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SELF-FORMATION TECHNOLOGY

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Abstract. An external formation based on lithography processes is not a single possible method of the IC manufacturing. In the self-formation the interaction between the forming object and chaotic medium is controlled by the object's structure, and the structure is changed by the interactions accompanied by the primary object increasing complexity. Three kinds of self-formation methods can be used for manufacturing: self-alignment, based on the interaction between an object and distinct sequence of chaotic media, development, where a single chaotic medium is sufficient and reproduction, where the developing objects generates primary objects. There are known a lot of methods for submicrometer structures manufacturing and lithography processes reducing.

Key words: self-formation, self-aligned, development, reproduction, IC manufacturing, solid-state technology.

Introduction. We live in the World where every structure is changing. We observe not only self-destruction processes, where a more complex structure turns to a more simple one, but development where the object complexity increases. The recent cases we can observe in animate nature and in human industrial activity.

Any real object can be seen as a complex of different materials located in a distinct manner in the Euclidean space and the manufacturing of such an object as a new relocation of these materials.

The most common methods of the manufacturing are based on assembling of the entire body from single details. Such methods are applied in the radioelectronics field, where uncounted number of circuits could be assembled by using a minimum detail collection: wires, resistors, capacitors, inductors and rectifiers. There we have a method of typical elements, which manufacturing includes a lot of different technological processes.

An alternative method based on typical processes for manufacturing of integrated circuits was announced in 1961. I mean a planar technique, where all the elements are produced in the single crystal by processes of lithography, diffusion or ion implantation. A changing of distinct regions of the wafer occurs on selective interaction between a forming object and a medium. The medium in this case must be a structural one. So the interaction localizations in space and time are controlled by man or automatics. Thus, we have a typical EXTERNAL FORMATION (Fig. 1, a), where any patterns are to be transferred from a medium to an object.

During the development of mictroelectronics we have had a changing of materials, processes, but never external formation principle. However, in the seventees a possibility to control a localization in space by an object itself was found out.

At the beginning we saw a number of methods, where manufacturing of a submicrometer structure without lithography (self-aligned technique) was performed (Fig. 1, b). Recently the methods of manufacturing of integrated circuits are known, where a number of lithographies are considerably reduced. It can be said with assurance that only one lithography is sufficient, while others can be changed by self-aligned techniques.

It is suggested that methods, where the localizations in space and time are controlled by an object itself, can be realized. The object forming occurs in the single medium and no external control is necessary. Thus, we have an analogous development in an animate nature (plant from a seed-corn, bird form an egg, etc.) (Fig. 1, c). Methods for realization of the development in solid-state technology are yet unknown.

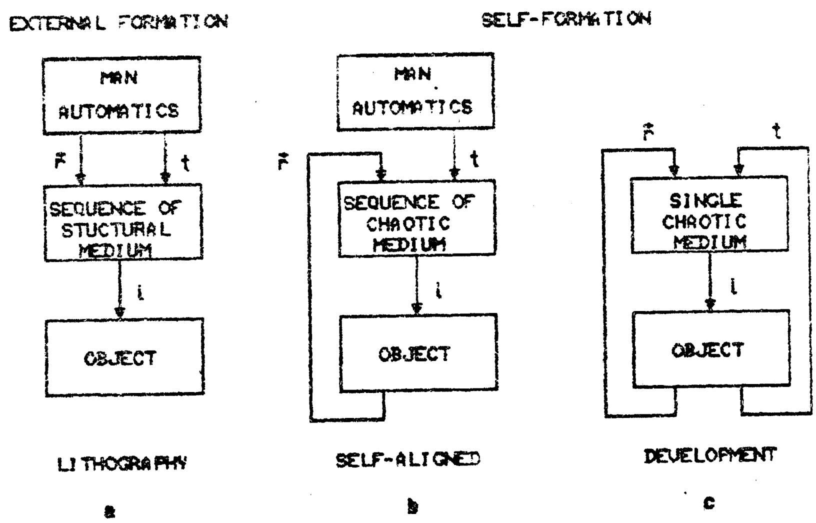

Fig. 1. Three kinds of formation.

So we have principles, where external control is reduced or is unavailable. This is a SELF-FORMATION technology, including self-aligned technique, development and other cases of internal formation.

In order to explain principles of self-formation we make a bipolar transistor structure choice.

