Negative Bias Effects on Mechanical Properties of Ultrananocrystalline Diamond on Cemented Carbide Substrate Prepared by Coaxial Arc Plasma Deposition

Ali, Ali M.
Dept. of Applied Science for Electronics and Materials, Kyushu University | Dept. of Physics, Al-Azhar University

Egiza, Mohamed
Dept. of Applied Science for Electronics and Materials, Kyushu University | Dept. of Mechanical Engineering, Kafrelsheikh University

Murasawa, Koki
OSG Corp.

Fukui, Yasuo
OSG Corp.

他

https://doi.org/10.15017/1961292

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 4, pp.88-89, 2018-10-18. 九州大学大学院総合理工学府
バージョン：
権利関係：

Negative Bias Effects on Mechanical Properties of Ultrananocrystalline Diamond on Cemented Carbide Substrate Prepared by Coaxial Arc Plasma Deposition

Ali M. Ali[1, 2], Mohamed Egiza[1, 3], Koki Murasawa[4], Yasuo Fukui[4], Hidenobu Gonda[4], Masatoshi Sakurai[4], and Tsuyoshi Yoshitake[1]
[1] Dept. of Applied Science for Electronics and Materials, Kyushu University, Kasuga, Fukuoka, 8168580, Japan,
[2] Dept. of Physics, Al-Azhar University, Cairo 11884, Egypt,
[3] Dept. of Mechanical Engineering, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
[4] OSG Corp. 2-17 Shirakumo-cho, Toyokawa, Aichi 442-0018, Japan.
abdelgawad_ali@kyudai.jp

Abstract: *Ultrananocrystalline diamond (UNCD)/amorphous carbon (a-C) composite (UNCD/a-C) films were deposited on cemented carbide (WC-Co) substrates, which were pulsed-biased at a voltage of –100, -500 volt, by coaxial arc plasma deposition. The film were deposited at a thickness of 9 µm, which is more than an order of magnitude more than that of comparably hard diamond like carbon films deposited by arc ion plating deposition and three time thicker than the UNCD/a-C film deposited without negative bias voltage. In addition, the deposition rate evidently increased under the negative bias. This might be because the negative bias voltage enhances the attraction of positively charged carbon species from the plasma to the substrates, which results in enhanced film adhesion on the substrates and the release of film internal stresses. In this work, effects of negative bias voltage on the mechanical properties of UNCD/a-C films prepared by CAPD, for the first time, were investigated.*

Keywords: Ultrananocrystalline diamond; hard coating; coaxial arc plasma; negative bias.

1. INTRODUCTION

Ultrananocrystalline diamond (UNCD) /amorphous carbon (a-C) composite (UNCD/a-C) films are new candidates applicable to hard coating because of the high hardness, extremely smooth film surface and large film thickness. Various methods have been employed for depositing UNCD/a-C films. Although microwave plasma assisted chemical vapor deposition (CVD) [1] and hot filament CVD [2] are representative methods, the deposition time of more than 10 hrs for several micrometers deposition due to low deposition rates. The deposition rate of CAPD is at least two orders of magnitude higher than that of CVD.

In our previous studies, we realized the formation of 51 GPa hardness for UNCD/a-C films on cemented carbide (WC-Co) substrates by CAPD, without applying negative bias to substrates [3]. The maximum thickness is limited to 3 µm, and the adhesion strength at interfaces between the substrates and films is not so large, as compares with that of hard DLC film. Moreover, all deposited DLC films were limited to the thickness range of a few hundred nanometers. This is mainly caused by an enormous internal stress and poor adhesion. For the application to hard coating for cutting tools, the maximum thickness to be deposited, the internal stress should totally be well reduced.

In this work, to improve the film thickness and deposition rate of UNCD/a-C films, negative bias voltages were applied to the substrates during the deposition. Since the application of the negative bias onto the substrates enhances the kinetic energies of ionized species, an improvement in the mechanical property of resultant films is expected. The aim of this work is to study the negative bias effects on the mechanical properties of UNCD films for the purpose of the enhancement of the mechanical properties.

