



PROCESSING, MICROSTRUCTURES, AND PROPERTIES OF MULTIFUNCTIONAL MULTILAYERS

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ABSTRACT

The development of coatings has experienced three generations. The first generation coatings, such as TiN etc., are widely used in industry; the second generation coatings such as Ti(C,N), (TiAl)N, Ti(B,N) etc., are currently under serious consideration for certain wear application; the third generation coatings are multicomponent and multilayers[1]. These composite coatings can combine attractive properties of the individual components but may also exhibit unique properties mainly due to synergistic and scale effects when the size of their components is <100 nm. These materials are thus, of great current research interest.

The mechanical properties of monolithic films have been widely studied and are known to be size-dependent as for example, expressed by the Hall-Petch[2,3] formalism. Similar size effects on properties have also been observed in nano-multilayered films as a function of layer thickness. However, the relationship between the microstructural characteristics and mechanical properties of multilayers has not been well established yet. In this work, three multilayer systems, namely Al/Al₂O₃, Ti/TiN and Cr/*a*-C, have been developed to study the relationship between the microstructure and properties. The film microstructures were characterized by using cross sectional transmission electron microscopy (TEM) and electron diffraction. The mechanical properties (nanohardness, HN, and elastic modulus, E_r) of the films were studied by nanoindentation at a load of 2 mN and Knoop microhardness (HK) experiments at a load of 10 g. The fracture toughness of Cr/*a*-C multilayers was studied by conducting Vickers micro-indentation testing. Pin-on-disc experiments were performed to assess the tribological behavior of the films.

In the Al/Al₂O₃ and Ti/TiN systems, three groups of multilayers were deposited by EBPVD with the thickness of the metallic and ceramic layer changing from 5 nm to 100 nm. In the first group, the metallic and ceramic layers were of equal thickness, ranging from 5 nm to 100 nm; in the

second and third group, the layer thickness of one component (metal and ceramic, respectively) was constant (40 nm), while that of the other varied from 5 nm to 40 nm. In the Cr/*a*-C multiplayer system, two groups of thin films were synthesized with the thickness of Cr and C layer changing from 10 nm to 40 nm. In the first group, the Cr and C layers were of equal thickness, ranging from 20 nm to 40 nm; in the second group, the layer thickness of C was constant at 40 nm while that of Cr was varied from 10 nm to 40 nm. The total thickness of each film was about 1 μ m. Therefore, depending on the thickness of the individual layers, the films were made up of a minimum of 5 layer pairs (e.g., in Al (100 nm)/Al₂O₃ (100 nm)) to 100 layer pairs (e.g., in Ti (5 nm)/TiN (5 nm)).

FIGURES AND TABLES

Figure 1 is a bright-field TEM image, showing a cross-sectional view of a typical multilayer structure of Cr (20 nm)/C (20 nm). The periodicity and continuity of the Cr and C layers is clearly shown in the micrograph. The bright and dark areas show C (20 nm) and Cr (20 nm) layers, respectively. It was found that Cr has a crystalline structure and C is amorphous (*a*-C). The microstructure of the Al/Al₂O₃ and Ti/TiN nanocomposite multilayers was also examined by TEM. The Al and Ti layers were found to have

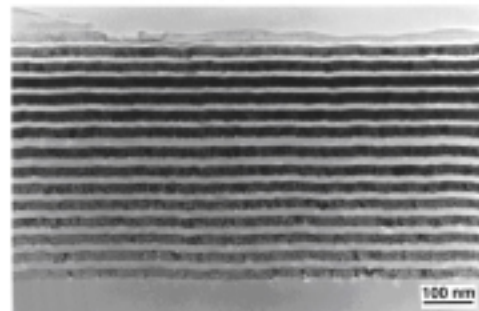


Figure 1. Bright-field XTEM image of Cr (20 nm)/*a*-C (20 nm) multilayers.

fcc and hcp crystalline structures, respectively. The TiN layers had fcc nanocrystalline structure while the Al₂O₃ layers were amorphous.

