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Properties of nano-multilayered hard coatings deposited by a new hybrid coating process: Combined cathodic arc and unbalanced magnetron sputtering

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Abstract

Nano-scale multilayered coatings of (Ti,Al)N/SiN, (Ti,Al)N/WN, and CrN/BCN were deposited by a new hybrid coating process that combined cathodic arc and unbalanced magnetron sputtering (UBM). Cross-sectional transmission electron microscopy (TEM) analysis of the coatings deposited by the hybrid process revealed that these coatings had a multilayer structure in that layers deposited by the arc source and the sputter source were stacked alternatively. The bilayer period of the multilayer system was the function of the substrate rotation speed and the input power to the each evaporation source, and it was typically in the range of 10–20 nm. From X-ray diffraction measurements, in case of Si or B_4C target used as a sputter target, the grain size was drastically decreased from 30 to 10 nm as the evaporation rate of the sputter source was increased. We confirmed from TEM observation that the grain growth of the (Ti,Al)N or CrN layer was interrupted at the interface and this resulted in much smaller grain size compared to the conventional (Ti,Al)N coating. Mechanical and tribological properties of different nano-multilayered coatings are discussed.

Keywords: Hybrid coating process; Cathodic arc; Unbalanced magnetron sputtering; Nano-multilayer; Cutting performance

1. Introduction

For more than a decade, cathodic arc evaporation has been widely used to deposit various kinds of refractory and wear-resistant coatings such as (Ti,Al)N [1–3] and its variants [4–6] for cutting tools, and CrN [7–9] coatings for automotive applications. The cathodic arc evaporation process is characterized by a combination of a high deposition rate and a high degree of ionization of evaporated species, which makes this process a versatile deposition technology for many industries [10]. Due to the nature of the high-current vacuum arc discharge, however, only target materials with good electroconductivity can be used as evaporation sources. Also materials with a too high or low melting point or poor mechanical strength cannot be used.

On the other hand, the sputtering process has less restrictions concerning the target material. Various kinds of materials, which are hard to use in the arc process, are usable in the sputtering process. One of the drawbacks of the sputtering process for the deposition of hard coatings is its low ionization ratio, which is in the range of a few percents. However, recently, this has been amended by the introduction of unbalanced magnetron sputtering (UBM) [11] or high power impulse magnetron sputtering (HIPIMS) [12], which enhances plasma irradiation during the deposition or ionization of sputtered species.

Recently, more complex coatings in composition and structure such as nano-composite coatings [13,14] and multilayer coatings [15] have been under development to increase the service life of the coated tools and machine parts. Considering this situation, combining the arc and the

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sputtering process can be a way to enhance the possibility of depositing a coating system with a more complex structure and composition for improved performance. For example, we previously reported that using a hybrid coater that combined arc and sputter and running each source alternatively, layered coatings such as UBM-deposited α-Al_2O_3 on arc deposited (Ti,Al)N can be synthesized [16].

In this work, nano-multilayered coatings such as (Ti,Al)N/SiN, (Ti,Al)N/WN, and CrN/BCN were deposited by a hybrid coating system that equips arc and UBM sputter source in the same deposition chamber. The structure of these nano-multilayered coatings was investigated by TEM and XRD in terms of crystal structure and grain size. Hardness, wear and friction performance, and oxidation resistance of these nano-multilayered coatings were investigated in terms of the structural property.

2. Experimental procedure

An R&D-type hybrid coater (Kobe Steel Ltd.) was used in this study. An arc source (plasma-enhanced type [4]) and a UBM source were installed in a counter-facing manner. Mirror polished WC–Co cutting inserts and ball-nose end mills (two flutes, 10 mm diameter) were used as substrates. $Ti_{0.5}Al_{0.5}$ and Cr were used as targets for the arc cathode, while various kinds of materials including Si (B-doped), W, and B_4C were used for sputtering targets. Samples were heated up to about 773 K and cleaned through Ar ion etching process. Ar–N_2 mixture gas was fed to the chamber at a pressure of 2.7 Pa with a N_2 partial pressure of 1.3 Pa. The arc source was operated at 100 A for a 100 mm diameter target. The sputter source was operated simultaneously with the arc source and the input power to the sputter source was varied from 0 to 2 kW (for a 160 mm diameter target). The substrates were mounted on a rotating sample holder and passed in front of the arc and the sputter source alternatively during the deposition. The rotation speed of the substrate holder was 5 rpm. Substrate bias was fixed to 30 V for all depositions. Coatings were subjected to compositional, structural (TEM, X-ray diffraction), and mechanical (nano-indentation) analyses. Tribological tests were conducted using reciprocating ball-on-plate-type tribological tester with sliding velocity of 0.1 m/s and normal load of 2 N. Test was conducted between a coated WC–Co insert against a bearing steel ball up to a length of 250 m.

