RESEARCH ARTICLE

High-Entropy Alloy Thin Films Deposited by Magnetron Sputtering for Extreme Environment Applications

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Abstract: We report the synthesis and characterization of AlCrTiVNb high-entropy alloy (HEA) thin films deposited by reactive magnetron co-sputtering for applications in aerospace turbine environments exceeding 800°C. The as-deposited films exhibit a single-phase body-centered cubic (BCC) solid solution with nanocrystalline grain size of 12 ± 3 nm, hardness of 14.8 GPa, and elastic modulus of 285 GPa. Oxidation resistance testing at 900°C for 100 h in air produces a protective Al_2O_3-Cr_2O_3 duplex scale with parabolic rate constant $k_p = 1.2 \times 10^{-13}$ $g^2 \cdot cm^{-4} \cdot s^{-1}$, two orders of magnitude lower than equimolar NiCrAlY reference coatings. Thermal cycling between 25°C and 900°C (500 cycles) shows no spallation or cracking, attributed to the sluggish diffusion kinetics inherent to high-entropy compositions. These results establish HEA thin films as promising next-generation thermal barrier and oxidation-resistant coatings.

1. Introduction

High-entropy alloys (HEAs), defined as multi-principal-element alloys with near-equiatomic compositions, have attracted intense research interest due to their exceptional mechanical properties, thermal stability, and corrosion resistance arising from configurational entropy stabilization of solid solution phases. While bulk HEA research has progressed rapidly, the application of HEA compositions as protective thin film coatings for extreme environments remains relatively unexplored.

Aerospace gas turbine engines operate with inlet temperatures exceeding 1,500°C, requiring sophisticated thermal barrier and oxidation-resistant coating systems on superalloy components. Conventional MCrAlY bond coats suffer from interdiffusion with substrate elements and phase transformations during thermal cycling. HEA thin films, with their inherent sluggish diffusion and phase stability, may overcome these limitations while providing superior mechanical hardness and wear resistance.

2. Experimental Methods

AlCrTiVNb HEA thin films were deposited on Inconel 718 and Si(100) substrates by DC magnetron co-sputtering from five elemental targets (99.95% purity) in a 3 mTorr Ar atmosphere. Substrate temperature was maintained at 400°C, and deposition time was varied to achieve film thicknesses of 2-5 μm. Post-deposition annealing was performed at 600°C for 2 h in vacuum.

Table 1. Deposition parameters and resulting film properties for AlCrTiVNb HEA coatings

Sample	Power (W/element)	Thickness (μm)	Grain Size (nm)	Hardness (GPa)	Roughness R_a (nm)
HEA-200	200	2.1	8 ± 2	16.2	12
HEA-150	150	3.5	12 ± 3	14.8	18
HEA-100	100	5.2	22 ± 5	11.5	28
NiCrAlY (ref.)	—	3.5	450 ± 80	6.8	45

Structural characterization employed X-ray diffraction (XRD), transmission electron microscopy (TEM), and atom probe tomography (APT). Mechanical properties were measured by nanoindentation (Berkovich tip, 10 mN max load). Isothermal oxidation was conducted at 800, 900, and 1000°C in laboratory air. Thermal cycling tests cycled samples between room temperature and 900°C with 10 min dwell at peak temperature.

3. Results and Discussion

XRD confirmed single-phase BCC structure for all HEA films with no detectable intermetallic compounds or amorphous regions. The nanocrystalline microstructure contributes to the exceptional hardness of 14.8 GPa, more than double that of conventional NiCrAlY coatings. APT analysis verified near-equiatomic distribution of all five elements with no significant compositional segregation.

