International Conference "Micro- and nanoelectronics – 2003" ICMNE-2003

AN INVESTIGATION INTO NANO-DIMENSIONAL FRACTAL FILM STRUCTURES

Igor N. Serov[1], Gennady N. Lukyanov[2], Vladimir I. Margolin[1,3], Nikita A. Potsar[3], Inga A. Soltovskaya[1], Valentin S. Fantikov[3]

1. Aires New Medial Technologies Foundation
2. St. Petersburg State Institute of Fine Mechanics and Optics (Technical University)
3. St. Petersburg State Electroengineering University "LETI"
St. Petersburg, Russia

ABSTRACT

This work is dedicated to experimental studies of the action of fraktal- matrix strukturizator "Aires" on the processes of increasing on the thin nano-dimensional films of copper, titanium and number of others.It is established that under the action of strukturizators it is possible to obtain films with the clearly expressed fraktal structure, moreover at different levels.Are given the results of a study with the aid of optics, SEM and AFM of the microscopy. As a result of a complex of the lead researches influence fractal-matrix strukturizators on the processes proceeding at condensation thin nano-dimensional films from vapor or the plasma environment with use of methods magnetron ionic - plasma spattering and thermal vacuum evaporation is revealed.

Key words: Fraktal- matrix topology, Strukturizator "Aires", Nano-dimensional structure, Magnetron ionic - plasma spattering, Scanning electron microscopy, Atomic-force microscopy.

1. INTRODUCTION

In work[1] author's ideas concerning ways of development nanotechnology and possible methods of the decision of a problem of reception nano-dimensional structures on a local site of a substrate with the help of group methods of processing are stated. Authors have come out with the assumption of an opportunity of use for processes of strukturization received nano-dimensional objects of directivity influencing physical agent. In a role of the agent it was offered to use in appropriate way structured electromagnetic field. It required an experimental substantiation. It was offered to apply to realization of processes of strukturization of an electromagnetic field fractal-matrix strukturizator (FMS) "Aires"[2]. The given work is devoted to the experimental researches lead by authors on depositing thin nano-dimensional films of various materials under influence FMS and to their discussion. Authors with profound gratitude will apprehend anyone positive (and especially negative) judgments concerning their reasons.

2. FRACTAL-MATRIX STRUCTURIZATOR "AIRES"AS CONVERTERS OF WAVE FIELDS.

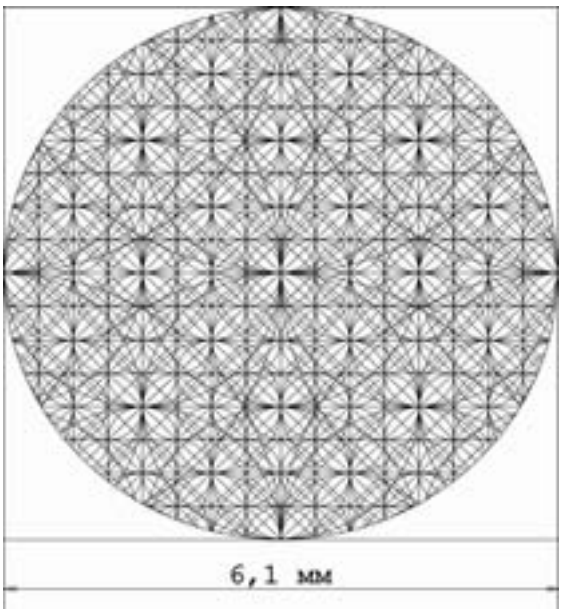
Fractal-matrix strukturizator "Aires" are curvilinear diffraction a lattice which image is transferred by methods of a precision optical photolithography on a substrate. A substrate are or single-crystal silicon plates, either glass plates, or the organic plastic carrier. Figure diffractions lattices represents the fractal-matrix topology executed as fractal of the collected matrix, consisting of a set of modules similar to[3] The determining factor of properties matrix schedules is the barrier effect of change of density of environment which sharply changes on border of contact of " a free field " and structural lines[4, 5].

Under fractal it is accepted to understand the structures self-organizing in open systems owing to the various phenomena, proceeding in similar systems and initiating processes of self-organizing and self-correction. We understand anyone as a fractal rigidly organized on principles of self-similarity and the self-coordination hierarchical structure. Sometimes a fractal name the object consisting of parts, similar to the whole, i.e. possessing self-similarity[6].

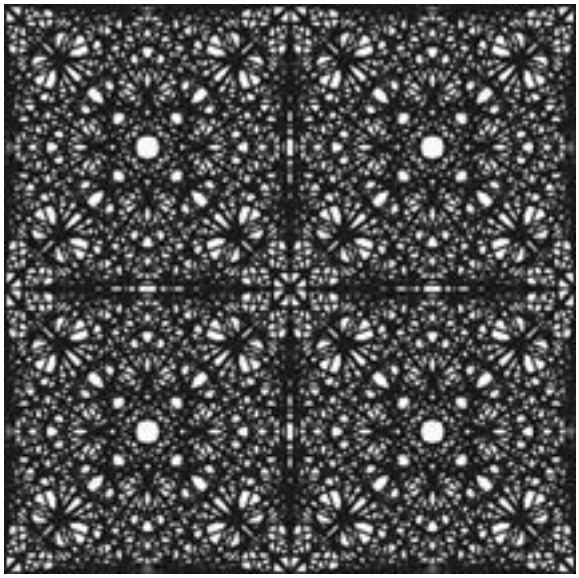
On fig. 1 fragments of topological figures FMS for strukturizator various generations are submitted. FMS the second generation represent matrix fractal the module in diameter of 66,56 mm with topological figure and are applied as optical filters to correction of various anomalies in biology and medicine[7].

