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SURFACE MORPHOLOGY OF SPUTTERED TITANIUM-ALUMINUM-NITRIDE COATINGS

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ABSTRACT

A study on the surface morphology of sputtered TiAlN coatings is presented. The coatings were deposited by DC magnetron sputtering on tungsten carbide insert tools. The surface morphology was characterized by using Atomic Force Microscopy (AFM), and the surface roughness was indicated by RMS roughness value. It was observed that the TiAlN coating surface morphology was rough as the negative substrate bias and nitrogen flow rate are increased. The evolution of the sputtered TiAlN coatings surface morphology was due to the competition between particle diffusion and re-scattering effect during the sputtering process. At high negative substrate bias and nitrogen flow rate, the re-scattering effect was prominent, leading to the high roughness of the sputtered TiAlN coating surface.

Keywords: TiAlN coating, surface morphology, sputtering, substrate bias, nitrogen flow rate

INTRODUCTION

Surface properties of sputtered TiAlN thin film (coating) are critical properties that influence the coating application performance, such as wear-resistance [1]. The surface properties in terms of surface energy relate to the surface roughness and adhesive behavior, which contributes to the tribological applications. It was revealed that the surface pattern of sputtered TiAlN coating effectively reduced the adhesive and abrasive wear at elevated temperatures [2]. Furthermore, the best tribology and mechanical properties of sputtered TiAlN coatings were attributed to its surface roughness and texture [3-5]. The surface morphology of the sputtered TiAlN coating also relates to other properties such as crystal structure and composition [6-8]. TiAlN coatings surface formed a columnar morphology in which the columns are separated by the void and grain boundaries. The coating morphology change as the coating crystal is growth, and it can be controlled during the sputtering process, such as bias voltage and nitrogen flow rate [3,9,10]. Thus, the study in controlling sputtered TiAlN coating surface morphology during the sputtering process is required to optimize the coatings application performance. In the present study, the influence of substrate bias and nitrogen gas flow rate on the surface morphology of sputtered TiAlN coatings are discussed.

METHOD

TiAlN coatings were deposited on tungsten carbide (WC) SPGN12030 insert tool (as substrate) by using reactive DC magnetron sputtering. TiAl alloy (50:50) was used as a target material in the sputtering process. The substrate was prepared by ultrasonically cleaning at room temperature in ethanol solution for 30 minutes. Prior deposition, the substrate surface was etched by using argon (Ar) ion bombardment with Ar gas flow rate of 180 sccm and substrate bias of -300 V for 30 minutes. TiAl interlayer was deposited to improve the adhesion strength of TiAlN coatings, at Ar gas flow rate of 123 sccm and the substrate bias of -100 V for 10 minutes. The deposition was performed in an Argon-nitrogen mixture at an Ar gas flow rate of 123 sccm, a target current of 5 A, and a substrate temperature of 350 ^{0}C for 90 minutes. The pump speed was maintained at 2050 l/s to keep an ultimate chamber pressure of 5 x 10^{-5} mbar. The coating surface morphology was characterized by using Atomic Force Microscopy (AFM) with Veeco Dimension V scanning probe microscopy technique in which the images were obtained from 25 μm^2 top areas of the coating surface.

RESULT AND DISCUSSION

The surface morphology of sputtered TiAlN coatings is identified by using Root Means Squares (RMS) roughness. Previous reports on the surface morphology of sputtered TiAlN coating in three-dimensional images of AFM have been published [11,12]. In this paper, two-dimensional images of AFM were presented. The substrate bias and nitrogen flow rate effect on the coating surface morphology at various nitrogen flow rates is given by two-dimensional images of AFM as shown in FIGURE 1 and FIGURE 2, respectively. The results are summarized in TABLE 1. It shows that surface roughness tends to increase as negative substrate bias and the nitrogen flow rate is increased up to above -150 V and up to 58 sccm, respectively. At low substrate bias (-100 and -150 V), the RMS coating surface roughness tends to decrease as an increasing nitrogen flow rate up to 60 sccm.

