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# APPLICATION OF THE SELF-ADAPTIVE AND SELF-RECONFIGURABLE COMPUTER DEVICES FOR MICRO- AND NANOELECTRONICS

*The method of the adaptively controlled process of synthesis and laser correction parameters of metal-semiconductor contacts for basic logic elements of digital devices and sensors of information-measurement and control systems was proposed. Expediency, advantages and disadvantages of use of self adaptive and self-reconfigurable of computer tools for solving technological problems of micro and nanoelectronics are described. It is determined, that functional efficiency, versatility and economic performance of the system can be increase through the use of multifunctional reconfigurable computer systems for process control and data processing. The use of intelligent measuring converters for data acquisition allowed to provide the flexibility, versatility and scalability of the system, simplifying software development, and provides remote access for telemetry measuring of the object parameters and process equipment.*

***Keywords:*** *semiconductor; Shottki diode; structural defect; laser annealing technology; self-adaptive system; self-reconfigurable computer.*

## Introduction

Tasks synthesis of modern micro and nanoelectronics devices require the use of precision control processes [1, 2]. First of all it is because the reduction of geometric dimensions of active elements to the nano range leads to the manifestation of nonlinearity characteristics and edge effects in semiconductor devices [3, 4]. In digital devices we can to prevent false triggering due to diversity of logic levels of signal, even at reduced voltage to the units and fractions of a volt. For semiconductor sensors of physical quantities, in particular photodetectors electromagnetic radiation of ultraviolet (UV), visible and infrared (IR) range or interference filters that are executed in the form of nanoscale multilayer thin film structures and is the basis for measuring transducers information and measurement systems, the quality of their electro-optical characteristics stays determining factor that affect the sensitivity, dynamic range and error converting of the recorded information signals. Improving the performance of such structures can be achieved using techniques of pulsed laser irradiation [5]. However, for the implementation and increasing control of this process, we need the high-quality models and very precise calculations that require considerable use of computing resources. Available and currently use for this purpose computer tools (CT), in principle are solve the problem of this class, but their efficiency is rather low. This is due to the space-time diversity process modelling and implementation processes and also with hardware redundancy of computer equipment, lack of the control of dynamic changes of process parameters. Therefore, the actual problem is the development of specialized computer tools for effective process control especially in a small-scale semiconductor manufacturing. The purpose of this paper is to study the requirements and methods to solve problems of analysis and synthesis design of multifunctional computer systems for semiconductor technology based on an analysis of the details of the technological process.

## Research methodology and objectives

In conditions of technological support small-scale semiconductor production [3 - 5], also as another modern advanced information technologies (IT) and cyber-physical systems (CPS), for example: in mobile telemetry systems for the study of the properties of distant objects, in the robotic systems and other cases of complex application of CT – often need to solve diverse problem characteristic for information and measurement systems, automation control, of numerical simulation of the characteristics and processes of physical objects [6]. The basic requirements that apply to the characteristics and parameters used in these cases CT and systems can be described by the term “multifunctionality”. It consists in the need to tackle diverse tasks in parallel or consequently in real time and using different devices distributed in the system. This approach requires specific architecture of specialized computer system (CS) for giving them significant power processing, of presence of an extensive system of communication with peripheral devices, of synchronization system and scheduling tasks performed. The use of universal CS with a typical architecture for solving these classes of

problems in our view can not be entirely correct. It requires additional costs of upgrading them to provide the appropriate level of multifunctionality and will result in significant of hardware-software redundancy of system, and subsequently to the decrease in efficient performance and increased of energy costs. Objectives of this study is to justify new approaches, methods and technical means of building of the self-adaptive and self-reconfigurable multifunctional CS for solving certain classes of technological problems.

