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A new approach to create isolated carbon particles by sputtering: A detailed parametric study and a concept of carbon particles embedded carbon coatings

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ABSTRACT

This article describes the in-situ creation of isolated carbon particles by quenching argon plasma with helium pulses. The carbon entities are created on the top of diamond-like carbon (DLC) coating by quenching the plasma with He gas during the coating deposition. A general four-phase model is presented to understand the mechanism of in-situ particle formation. The helium based plasma quenching does not produce carbon entities always. Thus, a parametric study is performed which involves the effects He pulse orientation to the plasma plume, He gas flow rate, He injection duration, and the target to substrate distance. The plasma quenching outputs depends on the above-described parameters and the different combinations creates isolated and identical particles or agglomerated entities or homogenous granular coating. He based plasma quenching creates isolated particles in the range of ~75 nm to ~800 nm with particles isolation distance from less than 1 μm to more than 20 μm at different quenching conditions. After repeatability and confirmation of particles formation with proposed plasma quenching method, the particles are created simultaneously to the DLC deposition. Thus a new coating architecture of isolated carbon particles embedded carbon coating has been developed.

1. Introduction

The role of zero-dimensional carbon structures [1] in advanced sensing techniques [2,3] is getting popular due to their improved sensing performance, particularly in micro-electro-mechanical system (MEMS) based devices. Recently, the important research focus is to create zero-dimensional carbon particles with good quality, identical shape, and simple approach. Similarly, the carbon particles have good potential to improve mechanical properties and tribological performance of diamond-like carbon (DLC) coatings. Recently, foreign element doped DLC coatings are common to improve toughness and friction coefficient of DLC. But on the same time, the foreign element doping usually reduces the hardness and enhances the wear loss of DLC coating. The carbon particles are presumed to increase hardness by making new sp^3 covalent bonds with the host amorphous matrix. Similarly, the carbon particles are expected to absorb fracture energy of crack tip and helps to enhance the fracture toughness. Moreover, the low shear strength of particles than matrix is presumed to reduce the wear loss. Similarly, besides improvement in sensing techniques and mechanical properties, the in-situ synthesis of isolated carbon particles have attractive applications in the plasmonic and biomimetic fields.

The origin of in-situ synthesis of carbon particles can be traced back to the 80s. Schmellenmeier [4] has reported a carbon coating in 1953 which got more attention after Eisenberg and Chabolt [5] experiments in the 1970s who developed carbon coating with ion beam deposition. Hereafter, a new research interest was developed to understand the basic mechanisms and building blocks which formed a homogeneous carbon coating. The initial outcomes were reported as a discovery of carbon C60 in 1985 by vaporizing graphite through laser irradiation [6] and in 1990 by evaporation of graphite under high helium pressure of ~100 Torr [7]. Similarly, the helical microtubules [8] were produced from graphite by arc discharging in 1991.

In the same realm of high energy discharge techniques, the carbon particles were found in the carbon soot produced with strong electron beam irradiation [9]. The presence of agglomerated carbon particles was found in the carbon soot. Later on, a mixture [10] of carbon particles and carbon nanotubes were produced with filter cathode vacuum arc under pressure gradient and plasma quenching. The carbon atoms got high kinetic velocity in high energy discharge methods and may disintegrate into onion-like structures [1,11] or agglomerate under high-pressure gradient once they reached on the substrate. Moreover, the high energy discharge technique produced a mixture of different carbons types in the range of C_{20} to C_{70} [10].

