SIMULATION OF ARTIFICIAL SYSTEMS BEHAVIOR IN PARAMETRIC EIGHT-DIMENSIONAL SPACE

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Abstract: Historically term of Self-formation was introduced for understanding of the processes occurring in microelectronics technology (Janusonis, 2000). The concept of Self-formation by itself was to some extend influenced by ideas coming from the artificial life problems related research but was focused not on biological but on artificial objects evolution problems. Self-formation was first of all oriented to understanding of processes and properties of devices developed by planar technology but there was always an open question about possibilities of self-formation to predict new technological applications. Now we can clearly state that self-formation is becoming interesting tool for technologists trying to create and optimize microelectronic devices – one of the possibilities to use simulation based on self-formation is presented here on the basis of optimization of Spatial Solar Cells. The next steps in presenting Self-formation possibilities can be demonstration of usual in biological life development and reproduction of the artificial object by applying self-formation principles. Here we will try to present few examples of self-formation, development and reproduction of artificial objects under certain strictly determined conditions.

Keywords: Artificial life, self-formation, artificial systems, evolution of artificial objects

1 Assumptions for simulation: topological space, object approximation, matrix of interactions

Describing object in space and its properties we need three-dimensional space for identification of the object geometry plus time dimension for description of object behavior in time. We also assume that we need at least one parameter to describe type of the object and/or its material. When discussing question about interactions between objects and/or objects and media we need unambiguously identification of state of the objects before and after interaction. We can assume that we have set of four independent parameters two from which are characterizing objects/media before interaction and two parameters after interaction. Therefore we need to introduce four-dimensional parameters space to describe interaction of the two objects. Taking into account object characterization in Euclidian space we need at minimum eight-dimensional space for unambiguous description of two objects interaction. Another approximation used in self-formation is understanding of planar object as set of parallel indexed planes along one of the Euclidian coordinates. Such approximation was introduced taking into account that planar objects dimension along x,y axes are per order or more large that along z axis (Fig.1).

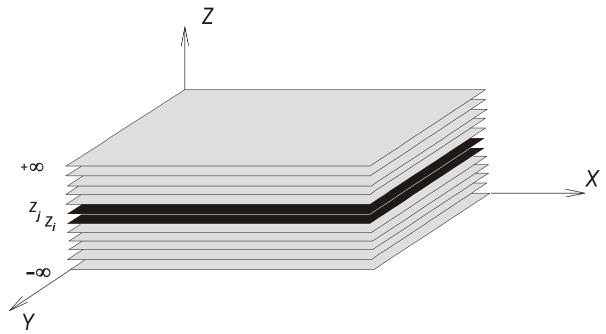

Fig. 1: Flat planar object approximation by set of planes

To formalize interactions between objects characterized by different sets of parameters we need to introduce so called “matrix of interactions”. Interaction between two objects characterized by different parameters can be presented as follow: let two parametrical points with parameters p_i and p_j at time moment t_i are coming into the neighborhood of the selected Euclidean point, and within time interval Δt = [t_i t_j] parameters of these points are changing into the new parameters p_k and p_l consequently. Such event can be described by combination of all four parameters $p_i\, p_j\; p_k\; p_l$ and called as interaction.

It is clear that there is infinite number of parameters (materials and their properties), which means also infinite number of interactions. When formulating practical technological tasks we can limit ourselves to the minimum number of parameters and interactions involved in the technological process. Interaction matrix is introduced as subset of interactions taking place in technological process. It is clear that all elements in interaction matrix are combination of the four parameters to which colors according Fig. 2 are assigned:

$$p_i \;\; p_j \;\; p_k \;\; p_l \qquad (1)$$

2 Cellular automata for evolution simulation

In order to analyze self-formation applications, we used cellular automata as evolution simulation mechanism.

As three-dimensional object is approximated by set of planes (Fig. 1), the evolution between planes is considered only in direction perpendicular to a plane. Therefore a two-dimensional cellular automaton is sufficient, provided it is adjusted to consider the neighboring planes (Fig. 3).