Note, that the term "adaptive system" in the context of this study, we understand primarily as the ability to programmatically controlled selection of functions performed with their set, specified in the design process, and the possibility of certain modifications of the parameters, such as speed or accuracy fulfilling the selected algorithm, based on a preliminary analysis of received start and input data. The term "reconfigurable system" in our sense is a bit wider, provides a self-correction of CS architecture [3]. In particular, such as dynamic change in the operation of the format commands or data correction or even replacement executable algorithm implemented in hardware also based on a preliminary analysis of initial input. The latter is achieved through the use of modern reconfigurable system environments based on programmable logic integrated circuits. The use of prefix "self" to the term "adaptability" and "reconfigurability" in this case is justified, in our view, as it involves changing the properties of the system on the results of its analysis of the data and the system for introspection and availability currently relevant hardware and software tools and solutions. This approach is not contrary to the general principles of self-organized systems, although the choice available to "self" CS decisions is limited and is determined at the stage of design. Improving intelligence of well organized CS for certain classes of problems can be achieved using the apparatus of artificial neural networks for the implementation phase of the analysis of input data. This is true, for example, for monitoring based on specific recognition of images, particularly in growing silicon crystals by the Czochralski method, solving problems of logistics in the management of traffic flows automated production lines, etc.

Note, that the question of synthesis of self-adaptive and self-reconfigurable CT as a separate object studies [7 - 10], and their use as elements of cyber physical systems are investigated in the literature [6, 11, 12]. However, in contrast to previously proposed approaches, in this case we offered the transparent synthesis of technological system in which the technical requirements to computer tools are determined by the results of the analysis of dynamic parameters of the technological object and system status.

## The typical processes of microelectronics

As typical processes that demonstrate the problem multifunctionality of specialized CS, used in semiconductor manufacturing, it is advisable to choose the processes of synthesis and laser correction parameters of semiconductor barrier structures based on metal-semiconductor (Fig. 1,a) and process of vacuum synthesis of multilayer interference filters [5, 13]. In the first case it is necessary to implement information-measuring system with additional control function laser emitter that conforms to the same adaptive CS. The second problem involves a simulation design synthesized structure and its optical characteristics and dynamic correction of synthesized models depending on the size of the error compliance with design parameters, determined by the results of control of the process. This problem can be solved using self reconfigurable CS (RCS) based on specialized processors of special control, management and problem-based evaluator [14]. According to previous studies [5, 13], the characteristics of the CMS Al-Si and PtSi-Si type, which are the basis for creating elements of the high-speed transistor-transistor logic with a Schottky diodes (TTLS) and photosensitive detectors UV and IR radiation, can be improved by precision controlled pulsed laser irradiation (PLI) of such structures.

Correction mechanism is to improve the physical properties of the boundary layer between the metal and semiconductor by the ordering of system structure-impurity defects at the semiconductor layer under contact, which is stimulated in the solid phase at PLI.

As indicator of upgrade CMS can serve as reducing reverse currents at a fixed value of reverse voltage (Fig. 1,b), or the increase of potential barrier (Fig. 1,c) of such structures.

In the adaptive model of the management process by modes PLI of CMS are needs to provide real-time monitoring of the following parameters: 1) of magnitude of the reverse current; 2) of values of experimentally determined potential barrier of the structure; 3) of temperature of exposure object; 4) of PLI intensity; 5) the duration of the laser pulse. An indicator of completion of the process is maximum approaching of the first two parameters to their theoretically possible values for different type of metal and semiconductor.

To determine law of the adaptive control by the process of laser synthesis and correction of parameters structures of metal-semiconductor used the results of mathematical modeling of the dependence of the potential barrier structures from the energy of irradiation (Fig. 1,c). For this we used the results of experimental studies of test structures of different dimensions - from 10×10 to 1000×1000 $um^2$ (Fig. 1,a).

To write analytical expressions of mathematical models we also used theoretical approximation of the experimental curves using polynomials of the form:

$$Y = a_0 + \sum_{n=1}^{9} b_n x^n ,$$

that were receiving in programming environment Origin 7.0. Here $a_0$ and $b_n$ - numerical coefficients, and the variable x - is the parameter of modeling, which in this case is the parameter of process control by the energy of the laser radiation.

