IOP Conf. Series: Journal of Physics: Conf. Series **803** (2017) 012145 doi:10.1088/1742-6596/803/1/012145

Energy-information modelling of the flat membrane on the fractal approach basis

O M Shikulskaya[1], M I Shikulskiy[2]

[1]Department of research activities, Astrakhan state university of civil engineering, 18 Tatischeva Str., Astrakhan, 414056, Russia
[2]Department of applied informatics in economy, Astrakhan state technical university, 16 Tatischeva Str., Astrakhan, 414056, Russia

E-mail: shikul@mail.ru

Abstract. Feasibility of the energy-information method use, both at a stage of conceptual design of control systems elements and at a stage of their outline designing is proved in the paper. It is shown that the use of the fractal approach to modeling of the physical principle of operation of sensors considerably increases possibilities of the power-information method, broadening the area of the synthesized technical solutions. The paper presents energy-information modeling of deformation of a flat membrane on the basis of the fractal approach. The offered approach unlike the classical approach allows taking into account anisotropic properties of semiconductor materials of a microelectronic membrane. The advantage of the provided method in comparison with other approximate methods consists in a possibility of transition from a stage of conceptual design to a stage of outline designing with the use of a single platform that considerably increases operational efficiency of designers.

1. Introduction

In connection with onrush of science and technology, the requirement to control systems elements continuously increases. The initial stages of sensors designing are the most important since at a stage of conceptual design developers make fundamental decisions on the structure and the principle of operation of the developed device. The initial stages of designing are characterized by conversion of considerable amounts of information, a large number of the studied engineering implementation options. The solution of these tasks is in many respects determined how the developer will be provided with the new information technologies, strengthening his intellectual capacity, allowing to automate processes of search and information processing on the basis of application of the system approach to sensors and their elements development. The paper is devoted to creation of such technologies [1-2]. Most effectively this problem is solved by the theory of energy-information chains [3-6] with the use of the knowledge base based on a general concept about a class of objects [7-9]. The energy-information method allows describing the phenomena and processes of various physical nature by means of the equations, invariant to the nature.

Technical progress requires continuous development of the theory. The use of the fractal approach for the description of the principle of operating of technical devices allowed lifting a part of restrictions of the energy-information method and broadening the area of the found solutions [10]. Besides, the offered approach can be applicable not only at a stage of conceptual design, but also at a stage of outline designing. This process is shown by authors by the example of energy-information modeling of a flat membrane deformation.

2. Materials and Methods

Designing the flat membrane working at small deflections, the classical method of calculation based on solution of the differential equations [11] is used. However, it does not consider mechanical anisotropy of semiconducting materials, of which microelectronic technical devices are made. On the other hand, development of new sensors and their analysis is essentially at a loss with the fact that the description of physical processes on which their principle of operation is grounded, is, as a rule, carried on in the language inherent to the given class of the physical phenomena. Thus, descriptions of various classes of the physical phenomena essentially differ from each other on the basis of traditionally used mathematical apparatus.

This problem is solved based on the theory of energy-information models of chains (EIMC) of the device of parametrical block diagrams (PBD). The EIMC Theory provides consideration of the phenomena of the various physical nature by means of the equations, invariant to the physical nature itself; graphical representation of the operation principle of the converter; deriving of analytical dependences of one value from another; the possibility concerning simple search automation of new technical solutions [2]. It is applied at a stage of retrieval designing to automation of synthesis of new technical solutions. Design of converters will become more effective if the EIMC Theory also will be used at the following stage for predesign of units of the synthesized converters. This causes a choice of a power-informational method for the approximate calculation of a flat membrane taking into account mechanical anisotropy of properties of semiconducting materials.

3. The model of a flat membrane deformation

The flat membrane can be presented as the round slice fixed on the edge and loaded with pressure or concentrated load. Limiting the task to the area of small motions (movements), we will consider that the slice works only in bending; therefore, during task solution it is possible to become limited by consideration of parameters and values only of the mechanical angular nature.