Let we have a cross-section of the bipolar transistor (Fig. 2), including collector region 7, base region 8, emitter

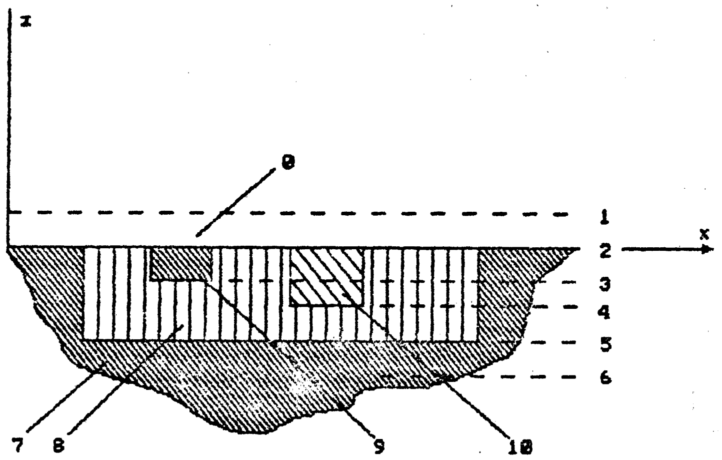

Fig. 2. Cross-section of the bipolar transistor.

region 9, p^+ base region 10 and atmosphere 0. Assume that we cross this structure by parallel planes 1–6. We will have the system of the parallel planes (Fig. 3, a), where the distinct value of a parameter is juxtaposed by any Euclidean point of the plane and represents the physical and chemical properties of the transistor regions such as "base", "emitter" and so on. After signing these values of the parameters by real numbers we have an approximation of the transistor to the parametric plane system, which can be substituted by planes arranged on the plane of the drawing as is shown in Fig. 3, b. If this approximation is made, the manufacturing of a solid-state device is represented by the formation of the distinct topology on the plane system, e.g., the changing of the primary values of the parameters. Such a changing may be caused only by interaction between the parameters.

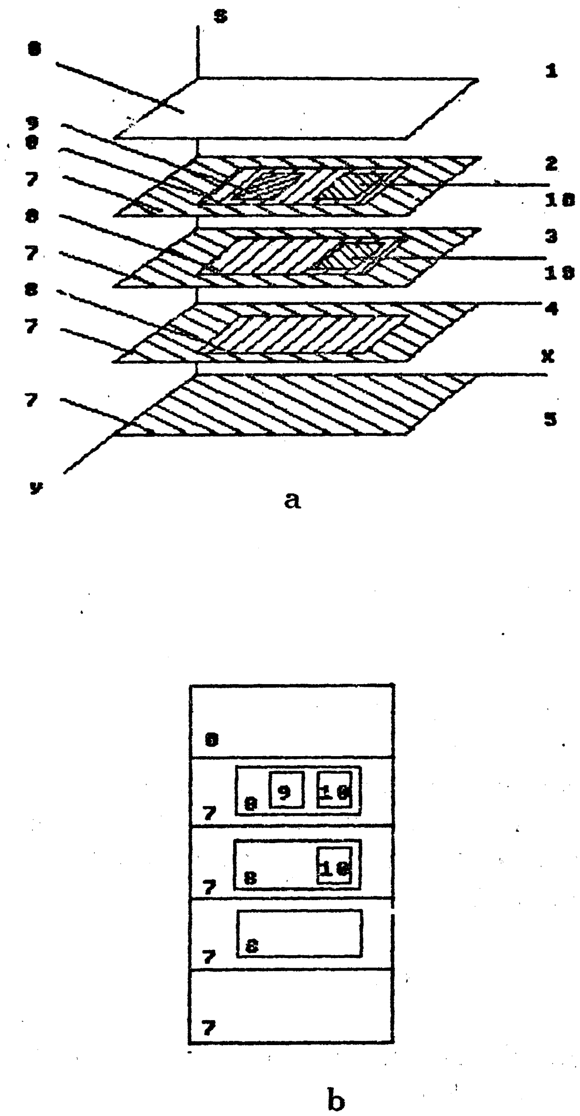

Fig. 3. Aproximation of the transistor.

Theory. Let's construct a topological space providing an evolution of topological systems. Topological space is presented by a Cartesian product of sets X_i :

$$\mathsf{T} = \prod\{X_i : i \in \mathsf{N}\}.$$

The Cartesian product of sets is expressed in the form of multi-dimensional space with orthogonal coordinate axis.

