, for a number of obvious reasons. It is a programming language focused on improving developer productivity and code readability. The Python core syntax is minimalistic. At the same time, the standard library includes a large set of functions.

Python supports structured, generic, object-oriented, functional, and aspect-oriented programming. The division of programs into modules is supported, which, in turn, can be combined into packages.

The reference implementation of Python is the CPython interpreter, which supports most of the actively used platforms [32], as we have chosen. It is distributed under the free Python Software Foundation License, which allows you to use it without restriction in any application, including proprietary [32]. There is an interpreter implementation for the JVM with the ability to compile, CLR, LLVM, other independent implementations [32].

We used an interpreter based on the language C - CPython, as supplied by default for the Linux operating system (UBUNTU).

We chose PyCharm - an integrated development environment for the Python programming language.

This framework provides code analysis tools, a graphical debugger, a unit test runner, and supports web development with Django.

PyCharm is a cross-platform development environment that is compatible with Windows, MacOS, Linux. PyCharm Community Edition (free version) is licensed under the Apache License and PyCharm Professional Edition (paid version) is proprietary software [6,32].

With the help of the developed software, the interface of which is shown in Fig. 1, we managed to reduce the labor costs of solving the problem of predicting and predicting manufacturing defects in substrates of functional optical components of MOEMS, not only to visualize part of the technological process of manufacturing a substrate of a functional component (in terms of predicting and predicting defect formation), but also to improve accuracy; the reliability of the information received;

development of a technological process for the manufacture of such objects in general.

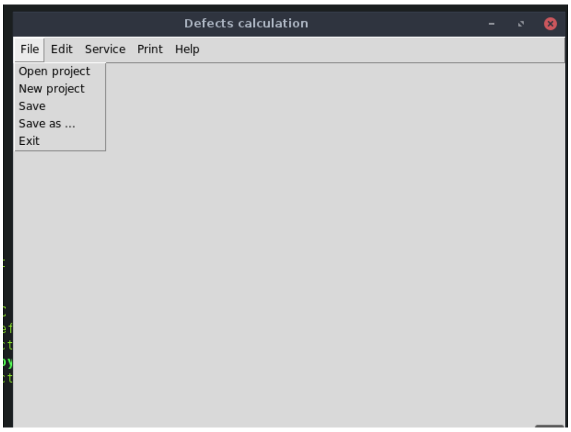

Fig. 1. Software for predicting and predicting and predicting manufacturing defects

The program has in its arsenal of functions for selecting a standard TP for an enterprise and the ability to adjust the parameters of the technological process of manufacturing a planned object (fig. 2), there can be up to 50 such tabs.

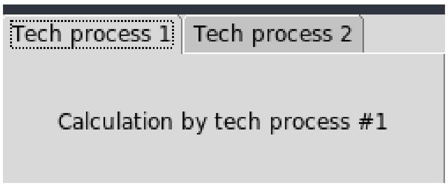

Fig. 2. Tabs for the selection of TP production for prediction and prediction and prediction of manufacturing defects

You can create new projects, save them and change the parameters, with the help of adjustments, the possibility of changing each parameter individually or adjusting the parameters of the manufacturing process is presented, to predict defectiveness and equipment in production conditions. Fig. 3 shows the program window and a graphic representation of one of the parts of the technological process.

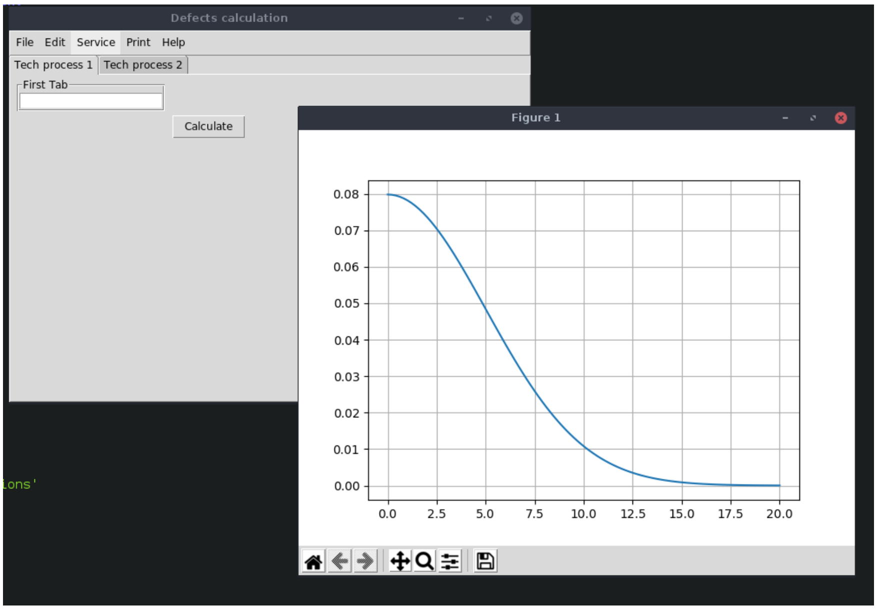

Fig. 3. Graphical representation of the technological process of corrosion

Conclusions

A mathematical model of the development of manufacturing defects of the surface layer of functional optical components MOEMS has been developed, which differs from the known ones in that it takes into account the occurrence of a random value of the component of the model with the possibility of prediction, which allows, on the basis of the developed software, to visualize the development of manufacturing defects, to increase the accuracy and reliability of the information received; reduce the labor intensity of the manufacturing process of functional optical components MOEMS.

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