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Characteristics of phosphorus-doped diamond-like carbon films synthesized by plasma immersion ion implantation and deposition (PIII and D)

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Abstract

Plasma immersion ion implantation and deposition (PIII and D) is an effective approach to synthesize high quality thin films for different industrial applications. This dual implantation and deposition process can produce a graded layer that mitigates delamination and poor adhesion. In this work, phosphorus-doped diamond-like carbon (DLC) films were synthesized by PIII and D. Thin DLC films with various phosphorus concentrations were produced by using different experimental parameters. The chemical composition was determined by X-ray photoelectron spectroscopy (XPS) and electron energy loss spectroscopy (EELS). Micrographs obtained by cross-sectional transmission electron microscopy (X-TEM) reveal good adhesion between the films and substrates. The biocompatibility was evaluated using platelet adhesive tests. The results show that the sample doped with an optimal amount of phosphorus exhibits less platelet adhesive and activation, and the overall results are better than that observed on low-temperature isotropic pyrolytic carbon (LTIC). Phosphorus-doped DLC films thus have potential applications in blood contacting medical devices.

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Keywords: Plasma immersion ion implantation and deposition (PIII and D); Phosphorus; Diamond-like carbon (DLC) films; Biocompatibility

1. Introduction

Since the development of chemical vapor deposition to produce diamond, polycrystalline and amorphous carbon materials have attracted considerable attention. The materials have achieved great successes especially for mechanical applications such as low friction coefficient, high wear and chemical resistance, etc. Recently, development of carbon materials has focused on the nano- and doping technology. The results of doping carbon materials are exciting from the perspective of not only mechanical properties but also applications in the semiconductor [1], optical [2], magnetic [3], and biomedical [4,5] industries. The objectives of doping diamond or DLC films include reducing the internal stress, altering the semiconducting and magnetic properties, etc., but there are limited studies in the area of biomedical engineering. Our preliminary study [6] shows that phosphorus-doped diamond-like carbon (P-DLC) film

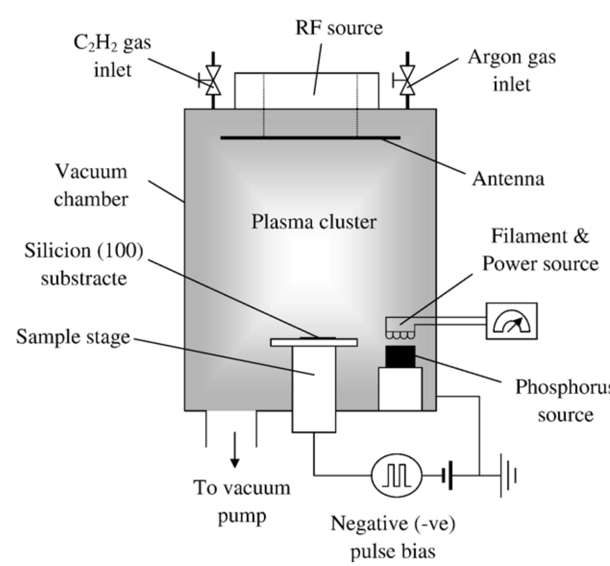

Fig. 1. Schematic diagram of plasma immersion ion implantation and deposition (PIII and D) system.

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Table 1
Experimental parameters

Sample	Ar/C_2H_2 (sccm)	Bias voltage (kV)	Filament power (W)
A	8/4	15	42
B	10/10	30	42
C	10/10	15	42
D	10/10	15	16

Bias frequency = 100 Hz; pulse length = 100 μs.

Table 2
P:C ratio of the samples

Sample	P:C ratio
A	0.41
B	0.24
C	0.21
D	0.16

exhibits good biocompatibility. The blood compatibility is better than that of undoped DLC and low-temperature isotropic carbon (LTIC). In this paper, we present further works on P-DLC films. Thin P-DLC films with different dopant concentrations were synthesized by plasma immersion ion implantation and deposition (PIII and D), and various techniques including X-ray photoelectron spectroscopy (XPS), transmission electron microscopy (TEM), electron energy loss spectroscopy (EELS) as well as contact angle test were employed for film characterization. The *in-vitro* platelet adhesion test was utilized to estimate the biocompatibility behavior. Our results show that the sample with an optimal P content exhibits the best blood contact compatibility.