Let the first set be the axis X of an Euclidean space

$$X = \{(x) : x \in X\}.$$

The second one can be determined as the second axis of the Euclidean plane:

$$Y = \{(y) : y \in Y\}.$$

The direct product of sets X and Y comprises an Euclidean plane:

$$\mathbf{R}^2 \leftrightharpoons (X \times Y) = \{(x, y) : x \in X,\ y \in Y\}.$$

The set $\mathbf{R}^2$ represents all the combinations of (x, y).

The third axis could be the axis Z of the Euclidean space. But in the present state of affairs we have a chance to change the set Z by a numerical set $\mathfrak{S}$

$$\mathfrak{S} = \{(s) : s \in \mathbf{Z}\},$$

Where the axis $\mathfrak{S} \| Z$ in the Euclidean space and represents the indication of planes.

Thus we have a three-dimensional space

$$\mathcal{K} = (\mathbf{R}^2 \times \mathfrak{S}) = \{(x, y, s) : x \in X,\ y \in Y,\ s \in \mathfrak{S}\},$$

represented by a complainer Euclidean space, containing the ordered system of parallel indexed planes with undetermined distance between them.

Then the fourth axis – a parameter set P can be added:

$$\mathsf{P} = \{(p) : p \in \mathbb{N}\}.$$

This is the case where any point of the Euclidean plane is juxtaposed by distinct value of the parameter. If the parameter represents some material, the set P encloses all-inclusive definition of the materials denoted by numbers.

If the value of the parameters is juxtaposed by a colour, we have a system of parallel coloured planes with coloured figures on them.

No changes can occur in the space not including time axis:

$$\mathsf{T} = \{(t) : t \in \mathsf{R}\}.$$

Now we can determine the causes capable of changing the topological systems in our space. The axis X, Y, $\mathfrak{S}$ are not changeable. One parameter P only can be changed in time. It does not mean that the time causes a changing. Our topological space yet not includes the cause of change.

Any change in nature is caused by interactions between an object and media. Such substances in a topological space are represented by parameter values p_i.

Thus, a set of interactions between two parameters can be written out as:

$$\mathsf{P}^4 = \{(p, p, p, p) : p \in \mathsf{P}\},$$

where the combination $(p_k p_l p_r p_s)$ implies that the change of the parameters p_k and p_l to p_r and p_s, respectively, takes place if they occur in the neighbourhood of the Euclidean point

$$(x_i, y_i, s_i) \cup (x_j, y_j, s_j) \subset V.$$

So the point (x_i, y_i, s_i, p_k) and (x_j, y_j, s_j, p_l) changes to points (x_i, y_i, s_i, p_r) and (x_j, y_j, s_j, p_s) respectively.

Thus, the processes of etching and evaporation can be represented by interaction $p_i p_j p_i p_i$, exposition of photoresist, diffusion, ion implantation by $p_i p_j p_i p_k$, vacuum deposition, electrochemical coating by $p_i p_j p_j p_j$, diffusion followed by oxidation – by $p_i p_j p_k p_l$ etc.

Thus, we have the eight-dimensional topological space

$$\mathcal{L} = (\mathsf{R}^2 \times \mathfrak{S} \times \mathsf{P}^4 \times \mathsf{T}).$$

Four-dimensional systems in the form of set of parametric planes exists in space $\mathcal{L}$:

$$\mathcal{E} = (\mathsf{R}^2 \times \mathfrak{S} \times \mathsf{P}).$$

They approximate solid-state devices and integrated circuits as well. The evolution of these systems fits the manufacturing processes adequately.

External formation. The investigation of a system evolution can be performed on the determined topology. If the starting system is represented by a homogeneous plane $\{p_s\} \subset \mathrm{E}_0$, our problem is to find a set of interactions sufficient to change an initial plane to a system (Fig. 4):

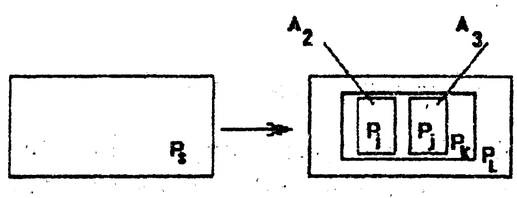

Fig. 4. Initial and final planes.