As the slice has polar symmetry, for a material with isotropic properties, power factors of power and deformation are constant along a circle, but can vary on the plate radius. For membranes from semiconducting materials, deformation in various points of a surface differs not only in a radial, but also in a district direction. Therefore, when defining values and chain parameters, it is necessary to consider the corner value between the selected direction of consideration of deformation and the main axis of the material. It is proved that the membrane can be considered as a line with the distributed parameters [3]. In figure 1, the circuit of load of a flat membrane is presented.

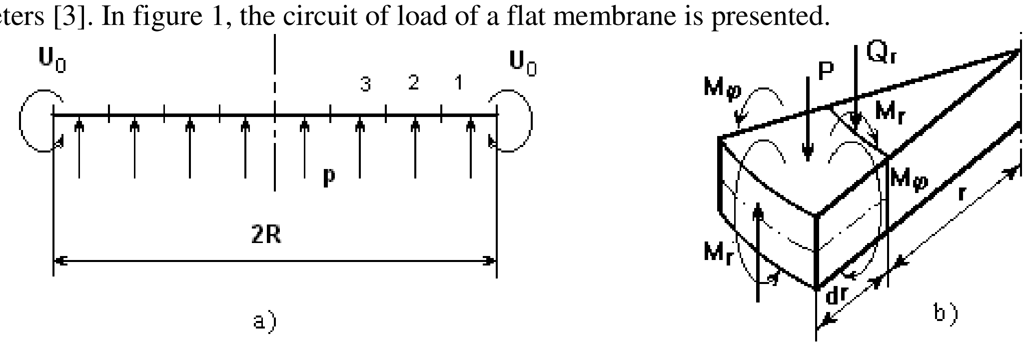


Figure 1. The circuit of load of a flat membrane: a) along radius, b) a segment.

On the basis of analogies and similarity of chains of the various physical nature, the first and second Kirchhoff laws, the Ohm's law, the Hooke's law, the model of deformation of a flat membrane has been developed for biaxial stress. Its parametrical block diagram is presented in figure 2. Analytical dependences for calculation of deformation of a flat membrane (1-10) are derived.

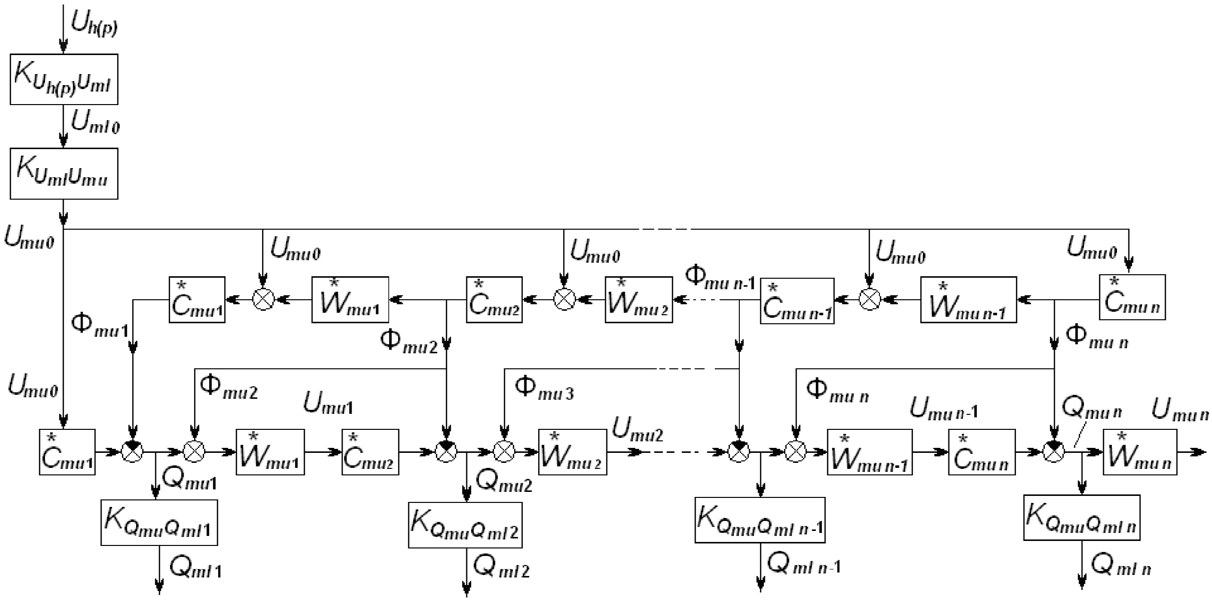


Figure 2. The parametrical block diagram of deformation of a flat membrane.

