Int. Journal of Refractory Metals and Hard Materials 57 (2016) 134–138

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

journal homepage: www.elsevier.com/locate/IJRMHM

Surface topography of CVD-W coatings on graphite substrate with a PVD-Si intermediate layer after thermal fatigue testing

X.M. Zhao [a], J.P. Song [b], Y. Yu [b], Z.G. Zhuang [c], B.Z. Sun [a,*], Y. Qi [a,d,**]

[a] Institute of Materials Physics and Chemistry, Northeastern University, Shenyang 110819, China
[b] Xiamen Honglu Tungsten Molybdenum Industry Co. Ltd., Xiamen, 361021, China
[c] China National R&D Center for Tungsten Technology, Xiamen Tungsten Co. Ltd., 361026 Xiamen, PR China
[d] Key Laboratory for Anisotropy and Texture of Materials, Ministry of Education, Northeastern University, Shenyang 110819, China

ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 1 March 2016
Accepted 7 March 2016
Available online 10 March 2016

Keywords:
Thermal fatigue testing
Surface topography
CVD-W coatings
Shallow melting pools
Recrystallized grains

ABSTRACT

This work deals with the effects of thermal fatigue testing on the surface topography of W coatings on graphite substrate with Si intermediate layers, where W coatings were deposited by chemical vapor deposition (CVD-W coatings) and Si intermediate layers were prepared by physical vapor deposition (PVD-Si layers). The surface topography of samples both as-deposited and after thermal fatigue testing were characterized by X-ray diffraction (XRD) and scanning electron microscope (SEM). Comparative studies show that CVD-W coatings have so excellent thermal conductivity that electronic beams are only absorbed by a thin layer on the coating surface. The absorbed thermal loads give rise to the melting of the pyramid-like W grain tips and the formation of shallow melting pools. Meanwhile, the size of the recrystallized grains on the surface is much smaller than those of the initial grains after cooling. Since the fine recrystallized grains can undoubtedly suppress the crack propagation, no visible failure was found in sample after thermal fatigue testing.

1. Introduction

As one of the most important candidates as plasma facing material (PFM) for the International Thermonuclear Experimental Reactor (ITER), tungsten (W) has excellent physical properties, such as a high melting point (3773 K) and high thermal conductivity (235 W/(m·K) at 273 K–373 K), low retention of tritium and a low erosion rate under plasma loading [1]. However, the main disadvantage of W is its brittleness, especially recrystallization brittleness [2]. In addition, the ductile to brittle transition temperature (DBTT) is high (approximately 400 °C), leading to difficulties in forming and machining. Consequently, on the one hand, to make tungsten ductile, it is necessary to decrease the DBTT by reducing the strain rate [3] or refining the grain size [4]. On the other hand, in order to apply and explore tungsten materials for repairing or updating the plasma facing components (PFCs) of the first wall and divertor in existing or future tokomaks, a promising and feasible method is that a thin W coating is deposited on a heat sink (copper and its alloys) or structural materials (steel). Unfortunately, there is a thermal expansion mismatch between the substrate, such as copper and steel. The coefficient of thermal expansion (CTE) of Cu and steel is about 17×10^{-6}/K and 12×10^{-6}/K respectively, and 5×10^{-6}/K for W. Such a coating can result in severe interface stress and failure of PFCs [5]. Hence the performance of PFCs is not only dependent on the W coating but also on the substrate materials and the bonding between them.

At present, to improve the thermal expansion mismatch, one method is to use functionally graded materials (FGMs) as an interlayer. For example, using W–Cu FGMs can mitigate the CTE between the W coating and Cu substrate [6–8]. These PFCs have shown good performance in resisting the heat flux loads [9–11]. Another method is to use metal (Ti) or nonmetal (Si and SiC) as an interlayer if the graphite or the carbon fiber reinforced composite (CFC) is chosen as substrate. For instance, when Si acts as the interlayer, an excellent option is the combination of W coating prepared by chemical vapor deposition (CVD-W coating) and Si interlayer deposited by physical vapor deposition (PVD-Si interlayer). It can endure the thermal fatigue tests with an absorbed power density of 4.62 MW/m^2, loading cycles of 5 on/25 off and thermal fatigue cycles number of 200, and that no catastrophic failure was found in the CVD-W coatings [11]. Compared to the Cu substrates and the FGMs or Ti interlayers, the graphite substrates and the PVD-Si interlayers have significant advantages, such as low cost and simple preparation. Meanwhile, the deposited PVD-Si interlayer can avoid the reaction between graphite substrates and W coatings. However, after thermal fatigue testing, the surface topography and the crystalline states of CVD-W coatings have not been unclear yet. The microstructural information is associated closely to the physical properties. In this work, phase composition and surface topography of the CVD-W/PVD-Si/Graphite sample

* Corresponding author.
** Correspondence to: Y. Qi, Key Laboratory for Anisotropy and Texture of Materials, Ministry of Education, Northeastern University, Shenyang 110819, China.
E-mail addresses: bzsun@imp.neu.edu.cn (B.Z. Sun), qiyang@imp.neu.edu.cn (Y. Qi).