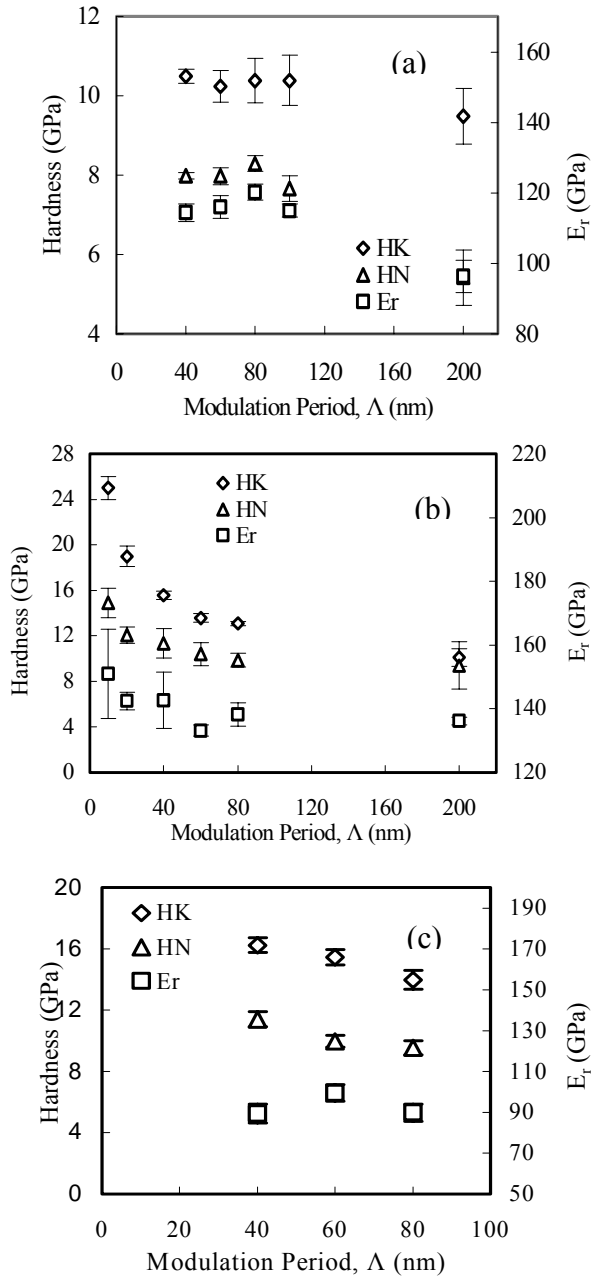


Figure 2. E_r , HN and HK versus Λ for: (a) Al/Al₂O₃; (b) Ti/TiN; and (c) Cr/a-C.

For Al/Al₂O₃ multilayers with equal layer thickness of Al and Al₂O₃, the hardness and E_r exhibit a maximum value at about 40 nm, which is in good agreement with Koehler's predictions. In a multilayered system, while a thickness of the layer with lower dislocation line energy less than a critical thickness l_c , the Frank-Read dislocation source could not operate.[4,5] The l_c is given by: $l_c = 32\pi \mathbf{b}_B (\mu_A + \mu_B) / (\mu_A - \mu_B)$, where μ_A and μ_B are the moduli of rigidity of

metals A and B, respectively; \mathbf{b}_B is the Burger's vector of metal B. The theoretical critical thickness for Al is 41 nm [6], after which the hardness is not expected to increase by further decreasing the layer thickness. It should be noted that all microhardness values are higher than those by nanohardness since the indentation depth in the former was around 500 nm and thus it contained substrate contributions. The nanoindentation depth was less than 10% of the film thickness. In Ti/TiN and Cr/a-C multilayers, hardness was found to increase as the layer thickness decreases. In Al₂O₃ and Ti/TiN multilayers, E_r increases as hardness increases; Cr/a-C multilayers shows a same trend in E_r , but the last point drops due to interface effects.

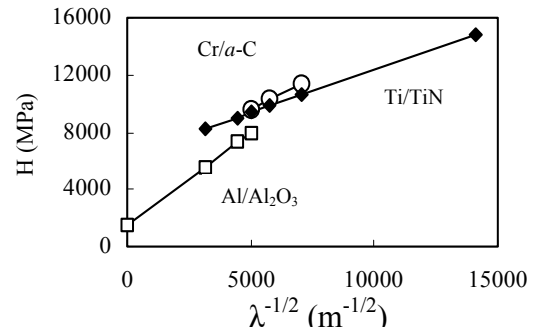


Figure 3. Hall-Petch relation describing hardness behavior of multilayers, λ is the metallic layer thickness.

Figure 3 summarizes the hardness behavior of all three multilayers. It is evident that the Al/Al₂O₃ system exhibits the lowest friction stress (i.e., Al has fcc structure) but the highest slope or ability to strengthen faster as a function of metal layer thickness. On the other hand, the Ti/TiN system was the one being able to attain the highest hardness among the three systems tested.

ACKNOWLEDGMENTS

The authors would like to thank Dr. J.C. Jiang for his help with TEM. The TEM work was performed at the LSU Materials Characterization Center. This work was supported by ARO Grant DAAG55-98-1-0279 and the Louisiana Board of Regents.

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