Abstract

Titanium-based alloys have gained significant prominence in aerospace and biomedical industries due to their superior mechanical properties and biocompatibility. Despite their widespread adoption, the current alloy systems encounter critical challenges regarding their application in shape memory applications and medical implants. This thesis investigates the development and characterization of novel Ti-Zr-Mo ternary alloy thin films for dual applications in high-temperature shape memory actuators and biomedical surface modification. This research specifically addresses the limitations of nickel-free high-temperature shape memory alloys (HTSMAs) for aerospace applications operating above 200 °C, and the surface associated limitations of Ti-6Al-4V implants including poor wear resistance and osseointegration.

Through magnetron sputtering deposition, stoichiometric $Ti_{68}Zr_{26}Mo_6$ thin films were successfully developed with precise compositional control achieved by layer-wise deposition. This work demonstrates that the annealing temperature plays a crucial role in determining film properties, with annealing at 500 °C resulting in the formation of martensite (α′) and austenite (β) phases. However, annealing of the films deposited on Si substrates at temperatures above 600 °C has led to detrimental film-substrate interactions and formation of brittle Mo_3Si intermetallic compounds. To overcome these challenges, a protective SiO_2 buffer layer strategy was implemented, enabling optimal heat treatment at 700 °C without compromising structural integrity. The $Ti_{68}Zr_{26}Mo_6$ alloy films deposited on Si/SiO_2 substrate have exhibited exceptional shape recovery strain of approximately 6.7%, demonstrating excellent high-temperature shape memory functionality. Additionally, the mechanical properties of such films have been significantly enhanced, with hardness increased by 52% and superior wear resistance achieved through nanocrystalline grain boundary strengthening.

For biomedical applications, the Ti-Zr-Mo coatings have been successfully deposited on the Ti-6Al-4V alloy substrates and subjected to heat treatment at 700 °C for 15 min. The heat-treated coatings demonstrated transformative surface modification capabilities through the formation of synergistic ZrO_2-MoO_3 passive layers that provide exceptional corrosion resistance in physiological media. Biocompatibility studies have revealed enhanced biomineralization, improved cell adhesion, and superior cell proliferation compared to uncoated Ti-6Al-4V alloy substrate. The research establishes critical processing-structure-property relationships in the Ti-Zr-Mo alloy systems, demonstrating that strategic use of buffer layer and optimized heat treatment procedure can simultaneously enhance multiple functional properties. Tribological testing have shown significant improvements in the wear resistance for both shape memory and biomedical applications.

This work advances the understanding of ternary thin film processing and multifunctional surface engineering, demonstrating that the Ti-Zr-Mo alloy thin films can be effectively used in both aerospace and biomedical applications. The findings establish Ti-Zr-Mo alloy thin films as the promising candidates for next-generation orthopaedic and dental implants, while simultaneously offering solutions for high-temperature actuator applications in aerospace systems. The dual-functional approach demonstrates that the Ti-Zr-Mo alloy thin films can effectively serve in both aerospace and biomedical applications, contributing fundamental knowledge to advanced thin film materials and multifunctional surface modification technologies.

Keywords: *Shape Memory Alloys; Thin Films; Biomedical Coatings; Magnetron Sputtering; Surface Modification.*