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# Development of Optimization Subsystem for Integrated Circuits

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**Abstract:** Optimization subsystem – one of the most important part of the control system in the manufacture of integrated circuits. In this paper a modular structure of the optimization subsystem is developed. The basis of this system is an algorithm of adaptive management with adjustable parameters of the model. The algorithm can reduce the influence of uncontrollable parameters on the quality of the product and leading to increase the number of yield of integrated circuits.

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**Keywords:** Adaptive algorithm, optimization, integrated circuit, process management

## 1. Introduction

Under modern conditions, one of the most important problems in the manufacture of microelectronic products is the necessity to improve the quality and increase the absolute yield of usable products [1]. The solution of this problem is compounded by permanent decrease of design standards, as well as a significant increase in the complexity of manufactured products [2].

For these purposes, in the production various quality management system of the manufactured products are used. These systems include product optimization subsystem – automation system, that provides different kinds of impacts on the technological process of the production of integrated circuits at any point of it in order to improve the quality of manufactured products: reduce the number of defective (or not meeting according to the technical requirements products) and to improve the quality of currently produced series of chips, using previously obtained data [1, 3, 4].

The purpose of this work is development of the structure of optimization subsystem (optimization module) of production of integrated circuits (chips), using adaptive management algorithm.

## 2. Material and Methods

In general, the necessity of process management is determined by the following factors:

- to provide product quality: structure the number of input components must be maintained at a certain level;
- depreciation of tools and variable composition of raw materials demands continuous changes (adjustment) of the parameters of the technological process;
- starting and stopping some technological process requires the fulfillment of specific exactly synchronized operations and others [5].

Structure of the subsystem process optimization of integrated circuits is determined by efficiency of requirements for the production process, by a variety of manufactured devices and by the opportunity of flexible configuration for each type of manufactured chip and by load the possibility of changing parameters during technological process by the operator, using previously obtained values of process parameters [6].