http://dx.doi.org/10.1016/j.ijrmhm.2016.03.003
0263-4368/

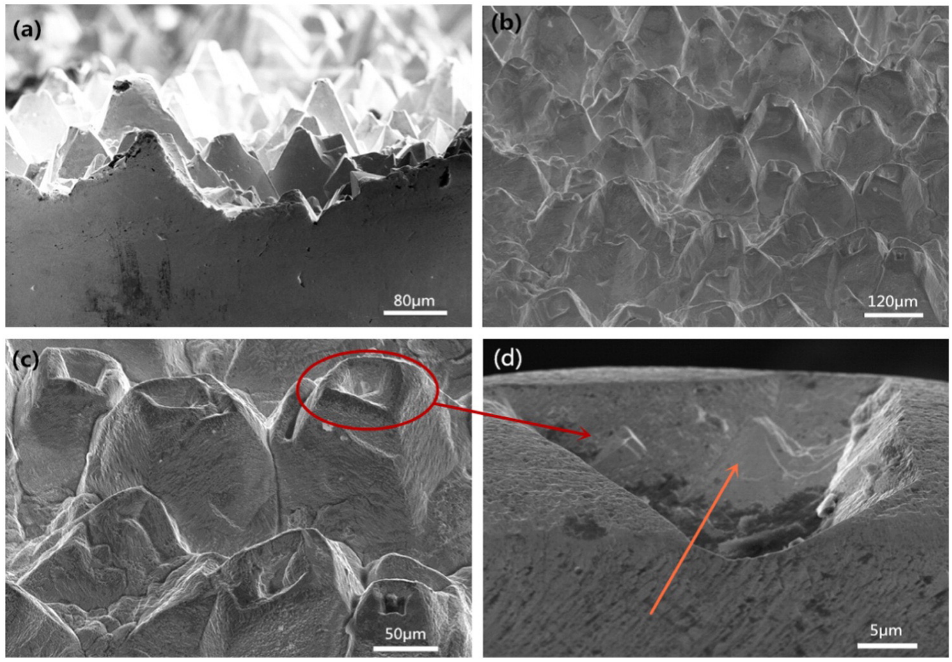

Fig. 1. The SEM images showing the surface topography of CVD-W coatings: (a) as-deposited, (b) after the thermal fatigue testing, (c) the enlarged image of (b), (d) the amplification of melting pool in (c).

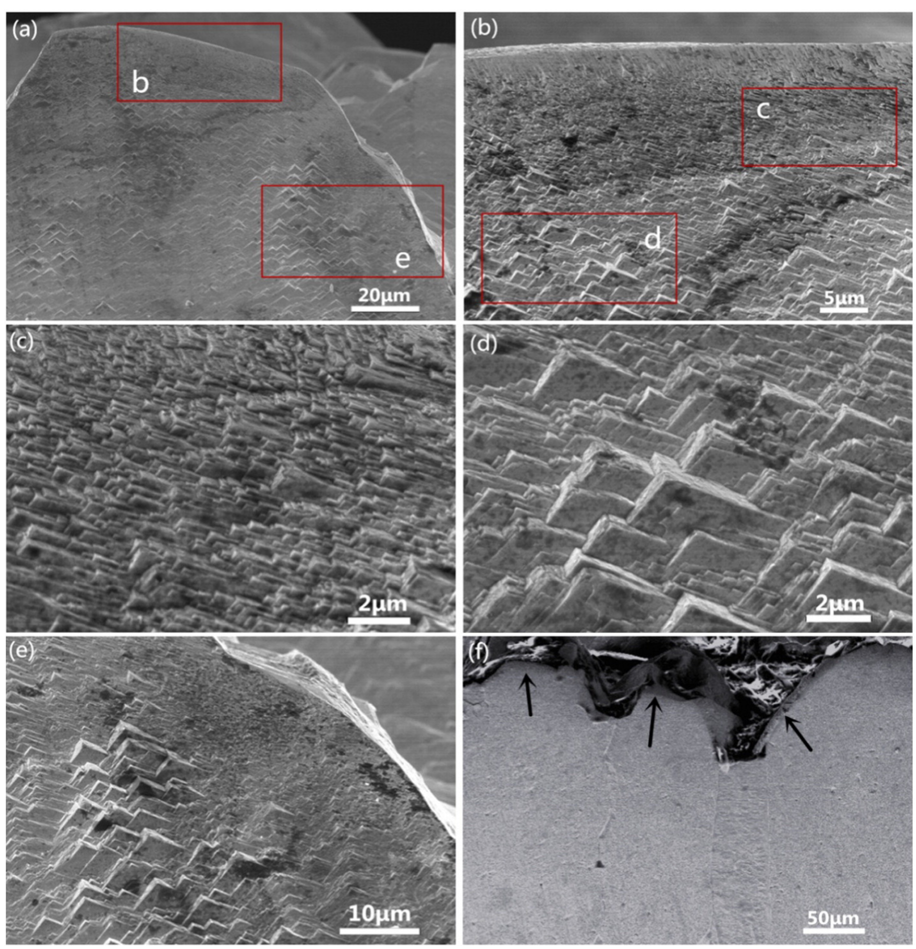

Fig. 2. The SEM images of the surface and the cross-section of CVD-W coatings after the thermal fatigue testing: (a) the morphology of outer wall of melting pools at the top of pyramid-like grains, including (b) the top of (a), including coarse grained region and fine grained region the right side of (a), (c) and (d) is (b) enlarged image of coarse grained region and fine grained region in (b), respectively. The locations are indicated as "b" "e" in (a), "c" "d" in (b).