The decrease of RMS surface roughness of sputtered TiAlN coatings as increasing negative substrate bias is due to the increase of coatings density, and it causes the smoother coating surface morphology. At high negative substrate bias, the number of large particles on the coating surface decreased led to a clean and smooth surface [9]. When the substrate bias is high, the surface diffusion process is prominent; thus, the solid solution particles of the coating are diffused and linked together, causing the decrease of coating surface roughness [13]. Meanwhile, [3] observed that at high voltage bias, the coating roughness was increased due to the increase of the ion bombardment. Similar to this study, the surface roughness of TiAlN coatings increased as the negative substrate bias was increased. The rough coating surface morphology of sputtered TiAlN is related to the increase in residual stress resulted from the grain growth of coating crystal. At high negative substrate bias and nitrogen flow rate, the coating surface roughness increases due to the increase of crystal size and residual stress [9,14,15].

The surface morphology of sputtered TiAlN coating is composed of the columnar crystallite which the columns are separated by porosity on the grain boundary [6,10,16]. The individual columns of coating surface morphology are eliminated on the top by tetragonal pyramids indicates a NaCl-Type of TiAlN crystal lattice [17]. It was found that the coating surface roughness of sputtered TiAlN coating also depends on the amount and the size of the coating porosity [18]. The re-nucleation process interrupts the columnar growth repeatedly. At further increasing substrate bias, the columnar structure of the coating surface changes to the granular structure [19]. The granular structure composed of small crystals size indicating the growth disturbance and frequent re-nucleation due to the ion bombardment process during deposition [3].

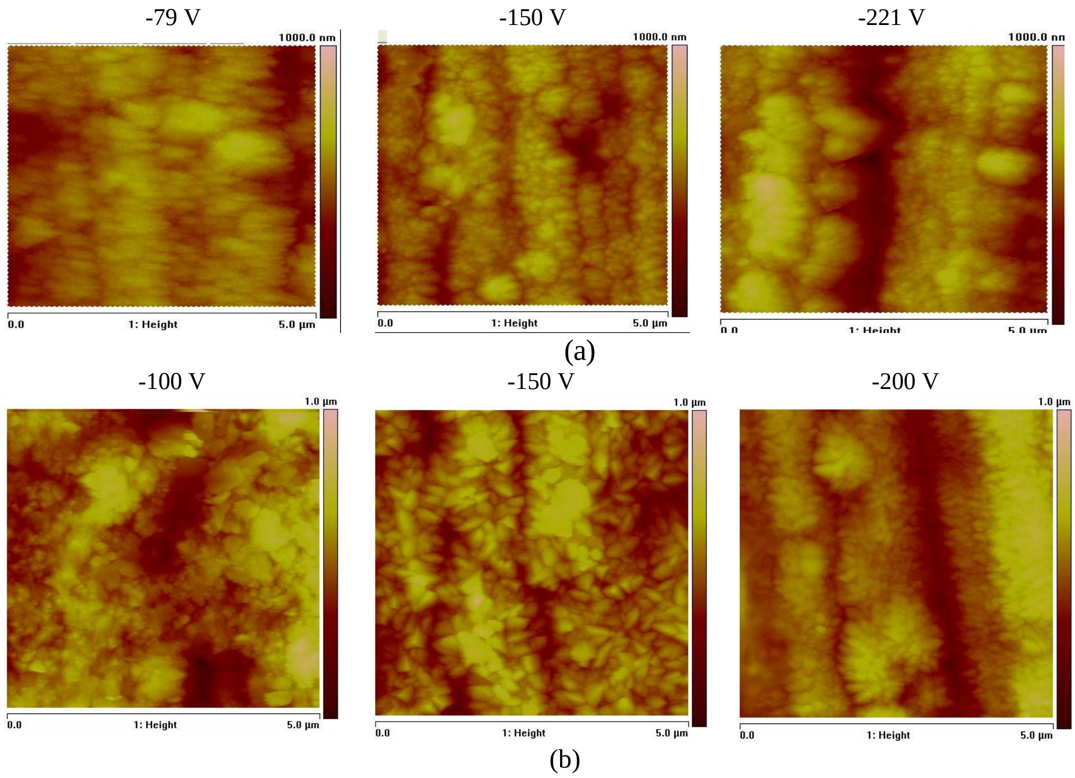

FIGURE 1. The surface morphology of sputtered TiAlN coatings at snitrogen flow rate of (a) 65 sccm (b) 30 sccm.