Input data for a simulation are set of planes with geometrical figures of objects, and set of interaction rules.

The object figures are colored according to assigned parameters: each parameter value is assigned with particular color.

Each plane is divided into a uniform grid of square cells. Each cell consists of uniform color. Grid cell approximates Euclidean point neighborhood. The finer the grid, the more accurate simulations can be produced.

Evolution is performed in discreet time steps.

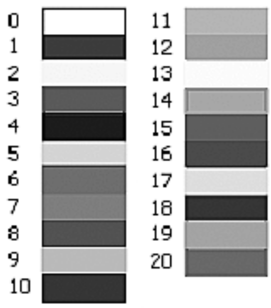

Fig. 2: Color identifiers of interactions

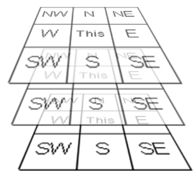

Fig. 3: Cell neighbours

Color of each cell in a given time step is determined by specialized rules derived from generic two-dimensional cellular automata rules. These rules contain several enhancements, which are essential for self-formation simulation:

- circular evolution support
- interaction rule support
- coplanar evolution support

Circular evolution ensures essential self-formation requirement, that object's boundary (contour) evolves according to certain rules: angles larger than π are rounded, and angles lower than π keep the same angle at the side of evolution direction. This produces circles out of, e.g. rectangular, objects in outside bounded evolution.

Coplanar evolution support ensures that self-formation spreads in all planes. Unlike generic cellular automata with 8-neighbour cells, this cellular automata has 10-neighbours cells: 8 neighbors in the same plane, one neighbor from the plane above, and one neighbor from the plane below.

Interaction rules provide means to define self-formation "laws of nature". Interaction rule is a two pair combination. The first pair defines parameters (or colors) of two neighboring cells before evolution step, and the second pair defines parameters after the evolution step. If parameters of neighboring cells do not match the first pair, the rule is not applicable. The complete set of interaction rules defines object behavior in the course of evolution.

3 Self-formation of the artificial object

Self-formation of the object occurs by definition [1] with evolution of the initial system leading to the increase of its complexity under object interaction with chaotic medium sequence. Interactions in space are defined by object under evolution itself, and are changing with time depending on media changes. Possibility of media changes is defined by assumption of openness to the information flow of the system under investigation. It is supposed that evolution of the object have defined starting point in time and definite end. It means that before starting point we need to have equilibrium (means no interactions allowed) of initial object with media and after the end of evolution final object also must retain in equilibrium with medium. It must be pointed out that initial object is not caused by self-formation; we assume that it has been formed by external formation before starting point of our simulation.

These all assumptions must be taken into account when constructing matrix of interactions for particular evolution case and initial object/media system. To start simulation of the process for example transistor self-formation we assume that we have initial object A_1 and sequence of different medium (Fig. 1) interacting with initial object in defined time sequence.

The set of interactions can be defined as

$$I = \{(p_i p_j p_k p_e) : i, j, k, e \in \{0,1,...,8\}\}. \quad (2)$$

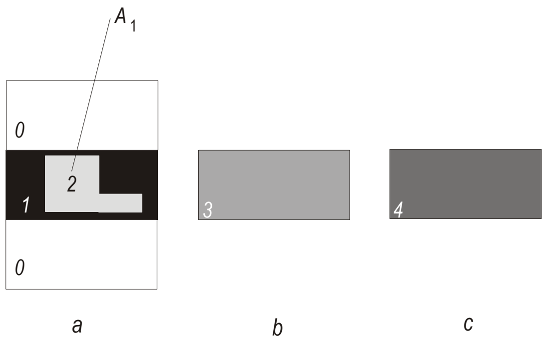

Fig. 4: System for self-formation: a -initial system, b-c – media

Interaction matrix is constructed on the basis of necessary for planar object self-formation interactions:

1353 defines interaction between medium of parameter 3 and object of parameter 1 followed by parameters change from 1 to 5.

