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Overview of Diamond-Like Carbon (DLC) Coatings

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Abstract

Carbon materials have been pivotal in shaping human history and driving industrial progress. The versatile applications of carbon materials have significantly accelerated industrial development. Among the array of novel carbon materials, Diamond-like Carbon (DLC) Coatings have emerged as a focal point of global research due to their outstanding properties. This paper extensively explores the composition, unique characteristics, diverse applications, and various preparation techniques of DLC Coatings. By shedding light on the intricacies of DLC Coatings, this study aims to underscore their significance in the realm of materials science and technology, offering insights into the potential advancements they can facilitate in various industries.

Keywords

Diamond-Like Carbon; Carbon Materials; Chemical Structure.

1. Introduction

In 1971, Aisenberg and Chabot et al. used graphite as a film material by using the ion beam evaporation method, disintegrated and ionized the graphite through argon arc discharge to generate carbon ions [11], which were focused into a beam by a magnetic field. Carbon-thin-films were deposited on the substrate under greenhouse condition in the low-pressure deposition room. This carbon film has some properties similar to the properties of diamond, including high transparency, high resistance, and high hardness. Aisenberg first referred it diamond-like Coatings in 1973 [2].

2. Chemical Structure, Main Properties And Current Applications Of DLC Coatings

2.1 Chemical Structure

Carbon is the main component of DLC coatings. Carbon has three allotropes [18], namely diamond, graphite, and various amorphous carbons. Carbon atoms [14] have three different forms according to the different bond formation, namely sp1, sp2 and sp3 [6]. DLC is a metastable amorphous material that is covalently bonded between carbon atoms [5]. Its covalent bond mainly contains sp2 and sp3 hybrid modes.

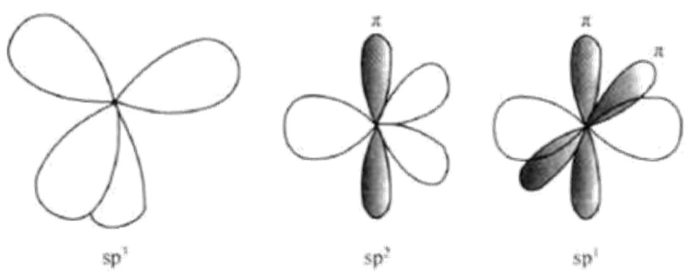

Figure 1. The chemical bonding type of carbon [6,7]

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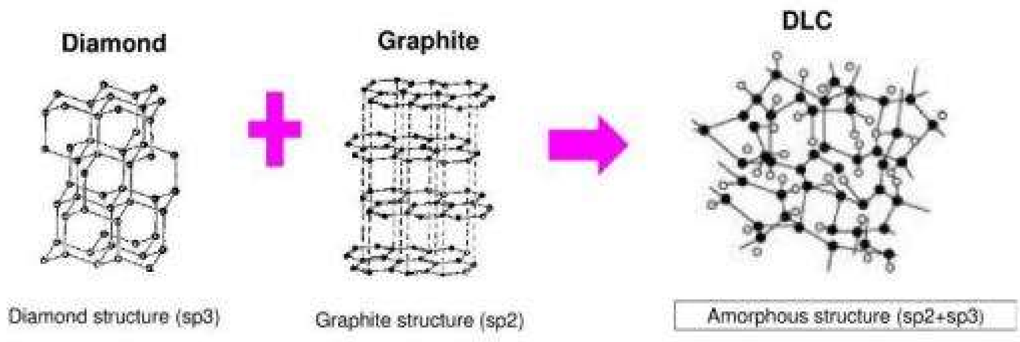

Figure 2. The chemical structure of DLC [13, 15]

Due to the difference in carbon source and preparation technology, DLC can be divided into two categories: hydrogen-free DLC (a-c films, amorphous carbon films) and hydrogen-containing DLC (a-c: H films, hydrogen-containing amorphous carbon films). According to the bonding modes of atoms (c-h, c-c, sp3, sp2, etc.) and different bond [19] proportions, DLC films can be divided into amorphous carbon (a-c): hydrogenated amorphous carbon (a-c :H) and tetrahedral amorphous carbon (ta-c).

