THE LAW OF DIAMOND CRYSTALLOGENESIS.

Volodymyr Kaplunenko
"Nanomaterials and Nanotechnologies Ltd",
Ukraine
e-mail: kaplunenkov@gmail.com
Mykola Kosinov
"Nanomaterials and Nanotechnologies Ltd",
Ukraine
e-mail: nkosinov@ukr.net

Abstract. *A new electronic mechanism for diamond crystallogenesis is proposed that considers diamond synthesis at the microscale (atomic and subatomic levels) rather than in terms of the traditional macroscale conditions of high pressure and temperature (P-T). This challenges the traditional understanding of diamond formation and demonstrates for the first time that the fundamental Coulomb interaction is involved in the synthesis process. The law of diamond crystallogenesis is derived from this synthesis mechanism. This law states that the rate of diamond growth is determined by the number of electrons involved and the oxidation state of carbon. Pressure and temperature play a supporting role and serve as triggers that initiate the electronic mechanism of diamond synthesis. This law suggests that electrons act as crucial catalysts, facilitating the transition of carbon to the* C^{-4} *state, where it can form the diamond lattice through the Coulomb interaction, which is much stronger than the forces achieved by pressure. Electrons play a fundamental role in modifying the reactivity of carbon and a key role in the formation of covalent bonds. The law is mathematically expressed using fundamental constants. The discovery of the law of diamond crystallogenesis dispels the myth of millions and billions of years required for diamond formation, as well as the myth of pressure and temperature as direct factors in diamond formation. The law of diamond crystallogenesis and the electron mechanism of diamond crystallogenesis point to the reality of ultra-fast diamond synthesis at atmospheric pressure and low temperatures.*

Keywords: *diamond synthesis, law of diamond crystallogenesis, electron as a catalyst, oxidation degree concept.*

1. Introduction

The first theoretical justification for diamond synthesis was Leipunskii's work [1], which laid the foundation for diamond synthesis, specifying the pressure and temperature conditions under which diamond is stable. Leipunskii's diagram was refined and improved by Bundy F. P. [2, 3].

Leipunskii's thermodynamic calculations were confirmed by practical experiments in the 1950s and 1960s [4]. A method for producing artificial diamonds, HPHT, was developed. This served as a convincing reason to believe that pressure and temperature are essential conditions for diamond synthesis. Moreover, pressure and temperature began to be considered direct factors in diamond formation.

At the same time, an increasing number of studies are describing new methods of diamond synthesis that do not require high pressures and temperatures [5-11]. In [5, 6], it was shown that diamonds can be synthesized from adamantane solely using an electron beam. This new method for synthesizing nanodiamonds involves exposing adamantane (a hydrocarbon $C_{10}H_{16}$) to an electron beam at low temperatures, which breaks the C–H bonds, forming a diamond lattice. Nanodiamond synthesis occurs in a vacuum and lasts a short time—tens of seconds. This breaks all the rules and traditional understanding of diamond formation. This new method for synthesizing nanodiamonds demonstrates that extreme temperatures and pressures are not required for diamond formation. Only electrons in a vacuum are required to transform adamantane into diamond.

Controversies have also arisen in the concept of natural diamond formation. Increasing geological data indicate the possibility of diamond crystallization outside the P–T stability region of diamond [12]. Diamonds have been discovered in rocks that do not contain high-pressure minerals [13–15]. These discoveries in geology and laboratory synthesis demonstrate the inconsistency of the concept of diamond formation based on extreme pressure and temperature. A paradoxical situation has arisen: on the one hand, we have Leipunsky and Bundy's calculations, confirmed by the HPHT synthesis method, which indicate the need for extreme pressures and temperatures. On the other hand, we have new geological data and new diamond synthesis methods that do not require extreme pressure and temperature and allow diamonds to be produced outside the P-T stability region. This contradiction requires an explanation.