---

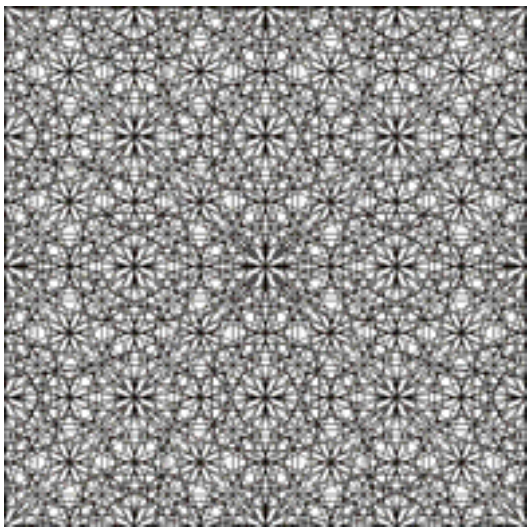
*



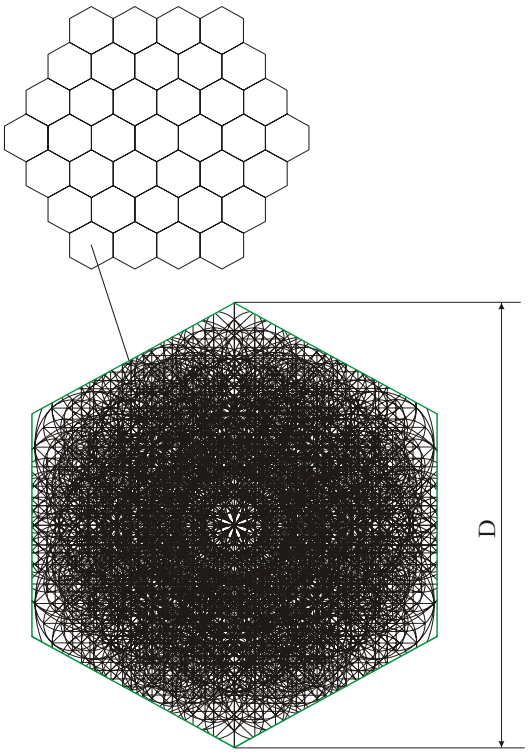
1 a



1 b



1 c



1 d

Fig 1. Variety of topology of FMS of different generations. 1 a – the first generation (applicator); 1 b – the second generation (optical filter); 1 c – the third generation (Silicon chip); 1 d the fourth generation (hexagonal structure)

The width of a line in FMS the second generation makes for different updating from units up to tens micron. FMS the third generation represents the the single crystal silicon chip made Open Society "Angstrom" on technology "Aires". The size of a line of topological figure makes size about 1,0 microns. FMS the fourth generation are placed on glass substrates. The size of a line 1 microns. In experiments spent by us all types strukturizator and their various combinations were used.

3. TECHNIQUES OF EXPERIMENTAL RESEARCHES AND EQUIPMENT.

In experiments on studying influence of structures FMS on properties thin films various combinations of a plane arrangement strukturizators were applied. Formation of nano-dimensional layers of copper, titan and nickel was carried out by means of magnetron spattering on the basis of modified standard vacuum post VUP-4. Distance the cathode - a substrate equally 80 mm. Submission on a working table of constant potential in limits from 0 up to 300 V. Magnetron is made on the basis of a baric magnet and allows to make change of the cathode easily. The cathode voltage is about 700 V, a current of the gas discharges up to 2,5 A. And, time of depositions is from 10 to 35 sec. Working gas - Ar with pressure in the chamber $3\text{-}10^{-4}$ m.Hg. Size of residual vacuum $3\text{-}10^{-5}$ m.Hg.

The visual control was carried out by optical microscopy with the help of interferometer MII-4 and optical microscopes OLYMPUS BX60, Wild Epimakroskop M-450 and SM-LUX HL with registration by digital chambers VNC-702 and "Minolta Dimage 7 ".

The analysis of details of fractal structures in micro- and nano-dimensional was carried out by methods of AFM power microscopy (microscope Auto Probe M5, AFM microscopes Solver P47 and Solver P47H) and scanning electronic microscopy on SEM microscopes Hitachi S-3500N and JSM-35, with detectors " Robinson " and with an opportunity of increase from 15 up to 300000* and change of an accelerating voltage from 0,3 up to 30 KV. Researches phase and a chemical compound it was carried out by methods x-ray diffraction on installation Dron - 2, and microprobe the analysis was carried out on the x-ray micro analyzer such as Link 860.

4. THE RESULTS OF EXPERIMENTAL RESEARCHES RECEIVED WITH THE HELP OF OPTICAL MICROSCOPY.

The structure of copper thin films, received on silicon plates without influence of strukturizators fully complies with traditional representations and the classical theory of condensation[8,9] and represents a homogeneous fine-grained layer[10] (fig. 2 a). Character of structural formation of films, received on silicon plates with 1 neutralizer practically does not differ from the previous samples received without influence of FMS, and is in regular intervals distributed on a surface as fine grains. Too most concerns and to the samples received on a surface of optical polished glass substrates.