$$U_{mui} = \overset{*}{W}_{imu}\left(Q_{mui} + \Phi_{mu(i+1)}\right) \tag{1}$$

$$Q_{mui} = \overset{*}{C}_{mui}\, U_{mu(i-1)} - \Phi_{mui} \tag{2}$$

$$\Phi_i = \sum_{j=i}^{n} U_{pj} \cdot \overset{*}{C}_i \cdot \Psi_{ij} \tag{3}$$

$$\Psi_{ij} = \begin{cases} 1 & \text{if } j \le i \\ \Psi_{i(j-1)} \cdot \left(\overset{*}{C}_{j-1} \cdot \overset{*}{W}_{j-1}\right) & \text{if } j > i \end{cases} \tag{4}$$

$$\overset{*}{W}_{mu(n-i)} = \begin{cases} \overset{*}{W}_{mun} & \text{if } i = 0 \\ \dfrac{1}{\dfrac{1}{\overset{*}{W}_{mu(n-i)}} + \overset{*}{C}_{mu(n-i+1)}} & \text{if } i > 0 \end{cases} \tag{5}$$

$$\overset{*}{C}_{mu(n-i)} = \frac{1}{\dfrac{1}{C_{mu(n-i)}} + \overset{*}{W}_{mu(n-i)}} \tag{6}$$

$$U_h = p$$

$$U_{ml0} = 0.5 \cdot pR^2 \tag{7}$$

$$U_{mu0} = pR^2 / 2n \tag{8}$$

$$W_{mui} = \frac{h^3 n \cdot \left(E_1 \cdot \sin^2\alpha + E_2 \cdot \cos^2\alpha\right)}{12(1 - \mu_{12}\mu_{21})} \tag{9}$$

$$C_{mui} = \frac{12(1-\mu_{12}\mu_{21})(n-i)}{h^3 n\cdot\left(E_1\mu_{21}\cdot\sin^2\alpha + E_2\mu_{12}\cdot\cos^2\alpha\right)} \tag{10}$$

There are the following legends in figure 2 and in formulas (1-10):

U_{mui}—angular mechanical effect in theory PIMC terms, Q_{mui} — angular mechanical charge, $\overset{*}{W}_{mui}$, $\overset{*}{C}_{mui}$ — parameters defining accordingly the mechanical angular rigidity and the mechanical angular capacity, p – pressure; R — membrane radius; $h_м$ — thickness of a membrane; E_1, E_2 — modulus of elasticity of Young on axes x and y of Eulerian coordinates, m_{12}, m_{21} — Poisson's ratios concerning axes x and y of Eulerian coordinates (for isotropic material, $E_1=E_2=E$, $\mu_{12}=\mu_{21}=\mu$); n — quantity of links of a chain of a membrane, α — the angle of the section direction relatively the main axis.

Recursive functions have been used to simplify the analytical expressions. The analysis has resulted in the definition of their physical sense. The function is dimensionless and characterizes elastic properties of a material. The function has the dimension of a charge in terms used in theory EIMC, and represents the factor of the distributed effect on a sensitive unit.