2. The prevalence of empirical research in artificial diamond synthesis, rather than the scientific method.

Currently, laboratory diamond synthesis is more of an art than a science. The selection of catalysts for diamond synthesis lacks a rigorous scientific basis, and their preparation recipes must describe all steps in detail to ensure reproducibility. This is typical for catalytic processes. A similar situation has long been known in catalysis [16-18]. Diamond synthesis as a catalytic process is plagued by the same problems. A successful "recipe" must be developed through trial and error, rather than based on a scientific analysis of the processes occurring during synthesis. The statement cited in [18] is entirely applicable to laboratory diamond synthesis: "*it is more like the art of cooking than stoichiometric chemical synthesis.*"

The development of a scientific theory of diamond formation is a pressing issue. This is driven by recent breakthrough discoveries in diamond synthesis methods, described in [5, 6, 7]. This is driven by the contradictions of the modern concept of diamond formation, based on extreme pressure and temperature. Perhaps we won't have to wait long for a quantitative theory of diamond formation that could universally, using a single equation, describe the process of diamond synthesis from various precursors and indicate the parameters that determine the rate of diamond growth. The lack of a scientific theory of diamond formation hinders the development of diamond synthesis technologies. The lack of a scientific theory of diamond formation has given rise to two myths: the myth of millions and billions of years required for diamond formation, and the myth of pressure and temperature as direct factors in diamond formation.

3. Diamond formation obeys a fundamental physical law.

In our work [19], a unified mechanism of diamond crystallogenesis in nature and in laboratory synthesis was presented, which showed that fundamental particles – electrons – participate in the synthesis of diamond together with the carbon contained in the precursor. The electronic mechanism of diamond synthesis demonstrates stable, repeating relationships between physical quantities and regularly recurring states of the material objects involved in the synthesis. This indicates the existence of a physical law of diamond crystallogenesis that can be represented in a rigorous mathematical formulation. The existence of a physical law of diamond crystallogenesis is also confirmed by the fundamental nature of similar physical processes in various diamond synthesis methods and the participation of a fundamental particle—the electron.

The electronic mechanism of diamond crystallogenesis demonstrates that diamond synthesis involves the fundamental Coulomb interaction of electrons with carbon atoms. To derive the physical (physicochemical) law of diamond crystallogenesis, it is necessary to determine which electronic and carbon parameters should be represented in the law of diamond crystallogenesis. Of all the fundamental parameters of the electron (mass ($m_e \approx 9.109 \times 10^{-31}$ kg), electric charge ($e \approx -1.602 \times 10^{-19}$ C), spin (1/2), radius ($r_e \approx 2.818 \times 10^{-15}$ m), it is the electric charge that exerts force. Electric charge can compete with extreme pressure. The Coulomb electrostatic force is many orders of magnitude greater than the mechanical force caused by any arbitrarily high extreme pressure in the HPHT method. Therefore, we chose electric charge as the parameter of the diamond crystallogenesis law.

The fundamental parameters of carbon are the atomic number (6), mass number (about 12 amu for ^{12} C), atomic radius, and electron configuration, which determines the chemical properties of the atom. Four electrons in the outer energy level allow the carbon atom to form four strong covalent bonds, characteristic of diamond. The degree The oxidation state of carbon is a quantitative measure related to the electron configuration. Therefore, we chose the oxidation state of carbon in the precursor as the parameter for the law of diamond crystallogenesis.

To derive the physical law of diamond crystallogenesis, it is necessary to define a physical quantity useful for comparing the efficiency of different diamond synthesis technologies. Such a practical physical quantity should be a quantitative characteristic of the diamond synthesis process. This practical physical quantity is the rate of diamond formation v_D, which has the dimension in the SI system [mol/s].

The rate of diamond formation v_D must be represented as a function that depends on the parameters of the main participants in the diamond formation process. Representing the diamond formation rate v_D as a function of electron and carbon parameters, expressed by a single mathematical formula, leads to the law of diamond crystallogenesis.

4. The law of diamond crystallogenesis.

The law of diamond crystallogenesis is as follows:

$$\boxed{v_D = \frac{e \bullet M_e}{F \bullet t \bullet (q_C - q_{C\min})}}$$

Fig. 1. The law of diamond crystallogenesis. v_D is the rate of diamond formation (mol/s); e is the electron charge; M_e is the number of free electrons participating in the synthesis; F is the Faraday constant; q_C is the oxidation state of carbon; $q_{C\min}$ is the minimum oxidation state of carbon (-4); t is the time of diamond synthesis.

