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<https://doi.org/10.36073/1512-0996-2025-1-334-346>**Concept of Development of Laser Plasma Technologies for 2D Nanosystems Preparation**

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Abstract. The transformation of digital information devices from large installations to portable systems has been enabled by advanced processing technologies that allow ultrahigh integration of devices with atomic-scale dimensions.

Most of the research has primarily focused on two-dimensional 2D planar nanostructures where the film thickness is significantly smaller than the planar dimensions. However, with advances in nanofabrication techniques and the increasing demand in the field, it is possible to exploit the effect of film thickness on many applications such as medical, photovoltaic cells improvement, spin, and quantum electronics.

For obtaining of 2D and even 3D materials (semimetals, semiconductors) for novel spintronic and spinquant devices including high efficient solar cells on the

basis of our previous investigations we developed and use the Laser-Plasma method which enables preparation of nanostructured layers with perfect structures and high purity.

Keywords: 2D Nanosystem; Dynamic Fractal; Laser-Plasma; Spintronics and Spinquant Devices.

Introduction

Nanosystems represent a transformative frontier in science and engineering, characterized by the manipulation of materials and devices at the nanoscale (1 to 100 nanometers). These systems leverage unique properties that emerge at this scale, such as increased surface area, quantum effects, and enhanced reactivity, paving

the way for groundbreaking applications across diverse fields, including medicine, electronics, energy, and environmental science.

In nanomedicine, for instance, nanosystems enable targeted drug delivery and improved imaging techniques, significantly enhancing therapeutic efficacy and patient outcomes. In electronics, they facilitate the development of smaller, faster, and more efficient components, contributing to the advancement of nanotechnology in computing and communications.

Furthermore, nanosystems play a critical role in renewable energy technologies, such as in the development of efficient photovoltaic cells and catalysts for sustainable chemical processes. Ongoing research in nanosystems focuses on overcoming challenges related to scalability, biocompatibility, and environmental impact, ensuring that nanotechnology can be safely and effectively integrated into everyday applications, thus shaping the future of technology and society [1-3].

The physical properties of materials are determined by their physical structure, which means atomic arrangement. Hence, restructuring of different materials provide different physical properties that could be very promising in various industries and applications. According to the nanosize of particles, structure stabilizing is significant, and thin film on a substrate plays the main role.

Thin film technology involves the deposition of materials in layers ranging from fractions of a nanometer to several micrometers in thickness. This advanced technique is pivotal in various fields, including electronics, optics, and materials science, enabling the creation of high-performance devices such as transistors, photovoltaic cells, and sensors. The methods of deposition, such as Chemical Vapor Deposition (CVD), Physical Vapor Deposition (PVD), and Atomic Layer Deposition (ALD), allow for precise control over the film's properties and composition [4-6]. Recent advancements have focused on enhancing the efficiency and scalability of these processes, leading to innovations in flexible electronics, energy storage, and coatings with tailored functionalities. As the demand for miniaturization and improved performance in technology continues to grow, thin film technology stands at the forefront, driving

significant progress across multiple industries.

Destructuring and Restructuring of matter refer to the processes through which materials undergo significant transformations at the molecular or atomic level, leading to changes in their physical, chemical, and functional properties. Destructuring involves the breakdown of complex structures, often through methods such as chemical reactions, physical forces, or thermal processes, resulting in the disassembly of materials into other components. Conversely, restructuring encompasses the reorganization of these components into new configurations, which can enhance material performance or introduce novel functionalities. Techniques such as self-assembly, crystallization, and additive manufacturing exemplify restructuring processes. Together, these mechanisms play a vital role in the development of advanced materials, enabling innovations. Then, it is important to know the structure of the material not only through restructuring but also through destructuring [7, 8].

Main Part

Thin-Film's Structural Properties and their Preparation

A thin film is a layer of material with a thickness in the range of a nanometer to a few micrometers. Thin films with thickness below 100 nm are called 2D (two dimensional materials). Today thin films preparation technologies are based on Physical Vapor Deposition (PVD) methods, such as sputtering, thermal evaporation, and pulsed laser deposition, etc. In chemical deposition, the reaction of a precursor fluid on the substrate results in the formation of a thin layer on the solid. Electroplating, sol-gel, dip coating, spin coating, chemical vapor deposition (CVD), plasma enhanced CVD (PECVD), and atomic layer deposition [9].

Chemical Vapor Deposition (CVD) is a widely used technique for producing thin films by chemically reacting gaseous precursors to form solid materials on a substrate. This process allows for the precise control of film thickness, composition, and microstructure, making it ideal for applications in electronics, optics, and coatings. During CVD, gases are introduced into a reac-

tion chamber, where they undergo chemical reactions, resulting in the deposition of a thin film on the substrate surface as shown in Figure 1. The versatility and

scalability of CVD make it a cornerstone technology in the fabrication of advanced devices such as integrated circuits and solar cells.