2,5,6,5 self stop, 8 steps - change of parameter 2 to 6 when in contact with parameter 5 and causing narrowing of figure A_1 to figure A_2

6474 - interaction between medium with parameter 4 and object with parameter 6, causing immediate change of parameter 6 to 7

7282 self stop, 11 steps – change of parameter 7 to 8, when in contact with parameter 2. Since this is a self stop interaction, a ring of parameter 8 occurs.

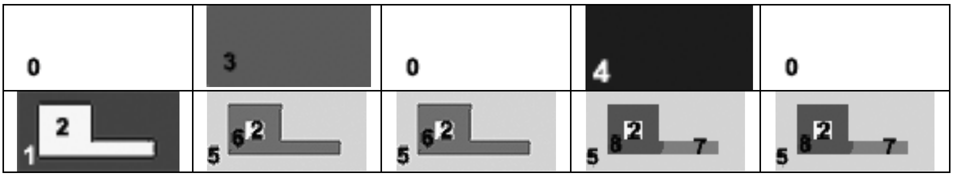

Fig. 5: Self-formation of topological system

As it is clear from the Fig. 3 simple set of rules – interaction matrix can lead to the establishing route for self-formation of artificial object – this time transistor type structure. It is matter of knowledge of technological processes available to provide technological background for simulative interactions used in planar object self-formation.

Self-formation principles used for establishing route for mictroelectronic devices development recently were used introducing tools for simulation of technological processes and in parallel electrical properties of Spatial Solar Cells manufacturing (Leonas, 2003; Ulbikas 2003). In following pictures below (Fig. 6 – Fig. 8) are presented some results for Spatial Solar Cell properties optimization depending on geometry of SSC. It can be noted that SSC efficiency is influenced by some geometrical parameters to large degree while it is almost insensitive to the variation of the others. Therefore it can be stated that physical properties of the SSC will strongly depend on proposed SSC structure and geometry. As it is clear from the figures bellow introduction of spatial structure for Solar Cells can result in obtaining considerably higher performance characteristics.

4 Development and Reproduction of artificial and planar object

More complicated behavior of the initial system i.e. *development* and *reproduction* of the artificial objects is still lacking experimental evidence. Here we are presenting examples of simulation results demonstrating such behavior of artificial objects according to the artificially constructed interaction matrix.

Other possible interaction of medium/object can be presented as interaction of the object coming into the contact with structurized medium causing development in this medium object with increased complexity. It is assumed that for this kind of development there is no need of externally changing sequence of the chaotic medium as in the case of simple self-formation or other objects. Other assumptions are the same as in the case of self-formation: Localization of interactions in space and time are controlled by evolutionary object itself. Evolution goes on at finite interval of time what means that system must be in equilibrium before and retain in this stage after evolution.