$$\mathrm{E}_1 = \{(A_2, p_i)(A_3, p_j)(A_1, \backslash A_2, \backslash A_3, p_k)(\backslash A_1, p_l)\}.$$

Suppose we have a plane system including two planes: an upper plane $\{0\}$ representing the medium and the bottom one $\{5\}$ representing the initial object (Fig. 5, left column). Suppose the medium plane is changed with time by a distinct sequence:

$$\{0\} \to \{A_1, 2)(\backslash A_1, 1)\} \to \{(A_2, 3)(\backslash A_2, 1)\}$$
$$\to \{(A_3, 4)(\backslash A_3, 1)\} \to \{0\}.$$

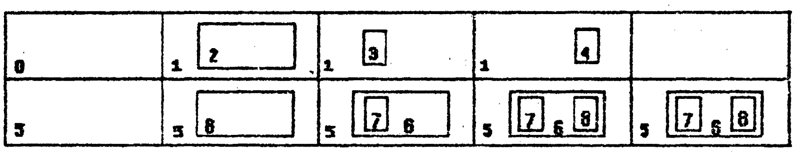

Fig. 5. Enternal formation technology.

The set of interactions is given by:

$$\mathrm{P}^4 = \{2526\ 3637\ 4648\}.$$

The evolution will occur in the following manner:

$$\{0\}\{5\} \to \{(A_1, 2)(\backslash A_1, 1)\}\{5\} \to \{(A_1, 2)(\backslash A_1, 1)\}$$
$$\{(A_1, 6)(\backslash A_1, 5)\} \to \{(A_2, 3)(\backslash A_2, 1)\}$$
$$\{(A_1, 6)(\backslash A_1, 5)\} \to \{(A_2, 3)(\backslash A_2, 1)\}$$
$$\{(A_2, 7)(A_1 \backslash A_2, 6)(\backslash A_1, 5)\} \to \{(A_3, 4)(\backslash A_3, 1)\}$$
$$\{(A_2, 7)(A_1 \backslash A_2, 6)(\backslash A_1, 5)\} \to \{(A_3, 4)(\backslash A_3, 1)\}$$
$$\{(A_2, 7)(A_3, 8)(A_1, \backslash A_2, \backslash A_3, 6)(\backslash A_1, 5)\}$$
$$\to \{0\}\{(A_2, 7)(A_3, 8)(A_1, \backslash A_2, \backslash A_3, 6)(\backslash A_1, 5)\}.$$

The medium plane $\{0\}$ (e.g. atmosphere) changes by the plane containing the figure A_1 with the parameter 2 (for example, vacuum with boron ion flow). The implantation changes n-type conductivity to p-type represented by parameter 5. Thus, we have a base region of transistor. Later a changing of boron atoms for phosphorus atoms for emitter region 7 forming follows. The forming of the p^+ base region occurs in the same way.

The above presented method is the most radical one of external formation. A well known planar process is based on the same principles.

Self-alignement. Make an assumption that an initial system includes an object plane $\{(A_1, 2)(\backslash A_1, 1)\}$ (a bottom plane in Fig. 6) and a medium plane varying with time by the sequence $\{0\} \to \{3\} \to \{0\} \to \{4\}$. The set of interactions is given by

$$\mathrm{P}^4 = \{1353\ 2565\ 2728\ 4647\},$$

and the evolution occurs in the following way (Fig. 6):

$$\{0\}\{(A_1,2)(\backslash A_1,1)\} \to \{3\}\{(A_1,2)(\backslash A_1,5)\}$$
$$\to \{0\}\{(A_2,2)(A_1\backslash A_2,6)(\backslash A_1,5)\} \to \{4\}\{(A_2,2)(A_1\backslash A_2,7)$$
$$(\backslash A_1,5)\} \to \{0\}\{(A_2,2)(A_3,7)(A_1,\backslash A_2,\backslash A_3,8)(\backslash A_1,5)\}.$$

In other words interaction 1353 causes the change of parameter 1 by the parameter 5, and then interaction 2565 causes leads to the formation of the ring region around the figure A_1. Thus, figure A_1 converts to the figure $(A_2, 2)$, figures $(\backslash A_2, 6)$ and $(\backslash A_1, 5)$. Then we change the parameter of the medium plane 3 to the parameter 4. The interaction 4647 transforms the parameter 6 to 7 and the interaction 2728 causes the ring region to form around the figure A_2 with the parameter 8, which separates the figure A_3.