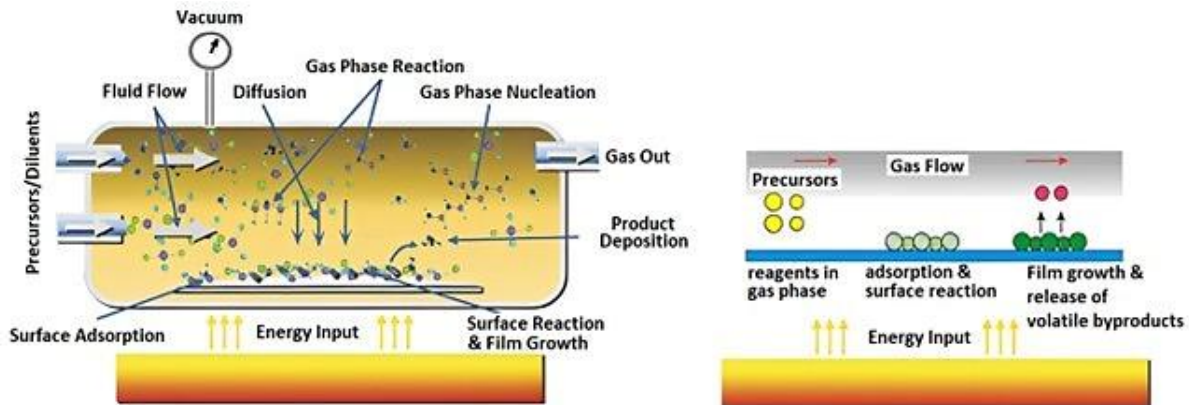


Figure 1: Chemical Vapor Deposition (CVD) scheme [10]

Physical Vapor Deposition (PVD) is a vacuum-based technique used to create thin films through the physical transfer of material from a solid or liquid source to a substrate. The process involves vaporizing the material through methods such as thermal evaporation or sputtering. As the energized atoms or molecules travel through the vacuum, they condense onto the substrate, forming a thin, uniform film. PVD is known for its ability to produce high-purity coatings with excellent adhesion and can be used for a wide range of applications, including semiconductor devices, optical coatings, and protective surfaces. The versatility of PVD allows for precise control over film thickness and composition, making it essential in modern manufacturing and materials science.

Pulsed Laser Vapor Deposition (PLD) is a sophisticated technique for creating thin films by using high-energy laser pulses to ablate material from a target. In this method, a focused laser beam strikes the target material, causing it to vaporize into a plasma cloud. The vaporized particles then travel through a vacuum or controlled atmosphere and deposit onto a substrate, forming a thin film. PLD is particularly advantageous for producing complex materials, including ceramics and multi-layered structures, due to its ability to

precisely control film composition and thickness. The process is also compatible with a variety of substrates and can be performed at different temperatures, making it suitable for applications in electronics, optics, and nanotechnology.

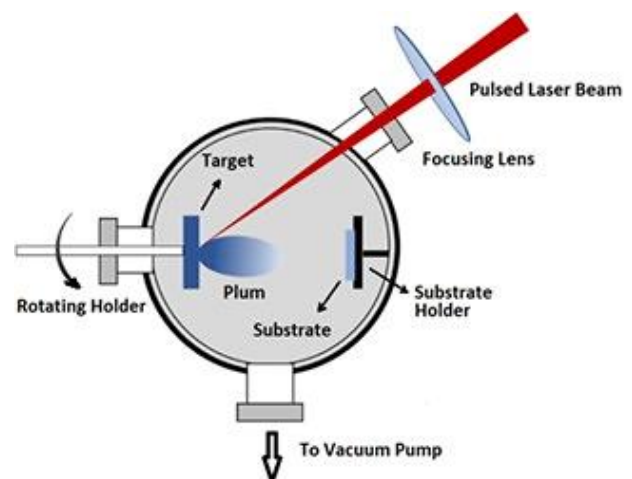


Figure 2: Pulsed Laser Deposition (PLD) Scheme

The quality of the thin film lattice on the substrate is correlated to its purity, uniformity, and regularity. Hence, PLD customization merges its advantages with CVD in large-area substrates

Continuous Wave Laser Deposition (CWLD)

When a high-energy laser pulse strikes a target material in Pulsed Laser Vapor Deposition (PLD), it generates plasma through the following steps:

- **Absorption of Laser Energy:** The laser beam, typically in the ultraviolet or visible spectrum, is focused onto the surface of the target material. The energy from the laser is absorbed by the material, leading to a rapid increase in temperature.
- **Material Vaporization:** As the laser energy is absorbed, the temperature of the target rises sharply, causing the material to vaporize. This destructuring occurs almost instantaneously and can lead to the formation of a plasma.
- **Formation of Plasma:** The intense energy from the laser pulse ionizes some of the atoms or molecules in the vaporized material. This ionization process strips electrons from the atoms, creating a cloud of charged particles, which constitutes the plasma. The plasma is characterized by a mix of free electrons, ions, and neutral atoms.
- **Expansion and Ejection:** The plasma cloud rapidly expands away from the target due to the pressure generated by the intense energy. This expansion propels the vaporized material toward the substrate, where it will eventually condense and form a thin film is called restructuring.
- **Cooling and Deposition:** As the plasma expands and travels through the vacuum or controlled atmosphere, it cools. The vaporized particles condense on the cooler substrate surface, forming a thin film.