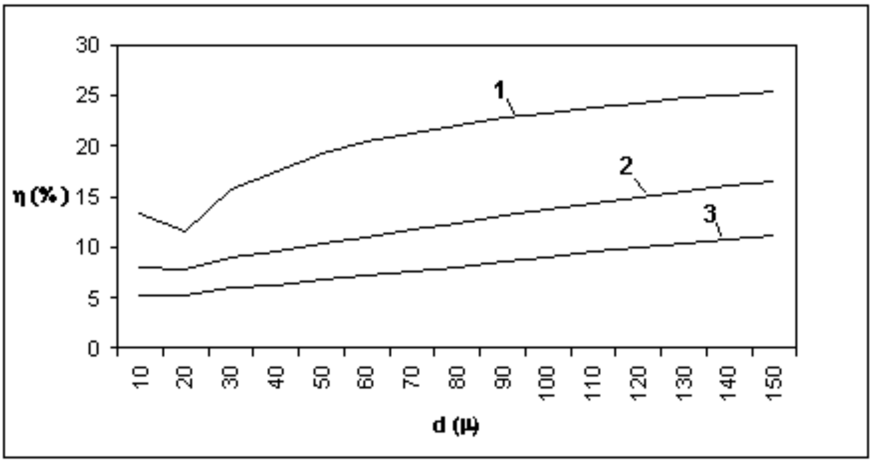

Fig. 6: Dependencies of spatial solar cell efficiency on thickness of segment d for different light absorption coefficient values: (1) α = 0.05 1/μ, (2) α = 0.01 1/μ, (3) α = 0.005 1/μ. Other parameters: thickness D = 300 μ, a = 10 μ, b = 60 μ, c = 10 μ, diffusion length Ln = 100 μ, diffusion coefficient Dn = 25 cm^2/s, recombination rate Sn = $1.0 \cdot 10^8$ μ/s, recombination rate S_Air = $1.0 \cdot 10^7$ μ/s, photon energy hv = 1.6 eV.

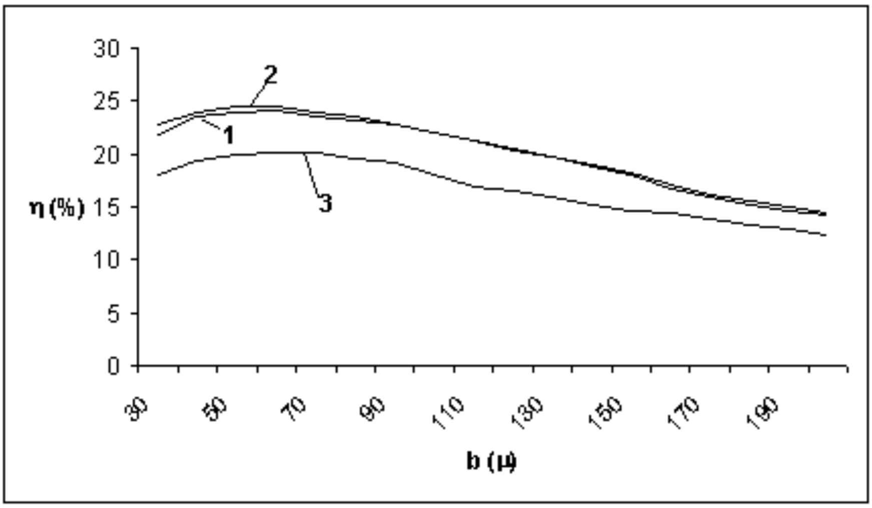

Fig. 7: Dependencies of spatial solar cell efficiency on thickness of segment b for different values of segment a: (1) a = 20 μ, (2) a = 10 μ, (3) a = 100μ. Other parameters: light absorption coefficient α = 0.1 1/μ, thickness D = 300 μ, c = 10 μ, d = 100 μ, diffusion length Ln = 100 μ, diffusion coefficient Dn = 25 cm^2/s, recombination rate Sn = $1.0 \cdot 10^8$ μ/s, recombination rate S_Air = $1.0 \cdot 10^7$ μ/s, photon energy hv = 1.6 eV.