There we have discussed the most complex self-aligned method, where only one lithography process is sufficient. The realization of such a case in solid-state technology is yet unknown. Hundreds of self-aligned methods change either one or several lithography processes by self-formation technique. I mean the methods for manufacturing of submicrometer structures.

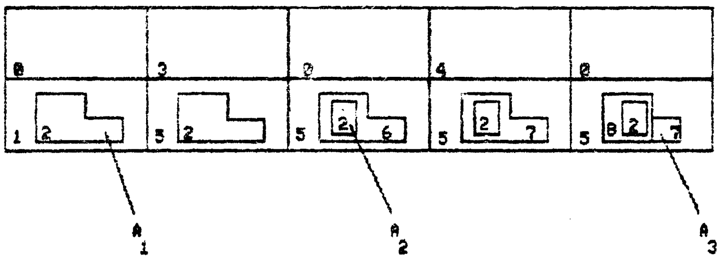

Fig. 6. Self-aligment technology.

Submicrometer structures can be obtained using one- (Fig. 7, c,d) or two- (Fig. 7, a,b) side evolution of a initial plane structure. In the first case the size of the structure is as follows:

$$x = a - 2vt,$$

where v – is the velocity of a movement of the phase boundary of an initial structure, t – is the duration of a process.

In the second case the size of the structure is as follows:

$$x = vt.$$

In order to form a submicrometer size by one- or two- side evolution we must use the selective etching or the oxidation followed by film deposition.

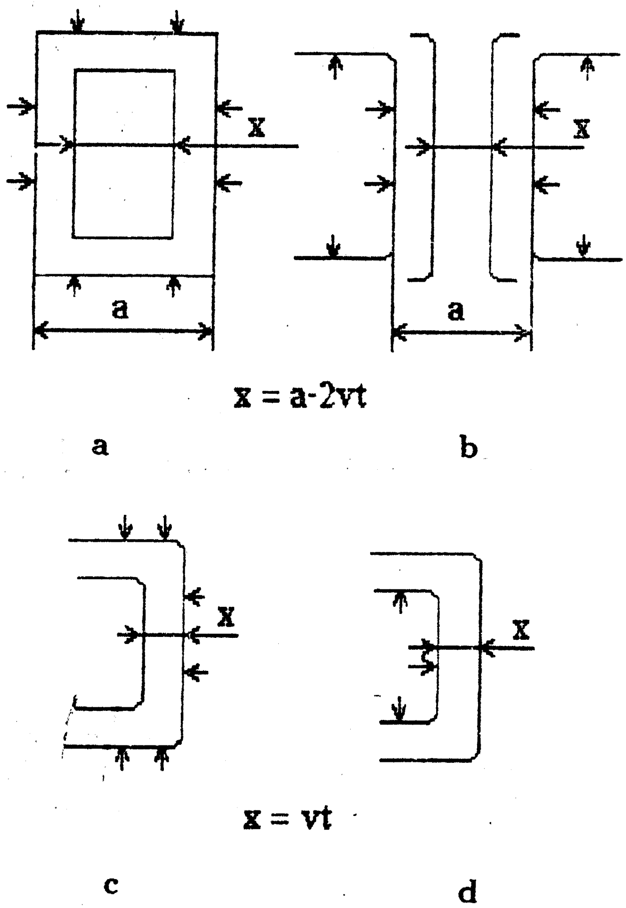

Fig. 7. One- and two- side evoliution of the primary structure.

Self-aligned technique is the simplest case of self-formation. But we can have and more interesting versions.

Development. An external formation (planar technology) and self-alignment are not single possible techniques for manufacturing of solid-state devices and integrated circuits.

Suppose we have two object planes $\{(A_1,2)(\backslash A_1,1)\}$ and $\{3\}$ separated by a medium plane $\{0\}$ (Fig. 8). The set of interactions is given by

$$P^4 = \{2324\ 2526\ 3435^*\ 4647^*\},$$

where the sign $*$ indexes the self-stopped interaction (for example, electrolytical oxidation), where radius of interaction $R^* > R_0$.