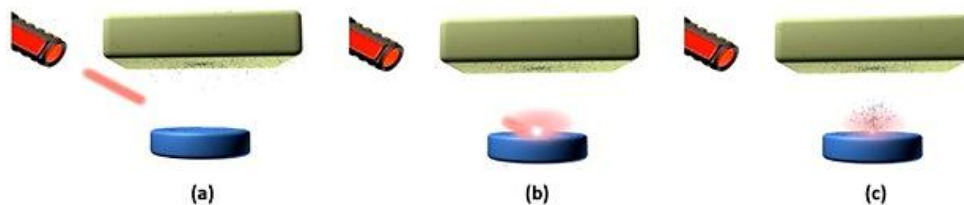


Figure 3. PLD steps. (a) Laser bombardment. (b) Laser destructuring. (c) Sputtering [11]

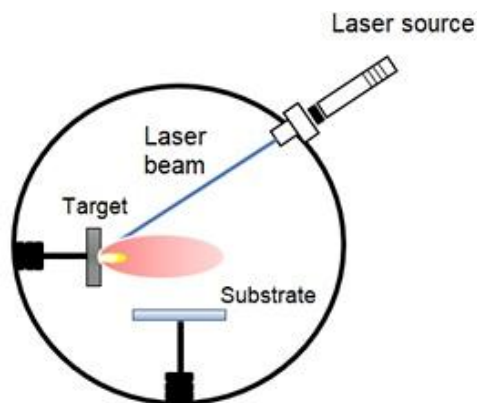


Figure 4: Continuous Wave Laser Deposition

Continuous wave laser instead of pulsed laser produces a laminar flow of plasma that makes efficient bonding through restructuring. On the other hand, 90-degree angular distance between the target and substrate; instead of the parallel target and substrate in PLD, provides a laminar settlement of plasma on the substrate that guarantees not only the regularity of lattice but also its uniformity through restructuring. CWLD destructuring and restructuring procedures produce high-quality thin film structure that provides efficient physical properties. On the other hand, the target and substrate perpendicular position remove parallel position restriction in PLD. (Figure 6).

The operants of any method make the procedure or final product quality and quantity control. CVD operants are chemical reactions and heat energy that affect a large area. However, there are 5 operants in Laser-Plasma method: 1. Laser Wavelength; 2. Laser Power; 3. Laser beam diameter; 4. Laser beam angle on the target; 5. Laser source distance from target.

These operants make the Laser-Plasma method not only a very precise process either a significant cost-effective process [12, 13].

Dynamic Fractal's Space

Regarding matter structure as very small-size particles arrangement, their dimension change means space manipulation. There are different methods of mathematical physics that try to explain space in different orientations, and physicists try to use which is suitable for their specific investigation. Therefore, matter study on a small scale and physical manipulation to find a new structure is related to space definition. On the other hand, matter destructuring (fission) and restructuring (fusion) depend on external energy that changes particles arrangement and somehow it can lead to a new structure with new physical properties. Therefore, the initial matter's particles arrangement on one hand, and manipulation by an external source of energy on the other hand, lead investigation to a novel dynamic space.

According to the *Energy Conservation Law*, energy is not born or disappear. Just it converts to different

types. Assume a glass of water at room temperature as an isentropic system. It seems nanoparticles move chaotically, but the temperature which is known as an indicator of matter small particles movement, doesn't change. No spontaneous temperature change in the glass of water under constant conditions represents that particles despite chaotic movement do not fight each other or lose their energy, then it must be a harmonic motion. In other words, particles in a glass of water sense each other movement and maintain balance in the whole matter in the way of Energy Conservation Law. This scenario represents nanoparticles in a glass of water at room temperature as a unique system with the harmonic movement of particles. Therefore, it could be shown as a Self-Control Closed-Loop (SCCL) system that manages itself to observe energy conservation.

Referring to SCCL principles, system auto-balance depends on feedback (5). In other words, the system senses itself at the output and sends feedback to the system input, hence observing energy conservation. Feedback in the SCCL is output and input energy difference that if it is continuous in time (non-periodic without any lag), always it should be zero, and there is no auto-balance. Therefore, SCCL should be a discreet phenomenon. Hence, the paradoxical motion of particles (chaotic but harmonic) represents quantitated time in the SCCL.



Figure 5. Self-Control Closed-Loop (SCCL)

SCCL concept represents the role of the processor (matter). In other words, different materials provide various SCCL system that regards diverse materials individuality. Consequently, if there is an external input such as initial conditions changing, not only the operator (input-cause) but also the operated (material-effect) is significant.

Basically, balance means energy conservation and leads to symmetry [13, 14]. On the other hand, symmetry needs particles tracing in time referring to a reference in space that is not possible in a chaotic system. But, particles movement is harmonic by SCCL system. Consequently, time should be the symmetry reference in the SCCL system. Obviously, time is not a geometrical dimension such as length. Hence, looking for an appropriate space is guided to an analytic space that can be found in a topologic frame [15].