To start the process of synthesis IR filters is necessary preliminary to simulate their performances and design. An indication of compliance requirements of the process is to minimize of deviation experimentally determined values of the thickness of the thin film layers synthesized from their theoretically calculated values. With the growth of such deviations beyond the permissible error in at least of one synthesized layer, need to hold a fully simulation of the structure and adequacy test models to specification of executable problem.

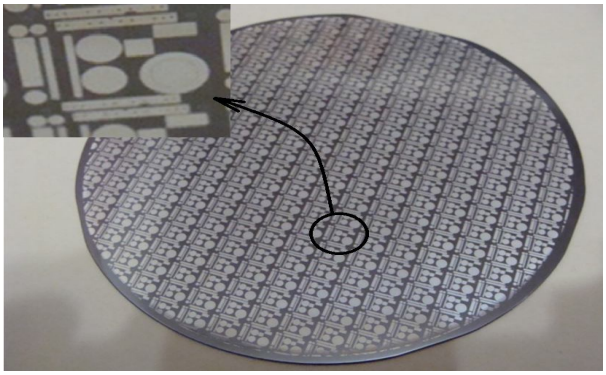
Sets of the input data $X = \{x_n\}$, which are related to general features of the technological system, of controlled parameters of possible processes $P = \{p_i\}$ and acceptable modes of control of process equipment system $Q = \{q_j\}$ are basic vectors for the functional synthesis of reconfigurable computer systems. The problem of structural synthesis of RCS resolved at an earlier stage, ie when justifying of an array of standard technological problems solvable system $Z = \{z_m\}$, which can be attributed to the selected class of problems $k_l$ on which are oriented projected systems ($k_l \in K$, where K - overall classification of classes of the certain field, in this case - for production of semiconductor devices).

The problem of multifunctionality RCS can be solved both on structural and functional levels for their synthesis, depending on their field of application. In the simpler case the concept of multifunctionality on stage synthesis RCS can be interpreted as a set of digital automats, or special processors designed to perform of diverse of functions or problem-oriented algorithms.

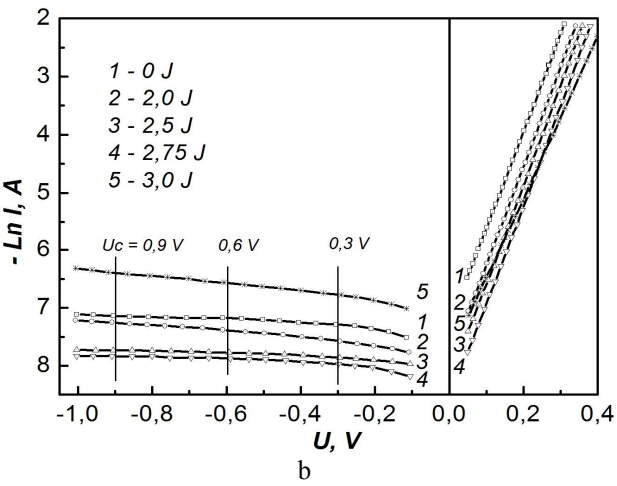
## Methods of synthesis of self-adaptive and self-reconfigurable CS

The main feature of the self adaptive / reconfigurable CS is the presence in their structural and algorithmic organization, and, respectively, and in architectural solutions, of intelligent module for collecting, processing and analyzing of input information. It can be implemented as a single structural unit, or as a set of structural units with separate functions and discrete hierarchical principles of organization, according to of typical generalized functional diagram of realized processes (Fig. 2).

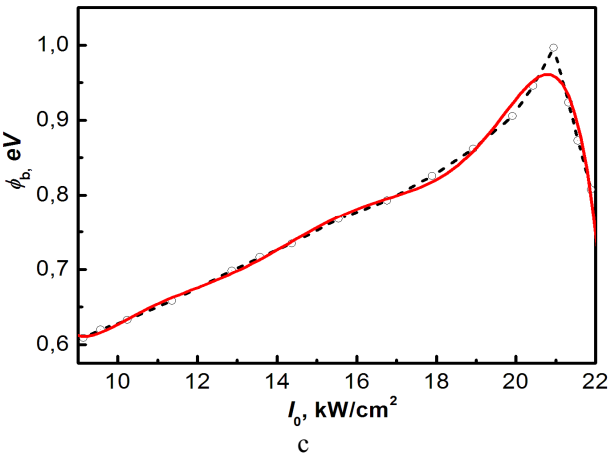
Defining of formation function of input data file with received signals from information-measuring device, as a separate stage of information processing, and also addition of encoding function of own parameters of object and of performed the task,