2. Experimental details

2.1. Film synthesis

The P-doped DLC films were fabricated using plasma immersion ion implantation and deposition (PIII-D) [7,8]. P doping was carried out by using a small container with 99.9% pure red phosphorus powders placed in the chamber as shown in Fig. 1. The phosphorus vapor was evaporated by the heated filament, mixed with acetylene (C_2H_2) and argon gases within the chamber, and ignited by a 500 W radio frequency (RF) source to produce the plasma. We controlled the evaporation rate of phosphorus by the power applied to the filament. It was found that a power of 42 W produced stable and maximum phosphorus evaporation, and thus we used this setting in our film deposition except for sample D. Si (100) substrates were cleaned by argon sputtering for 15 min before deposition. The experimental details are shown in Table 1. By varying the flow ratio of Ar to C_2H_2, substrate bias voltage, and power of the filaments, a series of P-DLC films with different dopant concentrations was produced.

2.2. Film characterization and biocompatibility test

Film characterization was conducted by a number of techniques. The surface elemental composition and chemical state were analyzed by X-ray photoelectron spectroscopy (XPS).

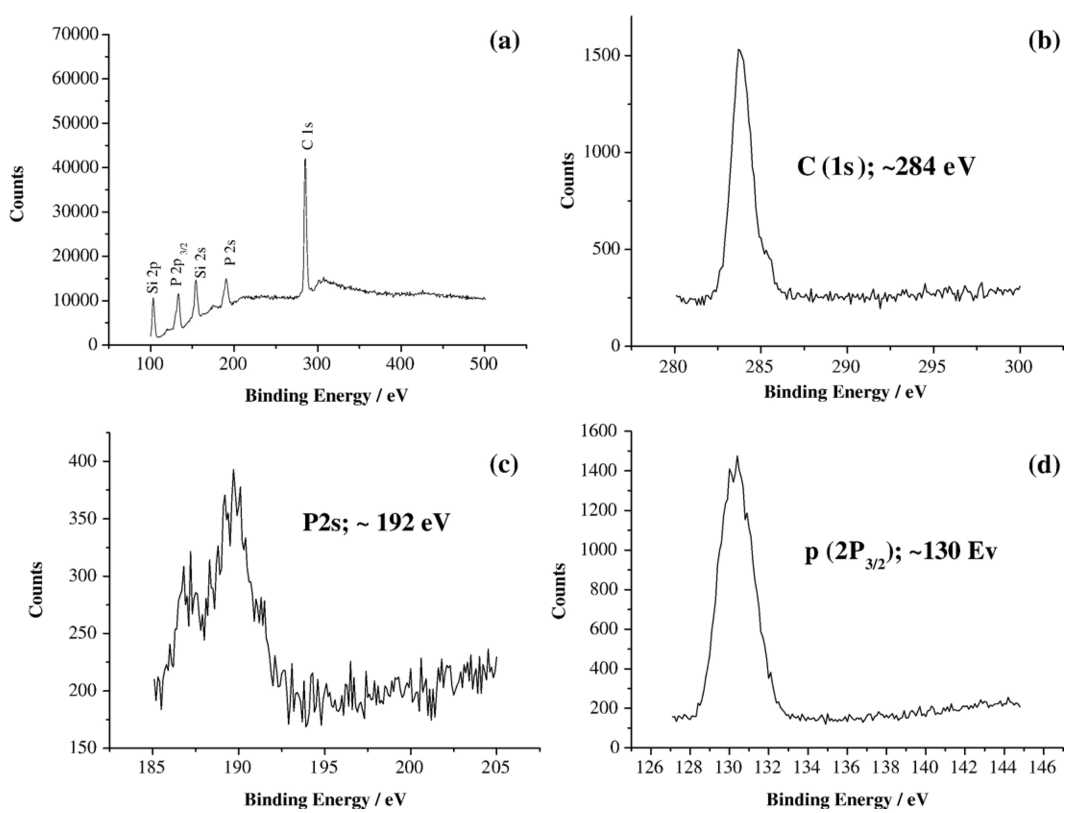

Fig. 2. Typical X-ray photoelectron spectroscopy spectra of the P-DLC films.