Evaluation parameter in HiPIMS method: proposal of tail time

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Abstract: We propose the tail time as an evaluation parameter for the HiPIMS method. First, we show an example of evaluating the film density of DLC films using the conventional evaluation parameter, peak discharge current. Next, we evaluate the film density using the proposed tail time and demonstrate its effectiveness as an evaluation parameter. Finally, we use the tail time to evaluate carbon bonding using Raman spectroscopy, and demonstrate its usefulness as an evaluation parameter.
Keywords: HiPIMS, DLC, X-ray reflectivity, Raman spectroscopy

1. Introduction

HiPIMS (High-Power Impulse Magnetron Sputtering) is a thin film-forming technology that inputs high power into single pulses, and is effective for enhancing the performance of DLC (Diamond-Like Carbon) films [1]. Evaluation parameters for this HiPIMS method have traditionally included peak discharge current, negative cathode applied voltage, and peak power density. However, when peak discharge current is large, there may be examples where correlation with film characteristics is lost, and it is possible that previous evaluation parameters have not correctly evaluated the film characteristics [2]. Therefore, we focused on the fact that HiPIMS discharge is an impulse discharge, and applied the definition of "tail time" of lightning impulse voltage waveform to the discharge current [3]. We attempted to use this tail time as an evaluation parameter. Therefore, we report on the relationship between the tail time and film characteristics of DLC film formation using the HiPIMS method.

2. Experimental setup

The HiPIMS method used the HF (High Frequency)-HiPIMS method that our research group is researching and developing [4]. The experimental conditions were as follows: a carbon target 3 inches in diameter and 5 mm thick was used. Silicon (100) substrates were used. The target-to-substrate distance was 100 mm, and the substrate was rotated at 5 rpm during deposition. The argon (Ar) gas flow rate was 5 sccm, the operating pressure was 0.5 Pa, and the DLC film was formed for 2 hours. Fig. 1. Shows the pulse waveform of applied voltage. The pulse conditions were as follows: the frequency was 200 Hz, the negative voltage was −780 V to −870 V, the bias voltage was floating (OFF), the pulse duration at negative voltage was 20 µs (T1 pulse), the pause period was 10 µs (T2 pulse), the pulse duration at negative voltage was 50 µs (T3 pulse), and 3 µs pulses were turned ON/OFF 6 times (T4 pulse, T5 = T6 = 3 µs).

The discharge current and voltage were measured using a current probe, current probe amplifier, and voltage probe connected to a digital oscilloscope. The film characteristics were evaluated using X-ray reflectivity (XRR) and Raman spectroscopy. The Raman spectrum obtained by Raman spectroscopy was separated into five bands (N : 1232 cm^{-1}, D : 1339 cm^{-1}, G^- : 1442 cm^{-1}, G^+ : 1542 cm^{-1}, D': 1621 cm^{-1}) using the Voigt function [5].

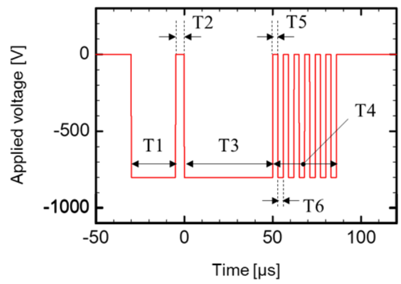

Fig. 1. Pulse waveform of applied voltage.

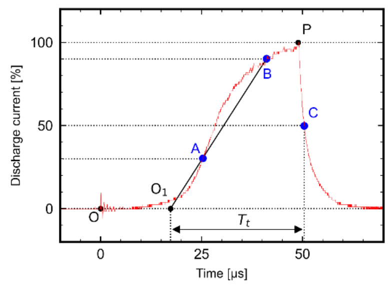

Fig. 2. Discharge current waveform with the definition of tail time applied to the discharge current.

Fig. 2 shows the discharge current waveform with the definition of tail time applied to the discharge current. The point P is the maximum value of the waveform. Points A and B are the 30% point P and 90% point P, respectively, and the intersection of the line connecting these points and the time axis is point O_1. Point C is the 50% point P, and the time between point O_1 and point C is the tail time (T_t).