At visual research under microscope MII-4 of samples thin nano-dimensional film of copper, received under influence FMS in system about family the neutralizers located under the circuit of a flat cut dense hexagonal of packing, at drawing films on glass substrates observe other picture. On periphery of a glass plate where as we are inclined to believe, there is a regional effect, the film will consist from enough chaotic system of the fine grains which are looking like ring formations of approximately identical diameter. Completely in an obvious kind the general order of an arrangement of these elements on some algorithm which is obviously distinct from chaotic distribution of grains of copper on samples, not exposed to influence FMS[11] is observed.

In process of promotion from edge to the center of a plate dome-shaped elements and formations of more complex form are observed not only ring, but also spherical and more complicated structures. In an central zone of a substrate the competition between elements of one type among themselves and elements of different types that results in their mutual penetration and distortion of the initial form of structural formations as it is shown on fig. 2 is observed. In a zone of the central stain there are large ring formations which height of a wall about some microns. And it is necessary to note, that the ring formations located in the central zone have essentially more complex structure, than located in a peripheral zone. In internal space of the elements located in the central zone, germinal grains are integrated, and their arrangement has not chaotic character. The form of the ring formations changes and is strongly deformed (fig. 2 в). Outside of these large ring formations finer ring elements of various diameter and dome-shaped elements, and both isolated one from another, and having complex interpenetrating structure are observed. The general picture represents the complex fractal formation, having, on our reasons, some levels of self-similarity.

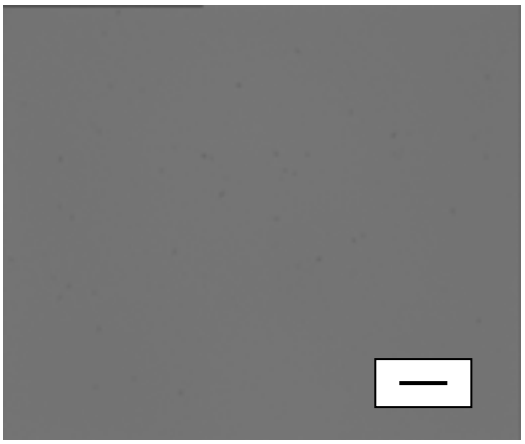


Fig. 2 a. Microphoto of the copper film received by dispersion without influence of strukturizators. Optics, mark - 20 microns, increase 400*

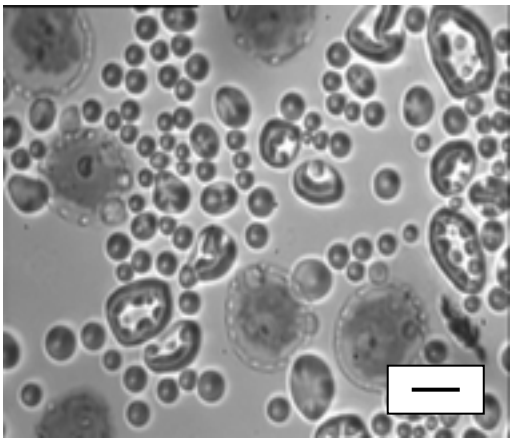


Fig. 2 b. Microphoto of the copper film received under influence of neutralizers, edge of a substrate. Optics, mark - 20 microns, increase 400*

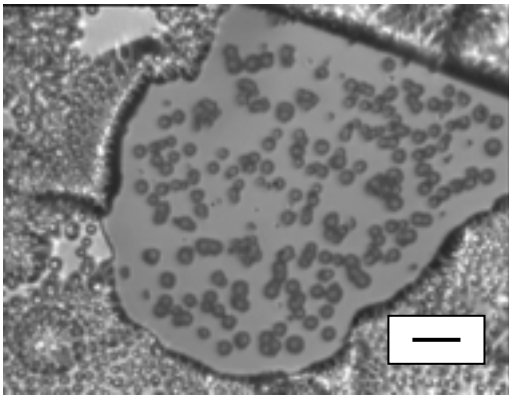


Fig. 2 c. The microphoto of the copper film received under influence of neutralizers, edge of a substrate, is closer to the center. Optics, mark - 20 microns. Increase 400*

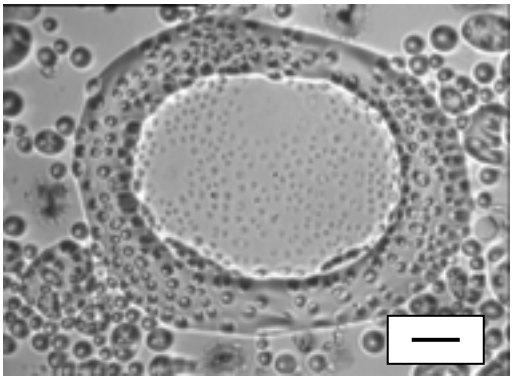


Fig. 2 d. Microphoto of the copper film received under influence of neutralizers, average area of a substrate. Optics, mark - 20 microns. Increase 400*

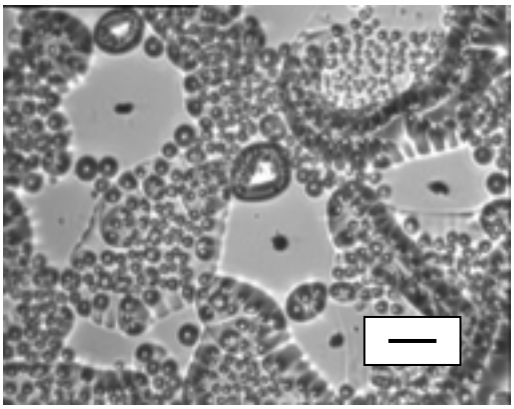


Fig. 2 e. Microphoto of the copper film received under influence of neutralizers, average area of a substrate. Optics, mark - 20 microns. Increase 400*

