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Fabrication of diamond like carbon cone for fast ignition experiment

Mayuko Koga [a,*], Kazuhiro Kanda [b], Tsuneo Suzuki [c], Takayoshi Norimatsu [d]

[a] Graduate School of Engineering, University of Hyogo, Himeji, Hyogo, Japan
[b] Laboratory of Advanced Science and Technology for Industry, University of Hyogo, Ako-gun, Hyogo, Japan
[c] Extreme Energy-Density Research Institute, Nagaoka University of Technology, Nagaoka, Niigata, Japan
[d] Institute of Laser Engineering, Osaka University, Suita, Osaka, Japan

HIGHLIGHTS

- We succeeded in making stand-alone DLC cones for fast ignition.
- Low gas pressure and low RF power condition are suitable for thick DLC deposition.
- The made DLC layers show typical hydrogenated amorphous DLC properties.

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ABSTRACT

In fast ignition research, a divergence of laser-generated hot electrons is a serious problem. Using diamond like carbon (DLC) cones is one of the realistic solutions to this problem. However, it is difficult to make a stand-alone DLC cone because it needs a thick DLC layer. In this paper, we report survey findings of preparation conditions for a thick DLC layer. DLC layers were prepared by using plasma–based ion implantation and deposition system. Acetylene gas or toluene vapor was used as a source. After trials of many deposition conditions, it is found that low gas pressure and low RF power condition is suitable for a thick DLC deposition. Properties of the made DLC layers were measured by near edge X-ray absorption fine structures (NEXAFS) and elastic recoil detection analysis (ERDA). It is found that these DLC layers have typical hydrogenated amorphous DLC properties. Based on these results, we succeeded in making stand-alone DLC cones.

1. Introduction

Fast ignition [1–4] is one of the proposed ways to achieve high fusion energy gain in inertial fusion research. In this scheme, a fuel shell is compressed by irradiating nanosecond pulse lasers. After that, a picosecond ultra intense short pulse laser is injected into the core plasma through a gold cone. Fusion reaction occurs in the heated core plasma. This scheme has an advantage that requirements of laser power and implosion process for ignition are not strict compared to those in central ignition. For a successful ignition, it is necessary to transport the energy of hot electrons to the imploded core effectively. However, many researchers have reported that hot electrons were diverged more than expected [5,6]. In addition, it is also concerned that hot electrons are scattered by high-Z plasma generated from a gold cone target. This may cause the drop of the energy coupling of the heating laser to hot electrons [7]. Therefore, low-Z materials, such as diamond like carbon (DLC) [8,9] and aluminum, are drawing attention as cone materials. For making a stand-alone DLC cone, a thick DLC layer is necessary. However, it is difficult because a DLC layer has a strong residual stress and breaks down easily. In this paper, we report survey findings of suitable preparation conditions and characteristics of a thick DLC layer.

2. Experimental methods

DLC layers were prepared by using plasma–based ion implantation and deposition (PBIID) system. The schematic diagram of the system is shown in Fig. 1. In this system, the RF (13.56 MHz) pulse for plasma generation is supplied to the substrate together with a negative high-voltage pulse (−10 kV) for ion implantation through a single electric feed-through. Samples are attached to this feed-through and biased together. All parts of samples are covered with plasma sheath. Therefore, this system is suitable for the deposition of three-dimensional samples. The samples are cleaned up with Argon and methane plasma before deposition. Acetylene gas

* Corresponding author.
E-mail address: koga@eng.u-hyogo.ac.jp (M. Koga).

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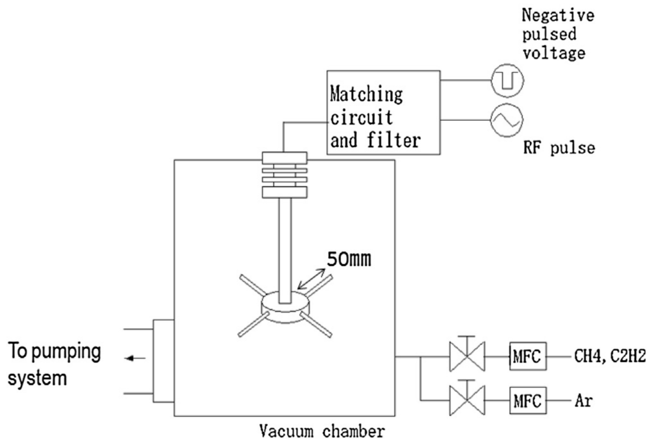

Fig. 1. Schematic diagram of PBIID system.

Table 1
Deposition parameters.

	Pretreatment	Deposition	
Gaseous species	Argon/Methane	Acetylene	Toluene
Flow (cc/min.)	10/30	50	30
Time (min.)	30	180	180
Pulse frequency (kHz)	0.5	0.5	1
Negative pulse width (μs)	5	3	3

Table 2
Surveys of DLC layer preparation conditions. Acetylene gas was used as a source.