a




b




c

Fig. 1. Influence of pulsed laser irradiation on the Schottky diodes Al-Si: a – general view of test structures; b – change of I-V characteristics; c – change of the potential barrier value (short dash – experimental data, straight – theoretical model)

allows to distance processes of collection and data processing, and if necessary - to apply telemetry principles for information processing.

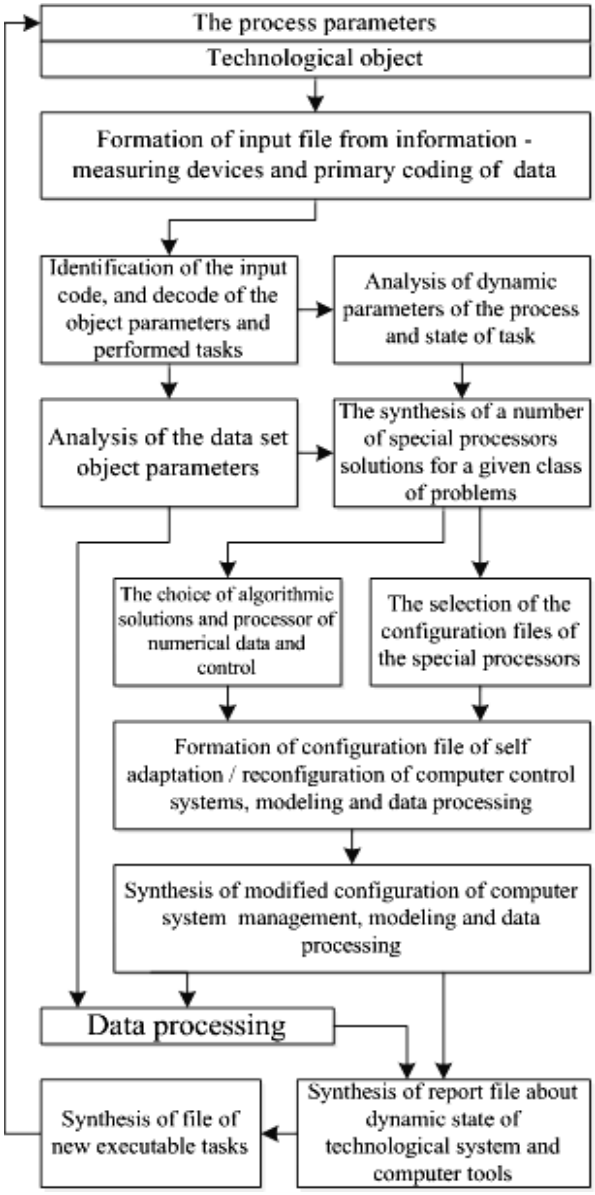



Fig. 2. The general algorithm of functioning of self-adaptive and self-reconfigurable computer system for micro and nanoelectronics technology

However, this approach requires additional hardware and software resources and reduces the speed of system response to dynamic change of input parameters. Application of functions identification and decoding of input file extends the functionality of the system, and gives it the properties of versatility and scalability for the number of served objects by allowing the switching RCS with of almost arbitrary number generators input files. The separation of stages analysis of process parameters and data set is necessary for next correction of modes of information processing. This allows more flexibility to form requirements for settings synthesized of special processors of control, information processing or modeling to process data arrays in the next stage. In addition, the code block on process parameters and state task simplifies decision question of using of adaptive settings or hardware reconfiguration of the system. The result of this decision is to create a new configuration file and modifying the system. Of course, to synchronize of information array processing is the need of using additional hardware decisions as buffer registers, interrupt devices, etc. In order to improve system reliability and simplify debugging, the set of file reports of parameters of whole technological system and a RCS as its component are formed.

