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A cathodic arc enhanced middle-frequency magnetron sputter system for deposition of hard protective coatings

HUANG Zhi-Hong YANG Bing FAN Xiang-Jun FU De-Jun*

(Accelerator Laboratory, Department of Physics, Wuhan University, Wuhan 430072, China)

Abstract A new cathode arc enhanced magnetron sputter system for deposition of hard protective coatings is reported in this article. This system consists of eight targets: four outer targets are mounted on the wall of the chamber and four inner targets are placed around the center of the chamber. The outer and inner targets form four pair targets and are powered by four middle frequency power supplies. One of the outer targets can run either in the cathode arc mode or in the magnetron sputter mode. The Ti-containing diamond-like carbon nanocomposite coatings were deposited by using this system. The prepared coating exhibits high hardness (~20 GPa), good adhesion (critical load is 50 N), very low friction coefficient (~0.07), and excellent tribological performance with a wear rate of 1.4×10^{-16} $m^3 \cdot N^{-1} \cdot m^{-1}$.

Key words Cathodic arc, Middle frequency magnetron sputtering, Diamond-like carbon.

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1 Introduction

Hard coating is a type of coating that includes metallic nitrides, metallic carbides, diamond, diamond-like carbon (DLC), and ceramic. These coatings can effectively reduce friction coefficients and wear rates of the workpieces and increase surface hardness, toughness, and resistance to chemical corrosion; hence, they are widely used as protective coatings on cutting tools and on wear-exposed components. [1-3] Plasma chemical vapor deposition (PCVD), magnetron sputtering, and cathode arc deposition are the three most popular methods for preparation of hard coatings. Among them, PCVD is a high-temperature process and is not appropriate for most metal substrates. Cathode arc deposition is one of the most reliable technologies for the production of hard coatings. The plasma of the cathodic arc delivers high degrees of ionization (up to 50%) at relatively low pressures (<1 Pa); hence, arc deposition is a high-rate process and arc deposited coatings exhibit good adhesion. During the process of arc deposition, the electric current at the cathode is concentrated on small, mobile "hot spots", which results in the production of not only fully ionized metal plasma but also tiny droplets of 0.1 – 10 μm size at these cathode spots. The morphology of such coatings prepared by the cathode arc method is rough. Macroparticle filters are used to separate the macroparticles from the plasma, but this significantly reduces the deposition rate. [4, 5]

Magnetron sputtering is a technique that has good reproducibility and controllability with technological advantages such as high deposition rates, coverage of large areas, and low deposition temperature despite low utilization ratio of the target materials. An unbalanced field has been introduced to effectively improve

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*Corresponding author. E-mail: djfu@whu.edu.cn
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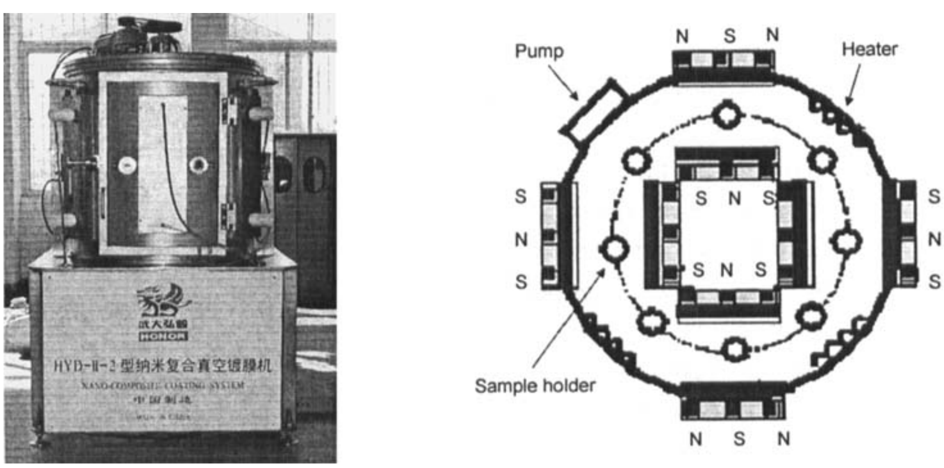
the adhesion and quality of the coating owing to the enhancement of the plasma density near the substrate in the magnetron sputter deposition. [6] Neighboring magnetrons are of opposite magnetic polarities and are arranged to form a closed field in the multimagnetron system. This arrangement confines to the plasma region and prevents losses of ionizing electrons, thereby resulting in significant enhancement of the plasma density. [7, 8]

There are three types of magnetron sputter deposition. The process of direct current (DC) sputtering is used for metallic coating, but it is unstable and has a lower plasma density. Radio frequency (RF) sputtering is used for insulating coatings. It produces finer particles and results in the film having higher density, but it has a lower deposition rate and may be harmful to health. Middle frequency (MF) sputtering technology offers a high deposition rate and is a stable process. It can be used for insulating coatings with low surface roughness and high mass densities due to effective elimination of arc discharge at the target surface. [9]

In hard coating deposition, the stability and reproducibility of the processing, the deposition rate, and the adhesion and thickness uniformity of the coatings are of great importance, all of which are influenced by the density and distribution of the plasma. A cathode arc enhanced middle frequency closed field unbalanced magnetron sputter system has been designed considering the above-mentioned parameters, and Ti-containing DLC noncomposite coatings were prepared in this machine. [10, 11]

2 Equipment

Fig. 1 shows a photograph and a schematic cross-section view of the arc-enhanced MF magnetron deposition system. The vacuum chamber is $\phi 1000$ mm × 1000 mm in size and is equipped vertically with 4 pair magnetrons, which are rectangular and 150 mm × 800 mm × 20 mm in size. Of the eight targets, four targets, i.e., the outer targets, are placed on the sidewall of the deposition chamber and the other four targets, i.e., the inner targets, are placed around the center of the chamber. Cool water is maintained at 15°C using a refrigerator to increase the ultimate power density of the target source and to prevent the production of macroparticles by restraining thermal evaporation. A background pressure of 7×10^{-4} Pa is attained using a diffusion pump with a Roots pump and two mechanical pumps as backing. The electric heaters mounted on the sidewalls of the chamber raise the substrate temperature and eliminate the adsorbed gases on the substrates and the coatings. The carrier gas and the reactive gas are leaked into the chamber through mass flow meters controlled by piezoelectric valves. The substrates are placed vertically on a rotating sample holder arranged between the inner and outer targets. The power supply consists of four bipolar 40 kHz MF power supplies, a 20 kW cathode arc supply, and a DC-pulsed bias voltage supply that can be varied between 0 and 2000 V.



(a) (b)

Fig.1 Photograph (a) and schematic cross-section view (b) of the cathode arc enhanced closed-field twin unbalanced magnetron sputter system.