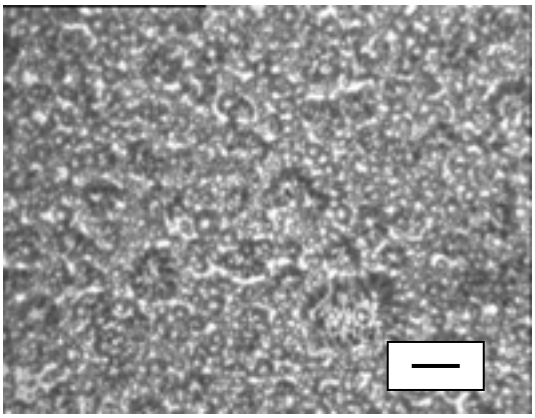


Fig. 2 f. icrophoto of the copper film received under influence of neutralizers, the central area of a substrate. Optics, mark - 20 microns. Increase 400*

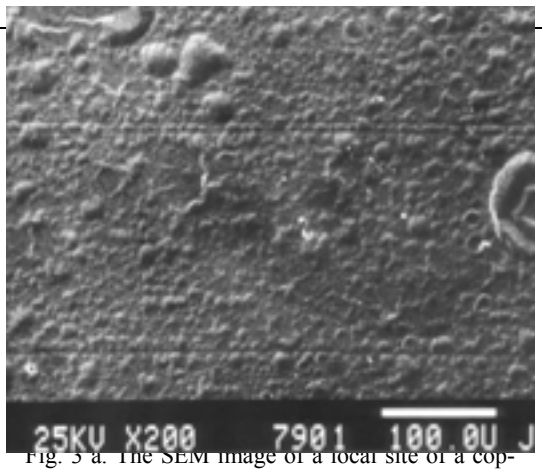


Fig. 3 a. The SEM image of a local site of a copper film on Si substrate, the first step of increase, fractal structure of the first level

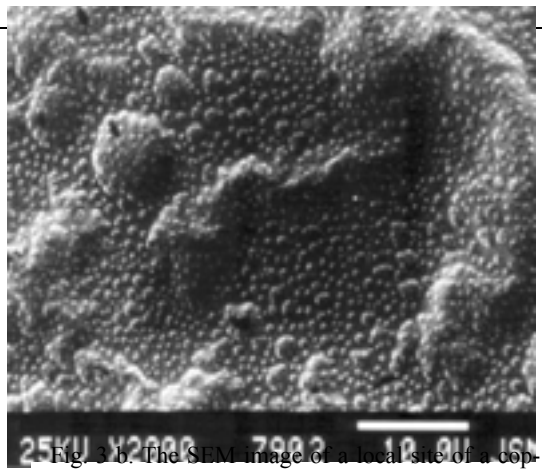
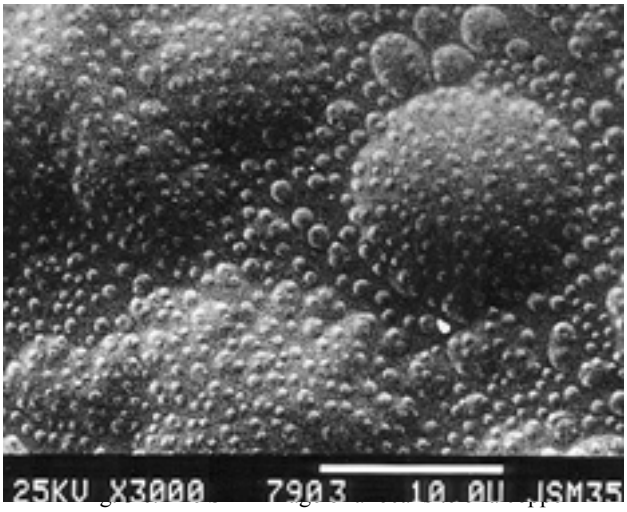


Fig. 3 b. The SEM image of a local site of a copper film on Si substrate, the second step of increase, fractal structure of the second level



film on Si substrate, the third step of increase, fractal structure of the third level

The similar structures reminding craters are received in work[12], as at use magnetron deposition. But in this case structures are formed of the continuous material, the representing stiffened micro drops, instead of thin-film formations. In a micro photo fig. 2 g it is visible, that on one local site structures with a different degree of fractalisation and different filling of the space, separated one from other border are formed. Various kinds of orderliness are observed, dome-shaped structures can be built in chains, form linear and cross-linked structures, and can form precise helicoids structures. We yet did not manage to find out correlation between character of ordering of received structures, technological modes of their reception and a relative positioning of FMS.

The opening of complete domes made after extraction of a sample from the vacuum chamber has shown, that a substrate under a surface of the big dome already field with fine domes, and not at one level. Formation of so original structure

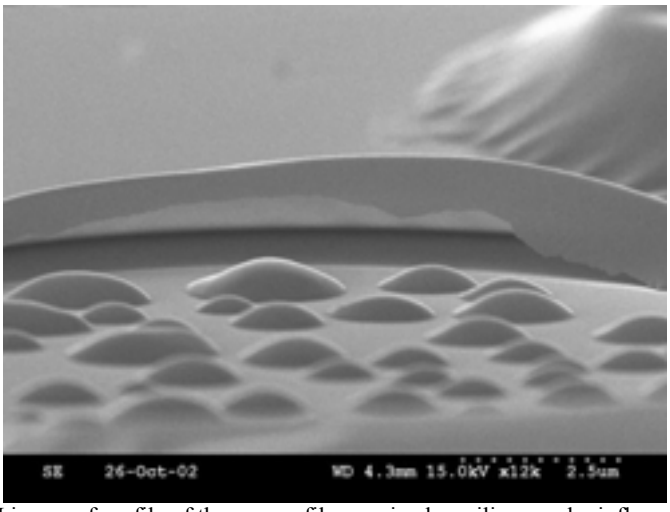


Fig 4. a. The SEM image of profile of the copper film received on silicon under influence of neutralizers.