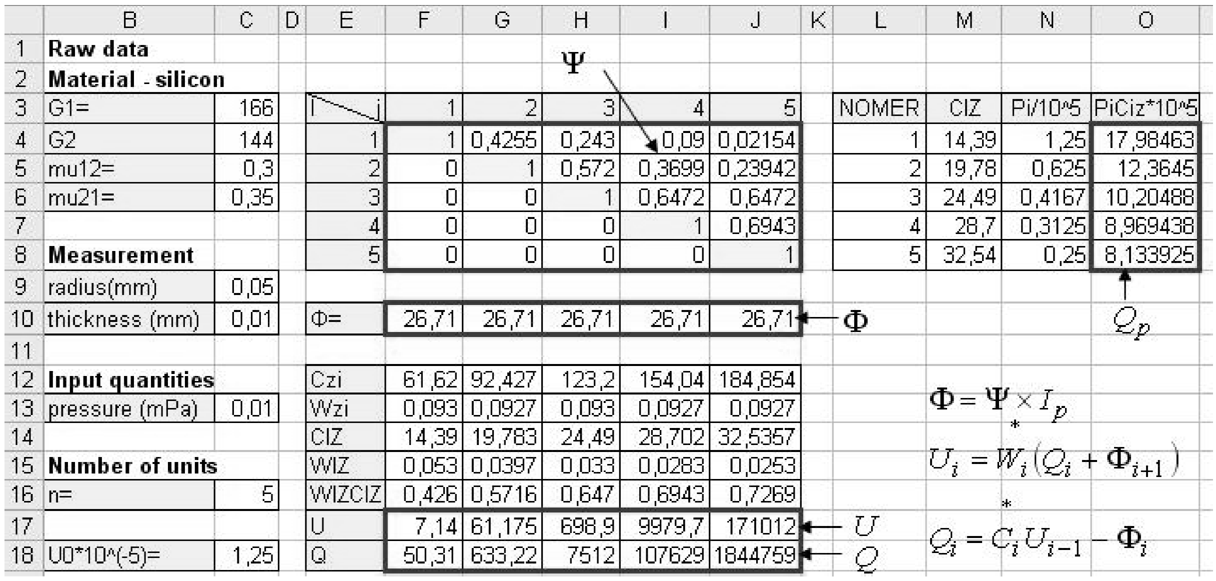
The value part of the functions for each elementary unit Φ_i is defined by a line matrix of distributing force factor Φ by dimension $(n\times 1)$ as a production of distributing parameters matrix Ψ by dimension $(n\times n)$ on a column vector of distributed reaction I_p of the dimension $(1\times n)$ (fig. 3).

i	Φ_i	$U_{p1}\cdot\overset{*}{G}_1$	$U_{p2}\cdot\overset{*}{G}_2$	$U_{p3}\cdot\overset{*}{G}_3$	$U_{p4}\cdot\overset{*}{G}_4$	$U_{p5}\cdot\overset{*}{G}_5$
		j=1	j=2	j=3	j=4	j=5
		Ψ_{i1}	Ψ_{i2}	Ψ_{i3}	Ψ_{i4}	Ψ_{i5}
1	$\sum_{j=1}^{5} U_{pj}\cdot\overset{*}{G}_j\cdot\Psi_{1j}$	1	$\left(\overset{*}{G}_1\overset{*}{R}_1\right)$	$\left(\overset{*}{G}_1\overset{*}{R}_1\right)\cdot\left(\overset{*}{G}_2\overset{*}{R}_2\right)$	$\left(\overset{*}{G}_1\overset{*}{R}_1\right)\cdot\left(\overset{*}{G}_2\overset{*}{R}_2\right)\cdot\left(\overset{*}{G}_3\overset{*}{R}_3\right)$	$\left(\overset{*}{G}_1\overset{*}{R}_1\right)\cdot\left(\overset{*}{G}_2\overset{*}{R}_2\right)\cdot\left(\overset{*}{G}_3\overset{*}{R}_3\right)\cdot\left(\overset{*}{G}_4\overset{*}{R}_4\right)$
2	$\sum_{j=2}^{5} U_{pj}\cdot\overset{*}{G}_j\cdot\Psi_{2j}$	0	1	$\left(\overset{*}{G}_2\overset{*}{R}_2\right)$	$\left(\overset{*}{G}_2\overset{*}{R}_2\right)\cdot\left(\overset{*}{G}_3\overset{*}{R}_3\right)$	$\left(\overset{*}{G}_2\overset{*}{R}_2\right)\cdot\left(\overset{*}{G}_3\overset{*}{R}_3\right)\cdot\left(\overset{*}{G}_4\overset{*}{R}_4\right)$
3	$\sum_{j=3}^{5} U_{pj}\cdot\overset{*}{G}_j\cdot\Psi_{3j}$	0	0	1	$\left(\overset{*}{G}_3\overset{*}{R}_3\right)$	$\left(\overset{*}{G}_3\overset{*}{R}_3\right)\cdot\left(\overset{*}{G}_4\overset{*}{R}_4\right)$
4	$\sum_{j=4}^{5} U_{pj}\cdot\overset{*}{G}_j\cdot\Psi_{4j}$	0	0	0	1	$\left(\overset{*}{G}_4\overset{*}{R}_4\right)$
5	$\sum_{j=5}^{5} U_{pj}\cdot\overset{*}{G}_j\cdot\Psi_{5j}$	0	0	0	0	1