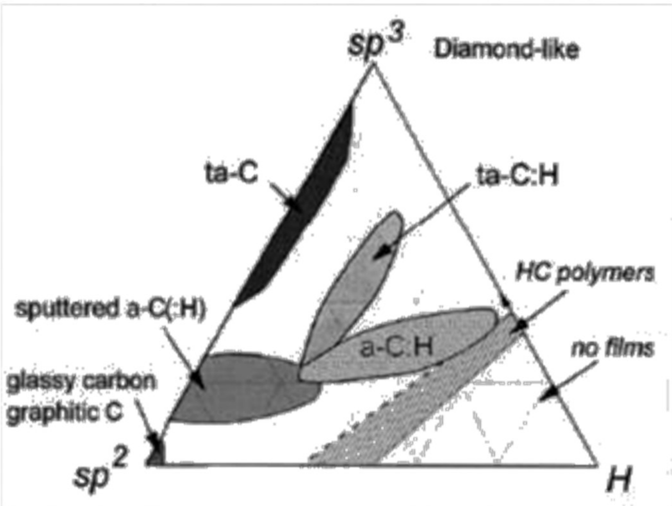

Figure 3. The DLC 3D phase diagram [13]

2.2 Main Properties and Current Applications Of DLC Coatings

2.2.1 Mechanical Properties and Applications

The most basic factor affecting the hardness of DLC is the ratio of sp3 bond with diamond chemical structure characteristics to sp2 bond with graphite characteristics (i.e., the ratio of sp3 to sp2). The higher the value is, the higher the hardness will be. The upper limit of hardness is 95GPa, nearly the hardness of diamond (100GPA). Moreover, DLC can be used as a protective coating for cutting tools and mechanical parts [15]. DLC has a low friction coefficient, high hardness, and excellent wear resistance, so it is very suitable for tool coating. In addition, DLC deposited on drill bits, and milling cutters can effectively resist non-ferrous metal bonding [15].

2.2.2 Electrical Properties and Applications

DLC has high resistivity, strong insulation, high chemical inertness, and low electronic affinity. The multi-layer structure of carbon film and DLC coatings can be used to construct the multi-quantum fine structure with resonance tunneling effect. Due to the low dielectric constant of DLC and its

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tendency to form the film on a large substrate, it is expected to replace SiO2 as the dielectric material for the next generation of integrated circuits [8].

2.2.3 Optical Properties and Applications

DLC has suitable optical properties, including good optical transparency and wide optical band gap. Its refractive index ranges from 1.8 to 2.5, and optical band gap ranges from 0.5 to 4.1eV [16]. Especially in infrared and microwave bands, it has high transmittance and optical refractive index [16]. Because DLC has superior optical properties in that it is transparent in the infrared range, and has high hardness, wear resistance and other features, it can be used as the anti-reflection and protective film in the infrared region.

2.2.4 Applications in Biomedical Materials

DLC can meet the requirements of biological compatibility in terms of chemical composition and has the characteristics of high hardness, low friction coefficient, and chemical inertia which allows for a broad application prospect in the field of biomedicine. Some people deposit DLC on the surface of the artificial joint to enhance the wear resistance of artificial joint and obtain good results [12].

3. Fabrication, Production, Characterization, and Testing of DLC Coatings

3.1 Fabrication, Production, Characterization of DLC Coatings

At present, there are many methods to prepare DLC coatings. In general,all of the methods that can be used to prepare diamond coatings can be used to prepare DLC coatings [7]. Compared to the preparation conditions of diamond coatings, the preparation conditions of DLC coatings are more easily realized. The methods of preparing DLC coatings can be divided into two categories according to the preparation mechanism: physical vapor deposition and chemical vapor deposition. Commonly used physical vapor deposition methods include ion beam deposition, filtration-type-cathodic-vacuum-arc (FCVA) technology, pulsed-laser-deposition (PLD) and magnetron-sputtering [7]. Commonly used chemical vapor depositions include plasma chemical vapor deposition plasma enhanced chemical vapor deposition and electron cyclotron resonance chemical vapor deposition, which is divided into direct current and radio frequency type depending on the amount of power used [17]. As shown in table 1, different preparation creates DLC coatings with different properties. However, previous studies show that the incident ions about 100eV form DLC coatings with excellent performance in various aspects [17].

Table 1. Basic properties of DLC coatings prepared by different methods [9]

Material	Preparation	Density/g· cm-3	sp3/%	Hardness/Gpa	Young modulus/Gpa	Friction coefficient
a-C:H	Rf biased sputtering	1.6~2.5	66~90	10~25	----	----
a-C	Vaccum arc	2.8~3.0	85~95	40~180	500	0.04~0. 14
a-C	Cathode arc	2. 14~3.0	39~85	23~60	245~500	0. 1~0. 16
a-C	Pulse laser	2.4~3	70~95	30~70	200~560	0.03~0. 12
a-C:H	Rf-PECVD	1.3~2.0	73~86	10~30	125~260	0.06~0.3
ta-C	FCVA	3.1	75~90	20~80	200~700	0.08~0. 11
a-C(:H)	Ion beam	1.8~3.5	----	32~75	----	0.06~0. 19

3.1.1 Ion Beam Deposition (IBD)

This refers to the formation of DLC on the substrate of carbon ions, which generated by ion sources.