Generalized structural solution RCS implemented on the basis of four major modules (Fig. 3): 1) universal CPU of control and data processing (CPU); 2) reconfigurable environment (RE); 3) intellectual mesurement transformer (IMT); 4) subsystem storage devices (MD). Features of rapid monitoring and visualization of executable files and data points can be displayed on a graphical display (LCD) or on a higher hierarchical level computer.

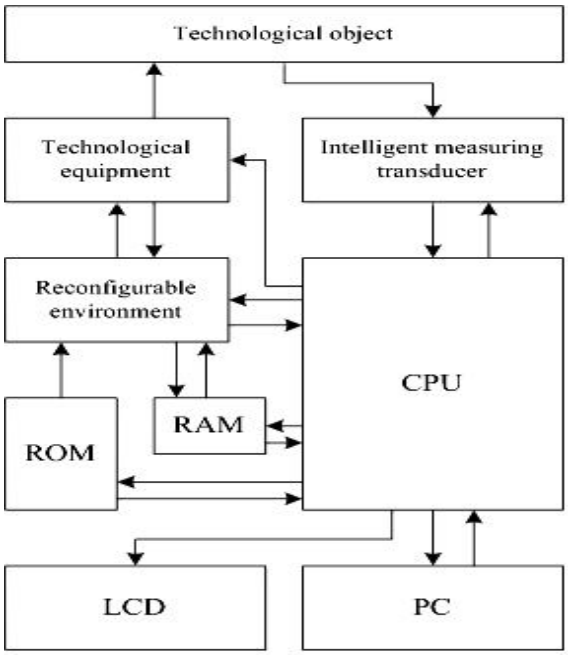



Fig. 3. Block diagram of a computer system with self-adaptability and self-reconfiguration for micro and nanoelectronics

The latter also performs the function of loading libraries of basic algorithms and hardware necessary files in of a new configuration. These files and libraries produced at the design stage and simulation software tools. A distinctive feature is just self reconfigurable system selection and implementation functions of analysis and synthesis of a new configuration file using the CPU, RE and MD mode of operation, in which the standard is carried out by reconfigurable systems.

Development of mock device of RCS is conducted

on the basis of standard debugging circuits of type Development Board EP2C8Q208 + 1602 LCD and Development board STM32F103VC EP4CE6E144 with embedded core of data processing on integrated elements CORTEX-M3 STM32 ARM and programmable environments Cyclone NIOS II or Cyclone IV 4 Altera FPGA. The use of 32-bit processors STM32F103VC with ARM core and built-in analog-to-digital converter in IMT enables to decrease measurement uncertainty and data processing better than 1%. As a model of technological equipment we use the laser system parameters "Quantum-12" with the transmitter on yttrium-aluminum garnet with wavelength $\lambda$ = 1,06 um, pulse duration $\tau$ = 1 ÷ 4 ms, the radiation energy E = 2 ÷ 4 J and diameter field radiation d = 0,05 ÷ 2 mm.

At the program level implemented standardized communication protocols between IMT and CPU on the radio and USB interface data link. The frame format allows you to combine data transfer performance information of the process parameters (time and duration of pulses PLI) and of the object (the type of structure, sample temperature, the coordinates of the irradiated area, etc.) with array of data (measured current and voltage), which simplifies scaling and reconfiguration of system for different types of objects.

