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Friction and wear properties of amorphous and nanocrystalline Ta-Ag films at elevated temperatures as function of working pressure

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ABSTRACT

Ta-Ag immiscible alloy film shows potential application as a protective coating during sliding contact at high temperatures. In this study, Ta-Ag films were deposited on carbon steel by DC magnetron sputtering at the ambient temperature. The microstructures of Ta-Ag films were adjusted by controlling working pressures (0.2–0.8 Pa) and sputtering powers of tantalum (90 W–100 W). The nano-crystalline α-Ta is deposited at the working pressure of 0.2 and 0.4 Pa while the amorphous Ta is produced at 0.6 and 0.8 Pa for Ta90-Ag8 films. The hardness and elastic of Ta-Ag films decreases with the increase of sputtering pressure. The friction coefficients of nanocrystalline Ta90-Ag8 films deposited at 0.2 and 0.4 Pa are lower than that of amorphous films deposited at 0.6 and 0.8 Pa from RT to 600 °C. A friction coefficient of about 0.32 and low wear rate (1.6×10^{-5} mm^3/Nm) is obtained for the Ta90-Ag8 film deposited at 0.2 Pa at 700 °C.

1. Introduction

Tantalum films have been extensively studied as protective coatings owing to their excellent properties such as high melting point, corrosion resistance, and high structure stability at high temperatures [1–5]. The deposited tantalum films usually exist in two crystal structure. The α phase, has high ductility, hardness (Knoop hardness of 300 to 400), stability and low electrical resistivity (13.5 μΩ cm^{-1}). The β-Ta phase was brittle, and with Knoop hardness > 900. For the application as the protective coating, the α phase with high ductility is preferred. Considerable efforts have been dedicated to the development of the depositing methods of α-tantalum (bcc) thin film [6,7]. Since more energy was needed for the deposition of α-Ta films, the depositing parameters of α-Ta are very harsh. The α-phase tantalum films were commonly deposited by heating the substrate temperature to above 350 °C or applying a bias voltage [8,9].

The structure of Ta films is sensitively influenced by the sputtering power, working pressure, and the base pressure [10,11]. A deposition on silicon and glass substrates in 0.5–0.7 Pa sputtering pressure led to α-Ta phase formation, while the β-Ta (tetragonal structure) was deposited at the lower or higher pressure [12]. The deposition of amorphous Ta and nanocrystalline α-Ta by PLD or DC magnetron sputtering were reported in the literatures [13,14]. Amorphous Ta films with 60 nm thickness were deposited on Si (100) substrate by pulsed laser deposition (PLD) [13]. Cao et al. [13] reported that amorphous Ta films were deposited on Si by DC magnetron sputtering at the ambient temperature. By increasing sputtering powder and heating the substrate, tantalum films transformed from amorphous to α phase [14]. There are few reports about transition between amorphous and α phase by adjusting the sputtering power or working pressure at room temperature.

When the tantalum is used as a potential protective coating for the sliding parts, its tribological properties are required to be evaluated, especially at elevated temperatures. There are several literatures about the structure and tribological behaviors of Ta-Cu immiscible alloy films [15–17], but the tribologicial properties of Ta-Ag immiscible alloy films are seldom reported. For the fact that silver is a solid lubricant at elevated temperatures, it is expected that the Ta-Ag immiscible alloy films may present novel tribological properties [18].

In this study, Ta-Ag films were deposited on carbon steel substrates by DC magnetron sputtering at ambient temperature. The microstructures of the Ta-Ag films were adjusted by controlling the working pressure and sputtering power during the film deposition. The effects of working pressures on the microstructure, mechanical and tribological properties of the Ta-Ag films were investigated.

2. Experiment

The Ta and Ta-Ag thin films were deposited by a DC magnetron sputtering system (JGP-450) with 1045 steel (φ 30 × 2 mm) as

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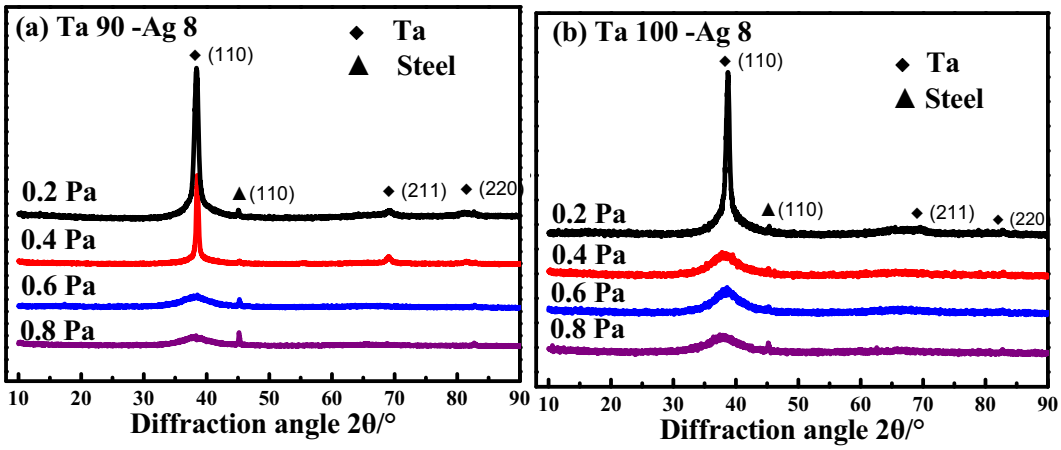

Fig. 1. XRD patterns of Ta-Ag films deposited at various powers and working pressures: (a) Ta90-Ag8; (b) Ta100-Ag8.

