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DC vacuum arc deposition system with coiled anode for ta-C films achieving a high deposition rate

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ABSTRACT

Tetrahedral amorphous carbon (ta-C) film, which is one of diamond-like carbon (DLC) film, is widely used for cutting tools and sliding parts because of their high sliding properties, high wear resistance, and high thermal stability. The deposition of ta-C films by vacuum arc discharge requires a reduction in the amount of droplet adhesion, which causes film quality degradation. We have shown that TiN films with a low number of droplets can be formed by using a coiled anode to efficiently transport plasma. In the present study, we applied the same method to ta-C deposition, where the arc current is about 100 A for TiN deposition, but only about 30 A for ta-C deposition. Therefore, we decided to use a coiled anode with about three times as many coil windings as the 3.5 coil windings used for TiN deposition. Comparison of the deposition rate between a 0-winding coiled anode and a 10.5-winding coiled anode showed that the deposition rate increased by a factor of 2 or more with the 10.5-winding coiled anode, and the number of droplets per film thickness was reduced by a factor of 2. The effectiveness of this method was demonstrated. However, it was also found that the ta-C film softens after a long deposition time. This suggests that appropriate cooling is necessary to obtain a hard ta-C film.

1. Introduction

Diamond-like carbon (DLC) is an amorphous carbon material composed of sp^2 and sp^3 structures [1–4]. Among them, DLC with a high sp^3 content and hydrogen-free is called tetrahedral amorphous carbon (ta-C) film. The ta-C film has mechanical properties [1] such as high thermal stability [5], high corrosion resistance [6], high hardness [1,4], and adhesion resistance to Al. Therefore, it has been widely used in cutting tools for Al and protective coatings for sliding parts for automobiles [1–9].

The deposition of ta-C films usually requires a high ionization rate of the plasma [1–4]. High deposition rates are also essential for industrial applications. Among several deposition methods [1–4,10–16], vacuum arc deposition (VAD) is considered to be the most suitable deposition method [15]. However, VAD has problems with droplets emitted from the cathode spot [17]. Droplets on the film cause a decrease in film uniformity and planarity, leading to delamination [17,18]. To address these issues, the steered arc method [19–21] and filtered arc deposition (FAD) [21–26] have been widely used. In the steered arc method, the cathode spot is driven by generating a transverse magnetic field on the cathode surface. Therefore, the emission of droplets due to overheating can be suppressed to achieve uniform wear of the cathode [19–21]. In FAD, the droplets are filtered with the magnetic field because the droplets have a large mass compared with ions and electrons and have large inertia [17,21]; only the plasma can be transported.

There are several types of FAD distinguished by duct shapes and other factors [16–18]. In particular, H. Takikawa et al. developed the T-shaped FAD (T-FAD) [27]. In T-FAD, there is an end pocket on the cathode facing, where droplets are collected. On the other hand, the plasma is bent by the magnetic field at right angles and transported in the substrate direction. The ta-C films deposited by T-FAD are droplet-free and high density, resulting in high mechanical hardness and dense film structure [27–33]. However, this equipment removes droplets and neutral particles that contribute to deposition [4]. Therefore, as shown in Table 1 by H. Takikawa et al., the deposition rate is approximately one-thirds of the normal VAD [27], which is much smaller for some applications such as coating for tools where a certain amount of droplet adhesion is acceptable. Therefore, for the deposition of ta-C

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