Now something about space definition. Cluster is a free place inside a Fractal. Hence, Fractal is a set of Clusters. A Knot represents a unit of a material structure such as a molecule. Then, a Cluster can be empty or filled. Also, any mathematical structure definition needs dimensions. There are 4 dimensions to find a Fractal as XYZT. Three of them (XYZ) are geometrical dimensions and T represents time (Figure 6).

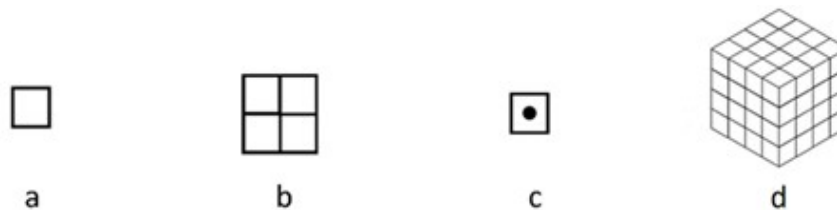


Figure 6: (a) Cluster, (b) 2-dimensional Fractal, (c) Filled Cluster, (d) 3-dimensional Fractal

Any Cluster in a Fractal is known by geometrical indices as C_{xyz} . Hence, the number of indices implies the number of geometrical dimensions. For instance, C_{xy} is a 2-dimensional Fractal and C_{xyz} is a 3-dimensional Fractal [14].

According to the set of F (Equation 1), possible elements (Clusters) represent a Tree Diagram of geometrical dimensions in a Fractal (Figure 8).

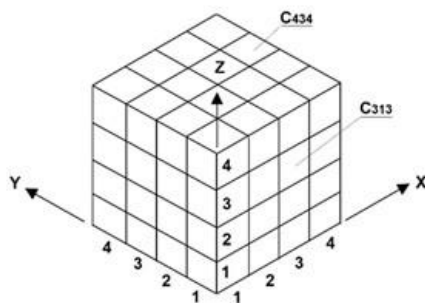


Figure 7: Clusters and indices

A Fractal is a set of Clusters.

$$F = \{C_{xyz} : C \text{ is a Cluster of a specific Fractal}\} \quad (1)$$

For instance, a 2-dimensional Fractal with 2 Clusters on any dimension will be

$$F = \{C_{11}, C_{12}, C_{21}, C_{22}\} \quad (2)$$

Consequently, as Figure 10 any matter can be Fractals integrity that is called Lattice.

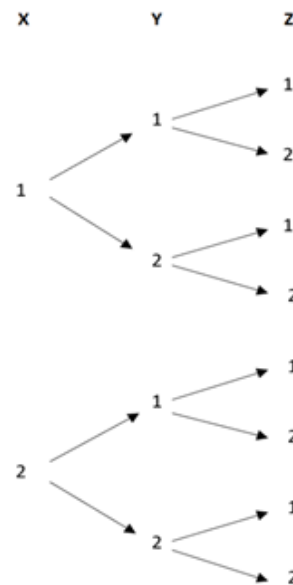


Figure 8. Tree Diagram of dimensions in a Fractal represents the number of elements in it

Then, the number of Clusters in a Fractal represents the number of the Fractal cardinality.

$$N = (n)^D, \quad (3)$$

Where N: Number of a Fractal elements, n: Number of Clusters on any dimension, D: Number of dimensions.

Clusters of a Fractal can be empty or filled. Anyway, *just 1 Knot can be placed in a Cluster*. Then, filled Clusters and empty Clusters union in a Fractal representing all elements.

$$F = N_f \cup N_e \quad (4)$$

F: Fractal, N: Number of a Fractal elements, N_f : Filled Clusters, N_e : Empty Clusters.

On the other hand, a Cluster can be filled or empty. Then,

$$N_f \cap N_e = \emptyset \quad (5)$$

N_f : Filled Clusters, N_e : Empty Clusters.

According to matter's Nanoparticle non-stop movement, a Nanoparticle of the matter (atom or molecule) moves from Cluster to Cluster frequently which has been shown in figure 9 as an example.



Figure 9. A Nanoparticle changes its position in the Fractal. As an example, Knot changes its position from (2,2) at (a) to (1,1) after a certain time

Filled Cluster in the Fractal is shown as figure 12 at (a) is shown as,

$$F = \{C11, C12, C21, C22\} \quad (6)$$

After a specific time Knot will change its position randomly as shown in Figure 12 as (b).

$$F = \{C11, C12, C21, C22\} \quad (7)$$

However, non-stop Knot position changing is not predictable, but at fixed condition (such as an isentropic system) changing speed is constant. The system's status represents the system's State of Energy (SE). Therefore, if the energy of the system (matter) is constant, the Knots changing speed will be fixed too.

A Knot movement speed implies a specific time of position change that is called the *Balance Period* (BP). Consequently, if SE increases, Knots movement will be faster and there can be more filled Clusters in the BP.

$$F = \{C11, C12, C21, C22\} \quad (8)$$

Every matter has specific structure that is correlated to its physical properties. Structure refers to nanoparticles (atoms or molecules) numbers and arrangement in a unit cell. It is clear, unit cells are like a Fractal. Therefore, Cluster should be sized refer to the specific material structure and its particles (atom or molecule). The r in figure 10 represents the size of Cluster.