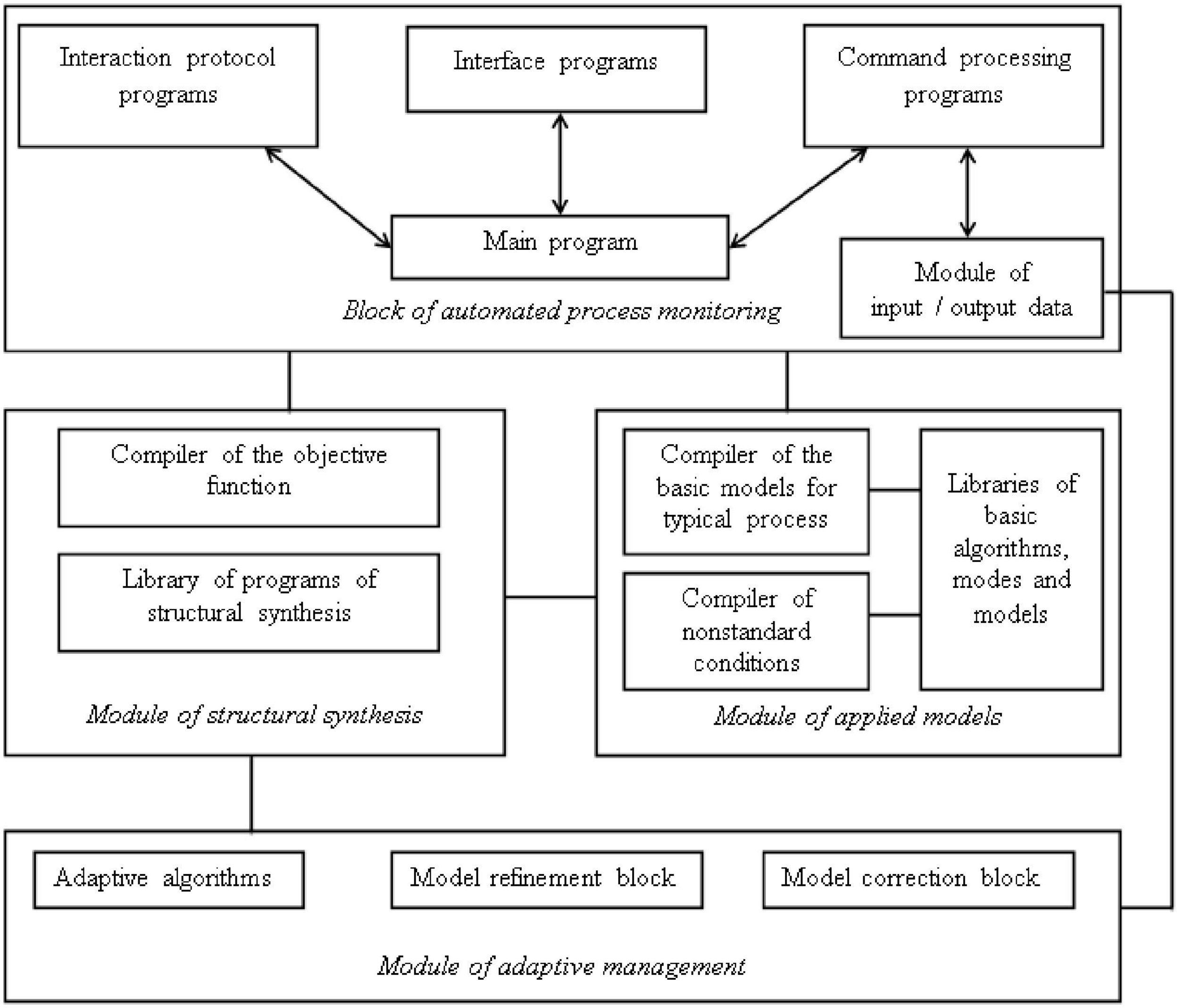
Analysis of the causes of defects in manufacture of integrated circuits in the finished product showed, that the input materials (raw materials) are characterized by a considerable degree of volatility parameters from batch to batch. Even if all parameters of raw materials remain within tolerance, they have an impact on the final result [1, 2].

During the process it is influenced by uncontrollable parameters, which can be divided into two components: constant, caused by the nonideality of technological equipment and accuracy of sensors, etc. and random – dirt, technological bugs and other.

## 3. Results

We need to reduce the influence of uncontrollable parameters on the parameters of technological process. To adjust parameters during process of production of integrated circuits can be used adaptive control of an adjustable parameters of the multiobjective mathematical model, that gives better results compared with statistical methods [4, 7, 8].

Functional diagram of the product optimization subsystem is shown in Fig. 1.



. 1. Functional diagram of the adaptive control subsystem.

Functional diagram of the optimization subsystem of production of an integrated circuits can be constructed in accordance with the principles outlined in the well-known works on this subject [7, 9-12].

The basis of the block of an automated process monitoring is the head program, that implements transfer of settings and parameters of the technological process and hardware settings for adjusting and match the quality of manufactured integrated circuits (chips). For the possibility of adjustments of the technological process in the manual mode, command processing programs are developed. Using the module of input and output data, the operator can unload from the database current settings of process or set them manually (entering or loading the history file with settings, used for the production of integrated circuit earlier), as well as to indicate the characteristics of the used materials (raw materials).

Module of structural synthesis examines the list of sequential operations, obtained from the automated control system of upper level for this (particular) technological process. Information transfers to the applied models module, which is characterized by the presence of analytical, statistical models of basic operations of technological process of manufacturing integrated circuits: annealing, oxidation, implantation and the other for the definition of "monitoring points". Here is a determination of input and output parameters for each sequential operation of the process and the formation of the objective function optimization. Due to the large number of influencing parameters and the nature of their interaction, it is proposed not to use in the objective function an ideal value of each influencing parameter, but a single parameter – the quality criterion of integrated circuits, which is the sum of all individual parameters with the coefficient - – influencing factor (the degree of influence) for each parameter [5, 9].