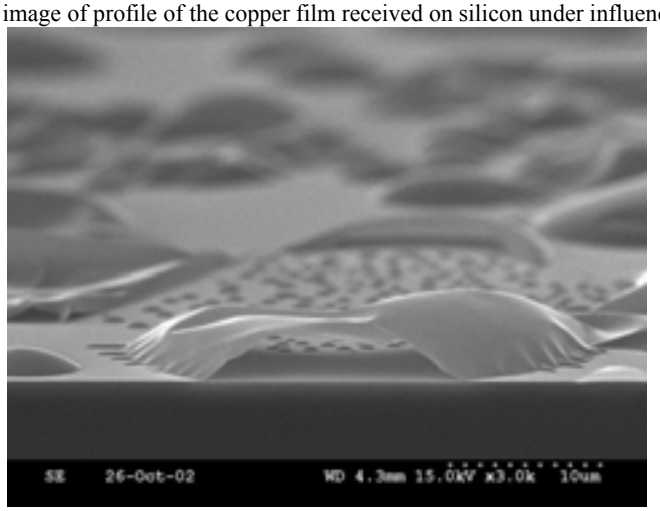


Fig. 4 b. The SEM image of profile of the copper film received on silicon under influence of neutralizers.

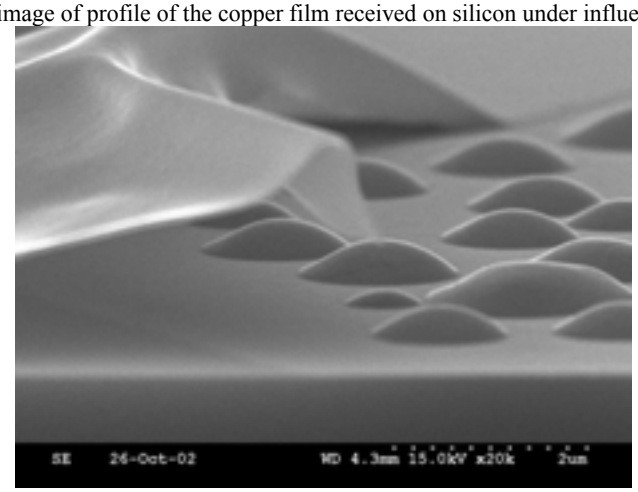


Fig 4 c. The SEM image of profile of the copper film received on silicon under influence of neutralizers.

representing a multilayered design from several thin-film layers, each of which represents system from dome-shaped elements of the various size as though enclosed one to others represents significant interest.

It is possible, that origin and growth of multiphase systems in this case takes place (each layer represents the separate phase understood not in thermodynamic sense), that demands studying processes of strukturization in such systems, laws of process of stratification of these phases at growth of a film. In such systems at growth films occurs not lateral stratification of phases, and mainly in a direction of growth[13].

We have two assumptions explaining process of origin of fine dome-shaped structures under a dome of the big structure. According to the first in the beginning on a surface of a substrate the germ which is transformed to a primary dome is

formed. In process of growth of a primary dome there is a swapping of a material from the bottom border of a film of a dome on a substrate. Thus there is a growth of a dome and increase in its external border. Thus process replicated itself on the fine domes, beginning to grow on a surface of a substrate due to a transferable material on them. Such mechanism demands the explanation though there are analogies to processes of growth on a substrate thin-film local structures and their migration on a substrate[14]. Nevertheless, in such hypothesis though and not inconsistent, questions contains more, than answers.

According to the second assumption before the moment of sedimentation of a film in near surface space of a substrate the suspension of besieged substance, similarly to a dense fog or very weak zol is formed. During this moment of sedimentation of a film does not occur yet. During accumulation of substance in this layer during any moment there is a phase transition and the multilayered film structure, on the parameters close to ideal is formed. During the subsequent moment there is the further, but already chaotic growth of this structure and the disorder growth of an external dome. Such explosive process of formation of complex multilevel system can be similar to process of formation micelles in a solution on Rusanov[15]. The similar explosive processes connected to explosive crystallization at reception films of gold, were directly observed in a column of an electronic microscope in situ[16].

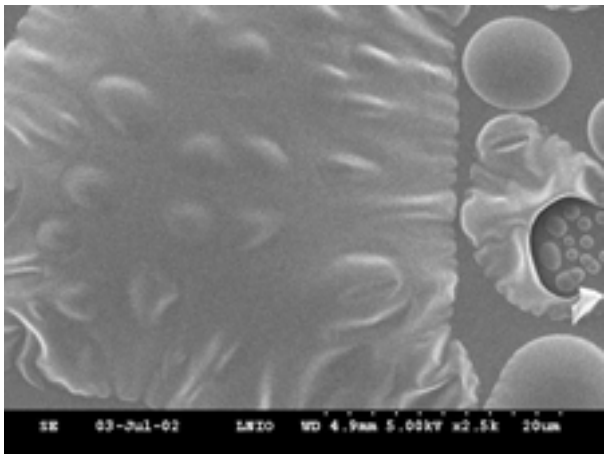
During researches it was possible to find out effect of replication of received films, consisting that the structure rendered films partly keeps the information of structure FMS, used during deposition. At drawing a film under influence FMS and removal FMS from the vacuum chamber with replacement by its substrate with put at deposition a film on a clean substrate on it film, but having higher degree fractal grows similar nano-dimensional fractal film. The lead experiments on drawing films with the help of similar iterations have shown, that complexity and organization of received structures grow with each subsequent iteration.