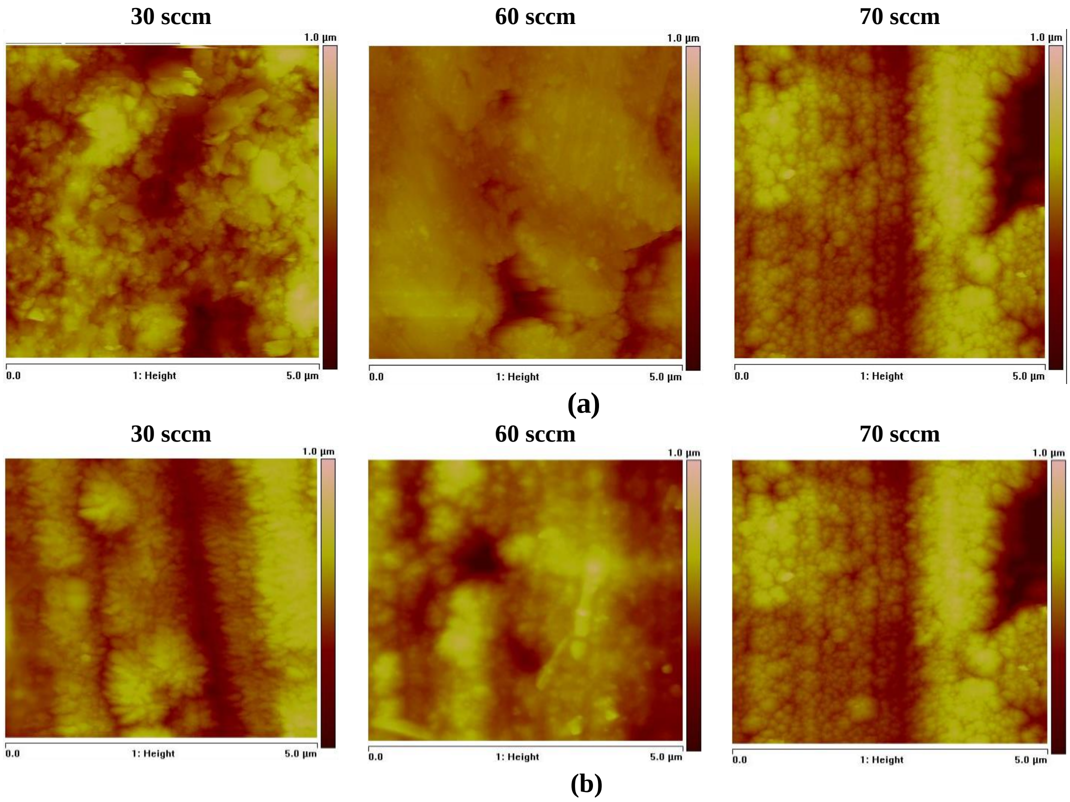

FIGURE 2. The surface morphology of sputtered TiAlN coatings at substrate bias of (a) -100 Volt (b) -200 Volt.

It was observed that the RMS surface roughness of sputtered TiAlN coating decreased with increasing nitrogen flow rate [7,10]. At a higher nitrogen flow rate, the sputtered TiAlN coating surface becomes denser and finer. However, this experiment's result showed that the RMS roughness of the TiAlN coating surface increases with an increase in the nitrogen flow rate. Three-dimensional models of RMS roughness of sputtered TiAlN coating as a function of negative substrate bias and nitrogen flow rate is shown in FIGURE 3.

The surface morphology of sputtered TiAlN coating is influenced by the kinetic energy of incident particles onto the substrate, and this energy can be raised by increasing negative substrate bias [11,12]. At high negative substrate bias, the coating roughness was high due to the re-scattering effect of incident particles [20]. The effect is prominent when the deposition pressure is high lead to the reduction of the kinetic energy of the sputtered particles. The low kinetic energy of incident sputtered particles produce the columnar morphology of the coating surface, which is separated by voids. This morphology formation is attributed to the low ability of incident sputtered particles in moving onto the surface coating. The effect will increase the surface roughness of the coating [12,21]. However, when the kinetic energy of incident sputtered particles is high, then the ability of incident sputtered particles to diffuse, in a mode of biased and athermal diffusion, onto the surface coating is high [12]. Therefore, in this study, at a high negative substrate bias and nitrogen flow rate, the roughness of the sputtered TiAlN coatings surface is enhanced due to the increase of the re-scattering effect.