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3.1.2 Sputtering Deposition (RFS and MS)

It refers to the application of hydrogen ions excited by RF oscillation or magnetic field to bombshell solid graphite targets to form sputtering carbon atoms (or ions), to deposit DLC coatings on the surface of the substrate. This method is characterized by a wide range of energy for depositing ions. It mainly includes DC sputtering, RF sputtering and magnetron sputtering [6].

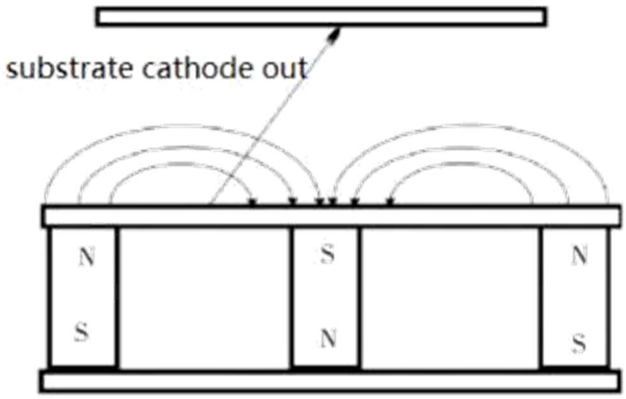

Figure 4. Magnetronsputtering [6]

3.1.3 Cathode Arc Deposition

Driven by a power supply and a magnetic field, the carbon vaporizes and dissociates wherever the arc passes. A magnetic filtration channel is added between the vacuum arc and the substrate. By adjusting the magnetic field intensity and bias, the large particle neutral components and some ions in the plasma are filtered out in the channel, to obtain the deposited ions composed of single carbon ions [6].

3.1.4 Pulsed Laser Deposition (PLD)

After the pulsed laser beam is introduced into the cavity through the focusing lens and quartz window, it is projected onto the rotating graphite target, and under the action of the laser with high energy density, laser plasma discharge is formed [10]. Moreover, the carbon ions generated the energy of 1keV, forming the four coordinate structure of sp3 bond on the matrix, and finally forming the DLC coatings. This method has a high deposition rate and can obtain a diamond-like film without hydrogen with high sp3 content, but with high energy consumption and small deposition area [10].

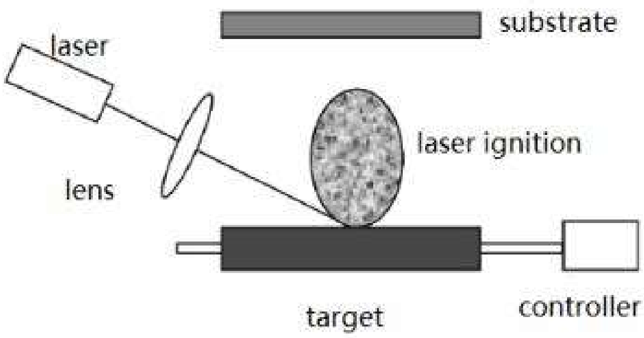

Figure 5. Theory of Pulsed laser deposition (PLD) [10]

3.2 Testing of DLC Coatings

3.2.1 Metallographic Microanalysis

The morphology of the layered surface was observed by the metallographic microscope, and the microstructure, defects and surface flatness of the DLC coatings were evaluated on the metallographic scale.

3.2.2 Microhardness

The hardness of the layers is usually tested with a microhardness tester using a Vickers or Knoop head. To avoid the influence of matrix deformation, the hardness of the coating should be tested with a small load as far as possible to reduce the depth of compression, which is generally considered to be less than 1/7- 1/10 of the thickness of the coating [7].

3.2.3 Friction Rotating Method

The actual conflict between DLC coatings and metal is simulated by using a rotating friction instrument.

3.2.4 Electronicprobe

The morphology and composition of DLC coatings were analyzed synchronously by electron probe, including point analysis, line analysis and surface analysis [3].

4. Summary

With the development of science and technology and the synthesis of materials, new carbon-based thin film materials have been discovered, which greatly enrich the subject of carbon-based thin film materials. In the past few decades, the research on DLC has mainly focused on the technical preparation, structural test, various performance research, and application field development and expansion, and these aspects should also be further studied.

4.1 Basic Research

It is important to think about how to deeply understand the precipitation process, mechanical properties and the nature of tribological properties of carbon-based film through theoretical calculation, computer-aided simulation, and new experimental means is worth paying attention to and thinking about [12]. Moreover, we should not ignore the essential influencing factors of mechanical properties such as internal stress and hardness of the film, and the external service environment [15]. Also, it is necessary to develop new characterization theories and methods to accurately define the proportion of sp3/sp2 hybrid bonds in DLC thin-film-materials.