## Conclusions

The novelty of our studies is as follows. In the industrial production of modern semiconductor components and structures now widely used programmable computer systems as for stage the modeling and design of semiconductor devices, also on the stage of control technological equipment in their manufacture. However, these steps - modeling, design and production, are separated in time and space, and implemented in different ways, and usually using very powerful computing capacity and other technical and economic parameters of equipment. But, researchers-experimentalists involved in the development of new semiconductor devices and their improvements in the conditions of small-scale or laboratory manufacturing, has quickly to solve these tasks in a real time. In addition, depending on the type of design devices and processes, such as described processes of laser synthesis of the barrier structures or interference filters and other, computer-solved problem have their own characteristics for stage of modeling, and to manage technological equipment. To solve of the outlined problems, we offer the use of self-adaptive and self-reconfigurable multifunctional computer tools. The novelty of our research is to create generalized models, approaches and technical solutions for the synthesis of these computer tools that can then form the basis for the implementation of intelligent, which is capable of self-improvement, computer and cyberphysical systems. The essence of the proposed approach is to apply the techniques of through designing of technical systems, which in contrast to the methods used now, combines the problem of designing a technical object, in this case of the micro- and nanoelectronics products, and design of computer tools with the properties of their dynamic reconfiguration in depending on the tasks at performed time intervals.

Thus, the set of technical parameters that are input to the synthesis of specialized computer means includes a plurality of output as well as input parameters of technological objects. This reduces the cost of hardware and increase the generalized productivity of computerized technological systems. Technical implementation of the proposed approach has been tested and made possible by the use of ARM controllers and FPGA programmable environments, that provides minimization of the error at measurements and data processing. The use of intelligent measuring converters for data acquisition allowed to provide the flexibility, versatility and scalability of the system, simplifying software development, and provides remote access for telemetric measuring of the object parameters and process equipment.

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## ЗАСТОСУВАННЯ САМОАДАПТИВНИХ І САМОРЕКОНФІГУРОВНИХ КОМП'ЮТЕРНИХ ЗАСОБІВ ДЛЯ ВИРІШЕННЯ ТЕХНОЛОГІЧНИХ ПРОБЛЕМ ЕЛЕКТРОНІКИ

***Г. І. Воробець, В. П. Тарасенко***

Запропоновано метод адаптивного контрольованого процесу синтезу та лазерної корекції параметрів контактів метал-напівпровідник для базових логічних елементів цифрових пристроїв і сенсорів інформаційно-вимірювальних і управляючих систем. Описано доцільність, переваги і недоліки використання самоадаптивних і самореконфігуровних комп'ютерних засобів для вирішення технологічних проблем електроніки. Встановлено, що універсальність, функціональну та економічну ефективність системи можна підвищити за рахунок використання багатофункціональних реконфігуровних комп'ютерних засобів для керування технологічними процесами та обробки даних. Використання інтелектуальних вимірювальних перетворювачів для збору даних дозволило забезпечити гнучкість і масштабованість системи, що спрощує розробку програмного забезпечення, а також надає віддалений доступ для телеметричних вимірів параметрів об'єктів та технологічного процесу.

**Ключові слова:** напівпровідник; діод Шотткі; структурний дефект; технологія лазерного відпалу; самоадаптивна система; самореконфігуровні комп'ютерні засоби.

## ПРИМЕНЕНИЕ САМОАДАПТИВНЫХ И САМОРЕКОНФИГУРИРУЕМЫХ КОМПЬЮТЕРНЫХ СРЕДСТВ ДЛЯ РЕШЕНИЯ ТЕХНОЛОГИЧЕСКИХ ПРОБЛЕМ ЭЛЕКТРОНИКИ

***Г. И. Воробец, В. П. Тарасенко***

Предложен метод адаптивного контроля процесса синтеза и лазерной коррекции параметров контактов металл-полупроводник для базовых логических элементов цифровых устройств и сенсоров информационно-измерительных и управляющих систем. Обосновано целесообразность, преимущества и недостатки использования самоадаптируемых и самореконфигурируемых компьютерных средств для решения технологических проблем электроники. Установлено, что универсальность, функциональную и экономическую эффективность системы можно повысить за счет использования многофункциональных реконфигурируемых компьютерных средств для управления технологическими процессами и обработки данных. Использование интеллектуальных измерительных преобразователей для сбора данных позволило обеспечить гибкость и масштабируемость системы, упрощает разработку программного обеспечения, а также предоставляет удаленный доступ для телеметрических измерений параметров объектов и технологического процесса.

**Ключевые слова:** полупроводник; диод Шоттки; структурный дефект; технология лазерного отжига; самоадаптивная система; самореконфигурируемые компьютерные средства.

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