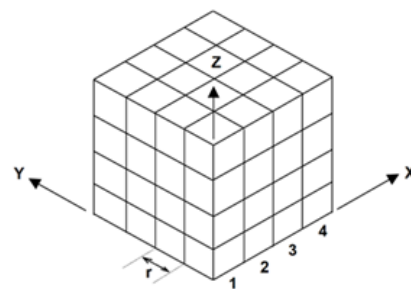


Figure 10. Clusters must be scaled refer to material structure and the atom or molecule size

Then, equation 3 is changed to

$$N = (nr)^D \quad (9)$$

N: Volumetric Fractal, n: Number of Clusters on any dimension, r: Unit size of a Cluster, D: dimension.

Refer to r in the above equation, N represents volume in a 3-dimensional Fractal as well as area in a 2-dimensional and length in a 1-dimensional Fractal.

The equation 9 refers to all Clusters with maximum D that can be 3 in the 3-dimensional space. But if the filled Clusters are in account, D cannot be an integer as 2 in 2-dimensional or 3 as 3-dimensional space. Hence, D will be a fraction.

$$D_d = \log(N_f) / \log(N_r) \quad (10)$$

D_d : Dimension fraction of the matter based on filled Clusters, N_f : Filled Clusters, n: Number of Clusters on any dimension, r: Unit size of a Cluster.

Therefore, Fractal volumetric size does not change at fixed SE. According to specific N_f at certain BP and

certain SE, Fractal Dimension Fraction (D_d) will be cleared. The defined space evokes Harsdorf space and Fractal Geometry. But, Harsdorf space is independent of time, then it cannot represent a dynamic space. Hence, this novel space is called Dynamic Fractal Space (DFS) More, investigation shows further applied orientation of DFS.[15].

Experimental case study related to 2D structures preparation by Laser-Plasma method

As a case study, Dynamic Fractal Space was applied to Laser-Plasma (CWLD) thin film technology In this process, a target is destructured by the laser beam to the plasma plume and restructured on the substrate as a thin film. Figure 4 shows the scheme of the process.

Graphene with its unusual structural properties is one of the most interesting 2D materials useful in different applications. Graphene's sensitive properties are highly correlated with its macro and nanostructure, hence the preparation process of Graphene structures is very significant.

During the last decades, several methods of producing Graphene-like structures and their thin films onto a substrate were developed and each of them has some advantages (Figure 11). At the same, it is still problematic to receive thin nanostructures with suitable lattice quality and uniformity. In this regard, the flexibility and accuracy of a method play the main role. Hence, the Graphene thin film preparation process based on a precise, accurate, and feasible method as Continuous Wave Laser Deposition (CWLD) was applied.

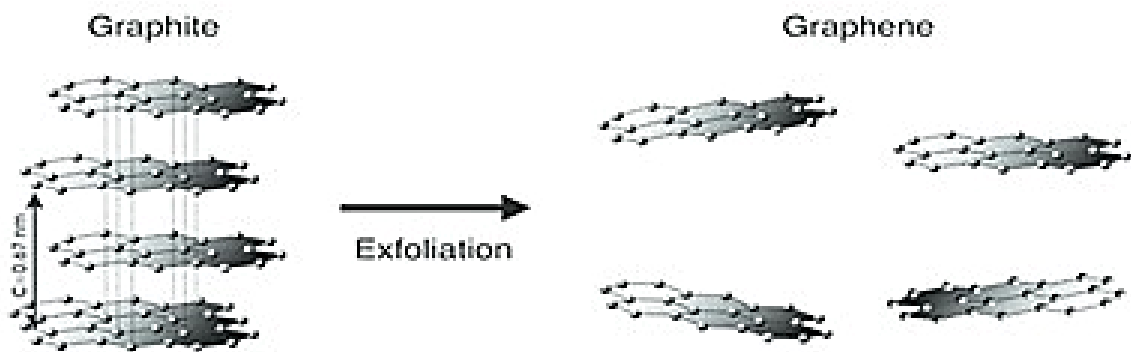


Figure 11. Graphite exfoliation provides Graphene

Generally, there are 3 well-known exfoliation methods: Mechanical, Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD).

Mechanical is based on the Geim - Novoselov method [16]. The graphene layer from Graphite should be stocked out with adhesive tape such as scotch and pasted onto the substrate. Physical and chemical vapor deposition are based on substrate immersion in the

vapor. Then, the substrate becomes a larger mass due to material transference from vapor onto the solid.

According to the SCCL concept, different operators as external sources of energy (such as laser wavelength, beam diameter, and radiation angle on the target) that have been shown at Figure 13 and the operated as the matter (such as different target materials and substrates) tested to find various structure of a material (Figure 12).