TABLE 1. RMS surface roughness of sputtered TiAlN coatings

No	Substrate bias (-Volt)	Nitrogen flow rate (sccm)	RMS roughness (nm)
1	150	65	106
2	150	58	50.1
3	200	70	149
4	150	65	134
5	100	60	62
6	150	65	91.9
7	150	65	79.9
8	221	65	123
9	150	72	73.2
10	79	65	84.2
11	200	60	111
12	100	70	106
13	150	65	99.1

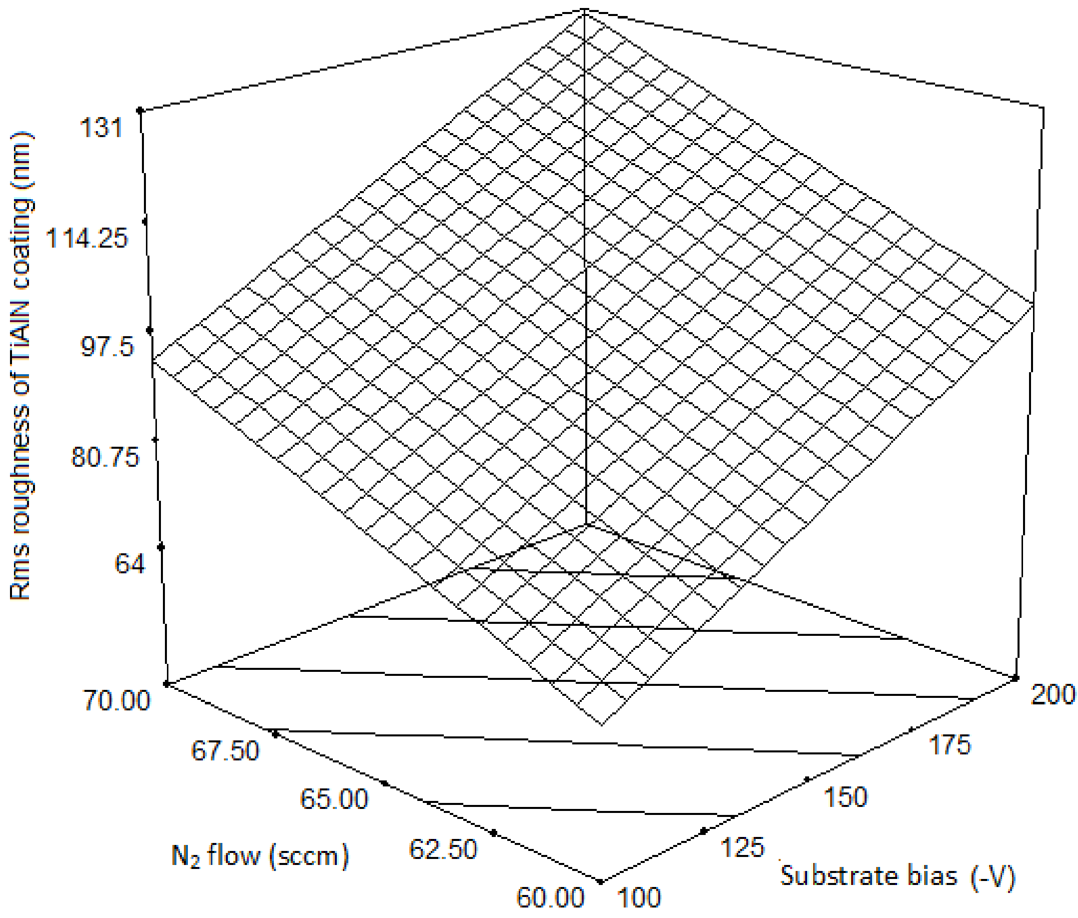

FIGURE 3. Three dimension graph of RMS roughness of sputtered TiAlN coatings as a function of negative substrate bias and nitrogen flow rate fall.

CONCLUSION

The surface morphology of sputtered TiAlN coatings depends on the negative substrate bias and nitrogen flow rate. The high surface roughness at high negative substrate bias and nitrogen flow rate is due to the re-scattering effect during the sputtering process. This effect reduces the kinetic energy of incident particles and particle diffusion that leads to an increase in surface roughness due to the formation of columnar morphology.

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