The law of diamond crystallogenesis shows the dependence of the rate of diamond formation on the number of M_e electrons involved in synthesis, the electron charge, and the oxidation state of carbon q_C in the precursor. The rate of diamond formation is proportional to the number of M_e electrons involved in synthesis and inversely proportional to the difference in carbon oxidation states (q_C - q_{Cmin}).

The physical law of diamond crystallogenesis follows from the mechanism of diamond crystallogenesis, which is based on the interaction of electrons with atomic carbon and the donor-acceptor interaction of C^{-4} carbon atoms with the diamond surface, forming covalent bonds via the donor-acceptor mechanism.

The law of diamond crystallogenesis demonstrates its universality and applicability to all methods of diamond synthesis. It is represented by a simple and elegant mathematical formula. The law of diamond crystallogenesis includes fundamental physical constants that characterize the participants in diamond synthesis. These participants in diamond synthesis are electrons and carbon atoms.

5. Electrons, not pressure and temperature.

The main player in the mechanism of diamond formation is the electron. It is represented in the formula of the law of diamond crystallogenesis by a fundamental physical constant: the elementary charge "$e = 1.60217663 \times 10^{-19}$ C" and the number of electrons M_e.

This law states that electrons are the primary driving forces in diamond growth, lowering the oxidation state of carbon to C^{-4}, which facilitates the formation of the diamond crystal structure. This is a revolutionary approach to understanding diamond synthesis in both natural and laboratory conditions. It suggests new technologies for ultra-fast diamond production.

A key aspect of the law of diamond crystallogenesis is that it considers electrons to be the most important catalysts in the diamond formation process, playing a fundamental role in the transformation of carbon into its diamond structure. Electrons act as catalysts to initiate and accelerate the diamond formation process. We view traditional catalysts (metals such as nickel and iron) as efficient electron carriers that activate carbon.

The mechanism of diamond crystallogenesis involves electrons, which change the oxidation state of carbon from higher positive or neutral states to the C^{-4} state required for diamond synthesis. This electronic transformation of carbon's reactivity "involves" the Coulomb interaction in the synthesis mechanism and initiates the diamond synthesis reaction. Discoveries arising from this law could lead to new technological approaches that could significantly speed up the process of growing diamond crystals, potentially reducing the process of artificial diamond synthesis to a few hours.

Extreme temperatures and pressures are not the best solution for creating an electron-rich environment. There are many other, more efficient methods for generating the electrons needed for diamond synthesis. Obviously, the simplest is direct irradiation of the precursor with an electron beam [6].

Therefore, the primary focus in diamond synthesis research should shift from the macrolevel (control of temperature and pressure) to the microlevel (control of electron flow and their impact on carbon atoms).

6. Faraday's constant in the law of diamond crystallogenesis

The law of diamond crystallogenesis (Fig. 1) includes Faraday's constant (F = $9.64853321233100184 \times 10^4$ C/mol). This fundamental constant is a physicochemical constant. It links physical and chemical quantities: the electron charge and Avogadro's constant. Faraday's constant is known to be part of the Nernst equation, the Goldmann equation, and Faraday's law of electrolysis. The law of diamond crystallogenesis is a physicochemical law that also includes Faraday's constant.

7. The key role of the degree of carbon oxidation.

The law of diamond crystallogenesis points to the key role of the oxidation state of carbon in the precursor q_C. The law of diamond crystallogenesis suggests that the highest rate of diamond formation is achieved using carbon-containing substances in which the degree of carbon oxidation is minimal (C^{-4}). This is observed in practice when using methane (CH_4) as a diamond-forming gas.

The inclusion of the oxidation state of carbon in the physical law of diamond crystallogenesis forces us to evaluate its status in chemistry differently. Oxidation states are not considered physical quantities. They are chemical characteristics of substances. Their presence in a physical law is unusual, as oxidation states are typically used in chemistry to describe the reactivity of substances. However, the degree of oxidation of carbon in the precursor q_C is included in the law of diamond crystallogenesis as a parameter together with and on par with the fundamental physical constants.