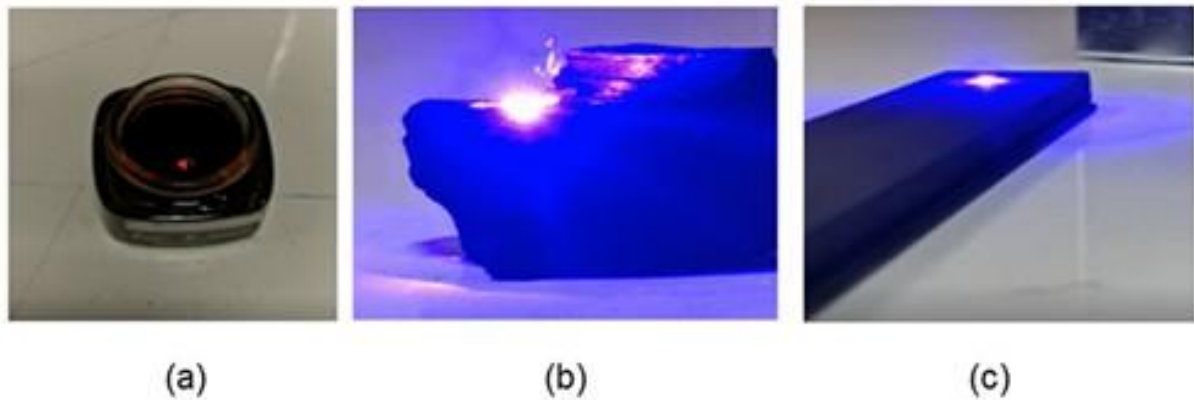


Figure 12. Different Operated (Targets)

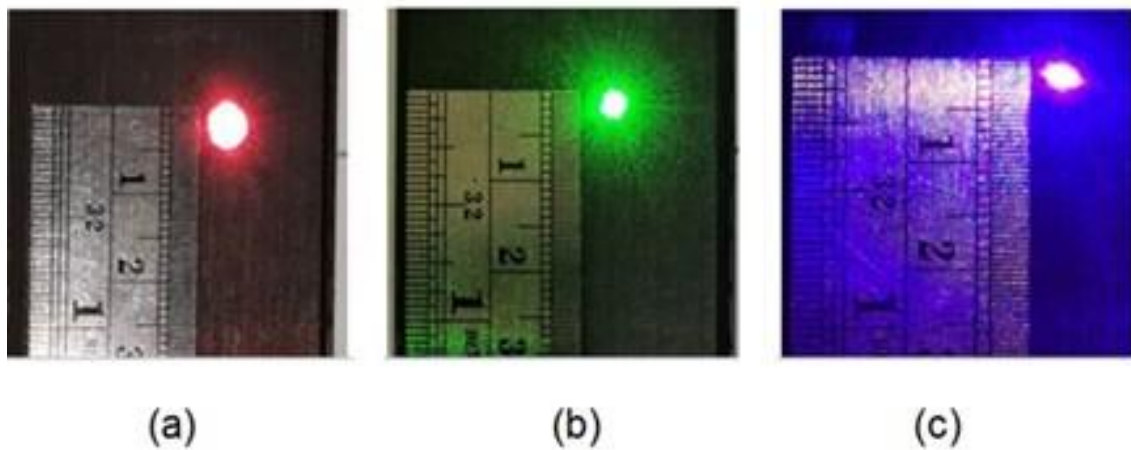


Figure 13. Different Operators (Laser beam)

For instance, in different laser wavelengths, and in all 1W powered cases the different responses were observed for same target at the same conditions that represent the matter reaction role. Also, it represents the regime of the process operators like the other para-

meters. Because the regime is correlated to material reaction as the operated reaction (N_f in a BP) and material structure (r as a Cluster size). Figure 157 comprises Ga thin graphene thin film on the Silicon silicon substrate by CWLD and mechanical exfoliation [17].

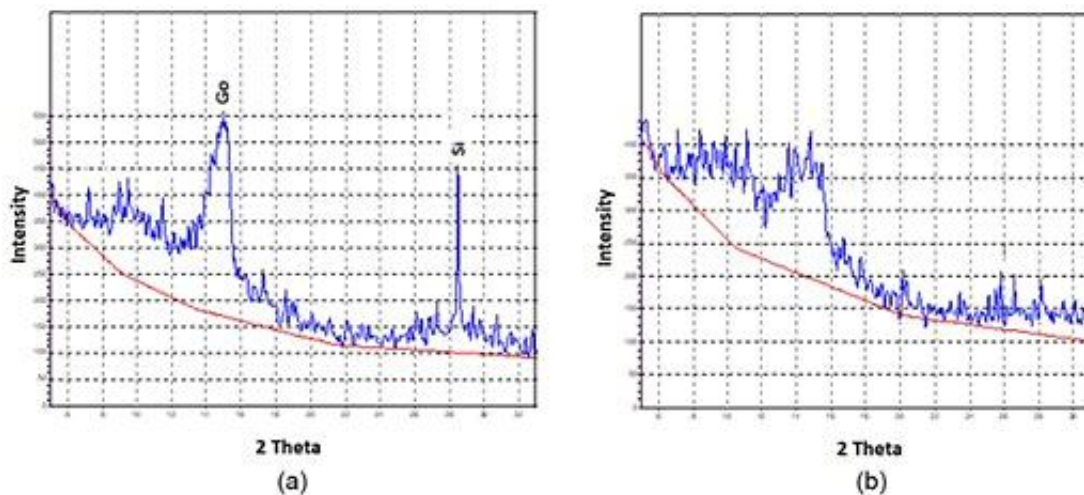


Figure 14. a) XRD of CWLD Graphene thin film. 2θ is 15° , FWHM is 0.0139626 radian, and d is 5.90 Å; (b) XRD of mechanical exfoliation of Graphite