For more profound researches of topology and morphology received films and their degrees of fractalisation the method of scanning electronic microscopy (SEM) was used. For formation of the electron-microscopic image signals secondary (SE) and reflected (RE) electrons were used, allowing to receive accordingly morphological and composite contrast of the image[17]. The morphology and topology of received films was investigated by methods of scanning electronic microscopy in various points and on various samples. The same local site of a sample was scanned at various degrees of increase that has allowed to determine at the further processing the received results of fractal dimension of local structures and to estimate presence of scale invariance that is the integral property of fractal structures.

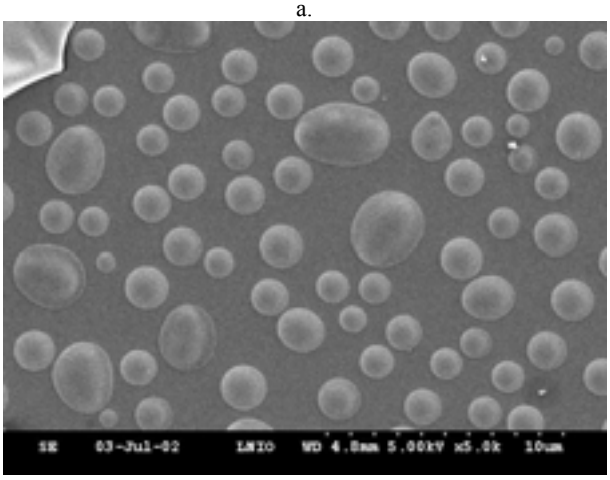
The example of such approach is resulted on fig. 3 on which it is shown generated in a mode true - secondary and reflected electrons the electron-microscopic image of the same site nano-dimensional copper film put on a silicon substrate, received at various degrees of increase.

Thickness of a film was determined by researches of a structure of a copper film on the silicon substrate, received methods SEM as it is shown on fig. 4 and where the structure of a film on a site of an opened dome is submitted. On fig. 4 the micro photo of a profile structure opened double ring-formed structures, and on fig. 6 in - a micro photo of opened dome-shaped structure with the fine dome-shaped structures filling under-dome space is submitted.

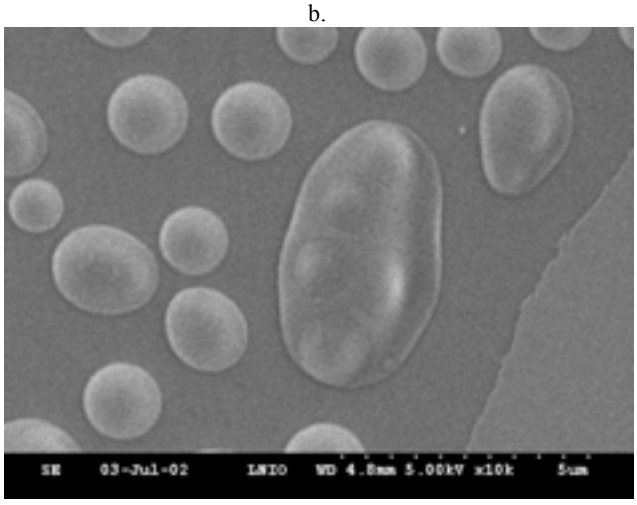
At fig. 5 are submitted SEM micro photos, illustrating formation under-dome systems. At fig. 5 a is submitted the opened fine dome with distinct under-dome structure, consisting of finer domes and ready to break a dome under which the structure is looked through similar under-dome structure, like is shown. On fig. 5 b at the greater increase it is resulted SEM the image under-dome structures. In the center of a micro photo and at the left by pointers are shown under-dome formations inside which growth under-dome structures of the second level is observed. On fig. 5 c in such local formation received at the greater increase is shown. Are observed under-dome structures of the following level, and black points represent structures of the following level of fractalisation. For their research we have taken advantage of methods of AFM microscopy.



a.



b.



c

Fig. 5. SEM images of fractal copper films; a - Whole and partly opened domes; b,c – under dome structures.

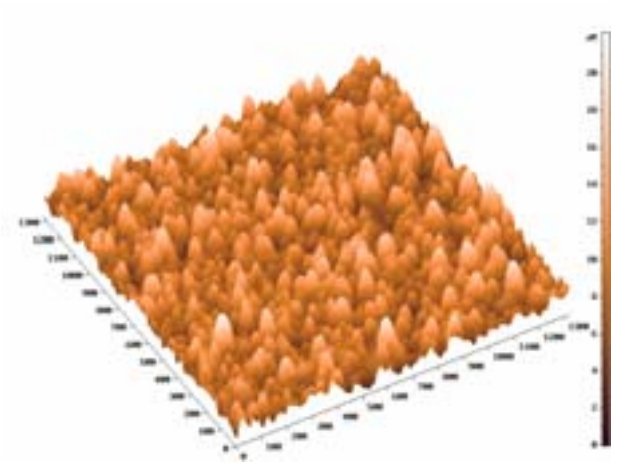


Fig.. 6. a. The AFM image of the copper film received on silicon without influence of neutralizers, the first point, the volumetric image