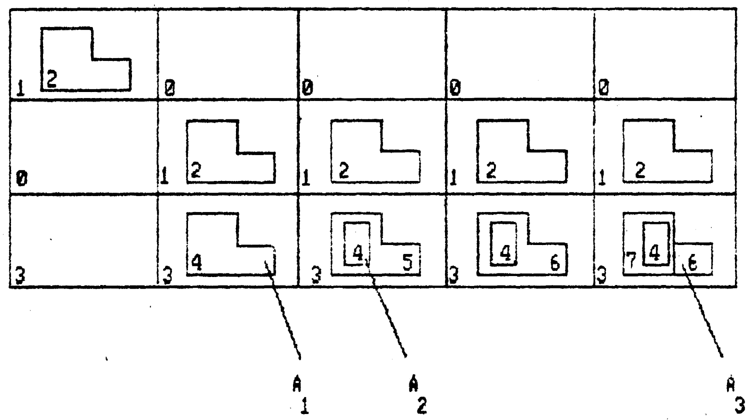

Fig. 8. Development of the system.

Assume that these planes come into contact. The evolution will occur in the following manner:

$$\{(A_1,2)(\backslash A_1,1)\}\{3\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_1,4)(\backslash A_1,3)\}$$
$$\to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,4)(A_1\backslash A_2,5)(\backslash A_1,3)\} \to$$
$$\to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,4)(A_1\backslash A_2,6)(\backslash A_1,3)\} \to$$
$$\to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,4)(A_3,6)(A_1,\backslash A_2,\backslash A_3,7)(\backslash A_1,3)\}.$$

The interaction 2324 causes the formation of the figure A_1 with the parameter 4 on the bottom plane. Then the interaction 3435* causes the ring region formation with the parameter 5. But the interaction 2526 changes the parameter

5 to 6. The last one causes the interaction 4647* and the formation of the ring region 7.

It is important to note some interesting features of this evolution. First, we have two equilibrium objects (object planes) which contact makes a nonequilibrium object and structure changing starts. Second, no interaction between an object and medium is not necessary. The system complexity rises without external disturbance.

Thus, we have an analogous to the living system development.

The theoretical base allows the construction of more exotic methods of manufacturing of solid-state devices.

Assume, that we have two initial objects $\{(A_1,2)(\backslash A_1,1)\}$ and $\{3\}\{4\}$ separated by the medium plane $\{0\}$, as shown in (Fig. 9). An asymmetry of the second plane system allows two kinds of contacts:

$$E_1 = \{(A_1,2)(\backslash A_1,1)\}\{3\}\{4\}$$
$$E_2 = \{(A_1,2)(\backslash A_1,1)\}\{4\}\{3\}$$

If the set of interactions is given by

P^4 = {1315 2326 5457 6468 8002 7001 5659* 6068
6860 9098 5750 292(10) (10)0(10)8 6(10)6(11)*
(11)0(11)8 141(12) 242(13) (12)3(12)(14)
(13)3(13)14 (14)0(14)(15) (15)034 3(14)30
(12)(13)(12)(16)* 2(16)2(17) (13)(17)(13)(18)*
(16)0(16)14 (17)0(17)(14) 18, 0, 18, 14 (13)0(13)(14).

The system E_1 evaluation is as follows:

$$\{(A_1,2)(\backslash A_1,1)\}\{3\}\{4\}\{0\} \rightarrow \{(A_1,2)(\backslash A_1,1)\}$$
$$\{(A_1,6)(\backslash A_1,5)\}\{(A_1,8)(\backslash A_1,7)\}\{0\} \rightarrow \{(A_1,2)(\backslash A_1,1)\}$$
$$\{A_1,6)(\backslash A_1,5)\}\{0\}\{(A_1,2)(\backslash A_1,1)\} \rightarrow \ldots \rightarrow \{(A_1,2)$$
$$(\backslash A_1,1)\}\{A_2,6)(A_1\backslash A_2,9)(\backslash A_1,5)\}\{(A_1,8)(\backslash A_1,7)\}\{0\} \rightarrow$$

$$\{(A_1,2)(\backslash A_1,1)\}\{(A_2,6)(A_1\backslash A_2,10)\}\{0\}\{(A_1,2)(\backslash A_1,1)\} \to \ldots \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,6)(A_3,10)(A_1,\backslash A_2,\backslash A_3,11)(\backslash A_1,5)\}\{(A_1,8)(\backslash A_1,7)\}\{0\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,6)(\backslash A_3,10)\}(A_1,\backslash A_2,\backslash A_3,11)\}\{0\}\{(A_1,2)(\backslash A_1,1)\} \to \ldots$$