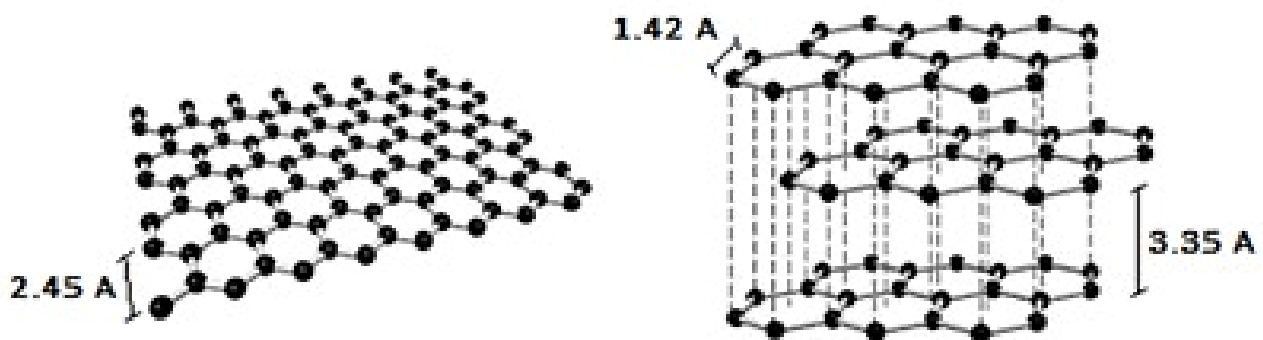


Figure 15. Ideal Graphene layer structure

In the graph, 2θ is 15° , FWHM is 0.0139626 radian, and d is 5.90 Å. Results comparison to an ideal Graphene structure (Figure 15) clears the CWLD capability.

Conclusion

Finding the different physical properties of the matter depends on the structural features of a material that its manipulation happening just at micro-nano scale. In this regard, sometimes premier matter's structure manipulation is inevitable and is based on destructuring (fission), and then restructuring (fusion).

Self- Control Closed-Loop can be a suitable justification for balance without spatial reference. SCCL repre-

sents the quality of the approach, but quantity orientation is necessary which leads to the novel Dynamic Fractal Space.

Matter structure manipulation at a predefined condition depends on the matter enforcement by an external source of energy. Therefore, new structure/physical properties are related to external energy specification (amount, intensity, etc) and the matter reaction. SCCL concept persists on the matter role (feedback) despite of external energy source (Input) besides the nonsymmetric balance explanation.

In destructuring and restructuring process, there are 2 main steps before and after energy enforcement and SCCL assumes the process after energy enforcement as

a Fractal approach; despite common approaches that just the final product (output) Fractal is considered. DFS as a novel mathematical and physical approach of SCCL with an applied orientation not only provides a deep understanding of Nanoscale before energy enforcement, but also after that. This concept is highlighted in precise technological processing such as 2D materials that structure defect tolerance is limited significantly.

Selection of laser sources and their parameters is giving the possibility to vary the energy of ionized atoms in plasma plume, activate them to the necessary level and deposit the hot atoms and their clusters on substrates of different origin (semiconductors: Silicon, GaAs, etc.; Metals: Fe, Ni, etc.; Insulators: Al₂O₃, etc).

For organization of these processes it is also possible to use the resonance wavelength of the light sources in order to have the direct and strong interaction with electron's bonding energies.

Concerning the Graphene - silicon Nanosystems, the long coherence times of single spins in silicon quantum dots make these systems highly attractive for quantum computation, but scalability of these kind of structures still needs to be developed. As a first step it is necessary to organize the strong coupling of a single electron spin and a single microwave photon. In these conditions the electron spin must be trapped in a silicon double quantum dot and the microwave photon must be stored.