2. EXPERIMENTAL PROCEDURES

UNCD/a-C films were deposited on negatively-biased WC-Co substrates at base pressure of less than 10^{-4} Pa by CAPD with a graphite target, as shown in Fig. 1 (a). A voltage of 100 V was applied to the arc plasma gun equipped with a 720 µF capacitor. The repetition rate of discharges was 1 Hz. The substrate holder was biased at – 100, -500 volt in pulse with a pulse duration of 8.7 µs. The substrate voltage and the current flowing from the substrate to the ground were measured by Tektronix probes during the film deposition. To estimate the film thickness, the film fabricated on WC-Co substrate and covered with rectangular–shape mask, and the thickness of the film was estimated using (KMLA-Tencor Alpha-step IQ surface profile) at edge-steps between the film and substrate as show in Fig. 1 (b). In addition, the thickness was also evaluated from cross-section SEM images.

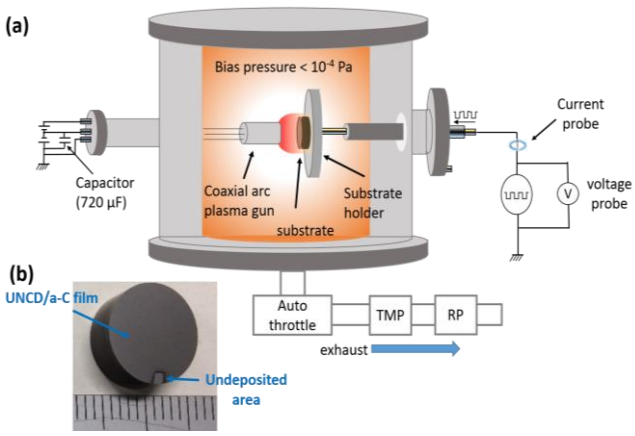

Fig. 1. (a) Schematic diagram of CAPD apparatus, and (b) optical image of UNCD/a-C film deposited on WC–Co substrate.

3. RESULTS AND DISCUSSION

The substrate voltage and current measured between the substrate and the ground at different negative bias applied voltages are illustrated in Fig. 2. Due to the high-density plasma and low capacity of negative bias power supply, the applied voltage immediately saturates. Owing to these characteristics, the substrate voltage is not increase with increasing the applied voltage by negative bias power supply from – 100 to – 500 volt. This constant substrate voltage results in limiting the current that flows from the substrate to ground.

The deposition rate as a function of the substrate voltage is shown in Fig. 3. The deposition rate increase with applying the negative voltage on the substrate. The negative bias should naturally electrically attract positively charged carbon species to the substrates, which results in an increase the deposition rate. The film thickness is increased to be approximately 9 μm without the film being peeled off from the substrates, as shown in Fig. 4. This might imply that the negative bias plays a role of reducing the internal stress of the films.

According to a grain boundary mismatch model (GBM) and an ion-peening model (Ion-P.) [4], which describe the residual stress as a function of the ion energy [5], films have high densities and compressive stresses for the deposition of high ion energies as show in Fig. 5. However, if the ion energy reach exceed some threshold, the compressive stress is inversely changed for the negative bias [6]. For a reason for the increase film thickness at which the films are not peeled off from the substrates, we supposes that the carbon ion energy reach the threshold in the models by applying the negative bias.

4. Conclusion

UNCD/a-C films were deposited on negatively biased cemented carbide (WC-Co) substrates by coaxial arc plasma deposition. It was found that the negative bias is effective for depositing UNCD/a-C films with a large thickness and high deposition rate. The substrate voltage did not response to the variation of the bias voltage, which applied by negative bias power supply, due to the high density of arc plasma. High intensity of substrate current represent the density of positively charged carbon ions which deposited on the substrate surface.

5. Acknowledgement

This research was partially supported by Osawa Scientific Studies Grants Foundation and JST A-STEP (Grant No. AS2511118 M).