A key feature of the subsystem of the optimization of production of integrated circuits is a module of adaptive management. It uses the adaptive control algorithm with the adjustable parameters of the model. This block during the production process creates and refines a mathematical model (procedures are carried out to maximize the objective function of discrete arguments for overlay of the functional and topology restrictions), derived from the “structural synthesis” module and transmits it to block of an automated control [1, 5].

Adaptive control algorithm is shown in Fig. 2.

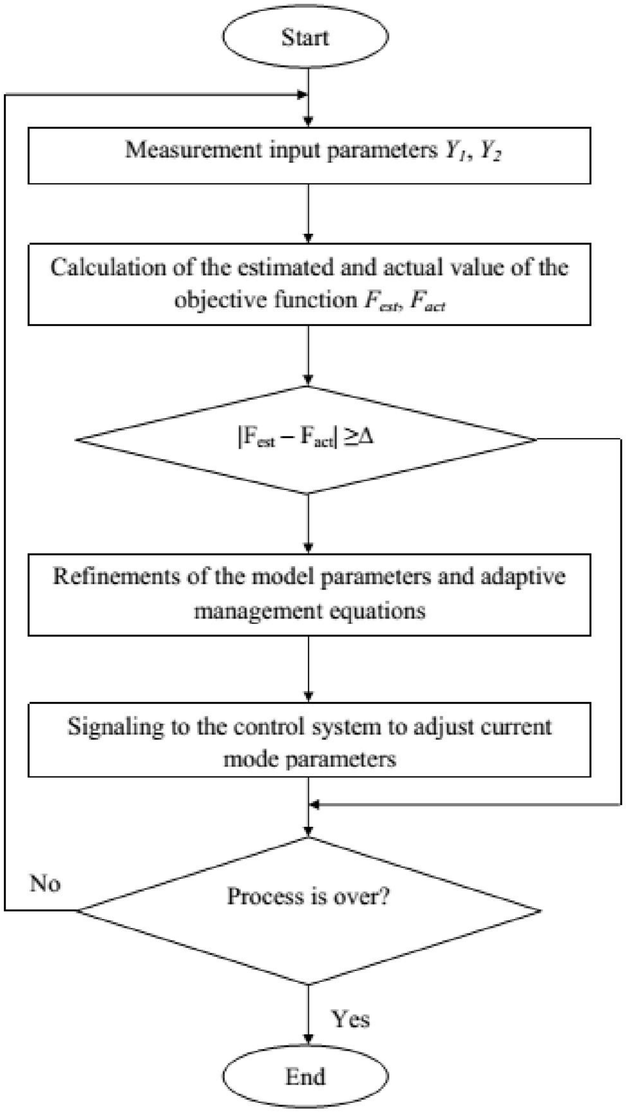


Fig. 2. Proposed algorithm for adaptive management.

In this algorithm after each technological operation the output variables of the manufacturing process of integrated circuits is measured and further by the proposed formulas are calculated and compared with some accuracy parameter $\Delta$ , that set by the operator.

If it necessary, values are being corrected by adjusting of the parameters of the model, then the optimal values $X_{EST}$ and calculated, for one-dimensional case the objective function value is [1, 5-7]:

$$F = \phi_1 \left(Y_{1EST} - Y_1\right)^2 + \phi_2 \left(Y_{2EST} - Y_2\right)^2 + \phi_3 \left(Z_{1EST} - Z_1\right)^2 + \phi_4 \left(Z_{2EST} - Z_2\right)^2$$