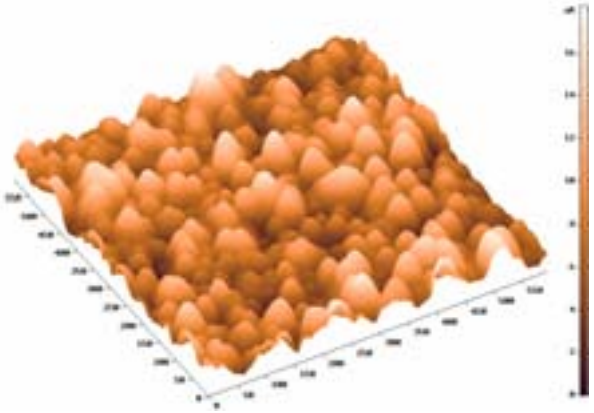


Fig. 6 b. The AFM image of the copper film received on silicon without influence of neutralizers, the second point, the volumetric image

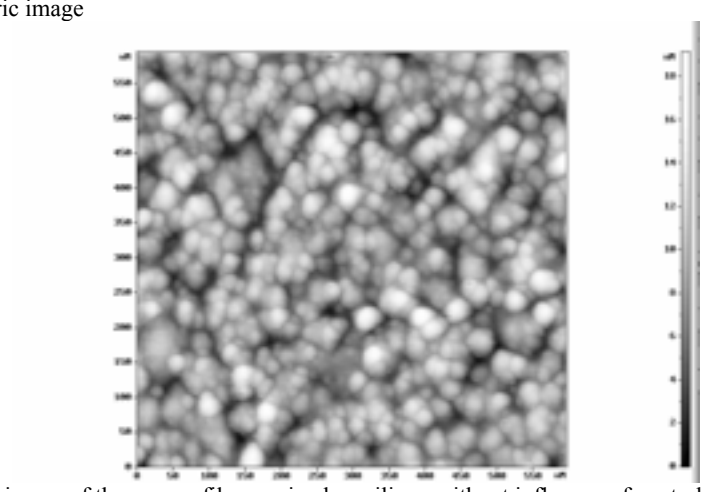
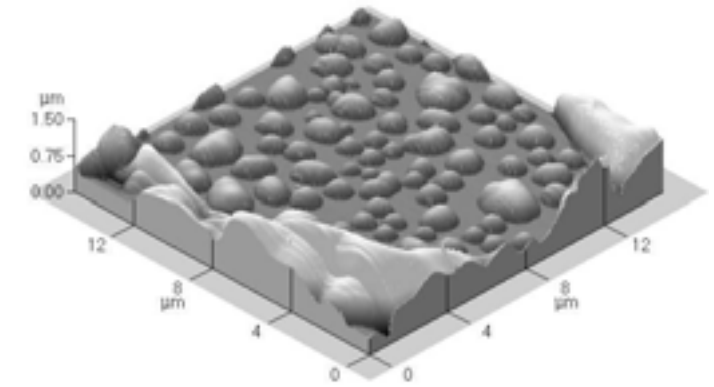
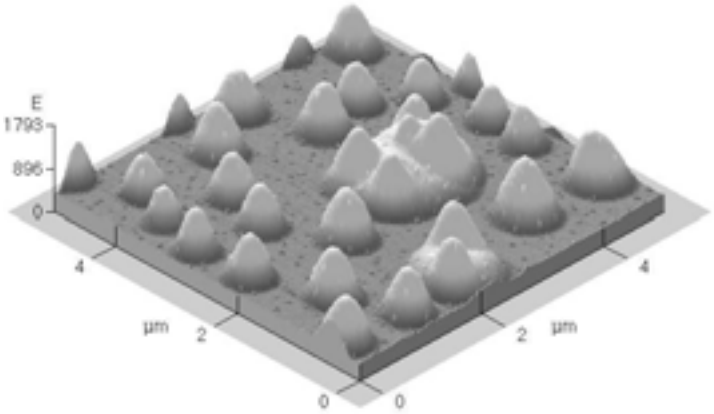


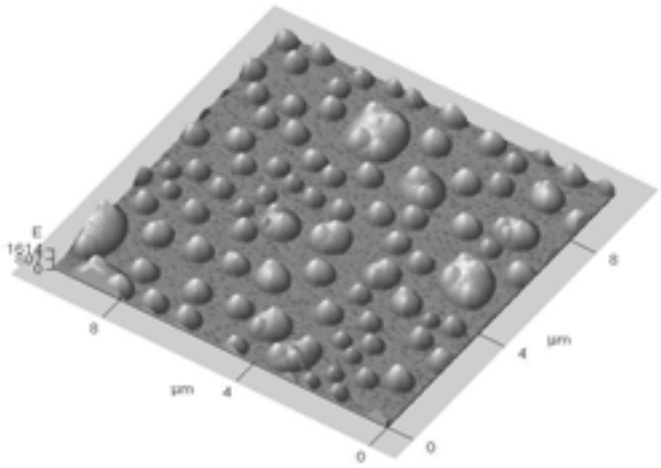
Fig. 6 c. The AFM image of the copper film received on silicon without influence of neutralizers, the first point. The plane image



a



в



c

Fig. 7. The AFM micro photos of fractal copper films on silicon substrate, obtained under influence of FMS at different degree of increase.