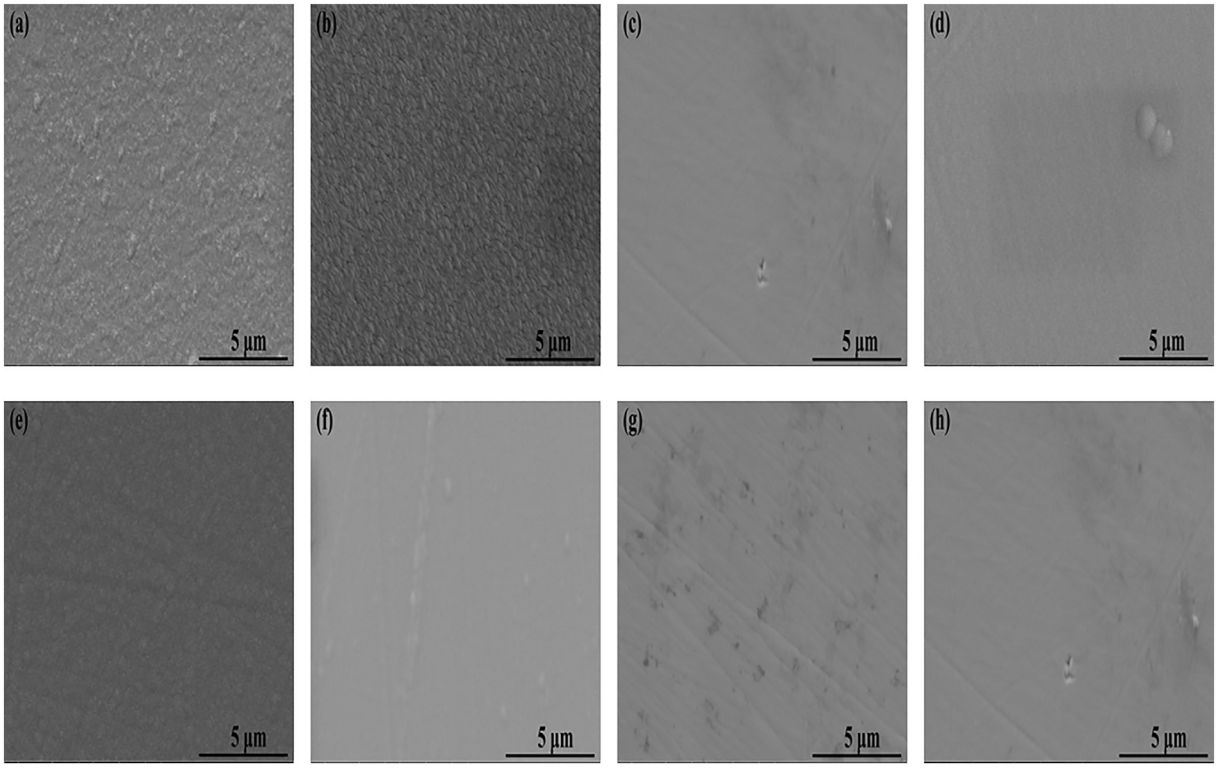

Fig. 2. Surface morphologies of Ta90-Ag8 films(a-d) and Ta100-Ag8 films(e-h) deposited at different working pressures: (a) (d)0.2 Pa; (b)(f) 0.4 Pa; (c) (g) 0.6 Pa; (d) (h) 0.8 Pa.

substrate. Pure Ta and Ag metal targets with diameters of 60 mm and the purity of 99.9% were used as target materials for sputtering. Before deposition, the substrates were ultrasonically cleaned in acetone and alcohol solutions for 5 min, and then mounted on a substrate holder. The target-to-substrate distance was kept at 13 cm for all sputtering runs. The chamber was draw to 5.5×10^{-4} Pa, followed by filled with argon as the protecting gas. Then, Ta and Ag were co-sputtered at the working pressure of 0.2–0.8 Pa and the sputtering power of 90-100 W for tantalum and 8 W for silver. The substrate temperature was measured by using a thermocouple contacted with the sample while the substrate temperature was held constant below 100 °C throughout the experiment.

The phases of the Ta-Ag films were identified by X-ray diffractmeter (D8 Advance, Bruker) with Cu Kα radiation (λ = 1.5418 Å) with an incidence angle of 1°. The surface and cross-sectional morphologies of Ta-Ag films were observed by field emission scanning electron microscopy (SEM, JSM-6380) attached with EDS. The topographies of Ta-Ag films were detected by the AFM(Multimode 8, Bruker) with the scanning area of 1 μm × 1 μm. The microstructure and its FFT pattern of Ta-Ag film was detected by the resolution transmission electron

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