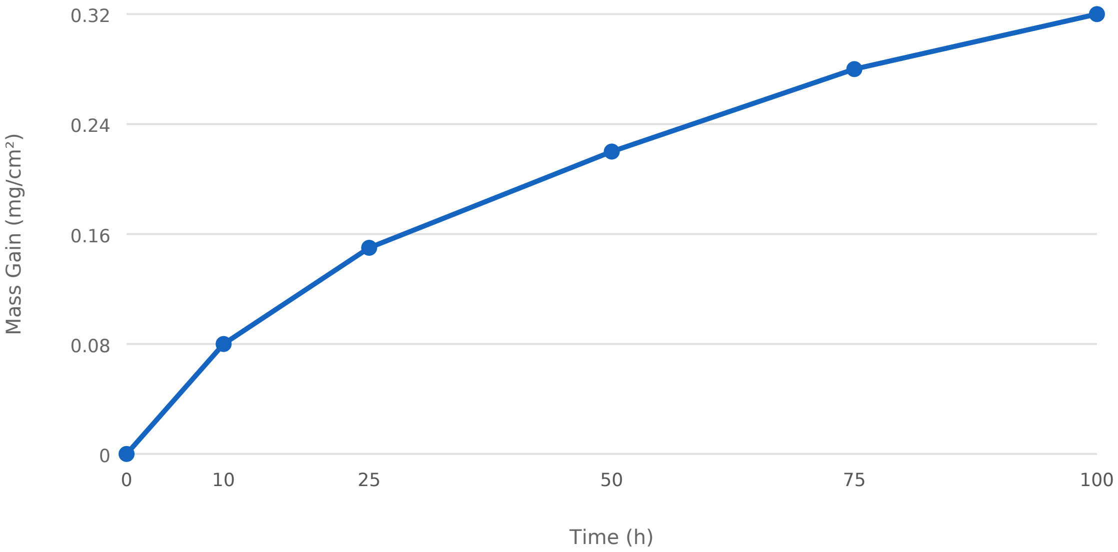

Figure 1. Isothermal oxidation mass gain kinetics at 900°C in air for HEA-150 and NiCrAlY reference coatings

The oxidation kinetics follow parabolic behavior consistent with diffusion-controlled scale growth. Cross-sectional SEM reveals a dense, adherent duplex oxide scale approximately

1.2 µm thick after 100 h at 900°C, composed of an outer Ti-V mixed oxide and inner continuous Al_2O_3 layer. In contrast, NiCrAlY develops porous alumina with extensive spallation after 50 h.

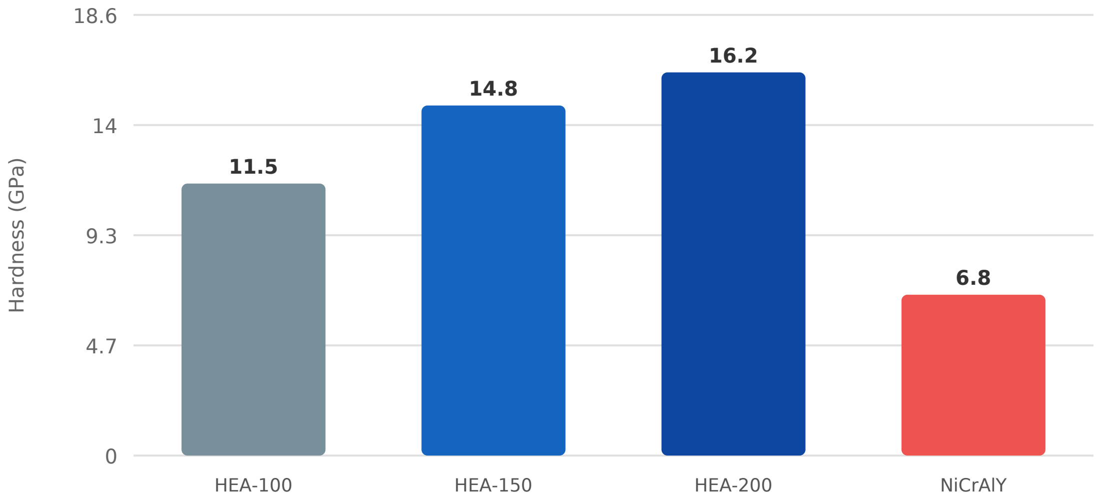

Figure 2. Hardness and elastic modulus of HEA films as a function of sputtering power, compared with NiCrAlY reference

4. Conclusions

AlCrTiVNb high-entropy alloy thin films deposited by magnetron co-sputtering exhibit exceptional combinations of mechanical hardness, oxidation resistance, and thermal cycling stability that surpass conventional MCrAlY coatings. The nanocrystalline BCC solid solution structure and sluggish diffusion kinetics inherent to the high-entropy composition enable formation of protective duplex oxide scales without spallation during 500 thermal cycles. These findings establish HEA thin films as viable candidates for next-generation thermal and environmental barrier coatings in aerospace and power generation applications.

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