X-ray phase analysis researches have shown that, received copper films have a crystal structure without dependence from type of a substrate, but there are also local sites with amorphous structure. It is necessary to recognize, that because film have small thickness, a signal from copper is very weak, that in turn results in necessity to make accumulation of a spectrum within several hours at high capacity of primary x-ray radiation. It, unfortunately, causes a high level of noise from brake radiation in the field of peaks of copper. Parameters of an elementary cell of copper do not differ from standard and make 3,615 angstrom. The phases which are distinct from Cu in a film in this case are not found out.

The excess in pique Cu (111) which can be approximated to two Gauss the distributions having different half-width and corresponding to different two types of areas of coherent dispersion is found out. It, apparently, designates, there represent formations clusters type with the characteristic sizes:d1 < 40 angstroms and d2 > 100 angstroms. Average size of this local sites makes 65 angstroms.

5. SUMMARY

As a result of a complex of the lead researches influence fractal-matrix strukturizators on the processes proceeding at condensation thin nano-dimensional films from vapor or the plasma environment with use of methods magnetron ionic - plasma spattering and thermal vacuum evaporation is revealed. The facts found out experimentally represent the big interest both from only practical point of view, and from the point of view of a deepening of representations about processes of condensation of materials and formations of solid-state phases.

Acknoledgments

Authors consider necessary to continue the researches started by them in the chosen direction and express the gratitude to the professor of St. Petersburg State University OlgaV. Frank-Kamenetskaya; to senior lecturer SPGTI (TU) Andry V. Gorjunov; to post-graduate student Sergy V. Koshcheev; to post-graduate student Michail A. Iosht.

References

1. I.N. Serov, V.A. Zhabrev, V.I. Margolin "Problems of Nanotechnology in Modern Materiality" // Phys. And Chem. Glasses, **29**, №2, 2003, pp. 242 – 256.
2. A.V. Aleksejtsev, G.N. Belskaja, B.E. Bonshtedt, N.B. Egorova, V.I. Margolin, N.A. Potsar, I.N. Serov "Research of Influence of Fractal-Matrix Headers on Properties of Received Thin-Film Structures" // Thes. dokl. XIX Russian Conference on Electron Microscopy, on May, 28 - on May, 31, 2002, Chernogolovka, 2002.-p. 26.
3. Patent of Russia. About delivery of the patent under the application № 2001111054/28 (011415 from 12.04.2001 the Optical Fractal-Matrix Filter. I.N.Serov.
4. I.N. Serov "Result of Approbation Matrix Applicators "Aires" // Saint Petersburg: Aires, 2002. 56 p.
5. I.N. Serov "General Rate BIP". Saint-Petersburg", Publishing house Aktsident.-2002, 492 p.
6. J.D. Tretiakov "Dendrity, Fractals and Materials" // SEJ, 1998, № 11. pp. 96 - 102.
7. L.A. Rybina, I.N. Serov, "Nejrofiziologichesky the Analysis of Adjusting Effects of Optical Filters with Fractal-Matrix Topology" // Saint Petersburg. Aires, 2002, 18 p.
8. V.A. Barvinok, V.I. Bogdanovich "Physical of a Basis and Mathematical Modeling of Processes Vacuum Ionic - Plasma Spattering" M. Mechanical engineering, 1999.-309 p.
9. Broyde I., Merey J. "Physical Bases of Micro Technology": M. Mir, 1985, 496 p.
10. I.N. Serov, G.N. Belskaja, V.A. Zhabrev, V.I. Margolin, V.A. Moshnikov, N.A. Potsar, I.A. Soltovskaja, D.B. Chesnokova "Research of an Opportunity of Reception Fractal-Structured Thin Films" // Materials of Sci. - Practical Conference ISM "New Functional Materials and Ecology ", M.: 2002, pp. 73 - 75.
11. I.N. Serov, G.N. Belskaja, I.A. Soltovskaja, V.A. Zhabrev, V.I. Margolin, V.A. Moshnikov, N.A. Potsar "Research Fractal-structured thin films" // Thes. dokl. IV Int. Scientific - conf. Electronics and computer science. M.: 2002.-Part 1, P. 123 - 124.
12. V.N. Kemenov, S.B. Nesterov, O.S. Zilova, E.N. Kapustin "Research of Quality of the Thin-Film Coverings Received on Installations Magnetron and Vacuum Plasma-Arc Sedimentation, With Use of Method SPM // Sb. Reports of the International Sci. - Practical Symposium " Functional Coverings on Glasses ".-Kharkov: NNC ChFTI, "Constant" 2003.-pp. 113 - 117.
13. V.M. Ievlev "Compact Film Nanostructures: Structural Aspect of a Problem // Sb. Reports of 15-th Int. Symposium "Thin Films in Optics and Electronics ".-Kharkov: NNC ChFTI, "Constant" 2003, pp. 82 - 96.
14. S.A. Kukushkin, A.V. Osipov "Process of Condensation Thin Films" // UFN, **168**, № 10.1998.-pp. 1083 - 1116.
15. A.I. Rusanov "Surprising the World of Nanostructures" // Magazine of the General Chemistry. 2002, **72 (134)**, №. 4.-pp. 532 – 549.
16. A.G. Bagmut, V.J. Kolosov, V.M. Kosevich "Development of Porosity at Crystallization Amorphous Nanostructures Films, Received by Laser Deposition" // Sb. Reports of 15-th Int. Symposium " Thin Films in Optics and Electronics ".-Kharkov: NNC ChFTI, "Constant" 2003, pp. 313 - 318.
17. Practical Scanning Electronic Microscopy . M., Mir. 1978. 656 p.