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ScienceDirect
Surface & Coatings Technology 201 (2006) 4266–4272
SURFACE & COATINGS TECHNOLOGY
www.elsevier.com/locate/surfcoat

Tribological behavior of CrN/WN multilayer coatings grown by ion-beam assisted deposition

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Available online 8 September 2006

Abstract

CrN monolayer coating and CrN/WN multilayer coatings were deposited on the silicon (100) substrate by ion-beam assisted deposition process. The bilayer period of these coatings was controlled at 8 nm and 30 nm. The cross-sectional morphology of nanoscaled multilayer coatings was characterized by scanning electron microscopy and transmission electron microscopy. The wear resistance of CrN/WN multilayer coatings and CrN monolayer coating was investigated using a pin-on-disc tribometer. The surface roughness (Ra) of the coatings was evaluated by atomic force microscopy, and that of CrN and WN monolayer coating was 6.7 and 5.9 nm, respectively. The employment of multilayer configuration in CrN/WN coating with bilayer period of 8 nm and 30 nm effectively reduced the surface roughness down to 1.9 and 2.2 nm, respectively. The friction coefficient of CrN monolayer coating and CrN/WN multilayer film with a bilayer period of 30 nm was 0.63 and 0.31, respectively. Owing to the high hardness/elastic modulus ratio, as well as the dense structure and the smooth surface roughness, the CrN/WN multilayer coatings exhibited better wear resistance in the consideration of friction coefficient and the worn surface morphology.

Keywords: CrN; CrN/WN; Pin-on-disc; Wear; Nanolayer; Hardness

1. Introduction

Transition metal nitrides have been used extensively for the deposition of hard protective coating in the past [1,2] mainly because of their excellent hardness, wear and corrosion resistance. Especially, chromium nitride (CrN) films have been investigated for years, and proved to exhibit favorable mechanical performance, thermal properties and anti-oxidation behaviors [3,4]. Recent studies also revealed that multilayer coatings composed of two kinds of transition nitride films showed much superior mechanical strength, hardness, adhesion, oxidation and wear resistance, as compared to single layer nitride coating due to their specific structures and interfaces [5–8]. Several new material systems, including TiN/NbN, TiN/AlN, CrN/AlN and CrN/TiN, exhibited proven enhancement of microhardness [8–11]. The enhanced hardness could be explained by dislocation blocking between interfaces, due to the shear moduli difference, and by coherency strain from lattice mismatch of the two different material systems [12]. Furthermore, it has also been evidenced that nanoscaled multilayer coatings showed better wear properties than single-layer coatings [13,14]. In this study, the combination of chromium nitride and tungsten nitride coating was prepared to form a nanostructured coating system. The difference of wear resistance between CrN/WN multilayer coatings and CrN monolayer coating was investigated using a pin-on-disc tribometer. The microstructure of CrN/WN multilayer coatings with different bilayer periods were analyzed by SEM and TEM. The tribological behavior of CrN monolayer coating and CrN/WN multilayer film was examined for their wear and friction.

2. Experimental procedure

CrN and WN single layer coatings and CrN/WN multilayer coatings were fabricated on the silicon (100) substrate by ion-beam assisted deposition (IBAD). Both chromium and tungsten target of 76.2 mm in diameter were 99.99 wt.% in purity. After loading of the substrates and targets, the vacuum chamber was degassed down to 2.1×10^{-4} Pa, followed by the inlet of argon and nitrogen gases as plasma source and reactive gas, respectively, to a working pressure of 1.2×10^{-1} Pa. The target-to-

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0257-8972/$ - see front matter
doi:10.1016/j.surfcoat.2006.08.078

substrate distance was fixed at 100 mm from sputtering target sources and ion gun. Before deposition, both chromium and tungsten targets were pre-sputtered for 2 min to clean the target surface, and then a Cr interlayer was deposited with a power of 300 W for 2 min. An assisted ion source with electron neutralizer (Mark II Gridless ion source, Veeco) was adopted during sputtering. The current of assisted ion beam and electron beam were 4.0 and 2.7 A, respectively. The voltage of assisted ion beam and electron beam were 45.3 and 18 V, respectively. Sputtering of Cr and W was proceeded alternately to form the sequential CrN/WN multilayer coating. Both the input power on Cr and W target were fixed at 300 W. The deposition time of individual nitride layer of the multilayer CrN/WN coating during sequential sputtering was modulated from 22 to 93 s. The total thickness of CrN/WN multilayer films was controlled around 1.0 μm. The wear resistance of CrN/WN multilayer coatings and CrN, WN monolayer coatings was investigated using a pin-on-disc tribometer equipped with a WC ball ($\phi=5$ mm). The rotational speed used in the experiments was 100 rpm, and the applied load was 2 N. Relative humidity of air was about 70%.

