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ScienceDirect
Surface & Coatings Technology 201 (2007) 5244–5248
SURFACE & COATINGS TECHNOLOGY
www.elsevier.com/locate/surfcoat

Nano-multilayered CrN/BCN coating for anti-wear and low friction applications

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Available online 28 August 2006

Abstract

Co-deposition of chromium nitride (CrN) and boron carbo-nitride (BCN) was performed using a hybrid PVD system combining cathodic arc and unbalanced magnetron (UBM) sputtering, thereby creating a novel nano-multilayer coating. Subsequent TEM observation of the CrN/BCN coating showed that the coating had a layered structure of crystalline CrN and amorphous BCN. The CrN layer was 20–100-nm-thick and the BCN layer was 1–5-nm-thick. The BCN layer was found to interrupt the grain growth of the arc deposited CrN layer. Therefore, the grain size of the CrN layer was reduced considerably. The increased hardness of the CrN/BCN multilayer coating might have been caused by reduction in the grain size. Sliding tests were conducted using a reciprocating-type tribotester against bearing steel ball under dry condition. The CrN/BCN coatings had a low friction coefficient of about 0.2, which was one-third that of standard CrN coating. The wear rate of counter body (bearing steel) was also markedly reduced.

PACS: 68.65.Ac; 68.55.-a; 68.55.Jk; 68.60.Bs
Keywords: Nano-multilayered coating; Cathodic arc; Unbalanced magnetron sputtering; CrN; BCN; Grain size

1. Introduction

Chromium nitride (CrN) coatings are widely used for various tribological applications from automotive components [1–3] to forming dies [4–6]. For automotive components such as injection valves and piston rings for diesel engines [2,3], a low friction coefficient under boundary lubrication is strongly desired to improve the fuel economy. High seizure resistance is required in the case of forming dies to avoid failure of the coating and dies under dry or semi-dry forming conditions. The friction and wear properties of CrN under dry or minimum lubrication have been reported as no better than those of other nitride coatings such as TiN and TiAlN [6], yet they must be improved. Various additives, such as Al, Si and B to CrN, have been reported to modify coatings' properties and improve hardness and oxidation resistance [7–11]. Among those elements, B has attracted particular attention for low-friction and low-wear applications because B might form lubricious sp^2 B–N bonds in a nitride coating. The authors reported addition of B to CrN coating using a hybrid coating system with combined arc ion plating and unbalanced magnetron sputtering [12]. This coating showed considerable improvement in hardness and tribological properties, but the mechanism for this improved tribological behavior has not been determined. This study is intended to elucidate the relationship between microstructure and tribological properties of CrN/BCN coatings in detail. Furthermore, the effects of the multilayer period on the crystal structure, mechanical properties and tribological properties were investigated.

2. Experimental details

Using a hybrid coating equipment with an arc ion plating (AIP) and an unbalanced magnetron sputtering (UBM) source in the same deposition chamber, CrN/BCN multilayer coatings were deposited. Details of the deposition equipment can be found in a precedent paper [12]. A Cr target and a conductive boron carbide (B_4C) target were attached respectively to AIP and UBM sources. Mirror polished WC-Co cutting inserts were loaded to the vacuum chamber, which was then evacuated to

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doi:10.1016/j.surfcoat.2006.07.165

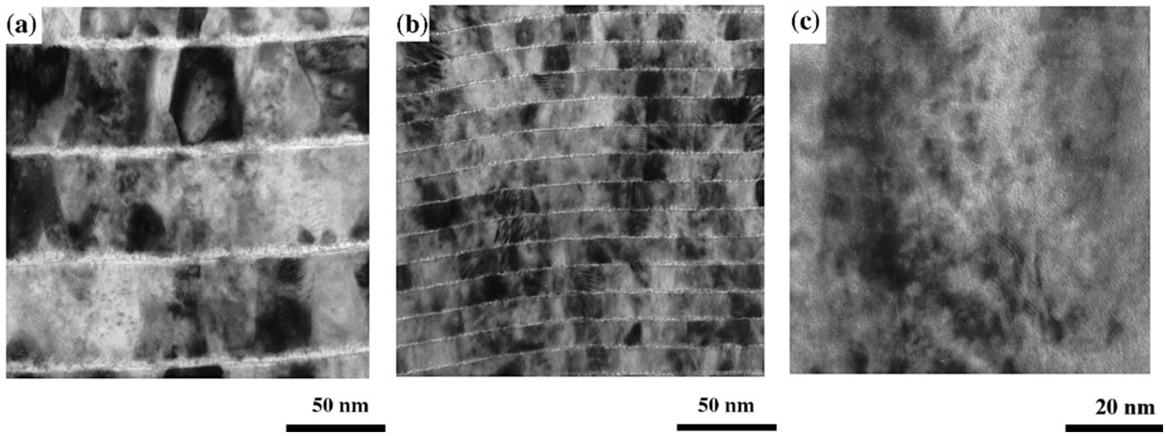

Fig. 1. Cross-sectional TEM images of CrN/BCN multilayer coatings with different substrate rotation speeds of (a) 1.5 rpm, (b) 5 rpm, and (c) 10 rpm.