The first initial object comes into contact with the upper plane of the second initial object. The interactions 1315, 2326, 5457, 64C8 cause the formation of the figure A_1 on the upper and bottom planes of the second object. Then the middle plane comes into development (see development, referred to Fig. 8). At the same time the interactions 8002 and 7001 cause the formation of the first kind of the initial object separated by the plane (0). It means an autonomy of these systems. Thus, we have a generation first kind of the initial object. The following infinite generation supports the iteractions 6068, 9098, (10)0(10)8 and (11)0(11)8.

If the primary object comes into contact with the bottom plane of the second system, we obtain the development of the system followed by infinite generation of the second kind of the initial object (Fig. 10). The comes the following evolution:

$$\{(A_1,2)(\backslash A_1,1)\}\{4\}\{3\}\{0\}\{0\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_1,13)(\backslash A_1,12)\}\{14\}\{15\}\{0\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_1,13)(\backslash A_1,12)\}\{0\}\{3\}\{4\} \to \ldots \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,13)(A_1,\backslash A_2,16)(\backslash A_1,12)\}\{14\}\{15\}\{0\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,13)(A_1,\backslash A_2,17)(\backslash A_1,12)\}\{0\}\{3\}\{4\} \to \ldots \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,13)(A_3,17)(A_1,\backslash A_2,\backslash A_3,18)\}\{14\}\{15\}\{0\} \to \{(A_1,2)(\backslash A_1,1)\}\{(A_2,13)(A_3,17)(A_1,\backslash A_2,\backslash A_3,18)\}\{0\}\{3\}\{4\} \to \ldots$$

So a possibility of the reproduction of such primitive artificial systems as transistors exists at least theoretically. We see a remarkable resemblance with reproduction of living systems. Two kinds of an initial object are necessary and sufficient.

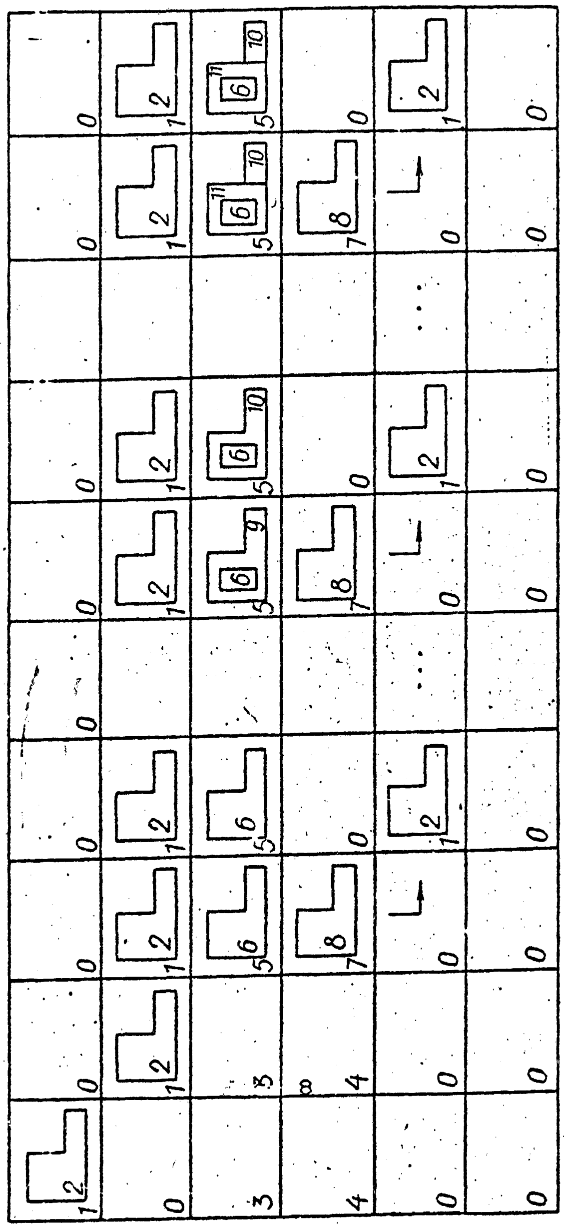

Fig. 9. Reproduction of the first kind of system.