Figure 3. Dependence of the size of distributing force factor Φ_i on a sensitive element from the depth of the fractal limit.

The derived dependences are used to create a numerical method of a flat membrane calculation basing on the use of matrixes with elements of fractal structures. This method can be implemented on the basis of the tabular processor (fig. 4).

IOP Conf. Series: Journal of Physics: Conf. Series **803** (2017) 012145 doi:10.1088/1742-6596/803/1/012145



	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Raw data**													
2	**Material - silicon**						Ψ							
3	G1=	166		i \ j	1	2	3	4	5		NOMER	CIZ	Pi/10^5	PiCiz*10^5
4	G2	144		1	1	0,4255	0,243	0,09	0,02154		1	14,39	1,25	17,98463
5	mu12=	0,3		2	0	1	0,572	0,3699	0,23942		2	19,78	0,625	12,3645
6	mu21=	0,35		3	0	0	1	0,6472	0,6472		3	24,49	0,4167	10,20488
7				4	0	0	0	1	0,6943		4	28,7	0,3125	8,969438
8	**Measurement**			5	0	0	0	0	1		5	32,54	0,25	8,133925
9	radius(mm)	0,05												
10	thickness (mm)	0,01		Φ=	26,71	26,71	26,71	26,71	26,71		Φ			Q_p
11														
12	**Input quantities**			Czi	61,62	92,427	123,2	154,04	184,854					
13	pressure (mPa)	0,01		Wzi	0,093	0,0927	0,093	0,0927	0,0927					
14				CIZ	14,39	19,783	24,49	28,702	32,5357					
15	**Number of units**			WIZ	0,053	0,0397	0,033	0,0283	0,0253					
16	n=	5		WIZCIZ	0,426	0,5716	0,647	0,6943	0,7269					
17				U	7,14	61,175	698,9	9979,7	171012		U			
18	U0*10^(-5)=	1,25		Q	50,31	633,22	7512	107629	1844759		Q			

$$\Phi = \Psi \times I_p$$

$$U_i^* = W_i(Q_i + \Phi_{i+1})$$

$$Q_i^* = C_i U_{i-1} - \Phi_i$$

Figure 4. The illustration of an engineering design procedure of the flat membrane deformation, using the matrixes with elements of fractal structures in MS Excel.

4. Results

Adequacy of the structurally-parametrical model of a flat membrane deformation has been checked up on the basis of the matching of its usage results with the result of a classical technique of solution of the differential equations applied in case a material with isotropic properties is used. The classical method is unacceptable for a material with anisotropic properties. Algorithmic knoware and the software have been developed to carry out the computing experiment. The result of experiment is presented in figure 5.