$$\frac{F(X_{CUR})}{\partial X_{CUR}} = 2(Y_{EST} - a_0 - a_1 X_{CUR})(-a_1)$$

$$Y_{EST} - a_0 - a_1 X_{CUR} = 0$$

$$X_{OPT} = X_{CUR} = \frac{Y_{EST} - a_0}{a_1}$$

where $F$ – the objective function [6]; $\phi_1$ – vector of output parameters, $\phi_2$ – vector of control variables [5, 6]; $Y_{1EST}$, $Y_{2EST}$ – the required output values for the first and second process step, $X_{CUR}$ – current value of the input parameters, $X_{OPT}$ – optimal value of the input parameters for the next operation, $a_0$, $a_1$ – coefficients, determined experimentally or from statistical data, $Z_{1EST}$, $Z_{2EST}$ – required values influences on the process for the first and second process step. Due to the fact, that the coefficients $a_0$, $a_1$ are determined experimentally, they are defined with some error, caused by the measurement error and error statistics.

In cases when the selected optimization option may not satisfy the decision maker, or there are several variants, selection of an optimization algorithm can be carried out by the operator by the module of input / output data. Also in this module the coefficients of the importance of the objective function for one or more influencing parameters (parameter groups) can be changed. This is usually required, it is needed to achieve not the highest quality of microelectronic product, but the product with certain restrictions on the application: for example, to use in certain areas of the space industry does not require long time of usage in the system; costs of producing chips for the devices for mass application is very important. During the process, the measured parameters (process temperature, time, etc.) and optimization parameters (coefficients of the importance of the objective function, equipment configuration, etc.) are being recorded in the database of process settings, also history files are being generated [7-9].

Computer modeling of the proposed algorithm was conducted. Objective function F was calculated according to the formula (1).

Modeling a regular component of the error was taken by changing in time and carried out according to the formula:

$$J(t) = A + K \sin(tA) + B$$

where $A$, $B$ – coefficients (determined experimentally), and $K$ – the growth rate of the error of an uncontrolled parameters in time. $A$, $B$, $K$ was accepted to simplify as 1.

Simulation of the random component of error was carried out using a random number generator with normal distribution law and distribution parameters: the arithmetic mean $Y = 0$, the standard deviation [rho] = $R \times Y$, where $R$ is the coefficient of variation, which was assumed to be equal to the average deviation of the parameters in the production of large-scale integrated schemes – 20% (0.2) [2, 4, 5, 12].

Thus, the actual value of the output variable Y * and modeled value written as:

$$Y = Y^* + J \mp \phi$$

The simulation results are shown in Table 1. For simplicity, values of the output parameters derived from simulation results, were normalized:

$$Y^0 = \frac{Y^*}{Y}$$

Table 4. Results of the modeling. The values of $Y^{o}$

| № | Before optimization | After optimization |
|---|---|---|
| 1 | 0.87 | 0.91 |
| 2 | 0.90 | 0.93 |
| 3 | 0.84 | 0.90 |
| 4 | 0.92 | 0.94 |
| 5 | 0.87 | 0.89 |

According to the results, the use of the proposed adaptive algorithm with adjustable parameters of the model for IC 564 series provides improvement of output parameters on an average of 7% due to the decrease the influence of random and regular component of the error on the final (desired) output parameters.

Considering the statistical data, up to 50% of defective chips 564 series is recognized as unfit by one of the parameters that goes beyond tolerance limit of not more than 5%, so we can conclude that the use of the adaptive management subsystem as part of the technological process may allow to reduce the unusable number of an integrated circuits at least twice [12, 13].

## 4. Discussions

According the results of the modeling, using the subsystem process optimization of production of integrated circuits, based on the algorithm of adaptive management with adjustable parameters of the model, allows to improve quality of the integrated circuit by decreasing negative influence of uncontrolled parameters of each technological operation, that eventually leads to improvement of quality of the whole product.

The proposed functional diagram of subsystem also allows manually set the necessary limits or coefficients of importance for each output parameter of the integrated circuit, in order to use the system for integrated circuits various series and types, and helps to configure subsystem for every process according to the technical requirements.

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