

# TiAlN film preparation by Y-shape filtered-arc-deposition system

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## Abstract

A Y-shape filtered-arc-deposition system, which has two arc sources and a common plasma-transport-duct, was operated under nitrogen gas, and a titanium aluminum nitride (TiAlN) thin film was prepared with Ti and Al cathodes. Two filtered-arc plasma beams were not completely combined into one beam even at the exit of the common duct. Thus, TiAlN film with composition-uniform distribution was not obtained at the fixed substrate position. However, different composition films were easily obtained at one time. Then various-composition films of TiAlN with different arc currents were prepared and film properties were measured. The surface roughness in arithmetical mean roughness was less than 3 nm on a 1.5-nm roughness substrate. The density of TiAlN increased with the Ti-content ratio, and its hardness tended to weakly increase with Al-content ratio. The maximum hardness was 36 GPa. Ti-rich film has internal compression stress and Al-rich film has internal tensile stress.

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## 1. Introduction

Cathodic arc deposition (CAD) using cathodic vacuum arc-discharge plasma, sometimes called vacuum arc deposition, arc ion plating, and arc PVD (physical vapor deposition), is one of the very important technologies to prepare thin solid films. Currently, CAD is mostly utilized to obtain the wear-resistant protection coating on cutting tools, dies, metal molds, and sliding parts. However, it is well-known that micron and/or sub-micron macroparticles, so-called droplets, are emitted by vacuum arc discharge from the cathode spot as well as electrons, neutrals and ions. The incorporation of droplets in the film under preparation causes a very rough surface, porous film, pinhole defects, and poor composition-uniformity. One of the promising methods to remove the droplets from the cathodic vacuum arc plasma and to make the droplet-free film is filtered arc deposition (FAD), sometimes known as filtered cathodic vacuum arc (FCVA) or filtered vacuum arc (FVA). After the first

filtered arc system developed by Aksenov [1], many other types of filtered arc systems have been developed and reported in various reviews [2–5].

Recently, multi-element nitride film has been attracting increasing attention [6–8]. One of the useful multi-element nitride films for high-speed cutting tools is titanium aluminum nitride (TiAlN) [9]. TiAlN has the great advantages of better oxidization resistance and high hot hardness, compared with conventional metal nitride and carbide films of TiN, CrN, and TiC [10,11]. The preparation of TiAlN in CAD usually requires a composition-controlled TiAl alloy target (=cathode of arc discharge). However, if pure Ti and Al cathodes are used instead of expensive TiAl alloy, the running cost is able to be reduced. Furthermore, a filtered system is necessary to obtain higher quality TiAlN film. Thus, we have developed a Y-shape filtered arc deposition system (Y-FAD) with two vacuum arc evaporators and a Y-shape filter duct. This system has a partial-common duct for plasma transportation, which is different from the previously developed system with a partitioned duct [12]. Y-FAD has been demonstrated to be able to prepare composition-controlled TiAl film [13].

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In the present paper, TiAlN film was prepared by means of Y-FAD, and its performance as a deposition system was checked from the viewpoint of distribution of composition uniformity and thickness. Then the film properties of surface roughness, hardness, crystalline structure, and tendency of internal stress, were measured or analyzed.

## 2. Preparation of TiAlN by Y-FAD

The development and details of the Y-FAD system have been reported [11]. The system consists of two cathodic vacuum arc generators, a Y-shape plasma transportation duct (=droplet filtering duct), plasma beam mixer, plasma beam scanner, and process chamber with beam aligner. In each arc generator, a cathode and anode were individually equipped, and the cathodic vacuum arcs were generated by individual power sources. The cathodes were pure Ti and Al. The plasma beams were extracted from the generators and transported to the process chamber through the Y-duct, the mixer, and the scanner by magnetic fields produced by electromagnetic coils applied from outside and an electrostatic field applied to the duct wall. Gas was introduced from an inlet placed on the wall of the process chamber.