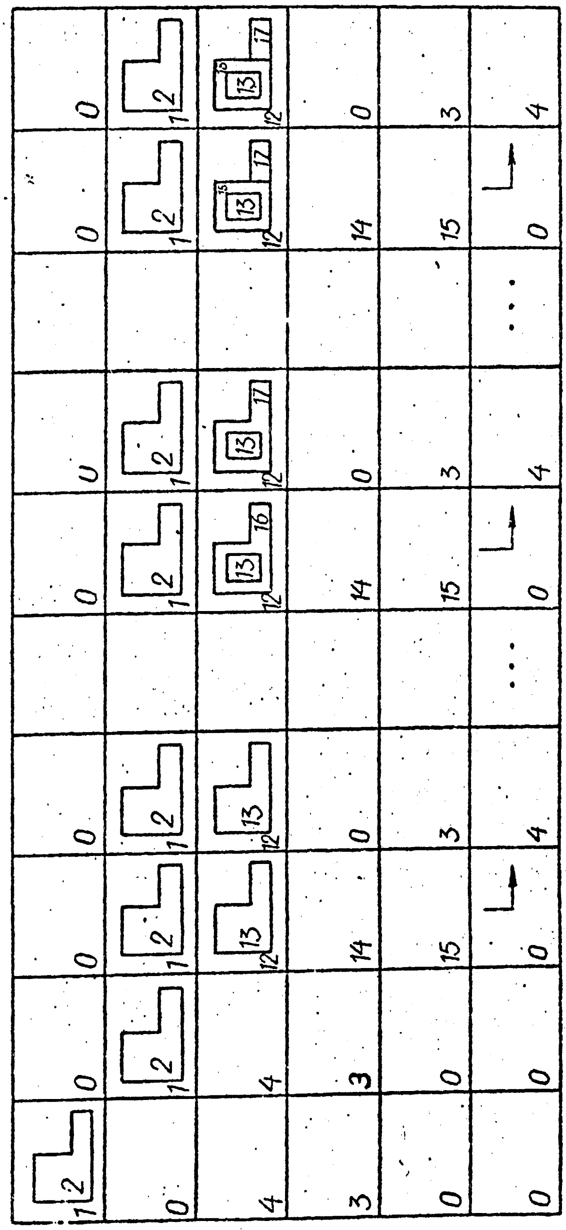

Fig. 10. Reproduction of the second kind of system.

To contact with side of second initial object is chosen the first or second kind of an object develops. The object developing is followed by generation of the first or second kind of the initial object, respectively.

A chance of meeting of two kinds of initial objects make a nonequilibrium developing object able to generate an initial object sequence.

Conclusion. An approximation of the manufacturing of solid-state devices and IC by eight-dimensional topological space and forming object by topological system has allowed to clear up fundamentals of formation in respect of physical processes and materials applied to distinct technologies.

The theory "permits" an existence of external formation as a class of well known methods for manufacturing of solid-state devices and IC. For the most part we mean a planar technology based on lithography processes. An object's formation accompanied by increasing of its complexity is caused by structural and chaotic media sequence controlled by a man an automatics.

Theory includes all known methods of self-aligned technique, where an object forming is caused by sequence of chaotic medium controlled by a man or an automatics. These methods have an application, when submicron structures are manufactured without electronolithography and where the number of lithography processes are reduced. A single lithography to the self-aligned technique only is sufficient.

Theory disclosed new unknown in practice methods of manufacturing of solid-state devices and IC analogous to development and reproduction in animate nature. The development can be thought of as self-aligned with one lithography and one chaotic medium. Even if a principal possibility to construct such a technology exits, its realization probably lays in the way of changing of a device construction and materials. It is not inconceivable that it will be a MOLECULAR ELECTRONICS.

REFERENCES

Janušonis, S., and V.Janušonienė (1985). *Self-formation in Semiconductor Technology.* Mokslas, Vilnius. pp. 192. (in Russian).

Janušonis, S., V.Janušonienė, S.Narkus and E.Žilinskas (1989). Self-formation for high speed MESFET fabrication. *Crystal Properties & Preparation,* **19**, **20**, 287–290.

Janušonis, S. (1989). Self-formation: A new conception in solid-state technology. In *Proceedings, 17-th Jugoslav Conference on microelectronics,* Vol.1. Niš, Jugoslavia. 197–202.

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