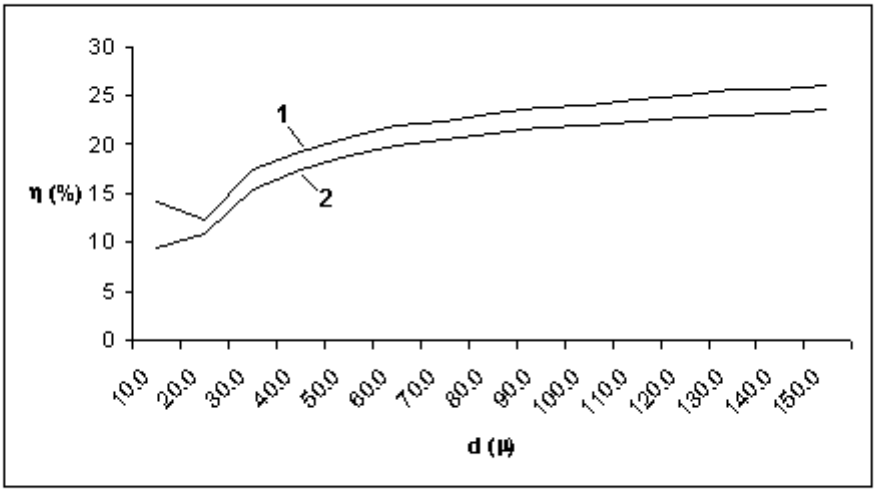

Fig. 8: Dependencies of spatial solar cell efficiency on thickness of segment d for different values of segment b: (1) b = 60 μ, (2) b = 100 μ. Other parameters: light absorption coefficient α = 0.1 1/μ, thickness D = 300 μ, a = 10 μ, c = 10 μ, diffusion length Ln = 100 μ, diffusion coefficient Dn = 25 cm^2/s, recombination rate Sn = $1.0\cdot10^8$ μ/s, recombination rate S_Air = $1.0\cdot10^7$ μ/s, photon energy hv = 1.6 eV.

Let us have a topological space characterized by the set of parameters

$$P = \{0,1,...,7\} \tag{3}$$

and object/medium in contact

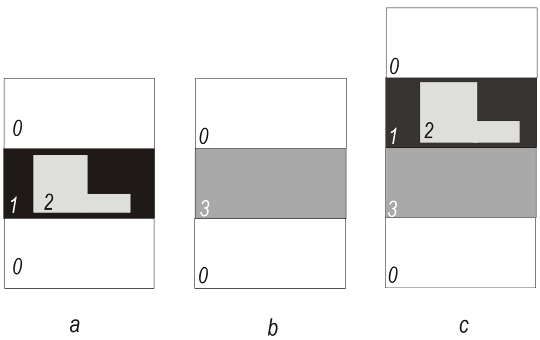

Fig. 9: Elementary systems in topological space: a - elementary system including a figure; b - elementary system without figure; c - initial system

The set of interaction rules necessary for this type of evolution are described as follow:

2,3,2,4 - defines interaction between medium with parameter 3 and object with parameter 2, causing transfer of figure into the medium plane and assigning parameter 4 to the figure.

3,4,3,6 self stop, 5 steps – forming a ring of parameter 6 in contact points of parameters 3 and 4.

2,6,2,8 – interaction between parameter 2 on another plane with parameter 6, causing immediate replacement of parameter 6 by 8 and emerging of the ring of parameter 8.

4,8,4,5 self stop, 8 steps – when ring with parameter 8 finally consumes parameter 6 and directly contacts parameter 4, a new ring of parameter 5 starts to form, now in opposite direction, and as this self-stop interaction is completed, system is coming to the new equilibrium state because no more interactions are allowed.

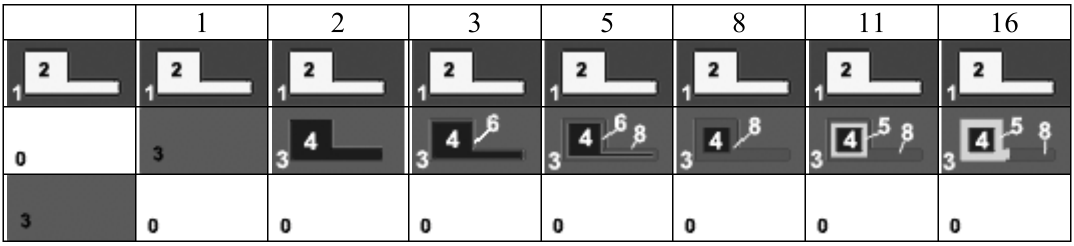

Fig. 10: Development of topological system

Simulation demonstrated here was focusing on presenting evolution of the initial system to the well-known topology of bipolar transistor without interaction with external systems. It is clear that it is possible to construct interaction matrix in such a way that development of artificial topological system can occur. As in the case of self-formation we need to appoint real technological processes and materials to the parameters able to reproduce simulated evolution.