3. Results and discussion

Fig. 3 shows the relationship between peak discharge current and film density. The film density of the DLC film showed an increasing trend in the range of peak discharge current from 0 to 55 A, and a decreasing trend in the range of 55 to 120 A. Furthermore, as reported in previous study [2], it was confirmed that when the peak discharge current

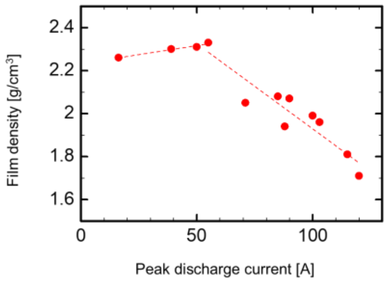

Fig. 3. Relationship between peak discharge current and film density.

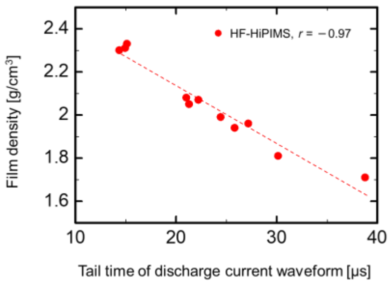

Fig. 4. Relationship between tail time and the film density.

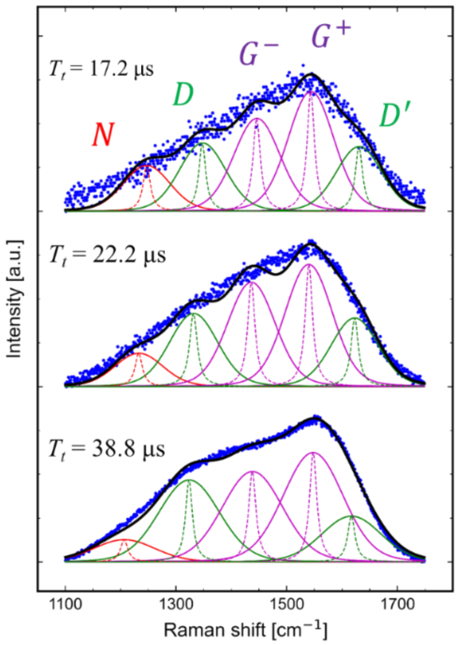

Fig. 5. Raman spectra.

is large, there is no correlation with the film characteristics. Fig. 4 shows the relationship between the tail time and the film density. The tail time shows a negative correlation with the film density, suggested that the film density can

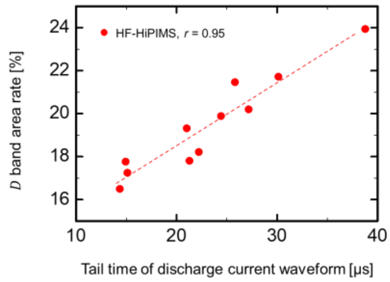

Fig. 6. Relationship between tail time and *D* band area ratio.

be controlled by the tail time. When the tail time is short, the discharge current waveform has a sudden rise and fall, meaning that the impulse of the discharge current waveform is strong. The tail time is part of the name of the HiPIMS method, "impulse", it suggests that the evaluation of the film density by impulse waveform and tail time is effective.

It is known that the film density of DLC films is correlated with carbon bonding in the film [1]. Therefore, we evaluated the carbon bonding of DLC films using Raman spectroscopy. Fig. 5 shows the Raman spectrum. The broken line in Fig. 5 indicates the components of the Lorentz function. In this study, we focused on the *D* band area ratio. Fig. 6 shows the relationship between the tail time and the *D* band area ratio. According to reports of DLC Raman spectra due to differences in film formation methods, the weaker the ion assistance, the stronger the *D* band intensity [5]. It was found that as the tail time increases, the *D* band area ratio also increases. Therefore, when the tail time is small, it is suggested that the ion assistance is strong. Furthermore, it was revealed that the tail time can be applied to the evaluation of carbon bonding.

4. Conclusion

We proposed the tail time as a new evaluation parameter for the HF-HiPIMS method. As a result, it was found that the tail time can be applied to the evaluation of film density and carbon bonding of DLC films formed by the HF-HiPIMS method.

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