The coating thickness, cross-section image and X-ray mapping were observed with a field emission electron probe microanalyzer (FE-EPMA, JXA-8500F, JEOL, Japan). A transmission electron microscope (HRTEM, JEM-2010, JEOL, Japan) was employed to investigate the detailed microstructure of the nanostructured coatings. The surface morphologies were examined by atomic force microscopy (AFM, DI-3100, Digital instrument, USA). The microhardness and Young's modulus of the coatings were analyzed with a nanoindentation apparatus (TriboScope, Hysitron, Minneapolis, MN) equipped with a Berkovich indenter under a maximum load at 5000 μN.

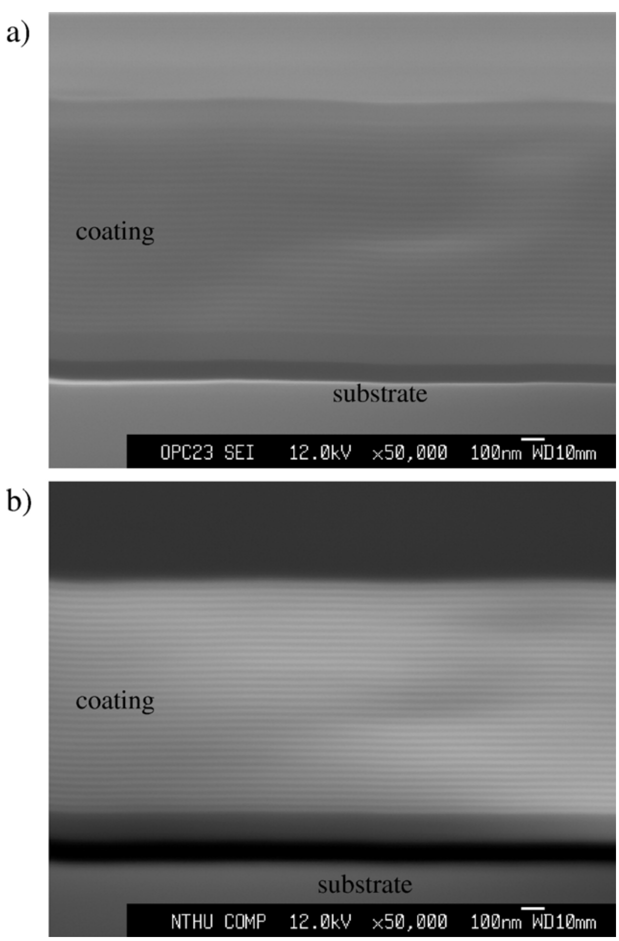

Fig. 1. The cross-section SEM micrographs of (a) SEI and (b) BEI modes for CrN/WN multilayer coating with bilayer period of 30 nm.

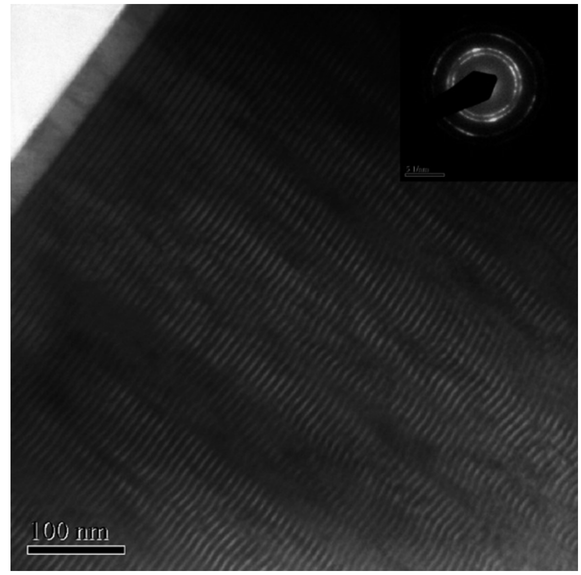

Fig. 2. TEM image and the selected area electron diffraction pattern of CrN/WN multilayer coating with bilayer period of 8 nm.

3. Results and discussion

3.1. Characterization

The CrN/WN multilayer coatings were fabricated with a total thickness of about 1.0 μm by IBAD process. The bilayer period was adjusted by controlling the deposition time of individual nitride layer. The cross-section SEM images in secondary electron image (SEI) and backscattered electron image (BEI) modes of CrN/WN multilayer coating with bilayer period of 30 nm are shown in Fig. 1a and b, respectively. Above the silicon substrate, there was a chromium interlayer with thickness of 100 nm for adhesional reason. It was found that the multilayer coating was composed of a layered configuration, stacking of one darker and another lighter nanolayer alternately. The bright layers were CrN, while the darker layers were WN. The thickness of CrN and WN single layer was 15 nm each. The total multilayer film thickness, composed of 67 layers, was around 1.0 μm. It was evident that smooth and dense coating configurations were developed by IBAD process. In the literature, it was found that the CrN deposit revealed a strong columnar structure [15]. The difference of mechanical property behavior between CrN and CrN/WN multilayer coatings may be ascribed to the cross-sectional structural variation. The com\-positional contrast shown by BEI image in Fig. 1b revealed a sharper layered configuration of CrN/WN multilayer coating with bilayer period of 30 nm.