SELF-ADAPTIVE THIN FILMS FOR MECHANICAL ENGINEERING

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ABSTRACT
The search for ultra-low friction materials must inevitably start at atomic scale. Recent advances in atomistic simulations open new horizons to further optimize coating architecture by addressing fundamental issues of nanoscale sliding. If we limit our search to typical engineering conditions, only two crystals exhibit almost frictionless sliding: graphite and transition metal dichalcogenides (TMD: molybdenum and tungsten disulfides and diselenides). Both these materials exhibit highly anisotropic layered structure with very weak bonding between layers. The atomistic simulations validated by experiments suggest that extremely low friction of these structures could be achieved. Not surprisingly, carbon-based and TMD-based materials, already used for decades as special additives to oil lubricants, are the most attractive ultra-low friction candidates.

Keywords: Thin films, dichalcogenides, TMD, lubricants, superlubricity.

INTRODUCTION
Diamond-like carbon (DLC) based films prepared by various methods are the most applied low-friction coatings. They exhibit low friction in humid air thanks to formation of thin graphite layer in the contact; however, their friction is typically much higher in dry air or vacuum. Although pioneering work of Erdemir et al. [1] on highly hydrogenated DLC showed that such coatings exhibited superlubricity, their unique performance was limited only to sliding in dry nitrogen. Doping with other elements could improve specific frictional properties; nevertheless, it is clear that multipurpose DLC coatings with low friction in all sliding regimes cannot be prepared. TMDs exhibit ultra-low friction in vacuum and they are often used in space applications. Their friction decreases with increasing load violating the classical Amonton’s law and they withstand enormous contact pressures. On the other hand, the presence of oxygen and, particularly, air humidity in the sliding atmosphere hinders low-friction behaviour and accelerates wear.

How could we prepare film combining beneficial properties of carbon and TMD? Voevodin et al. [2] deposited nanocomposite coating containing hard tungsten carbide and self-lubricant tungsten disulfide nanograins embedded into an amorphous carbon matrix. The tests showed that the friction indeed resembled that achieved for TMD in dry nitrogen and DLC in humid air; in fact, the work was only limited step forward towards ultra-low coating.

RESULTS AND CONCLUSION
We knew that ideal and well-oriented TMD crystal could be frictionless - but how to produce them on the surface and simultaneously replenish them during wear process? Again we started with combination of carbon and TMD and non-reactive magnetron sputtering; however, we prepared hairy-like nanostructure with separated molecular layers of
dichalcogenides randomly distributed in amorphous carbon matrix [3]. During the sliding process, a very thin tribolayer consisting of almost ideal optimally oriented TMD crystals was produced on the utmost surface (Fig. 1) [4]. Such tribolayer forms in all environments from vacuum to humid air and exhibit friction coefficients 0.05 or lower; interestingly, the tribolayer provides both low friction and resistance to environmental attacks.

The formation of TMD tribolayer was not clear. Was it mechanical re-orientation of randomly oriented TMD platelets, or was there chemical reaction at the surface? We deposited amorphous coating by doping of WSC film by chromium and the sliding tests resulted in identical TMD (in this case WS2) tribolayer formation. Therefore, the chemical process was dominant [5]. We can produce low and even ultra-low friction coatings; however, we do not understand many features related to their tribological performance. The role of doping element, carbon or nitrogen, is still not clear. The tribolayer looks identical for different coatings; however, the friction is different. Finally, the fundamental frictional properties of TMD crystals have to be studied more in detail. Recently we employed combination of ab-initio and molecular dynamics techniques to address the questions referred to above [6]. We believe that self-adaptive structure, which optimally reacts during the sliding process and produces specific tribolayer, is the key design of novel ultra-low friction coatings.

REFERENCES