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Structure and properties of diamond-like carbon nanocomposite films containing copper nanoparticles

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Abstract

Diamond-like carbon (DLC) nanocomposite films, containing copper (Cu) nanocrystallites, were synthesized and studied. Cu bonds very weakly with carbon, and does not form a carbide phase. Therefore, Cu nanoparticles can be easily formed in a DLC matrix by depositing Cu and carbon together. The mechanical properties of DLC films that contain Cu nanoparticles are interesting since the film toughness may be increased by grain–matrix interface sliding. Hard, tough and stress-free DLC/Cu films were prepared by a sputtering Cu target in an argon/acetylene atmosphere while biasing the substrate with a radio frequency power supply. The residual stress of the film, calculated by Stoney's equation, was as low as 0.7 GPa. The reduced stress and the increased film toughness increased the critical load from 66 N for a conventional DLC film to 80 N for the DLC/Cu film, as measured in a scratch test. However, the DLC/Cu films were slightly less hard than the DLC films.

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Keywords: Diamond-like carbon (DLC); Nanocomposite film; Copper; Nanoparticles; Mechanical properties

1. Introduction

Diamond-like carbon (DLC) films have been extensively investigated over the last three decades. DLC films exhibit superb mechanical properties, including high hardness and low friction coefficients. These films are very useful in precision machining and manufacturing. The importance of hard and abrasion-resistant coatings for machining application is evidenced by the rapidly growing market for cutting tools with wear-resistant coatings. Besides hardness, many film properties including toughness, high adhesion, and low surface energy, are yet to meet the requirements of various applications. DLC films have been synthesized by sputtering, laser ablation, cathodic arc and chemical vapor deposition (CVD) [1–5]. The bombardment of energetic carbon species during deposition is critical for the growth of DLC

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films. The ion energy is the most important parameter for determining the characteristics of DLC films. However, the ion bombardment tends to result in the highly-dense packing of carbon atoms in the film, yielding a very high compressive stress therein. The internal compressive stress depends strongly on the distortion of the bond length and the angle of sp^3-bonded carbon. A very high compressive stress tends to detach the film from the substrate, when the film thickness increases above a critical value. The internal stress can be reduced by different mechanisms. Adding a new element to the DLC matrix, which consists mostly of carbon and hydrogen, is a commonly used method. The third incorporated element is normally Si, Ti or W, all of which exhibit bond strongly with the carbon matrix. In this work, soft and ductile metallic copper nanocrystallites were embedded in the hard amorphous DLC matrix to increase the toughness and stress in the film. Copper was also used to prevent the formation of bonds between the nanocrystallite and the carbon matrix, facilitating grain–matrix interface sliding, which increases the film's ductility [6,7]. No Cu metal carbide phase has even been formed.

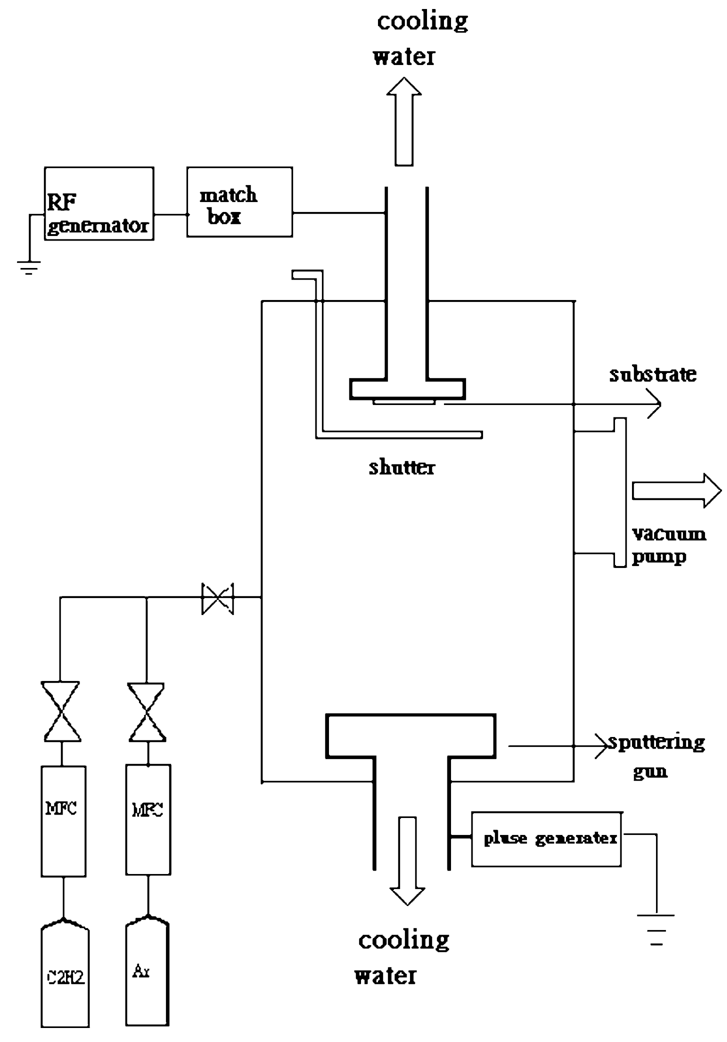

Fig. 1. A schematic diagram of the experimental set-up employed in this study.