In the process chamber, halogen lamps (1000 W) were arranged to heat the substrate. The substrate used was mirror-polished super-hard alloy (tungsten carbide (WC) containing cobalt (Co) binder, 12.7 mm × 12.7 mm, 5 mm thick). The film preparation process was as follows. The substrate was gently polished by diamond paste and wiped by acetone-immersed paper, and then fixed on a stationary substrate table in the process chamber. After the chamber was evacuated to less than 0.01 Pa, the substrate was cleaned by argon (Ar) bombardment

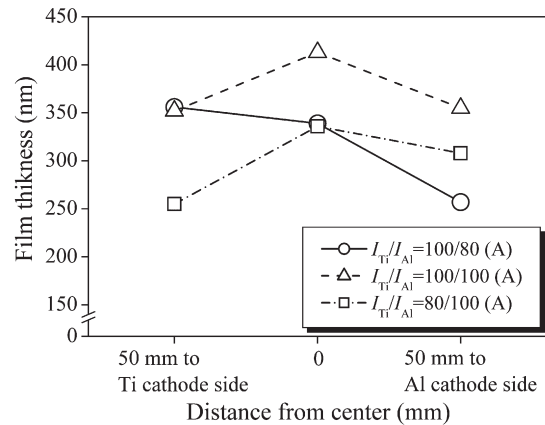


Fig. 2. Distributions of film thickness at different arc-current pairs.

at 3.0 Pa (25 ml/min) for 20 min with 500-W RF power. Then, the process chamber was once again evacuated to less than 0.01 Pa and the substrate was heated to 300 °C. Afterward, first, by discharging only Ti cathode, Ti film was prepared on the substrate for 10 s and then nitrogen (N<sub>2</sub>) gas (20 ml/min) was introduced to prepare TiN for 20 s. Without interruption, the Al cathode was discharged and TiAlN was deposited for 10 min. The pressure was 0.1 Pa during TiAlN preparation. Duct bias was +25 V and substrate bias was −50 V (DC) during Ti, TiN, and TiAlN preparation.

The film thickness was measured with CALOTEST (CSEM) with a 25.4-mm diameter ball (SUJ2) and an optical microscope. Surface roughness was measured with a surface profiler (Veeco, DEKTA-3). Surface appearance was observed with a scanning electron microscope (SEM; Hitachi, S-4500II). Composition of the film was measured with an electron probe micro-analyzer (EPMA; JEOL, JXA-8500F). Hardness and elastic modulus were measured with a nanoindenter (Hysitron, TriboIndenter) with 1.5-mN load. The film density was measured with an X-ray Reflectivity (XRR; Philips, X'Pert PRO MRD). Crystalline structure was analyzed by X-ray diffraction (XRD; RIGAKU, RINT-2500; Cu-K $\alpha$ , 40 kV, 200 mA).

## 3. Results and discussion

### 3.1. Deposition distribution

TiAlN films were simultaneously prepared on three WC substrates, which were placed at the center and at right and left positions 50-mm apart from the center corresponding to each cathode side. Three pairs of arc currents for Ti and Al cathode, ( $I_{Ti}$ ,  $I_{Al}$ ) = (80, 100), (100, 100), and (100, 80), were tested.

Fig. 1 shows a rough sketch of Y-FAD and photographs of the deposition results. The film color was clearly different, depending on the substrate position and arc current pair. Fig. 2 shows the film thickness distribution. It was found that the film was thicker on the higher arc current side and the thickness was different even at the same current, presumably due to the mixing effect.

The composition of N in the film was approximately 50 to 60 at.%, but is not discussed in this paper since it was usually not discussed in the conventional research. Table 1 shows the

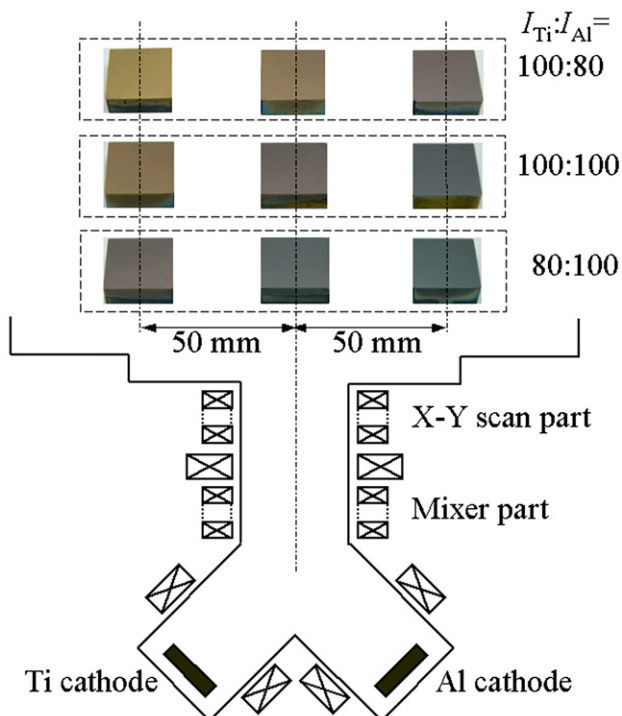


Fig. 1. Rough sketch of Y-FAD and photographs of deposited TiAlN films.

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