3. Results and discussion

3.1. TEM and XRD analysis

Fig. 1 shows cross-sectional TEM micrographs of nano-multilayer coatings (a) (Ti,Al)N/SiN, (b) (Ti,Al)N/WN, and (c) CrN/BCN. Each coating has a multilayer structure in that arc and UBM deposited layers are stacked alternatively. Due to the difference in the deposition rate of each evaporation source, the layers deposited by the UBM source are always thinner than the ones deposited by the arc. In case of (Ti,Al)N/SiN and CrN/BCN, thin layers with brighter contrast correspond to SiN and BCN layers. Due to heavier atomic mass of W, WN layers are observed as darker layers in the micrograph of the (TiAl)N/WN coating. The multilayer period depends on the coating system and it is about 10 nm for (Ti,Al)N/SiN, 20 nm for (Ti,Al)N/WN, and 15 nm for CrN/BCN. Electron diffraction spots in the electron diffraction patterns of each sample can be indexed, assuming the cubic rock salt structure and no other phases were observed. Electron diffractions of SiN and BCN layer using nano-sized electron beam revealed that these layers are amorphous. The chemical compositions of each layer measured by EDX are $(Ti_{0.55}Al_{0.45})N$, $Si_{0.35}N_{0.65}$, $W_{0.6}N_{0.4}$, and $B_{0.33}C_{0.32}N_{0.35}$.

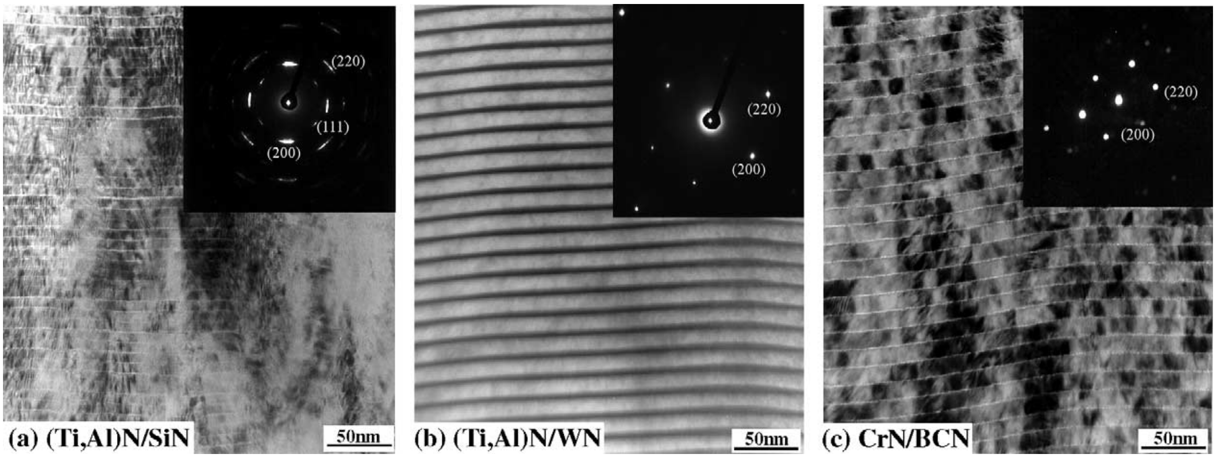

Fig. 1. Cross-sectional TEM images and electron diffraction (ED) patterns of nano-multilayer coatings: (a) (Ti,Al)N/SiN, (b) (Ti,Al)N/WN, and (c) CrN/BCN. Indices in the ED patterns are assigned, based on rock salt structure. I_{arc}=100 A, UBM power=1 kW for (Ti,Al)N/WN, 2 kW for (Ti,Al)N/SiN and CrN/BCN, substrate rotation speed=5 rpm.