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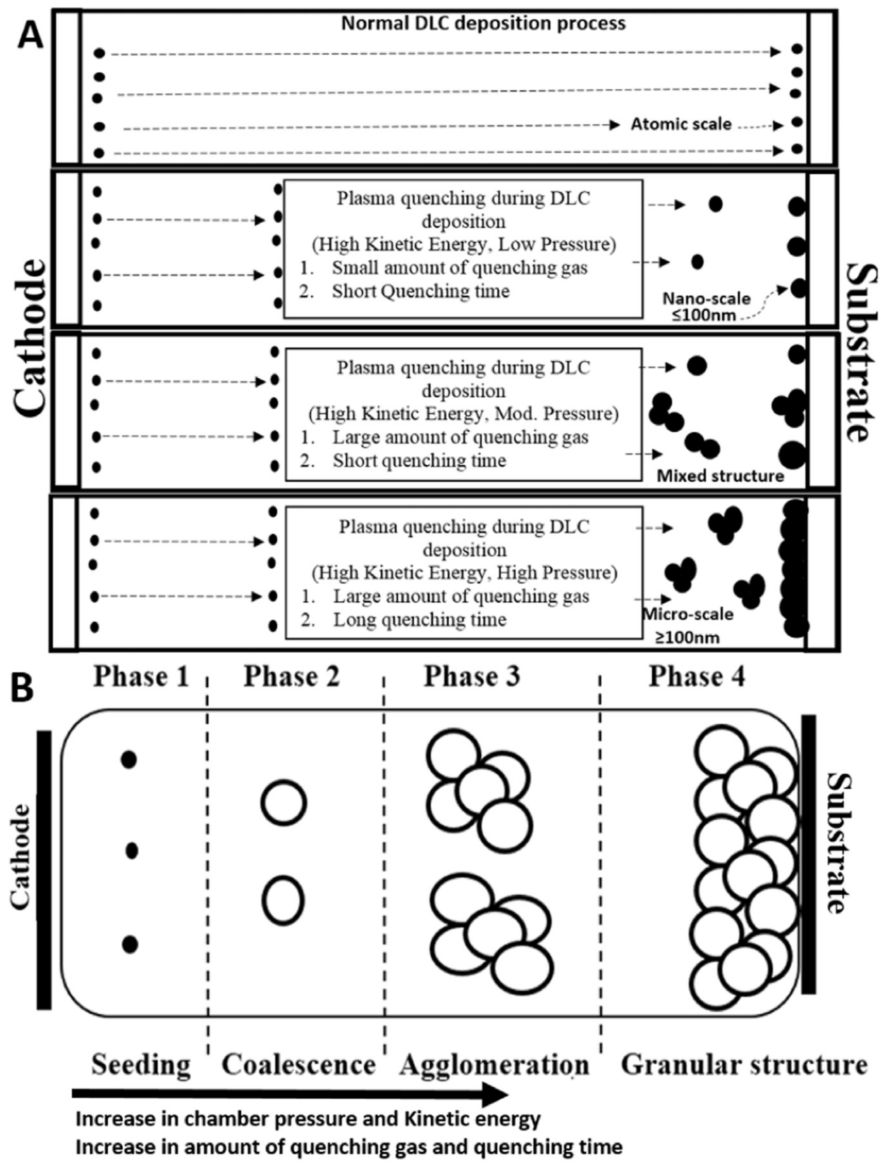

Fig. 1. (A) Effect of the quenching duration and amount of quenching gas on plasma on quenching outputs, (B) four phase model of in-situ particle growth from seeding to the homogeneous granular structure.

In parallel, the aerosol particles were also in-situ synthesized from dusty plasma [12] through sputtering. The graphite electrodes were exposed to radio frequency plasma for 4 h to 7 h with high bias in the range of −300 V to −500 V. The outputs contained cauliflower-like structure with a huge variation in particle size and distribution. Moreover, the large particles were agglomerated to make a string-like structures [13]. Similarly, graphite sputtering in gas phase produced carbon flakes and dust grains [14]. The dust grains contained small linked particles and the large agglomerated carbon particles. In the same way, the in-situ synthesis of carbon particles through plasma quenching was carried out in aggregation tube [15] which was installed inside the sputtering chamber. In summary, regardless of deposition method either laser ablation, arc discharge or sputtering, the carbon particles agglomerate and clot [13] due to several collision inside the plasma. Hence to produce identical, isolated, zero-dimensional and large area distributed particles always remain inspiring [15,16].

2. Four phase model

The literature survey has summarized that the in-situ particle formation highly depends on the kinetic energy of quenching gas and chamber pressure. These changes in these two factors greatly influence the plasma dynamics like mean free path, the number of collisions and thus changed the quenching outputs. The both parameters usually governed by the properties of quenching gas such as molecular weight, the amount of quenching gas, and the quenching duration. Fig. 1A presents the schemes of normal DLC process and the effect of quenching during normal DLC process. If the plasma had quenched for short time with the small amount of quenching gas, it usually had least effects on plasma dynamics. On these conditions, the chamber pressure slightly increased with a small decrease in the mean free path. Thus atomic clusters joined each other in a so-called quasi-static equilibrium and reached to the substrate as particles. However, if the plasma had quenched with an excessive amount of quenching gas and for the long quenching duration; the chamber pressure would significantly increase and the mean free path would decrease to the great extent. Thus due to a huge increase in collisions the atomic clusters will form a particle and rapidly transform into agglomerations.

Here a general four-phase model of in-situ particle formation during physical deposition process had proposed as shown in Fig. 1B. Based on the fundamental understanding, the model present four different phases of structure buildup which were (a) seeding, (b) coalescence, (c)