The history of the oxidation state concept spans approximately 200 years [20–23]. Despite its widespread use in chemistry, oxidation state is considered an auxiliary, conventional quantity with no physical meaning [24–27]. Scientists have long debated the role of oxidation state in chemistry [26, 28–30]. Some authors point to the universality and fundamental nature of oxidation state [31–33]. Pauling famously stated, "*If scientific progress continues, the next generation may have a theory of valence that is sufficiently precise and powerful to allow chemistry to be considered an exact science, on a par with physics*" [31, 32]. We regard oxidation states as a fundamental characteristic of substances that determines their reactivity. The inclusion of the oxidation state of carbon q_C as a parameter in the law of diamond crystallogenesis, together with fundamental physical constants, indicates the fundamental status of the oxidation state.

8. New knowledge arising from the law of diamond crystallogenesis.

The most important new knowledge provided by the law of diamond crystallogenesis is that electrons, not pressure and temperature, are the primary driving force in diamond formation. This overturns the generally accepted paradigm that extreme conditions are necessary for diamond synthesis. The law of diamond crystallogenesis challenges the accepted geological model, which requires extreme, long-term conditions of high pressure and high temperature for diamond formation.

In all known diamond synthesis methods, electrons are the primary driving force in the synthesis mechanism. For example:

- in detonation synthesis, the explosion creates not only high pressure and temperature but also electron flows, which facilitate the formation of nanodiamonds.

- in the HPHT method, pressure and temperature gradients occur [34], which are not represented in the Leipunsky and Bundy diagrams. Pressure and temperature gradients lead to electrical effects. Furthermore, the HPHT method uses electric current to generate heat. However, what escapes attention is the fact that, in addition to the thermal effect of the electric current, electrons are injected into the diamond formation zone.

- The CVD method uses plasma (an ionized gas rich in electrons).

The law of diamond crystallogenesis provides insight into the actual mechanism of diamond formation, which includes the following stages:

- formation of atomic carbon from a diamond precursor;
- creation of an electron-containing environment;
- change in the oxidation state of carbon to C-4;
- donor-acceptor interaction and formation of covalent bonds.

The law of diamond crystallogenesis does not include pressure and temperature parameters. Extreme pressure and temperature play a supporting role and act as triggers that initiate the electronic mechanism of diamond synthesis through the baroelectric and thermoelectric effects.

The law of diamond crystallogenesis does not include precursor parameters, but rather the parameters of atomic carbon (q_C and q_{Cmin}). This indicates that the atomic carbon of the precursor participates in diamond formation.

The law of diamond crystallogenesis allows us to resolve the contradictions faced by traditional theory. For example, it explains:

- the existence of diamonds in rocks lacking high pressure and temperature;
- the possibility of diamond formation at atmospheric pressure;
- the rapid growth rates of diamonds observed with some synthesis methods, which disproves the "myth" that diamonds require millions of years to form.

Understanding the role of electrons in diamond formation indicates the possibility of using many known physical effects and methods of electron generation in laboratory synthesis. Electrons are easily manipulated. For example, using electric and magnetic fields to control electron flows can significantly accelerate the crystal growth process. Electric and magnetic fields can directly activate reactions, both with and without the need for traditional chemical catalysts.

9. Selecting a Precursor for Diamond Synthesis.

The most important factors for the success of new diamond synthesis technologies that do not require extreme temperatures and pressures are the correct selection of the precursor and the creation of an environment enriched with free electrons. The law of diamond crystallogenesis emphasizes the oxidation state of carbon in the precursor, which helps select the best precursor for diamond synthesis.

The law of diamond crystallogenesis implies that precursors with a lower oxidation state of carbon are more suitable for diamond formation. This emphasizes the chemical composition of the precursor and the bonding properties of the carbon atoms, not just the synthesis conditions.

The law of diamond crystallogenesis implies that the synthesis rate is directly dependent on the precursor used. The mathematical expression of the law directly incorporates the oxidation state of carbon in the precursor (q_C). This means that some precursors can provide a higher rate of diamond formation (υ_D) than others, depending on how many electrons are required to reduce carbon to the C^{-4} state.

The advent of the diamond crystallogenesis law has made it possible to use a more informed, scientific approach to precursor selection. This includes:

- analysis of the oxidation state of carbon in the precursor: a more efficient choice will be a precursor that requires less energy (fewer free electrons) to convert carbon atoms to the C^{-4} state.
- development of new carbon precursors specifically designed for electron-catalytic synthesis.