4.2 Key Technique

The development of modern deposition technologies and film design concepts make it possible for future researchers to control the fine structure of DLC film. Through the combination of other techniques, researchers can gradually improve core problems such as high internal stress, poor thermal stability and service life shortage caused by environmental sensitivity. In addition, it is still urgent to break through large areas of uniform deposition, extreme size work piece plating, and other technical bottlenecks [4].

4.3 Coating Equipment

The design, optimization, and research of related equipment should be strengthened to develop new technologies and equipment for DLC deposition that can effectively and stably reduce the price of high-quality film deposition equipment [1].

4.4 Expanding Application Areas

The application of DLC film in the past few years has been concentrated in the light load condition, and the application in the heavy load condition is extremely rare. Therefore, great efforts should be made to develop the application of DLC in biology, and corrosion protection, field emission, semiconductors, and other fields.

References

[1] Duncan, Michael. Invited Review Article: Laser vaporization cluster sources. Review of Scientific Instruments. 2012, Vol. 83(No.4): 041101–041101–19.

[2] Evtukh, A. A., Litovchenko, V. G., Litvin, Y. M., et al. Silicon doped diamond-like carbon films as a coating for improvement of electron field emission. Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena, 2003, Vol. 21(No.1), p.627-630.

[3] Ford, Doug. The Secret World of Oscilloscope Probes, Silicon Chip. Silicon Chip Publications, 2009, p.16–23.

[4] Gillespie, R.J.. Teaching molecular geometry with the VSEPR model. Journal of Chemical Education. 2004, Vol. 81(No.3), p.298–304.

[5] Jin Zhong, Lu Wei, O'Neill, Kevin J., et al. Nano-Engineered Spacing in Graphene Sheets for Hydrogen Storage. Chemistry of Materials. 2011, Vol. 23(No.4), p. 923–925.

[6] Jung, T., & Westphal, A.. Zirconia thin film deposition on silicon by reactive gas flow sputtering: the influence of low energy particle bombardment. Materials Science and Engineering. 1991, Vol. A(140), p. 528-533.

[7] Modabberasl A, Kameli P. Fabrication of DLC thin films with improved diamond-like carbon character by the application of external magnetic field. Carbon. 2015, Vol. 94, P. 485-493.

[8] Mourou, Gerard A.. Optics in the relativistic regime. Reviews of Modern Physics. 2006, Vol.78, p. 309.

[9] Rashidian Vaziri. Monte Carlo simulation of the subsurface growth mode during pulsed laser deposition. Journal of Applied Physics. 2011, Vol. 110(No.4), p.34-43.

[10] Peng XL, Barber ZH.. The surface roughness of diamond-like carbon films prepared using various techniques. Surface and Coatings Technology. 2000, Vol. 138(No. 23), p. 32.

[11] Robertson, J.. Diamond-like amorphous carbon. Materials Science and Engineering. 2002, Vol. 37(No.4–6), p. 129–281.

[12] Roy RK, Lee KR.. Biomedical applications of diamond-like carbon coatings: a review. JOURNAL OF BIOMEDICAL MATERIALS RESEARCH PART B. 2007, Vol. 83(No.1), p. 72-84.

[13] Santra T S, Bhattacharyya T K, Patel P, et al. Microelectromechanical systems and devices. IntechOpen. 2012, p. 460-466.

[14] Savvatimskiy, A. Measurements of the melting point of graphite and the properties of liquid carbon (a review for 1963–2003). Carbon. 2005, Vol. 43(No. 6), p. 1115-1142.

[15] Singh S B, Pandey M, Kishore R, et al. Mechanical properties of diamond like carbon coatings prepared by microwave electron cyclotron resonance plasma chemical vapour deposition process. Journal of Physics. 2008, Vol. 114(No.1), p. 012-044.

[16] Sultanova N, Kasarova S, Nikolov I. Dispersion properties of optical polymers. Acta Physica Polonica A. 2009, Vol.116(No.4), p. 585-587.

[17] Wang Q, Zhou F. Progress in tribological properties of nano-composite hard coatings under water lubrication. Lubricants. 2017, Vol. 5(No. 1), p. 5.

[18] Wasy A, Balakrishnan G, Lee S, et al. Thickness dependent properties of diamond-like carbon coatings by filtered cathodic vacuum arc deposition. Surface Engineering. 2015, Vol. 31(No. 2), p. 85-89.

[19] Weinhold F. Discovering chemistry with natural bond orbitals. John Wiley & Sons. 2012. p. 13-16.