Gas pressure (Pa)	RF pulse power (W)				
	100	200	300	400	500
0.5	○	○	○	○	×
0.75	○	○	○	○	×
1	○	○	○	×	×
1.25	○	○	×	×	×
1.5	×	×	×	×	×

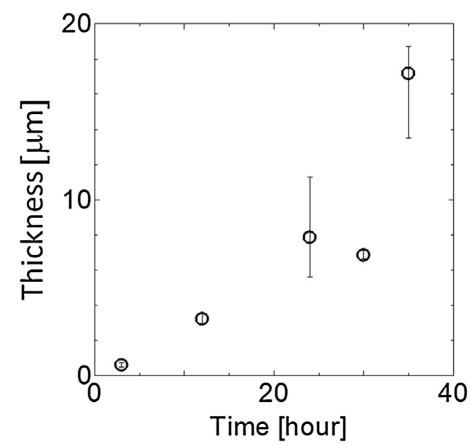

Fig. 2. The relationship between DLC layer thickness and deposition time.

or toluene vapor is introduced into the chamber after this cleaning. Detailed parameters are shown in Table 1.

The thickness of DLC layer was measured by using a step gauge. The structure and the SP_2 content of DLC were analyzed by near edge X-ray absorption fine structures (NEXAFS) spectra measured at NewSUBARU synchrotron radiation facility. Measurement conditions are as follows, ring mode 1.5 GeV, undulator gap 50 mm, grating 1200 groove/mm, slit width 100 μm, incident angle 54.7° (magic angle), and measurement mode is total-electron-yield. Hydrogen content was measured by elastic recoil detection analysis (ERDA) at Nagaoka University of technology. ERDA is one of ion beam analysis techniques. An energetic helium ion beam (2.5 MeV) is irradiated to a sample. Recoil hydrogen atoms from the sample are collected and investigated. Because ERDA required 400 nm-thick DLC layer on a silicon plate, the DLC layer was made by toluene vapor with 0.5 Pa of gas pressure and the 300 W of RF power.

Brass plates are used as base materials for DLC property measurements. Brass conical bars are used as base materials of DLC cone targets. Before DLC deposition, a thin gold layer was deposited on the brass conical bars as electron source. The made DLC cone targets were assembled at Osaka University.

3. Results and discussion

3.1. Suitable condition for thick DLC deposition

Many preparation conditions were tested in order to optimize a deposition condition. The results are shown in Table 2. Acetylene gas was used as a source. The deposition time was three hours. X-mark means that the deposited DLC layer was unstable and it broke after a while. It is clearly seen that low pressure and low RF pulse power condition are suitable for thick layer deposition.

Fig. 2 shows the relationship between deposition time and DLC layer thickness. The acetylene gas pressure was 0.5 Pa and the RF pulse was 100 W. It is clearly seen that the layer thickness is increased with the deposition time. We also examined deposition conditions using toluene vapor and obtained the similar result. In addition, deposition rate of toluene vapor was higher than that of acetylene gas (10 μm thickness/24 h). This higher deposition rate may result from higher carbon atom content of toluene. Moreover, the DLC layer made from toluene was more stable compared to that made from acetylene. This experimental fact indicates that the film adhesion of toluene sample was better than that of acetylene sample.

3.2. Classification of deposited DLC

Fig. 3(a) and (b) show NEXAFS spectra of DLC layers made by acetylene gas and toluene vapor, respectively. The RF power cycle was 500 Hz. The gas pressure was 0.5 Pa. Heavy lines show measured spectrum. Solid lines show decomposed peaks. Sharp peak around 285 eV indicates the pi peak originating from C=C bonds. This peak indicates graphite component. There are no recognizable structures in sigma range (290 eV–310 eV). This means that there are no heteroatoms and polymer like structure in the DLC layer. From these results, it is concluded that deposited DLC layers have typical amorphous structure. The second and third peaks are higher in Fig. 3(b) than that in Fig. 3(a). These peaks come from C=O bond and C—H bond, respectively. We think that more hydrogen content of toluene sample makes it softer and results in higher adhesion. SP_2 content was estimated from these spectra [10,11] by dividing the normalized area of pi peak by that of highly ordered pyrolytic graphite (HOPG). Estimated SP_2 content is 0.74 in Fig. 3(a) and 0.68 in Fig. 3(b). This means that obtained DLC is graphite rich DLC. DLC made by acetylene had slightly more SP_2 content than that made by toluene vapor. From the simulation [12], diamond rich structure, viz, low SP_2 content may be better for fast electron guiding. However, it has not been confirmed experimentally yet and suitable SP_2 content remains unknown.

DLCs are classified by SP_2 content and hydrogen content. Measured hydrogen content was 16 at%. This value is relatively low in hydrogenated amorphous carbons which are made by hydrocarbon gas. From the value of SP_2 content and hydrogen content, it is found