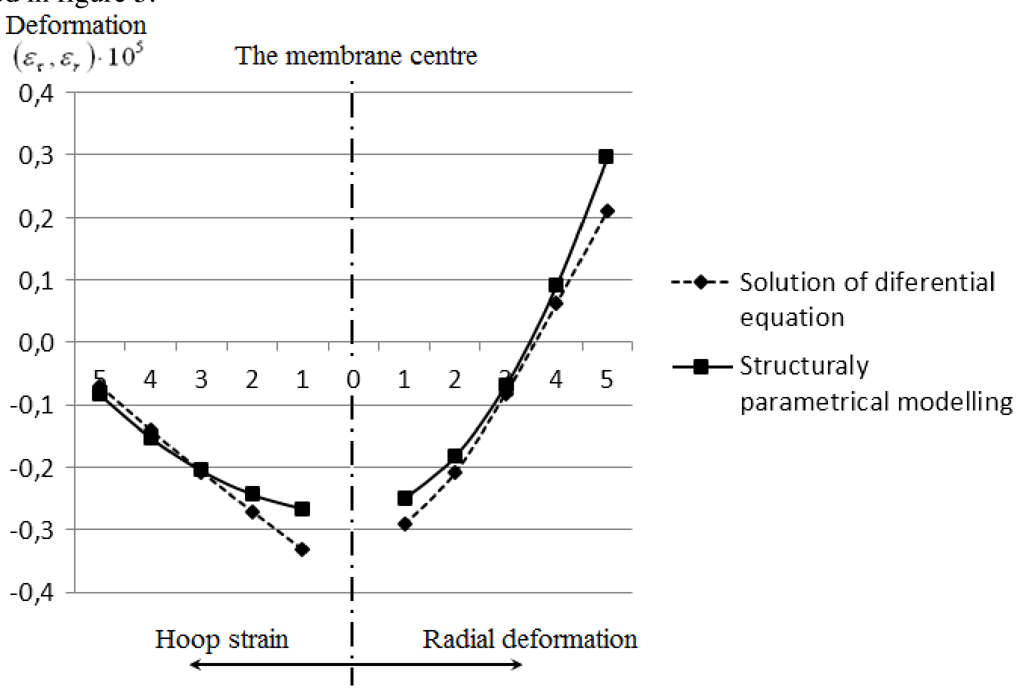


Figure 5. The diagram of a flat membrane deformation

The received inaccuracy of calculation with usage of the developed model is in the limits of 30 %, which is acceptable for using the developed method at the stage of sketch design.

5. Conclusion

The developed model of deformation of a flat membrane has two purposes: synthesis of new technical solutions and preliminary approximate calculation at a stage of sketch design.

The offered method unlike the classical approach allows taking into account anisotropic properties of semiconductor materials of a microelectronic membrane.

This approach makes the design more efficient by the reduction of expenses for the prototyping and field tests.

References

[1] Kizim AV, Chikov E V, Melnik V Y and Kamaev V A 2011 Journal of autonomous agents, Informatization and Communication, Software and information support Agent Sys Journal of Autonomous Agents and for the maintenance and repair of equipment in the interests of the subjects of the process, *Informatization and Communication* **3** 57-59

[2] Korobkin Dmitriy, Fomenkov Sergey, Kolesnikov Sergey and Voronin Yuriy 2013 *World Applied Sciences Journal 24* (Information Technologies in Modern Industry, Education & Society) pp 55-61

[3] Zaripova V and Petrova I. 2015 Progressin Systems Engineering, Proceedings of the 23rd International Conference on Systems Engineering, *Las Vegas, NV, Series: Advances in Intelligent Systems and Computing* **1089**, 365-73.

[4] lezhnina Yu, Khomenko T and Zaripova V 2014 *CCIS 466 proceedings (11th Joint Conference on Knowledge-Based Soft-ware Engineering (JCKBSE 2014)* 185-94.

[5] Shikul'skya O, Konstantinova O 2009 *Measurement Techniques* **52(8)** 829-32

[6] Zaripova V and Petrova I 2014 *Communications in Computerand Information Science* **466** 521-32

[7] Zaripov M, Petrova I and Zaripova V 2002 *IMEKO TC1 Symposium on Education in Measurement and Instrumentation: Challenges of New Technologies*

[8] Zaripova V and Petrova I 2015 *Journal of Physics: Conference Series* **588** 012031

[9] Zaripova V, Petrova I, Kravets A and Evdoshenko O 2015 *Proceedings of the 1-st Conference Creativity in Intelligent Technologies and Data Science (CIT&DS), Volgograd, Russia, September,* 15–17.

[10] Petrova I, Shikulskaya O and Shikulskiy M 2014 *Advanced Materials Research* **951(4)** 951-956

[11] Titus S.S.K., Kamlesh K. Jain, S.K. Dhulkhead, Poonam Yadav. 2009 19 IMEKO World Congress, Fundamental and Applied Metrology, September 6—11 *Lisbon, Portugal*.