6. REFERENCES

[1] X. Chen, J. Narayan, JJAP 74, 4168 (1993).
[2] Tang, Y., Li, Y. S., Yang, Q., & Hirose, A. Diamond and Related Materials, 19(5-6), (2010) 496-499.
[3] K. Hanada, T. Yoshitake, T. Nishiyama, and K. Naga- yama, Jpn. J. Appl. Phys., 49, 08JF09 (2010).
[4] Hoffman, R. W., Thin Solid Films 34.2 (1976): 185-190.
[5] N. Woehr. Diamond Related Material 16 (2007) 748.
[6] Anders, A., Anders, S., Brown, I. G., Dickinson, M. R., & MacGill, R.A. Vac. Sci. Tech. B12 (1994) 815.

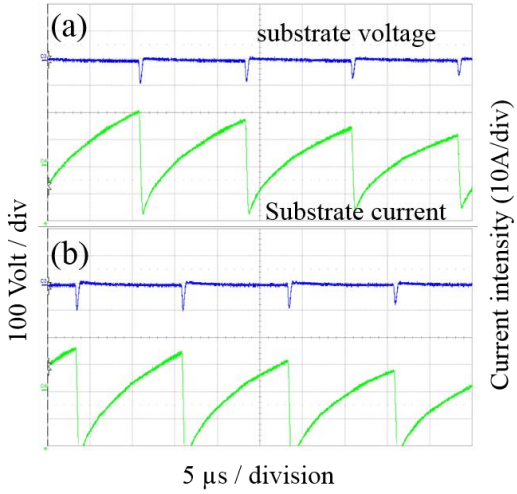

Fig. 2. Substrate voltage and electric current measured between substrate and ground at bias voltages of (a) –100 V, (b) –500 V.

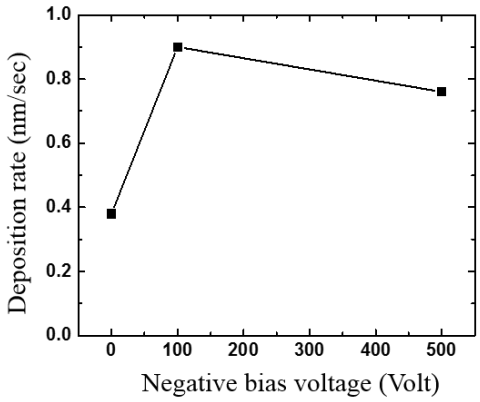

Fig. 3. Deposition rate as a function of negative bias voltage.

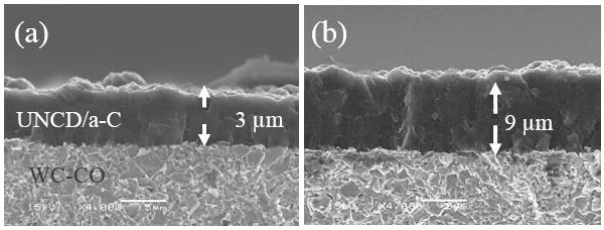

Fig. 4. Cross-section SEM images of UNCD/a-C films deposited (a) with and (b) without negative biases.

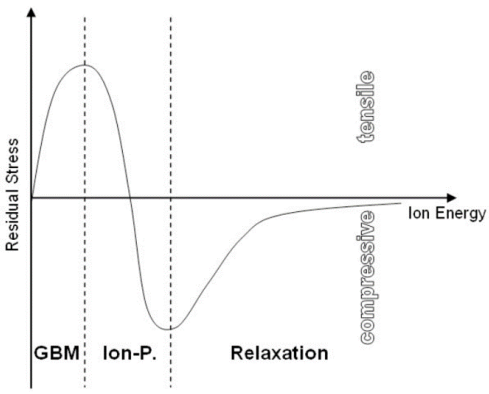

Fig. 5. Change in residual stress against ion energy based on grain boundary mismatch model (GBM) and ion-peening model (Ion-P.)