5 Reproduction of planar object

The next step in presenting possibilities of Self-formation concept to simulate evolution of artificial systems by introducing interaction matrix with specific set “laws of nature” is investigation of the possibilities to obtain reproduction of initial object. By *reproduction* of elementary systems we mean development of initial object through evolution process in addition with separation and a forming of elementary system by developing topological system, followed by the breaking them out from a developing system. For that we are using two elementary systems (Fig. 11):

Interaction rules for reproduction of self-formation:

1,3,1,5 and 2,3,2,6 – defines interactions leading to the formation of figure with parameter *6* on the second plane,

5,6,5,9 self stop, 7 steps – formation of the ring of parameter *9* in contact points of parameters 5 and 6,

2,9, 2,10 – immediate replacement of parameter *9* by parameter *10* in the neighborhood of parameters 2 and 9,

6,10,6,11 self stop, 9 steps – formation of the ring of parameter 11 as a result of the contact of parameters 6 and 10, Interactions leading to the reproduction of the initial system:

6,4,6,13 and 5,4,5,7 – appearance of the figure with parameter *13* on the third plane,

7,0,0,1 and 13,0,0,2 – transfer of figure to the fourth plane, and leading to the appearance of a parameter of medium 0 on the third plane, causing introduction and separation of two autonomous topological systems.

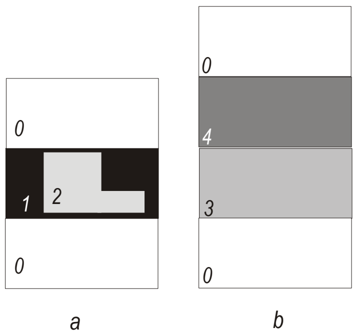

Fig. 11: Elementary systems used in reproduction simulation

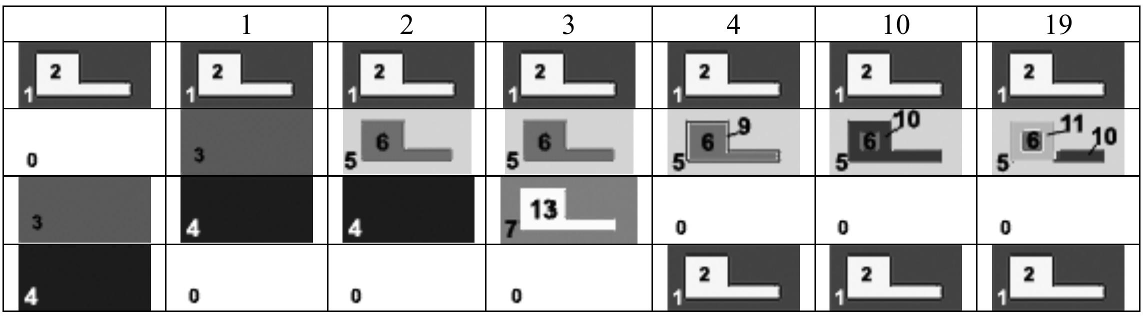

Fig. 12: Reproduction of topological system

6 Conclusions

Concept of Self-formation presenting possibilities to simulate technological processes by constructing topological space, introducing matrix of interactions and using cellular automata for evolution simulation can be seen as one of the ways toward development of theoretical technology. Simulation results presented in this paper can be perceived as examples of possibility to construct phenomenological matrix of interactions that can generate different behavior of initial system depending of interactions taken into the consideration. The next step toward experimental implementation of system development scenarios must be realized through adopting real technological processes to the phenomenological parameters. This was proved in the case of development of new generation Spatial Solar Cells.

More complicated behavior of the initial system i.e. *development* and *reproduction* of the artificial objects is still lacking experimental evidence. Therefore it is clear that this paper is more about future direction for the development of theoretical technology based on Self-formation concept, than presentation of simulation possibilities for artificial system evolution scenarios.

7 References

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