References

1. Fert, A. (2007. December 8). The origin, development, and future of spintronics. Nobel Lecture, Stockholm, Sweden.
2. Kervalishvili, Paata J. (4 – 7 October 2021). Laser technologies of nanosystems preparation. Conference “Nanotechnology”. Georgian Technical University, Tbilisi, Georgia, p. 62.
3. Kervalishvili, P. Lagutin, A. (2008). Nanostructures, magnetic semiconductors and spintronics. *Microelectronics Journal*, 39, 1060–1065.
4. Sun, L., Yuan, G., & Gao, L. et al. (2021). Chemical vapour deposition. *Nat Rev Methods Primers* 1, 5 <https://doi.org/10.1038/s43586-020-00005-y>.
5. Nedal Y. Abu-Thabit, Abdel Salam Hamdy Makhlouf. (2020). Chapter 1 - Fundamental of smart coatings and thin films: synthesis, deposition methods, and industrial applications. In Book *Advances in Smart Coatings and Thin Films for Future Industrial and Biomedical Engineering Applications*, Elsevier.
6. Bakhtiari, A. Berberashvili, T. & Kervalishvili, P. (July, 16-19, 2019). Clusters – Particles Balance in Matter by Dynamic Fractals. 11th Japanese-Mediterranean Workshop on Applied Electromagnetic Engineering for Magnetic. Superconducting Multifunctional and Nanomaterials. Batumi Shota Rustaveli State University, Batumi, Georgia.
7. Kervalishvili, P. Shalamberidze, S. (1997). Isotopic Effect during Boron Carbide Film Production by a Laser Plasma Deposition. *Journ. Material processing and Manufacturing Science*, vol.6, N 4.
8. Kervalishvili. (2009). Micro-Nano-Pico technologies: The main way of novel materials development. *Material Science Day*. Tbilisi: CNRS-TSU.
9. Oviroh P., Ozaveshe A., Rokhsareh P., Dongqing C., Rigardt Alfred M., & Jen Tien-Chien (2019). New Development of Atomic Layer Deposition: Processes, Methods, and Applications. *Science and Technology of Advanced Materials*. 20 (1): 465–496.
10. Hugh O. Pierson. (1999). *Handbook of chemical vapor deposition (cvd): Principles, Technology, and Applications*. Second Edition, Noyes publications. Park Ridge, New Jersey, U.S.A.

11. Ferguson, J. D.; Arikan, G.; Dale, D. S.; Woll, A. R.; & Brock, J. D. (2009). Measurements of Surface Diffusivity and Coarsening during Pulsed Laser Deposition. *Physical Review Letters*. 103 (25): 256103. arXiv: 0910.3601.
12. Bakhtiari, H. Berberashvili, T. & Kervalishvili, P. (2022). Preparation of Graphene Structures by Continuous Wavelength Laser Deposition Method, *American Journal of Condensed Matter Physics*, 12(1) 2-11.
13. Kervalishvili, P. Shalamberidze S. Esadze G. & Porta P. (1993). Semiconductor material film production by laser plasma deposition. *Le Vide, le Couches minces*, N-167, pp. 189-198.
14. Bakhtiari, A. Kervalishvili, P. (2021). Dynamic Fractal Doctrine as Nonlinear Systems Model. *American Journal of Condensed Matter Physics*, Volume 11, Number 1.
15. Bakhtiari, A. Berberashvili, T. & Kervalishvili, P. (March, 2024). About Dynamic Fractal Space. *American Journal of Condensed Matter Physics*.
16. Novoselov, K.S. Geim, A.K. & Morozov, S.V et al. (2004). Electric field effect in atomically thin carbon films. *Science*, 306: 666–9.
17. Bakhtiari, A. Berberashvili, T. Kervalishvili, P. Bilbilashvili, A. & Kushitashvili, Z. (17-21 July 2023). Study of Silicon-Graphene Properties. Presentation on the twelfth Japanese-Mediterranean workshop on applied electromagnetic engineering for magnetic, superconducting, multifunctional and nano materials (Japmed'12), Batumi.

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2დ ნანოსისტემების მიღების ლაზერულ-პლაზმური ტექნოლოგიების კონცეფციის განვითარება

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მკვლევართა უმეტესობა ძირითადად ორიენტირებულია 2დ განზომილების პლანარულ ნაწი-
წყოებზე, სადაც ფირის სისქე მნიშვნელოვნად მცირეა, ვიდრე მისი პლანარული განზომილებები.
თუმცა, ნაწილობრივად ტექნიკის განვითარებისა და ამ სფეროში მზარდი მოთხოვნის პირობებში,
შესაძლებელია ფირის სისქის გავლენის გამოყენება სხვადასხვა სფეროში, როგორცაა მედიცინა,
ფოტოვოლტური უჯრედების გაუმჯობესება, სპინტრონიკა და კვანტური ელექტრონიკა.

2დ და 3დ მასალების (ნახევრად ლითონები, ნახევარგამტარები) მოსაპოვებლად, რომლებიც გათვლი-
ლია თანამედროვე სპინტრონული და სპინკვანტური მოწყობილობებისთვის, მათ შორის მაღალი ეფექ-
ტიანობის მზის ელემენტებისთვის, ჩვენს წინა კვლევებზე დაყრდნობით შევიმუშავეთ და ვიყენებთ
ლაზერ-პლაზმის მეთოდს, რომელიც შესაძლებელს ხდის ნაწილობრივ ფენების სრულყოფილი
სტრუქტურებითა და მაღალი სისუფთავით მიღებას

საკვანძო სიტყვები: 2D ნანოსისტემა, დინამიკური ფრაქტალი; ლაზერულ-პლაზმა; სპინტრონიკი
და სპინკვანტური მოწყობილობები.

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