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Properties of high power pulsed magnetron sputtering plasmas for deposition of diamond-like carbon films
DLC成膜向け高電力パルスマグネトロンスパッタリングプラズマの特性

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Properties of pulsed magnetron sputtering plasmas and the relationship between the properties of deposited films and the operating conditions of the pulsed plasmas, such as Ar gas pressure and the magnitude of pulsed current, have been experimentally investigated. The maximum of the hardness measured by a nanoindenter increases with the magnitude of pulsed current and reaches 17 GPa at 20 A. On the other hand, with increasing Ar pressure, the hardness of the films decreases from 15-17 GPa at 3mTorr to 9-10 GPa at 20mTorr.

1. Introduction

Physical vapor deposition (PVD) has been widely used as a film deposition method in many industries. High power pulsed magnetron sputtering technology has been attracted, because target species sputtered by energetic ion bombardment are highly ionized and the energy of the ions is high enough to modify the surface of the substrate. [1,2] The magnetron operates at a pressure of 1-20mTorr with a magnetic field of 0.01-0.1T, and the instantaneous power density in the vicinity of the target electrode is on the order of kW/cm^2.

Diamond-like carbon (DLC) films have attracted for material industries because they have unique properties, such as high hardness, low friction, chemical inertness, high wear resistance and optical transparency. Most DLCs have been conventionally deposited by plasma enhanced chemical vapor deposition (PECVD). It is well known that the energetic ions can play a significant role on film growth even in PECVD process.

In this study, the properties of pulsed magnetron sputtering plasmas and the relationship between the properties of deposited films and the operating conditions of the pulsed plasmas, such as Ar gas pressure and the magnitude of pulsed current, are experimentally investigated.

2. Experiments

A schematic diagram of the experiment is shown in Fig.1. The distance between the target (80mm in diameter, carbon material) and substrate is 45mm, and the strength of magnetic field is approximately 0.04T in the vicinity of the target surface. Pulse repetition frequency is about 40Hz and the time-averaged dissipated power is about 40-50W. The film deposition on the silicon substrate is performed for 2-3 hours, so that the film thickness reaches 0.5-0.6 μm.

The electrical measurements are carried out by simultaneously measuring the applied voltage between the electrodes and the current across the discharge. The voltage between the electrodes is divided into 1/1000 using a voltage divider with a bandwidth of 100 MHz, whereas the current is measured using a current transformer (CT) with a bandwidth of 20 MHz. The optical emission measurement system consists of a slit, a fiber bundle, and a monochromator with a charge-coupled device (CCD) array detector. The measured optical emission spectra is line-averaged and time-averaged.

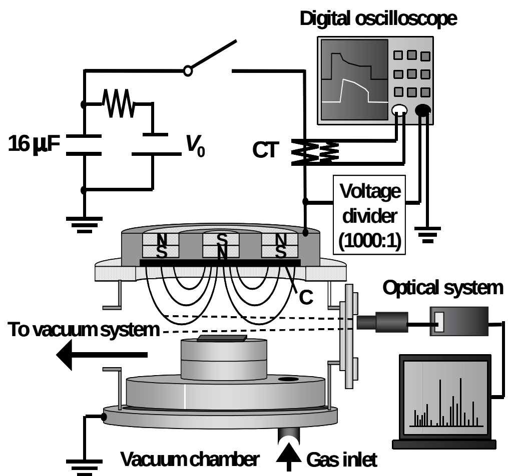

Fig 1 Experimental apparatus

Measurement of film hardness using a nanoindenter is performed up to a depth of approximately 60 nm of the film thickness, where the maximum of the load is around 500 μN. For each indentation, the load versus displacement curve is recorded, and then the film hardness is determined from the curve. Raman spectroscopy is used to obtain the structural information of the deposited films. The Raman spectra are acquired in a range between 1000 and 2000 cm^{-1} and fitted by two Gaussian peaks.

3. Results and Discussions

An example of the voltage-current waveforms is shown in Fig. 2. As shown in Fig.2, the discharge is ignited with the time delay of 20-30 μs after the voltage is applied between the electrodes. Such time-delay was observed at any experimental conditions. The duration of time-delay decreases with the increase in both pressure and applied voltage. In our experiment, time-averaged effective power is 40-50W, whereas the maximum of instantaneous power reaches 10-15 kW.

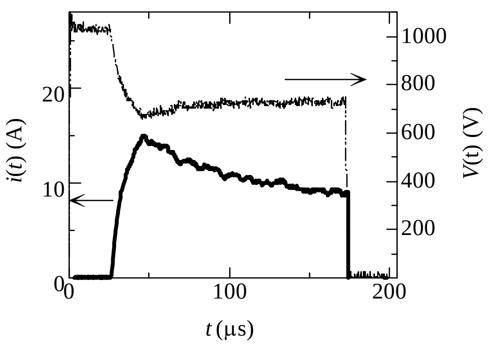

Fig 2 Typical example of voltage-current waveforms, where pressure is 5mTorr.

The optical emission intensities emitted from the excited Ar are predominant. The intensities emitted from CI and CII state cannot be clearly observed at any conditions, because the time-averaged densities of CI and CII state are not so high.

Fig.3 shows the relationship between the hardness and the Ar pressure *p*, whereas the relationship between the hardness and the magnitude of pulsed current is shown in Fig. 4. As shown in Fig.3, with increasing Ar pressure, the hardness of the films decreases from 15-17 GPa at 3mTorr to 9-10 GPa at 20mTorr. On the other hand, the maximum of the hardness measured by a nanoindenter increases with the magnitude of pulsed current and reaches 17 GPa at 20 A. The film hardness deposited at 20A is about two times higher than that deposited by DC magnetron sputtering.

For any deposited films, two, very broad overlapping bands, which are attributed to the G (graphite) and D (disorder) peaks, are clearly observed in the Raman spectra. Typical example of Raman spectroscopy is shown in Fig.5.

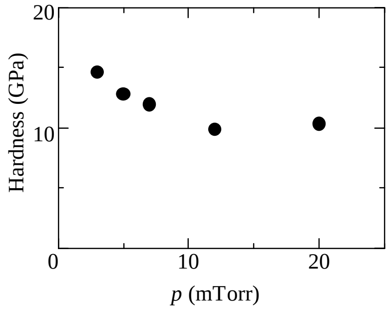

Fig 3 Relationship between the hardness and *p*, where the magnitude of current is 12A.

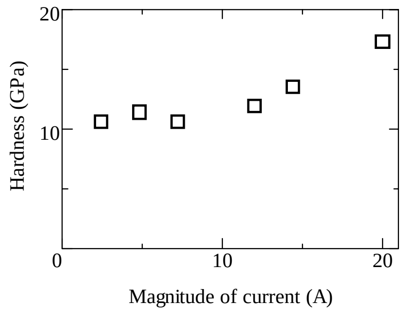

Fig 4 Relationship between the hardness and the magnitude of current, where *p*=5mTorr.

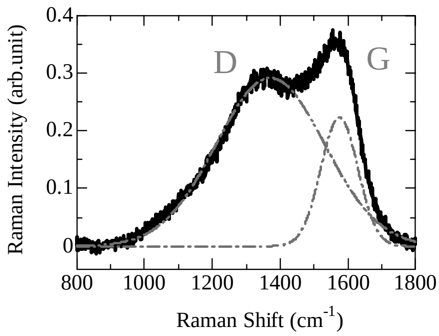

Fig 5 Typical example of Raman spectroscopy, where magnitude of current =17A and *p*=5mTorr.

Acknowledgments

This work is partially supported by Grant-in-Aid from the Japan Society for the Promotion of Science.

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