base pressure of less than 1 mPa. Followed by pre-heating and Ar ion etching process, deposition was conducted under Ar and N_2 (50 vol.% of N_2) mixed gas at a pressure of 2.7 Pa. During deposition, the substrates were on the rotating carousel and passed alternately in front of the both AIP and UBM sources. This substrate motion resulted in alternate depositions of AIP–CrN and UBM–BCN layers. The substrate temperature during deposition was approximately 400 °C; the applied substrate bias voltage was 50 V. The specimens' coating thickness was about 3 μm. Two series of experiments were conducted to deposit CrN/BCN multilayer coatings. In the first series of experiments, the coatings were deposited under various evaporation rates of UBM source, whereas the arc-source evaporation rate was fixed. In the second series of experiments, the coatings were deposited at different substrate rotation speeds to obtain coatings with different multilayer periods.

For compositional analysis, a SEM-integrated EDX system (EMAX; Horiba Ltd.) was used. The crystal structure was investigated using X-ray diffraction (Ultima PC; Rigaku Corp.) with Cu kα radiation in Bragg–Brentano mode. The grain size of a coating was calculated using Scherrer's equation with full width at half maximum (FWHM) of the CrN (111) peak. The coatings' microstructure was observed using the combination of focused ion beam (FIB) sample thinning and FE-TEM. The hardness and elastic modulus were measured using nano-indentation equipment (ENT-1100; Elionix Co. Ltd.). Load-displacement curves were obtained under different maximum normal loads of 1–2 mN; the hardness and elastic modulus were

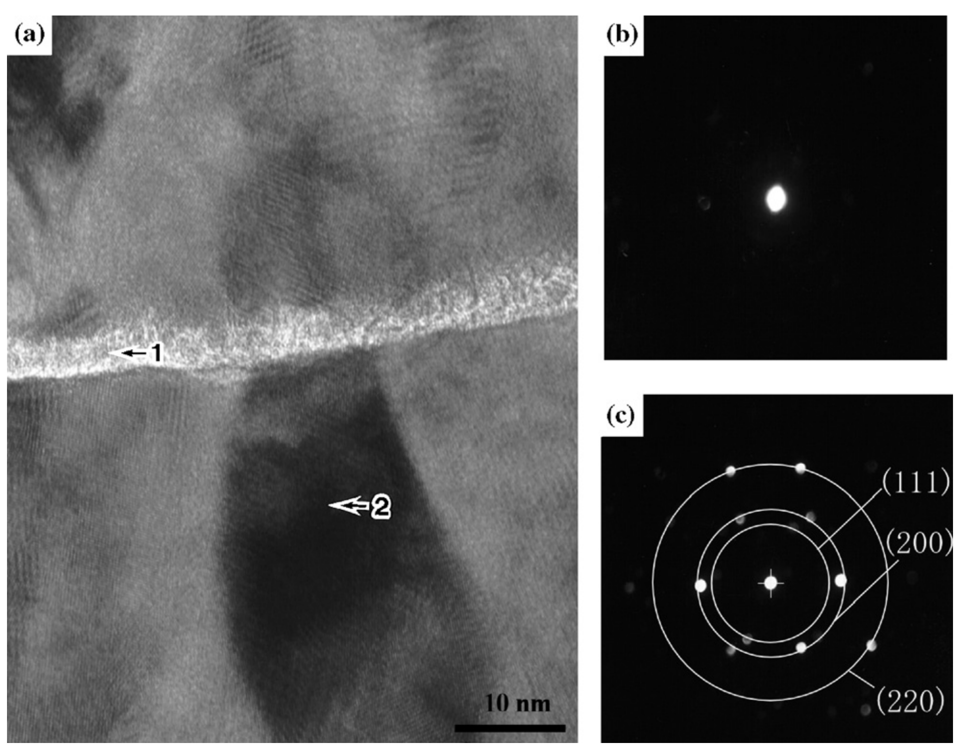

Fig. 2. A magnified TEM image of CrN/BCN multilayer with 1.5 rpm (a) and electron diffraction patterns of (b) point 1 (BCN layer) and (c) point 2 (CrN layer).