10. Experimental confirmation of the electron mechanism of diamond crystallogenesis.

Independent studies have confirmed the possibility of synthesizing diamonds using electrons. In 2025, Japanese scientists from the University of Tokyo announced that they had created nanodiamonds by irradiating adamantane ($C_{10}H_{16}$) with an electron beam [6]. The electrons allowed the carbon atoms to bond, forming a diamond lattice. Extreme temperatures and pressures were not required for the diamonds to form.

11. The future lies in electronic diamond synthesis technologies.

The electronic mechanism of diamond formation forces us to reconsider established ideas about how diamonds crystallize in the laboratory and in nature. The HPHT method is too complex for diamond synthesis. Since the law of diamond crystallogenesis assigns electrons the role of synthesis participants and catalysts, and pressure and temperature the role of "triggers," it opens the way to creating diamonds at lower pressures and temperatures than required by traditional HPHT methods. Systems that generate and control electron flows could replace giant presses and high-temperature furnaces. For example, new methods could use electric and magnetic fields, as well as electron beams, to achieve the desired result. Using electric fields to control electrons could significantly accelerate the crystal growth process.

The CVD method remains plagued by its low synthesis rate. The CVD method is rapidly developing and has already produced a record-breaking 34.59-carat CVD diamond, dubbed "Pride of India" [35, 36]. The CVD method now has the opportunity to further develop its development toward electronic synthesis.

New technical solutions based on the law of diamond crystallogenesis could lead to the development of synthesis methods that significantly accelerate the process of growing diamond crystals.

It is hoped that the transition from an empirical method to scientifically proven electronic synthesis will help researchers realize their dream of producing a large blue diamond in a laboratory [35, 37], comparable in size to the rare natural blue 46-carat Hope Diamond.

12. Conclusions

1. Both natural and laboratory diamond synthesis obey a fundamental physical law.

2. The law of diamond crystallogenesis shows that diamond formation is not mediated by a carbon-containing precursor, but by the atomic carbon of the precursor in its lowest oxidation state (C^{-4}).

3. The law of diamond crystallogenesis shows that fundamental particles—electrons—participate in diamond synthesis, along with the atomic carbon of the precursor.

4. The altered oxidation state of carbon, initiated by electrons, triggers the fundamental Coulomb interaction in the mechanism of diamond synthesis. It is known that the force of the Coulomb interaction is many orders of magnitude greater than the mechanical force caused by any extreme pressure in the HPHT method. As early as 1962, von Platen [38] suggested that no vice is strong enough to compress graphite into diamond.

5. Electrons change the oxidation state of carbon, converting the precursor carbon to the lower oxidation state C^{-4}, which is necessary for the diamond synthesis reaction.

6. A key aspect of the law of diamond crystallogenesis is that electrons are considered catalysts of the diamond formation process, playing a fundamental role in changing the reactivity of carbon and in the formation of the diamond structure.

7. Pressure and temperature parameters are not included in the law of diamond crystallogenesis. Extreme pressure and temperature play a supporting role and act as triggers that initiate the electron mechanism of diamond synthesis through the implementation of the baroelectric and thermoelectric effects.

8. Extreme temperatures and pressures in laboratory synthesis are not the best solution for creating an electron-rich environment. Many other, more efficient methods for generating the electrons necessary for diamond synthesis exist.

9. The law of diamond crystallogenesis dispels the myth of pressure and temperature as direct factors in diamond formation.

10. The primary focus in diamond synthesis research should shift from the macro level (control of temperature and pressure) to the micro level (control of electron flow and its impact on carbon atoms).

11. The law of diamond crystallogenesis implies that the rate of diamond growth depends on the number of electrons involved in synthesis and the oxidation state of carbon in the precursor. Electron transfer processes are very fast. Electrons are easily controlled. This opens the possibility of significantly accelerating the diamond synthesis process.

12. The law of diamond crystallogenesis dispels the myth of millions and billions of years required for diamond formation.

13. The law of diamond crystallogenesis is expressed mathematically. It links the rate of diamond formation to the number of electrons involved in synthesis, the electron charge, the Faraday constant, the oxidation state of carbon, and time.

14. The process of diamond formation, which was previously thought to require extreme conditions, can now be achieved under normal conditions using an electronic mechanism, paving the way for new ultra-fast diamond synthesis technologies.

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