Surface & Coatings Technology 254 (2014) 455–461

Contents lists available at ScienceDirect

Surface & Coatings Technology

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

Structure and property transitions of Al-based binary alloy coatings by magnetron sputtering

Xia Nie [a,b], Shoudong Mao [a,b], Minsheng Yan [c], Jinlong Li [b], Zhenlun Song [a,b,*]

[a] Key laboratory of Magnetic Materials and Devices, Zhejiang Province Key Laboratory of Magnetic Materials and Application Technology, Ningbo Institute of Material Technology and Engineering, Chinese Academy of Sciences, Ningbo 315201, China

[b] Key Laboratory of Marine Materials and Related Technologies, Zhejiang Key Laboratory of Marine Materials and Protective Technologies, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, Ningbo 315201, China

[c] Faculty of Materials Science and Engineering, Kunming University of Science and Technology, Kunming, Yunnan 650093, China

ARTICLE INFO

Article history:
Received 14 February 2014
Accepted in revised form 2 July 2014
Available online 9 July 2014

Keywords:
Al–based alloys
Amorphous
Solid solution
Hardness
Modulus

ABSTRACT

Al–M (M = Ti, Cr, Mo, W) alloy coatings were subjected to DC magnetron sputtering by a rapid method to analyze the evolution of coating structures with composition. Pure Al and M targets were used to deposit coating arrays across the entire binary range of Al–M alloys. All Al–M alloys exhibited a specific amorphicity range. Al–Ti and Al–Cr alloys were completely amorphous, whereas Al–Mo and Al–W alloys possessed a range of amorphous–crystalline mixtures. Results revealed that Al–Ti alloys had the widest amorphicity range. Nanoindentation tests indicated that the hardness and modulus of amorphous alloys were higher than those of solid solutions for Al–M alloys.

1. Introduction

Amorphous alloys possessed some excellent mechanical and corrosion properties for their homogeneous or single-phase systems with little structural defects (e.g., dislocations and grain boundaries) [1]. Given the formation ability of amorphous alloys, several empirical criteria and rules were proposed based on their specific properties and intrinsic characteristics [2–6]. However, a portion of the specifications only suit for some alloys with specific production techniques; and most of the rules are sufficient but unnecessary to form amorphous structures [7]. In addition, works on amorphous alloys are often painstaking because of alloy diversities and production methods.

Amorphicity ranges of alloys were predicted through simulations and calculations via an interatomic potential-based atomistic theory [7–9]. The predictions were verified by experimental observations; whereas the experimental amorphicity ranges were more or less narrower than the predicted values [7]. Therefore, the amorphicity ranges depended on the formation process.

For Al-based alloys, amorphous alloys could be obtained at narrow composition ranges [10–27]. Several alloys are expected to possess various amorphicity ranges [10,16,19,20]. However, the same types of Al-based alloys prepared by different methods also present various amorphicity ranges [7]. For instance, amorphous Al–Ti alloys possess an amorphicity range of about 25 at.% to 74 at.% Ti by ion beam mixing [22], and change to 25 at.% to 90 at.% Ti by mechanical alloying [23–25]. Furthermore, Al–Ti alloys produced by the same technique exhibit different amorphicity ranges. For instance, Metikoš–Huković obtained amorphous alloys with 20 at.% to 55 at.% Mo [17] and 20 at.% to 33 at.% W [18] by magnetron sputtering. On the other hand, Wolowik yielded amorphous alloys with 11 at.% to 55 at.% Mo [26] and 15 at.% to 46 at.% W [27] through the same method as Metikoš–Huković.

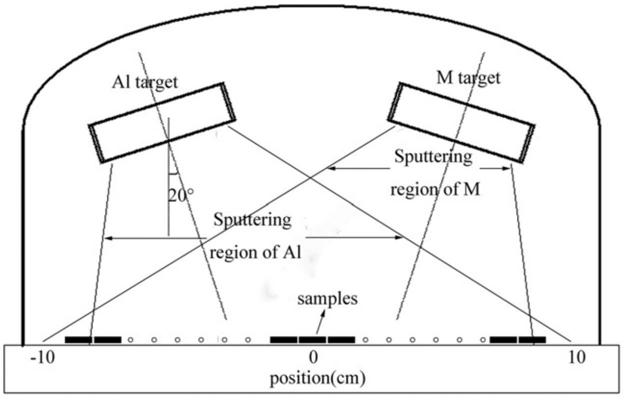

Fig. 1. Schematic of the magnetron sputtering apparatus.

---

* Corresponding author. Tel.: +86 574 87911131; fax: +86 574 86685159.
E-mail address: songzhenlun@nimte.ac.cn (Z. Song).

http://dx.doi.org/10.1016/j.surfcoat.2014.07.004
0257-8972/

Table 1
Deposition parameters for Al–M coatings.

Al–M alloy	Power (W)		Deposition time (h)
	On Al target	On M target	
Al–Ti	120	200	2
Al–Cr	140	140	2
Al–Mo	140	100	2
Al–W	120	120	2

The relationship between amorphicity range and production method induces the difficulty in comparing the amorphous structure-formation abilities of various alloys. Therefore, determining a platform that produces alloys under the same conditions is necessary. Hampshire proposed a convenient method that could prepare coating arrays with compositions across the entire binary range of alloys by co-deposition [28,29]. The method deposited coating arrays with comparable composition. Moreover, gradient transitions of alloy structures and properties could be studied. However, the amorphicity range was not observed in Al–Ti alloys in Hampshire's work; hence, the results were inconsistent with those previously reported [10–12,14,22–25].

Considering the nature formed oxide layers on the surface of the metals (e.g., Al, Ti, Cr) and the passivation behavior of AlMo [17,26] and AlW [18,19,27] alloys, amorphous Al–M (M = Ti, Cr, Mo, W) coatings may have application prospects in corrosion–protection areas. In this paper, a series of Al–M (M = Ti, Cr, Mo, W) alloy coatings were prepared by the aforementioned developed method. The coatings were analyzed to investigate the structure transitions and compare the amorphicity range of these alloys. Furthermore, the predominant factor that influenced the amorphicity range was studied. Finally, nano-indentation tests were carried out for application selection.

2. Experimental method

Al–M coatings were deposited on glass substrates by magnetron sputtering (Fig. 1). Pure aluminum (99.999% purity, Φ100 mm × 10 mm) and pure M (M = Ti, Cr, Mo, W; 99.99% purity, Φ100 mm × 5 mm) targets were used for deposition. Two DC power supplies (Pinnacle Plus, Advanced Energy) were separately supplied on the targets. The angle of the target axes with the horizontal plane was set at 70° (Fig. 1). The glass substrates were consecutively placed across the area beneath the two targets. From this method, the coatings on left and right substrates were respectively Al-rich and M-rich, thereby yielding coating

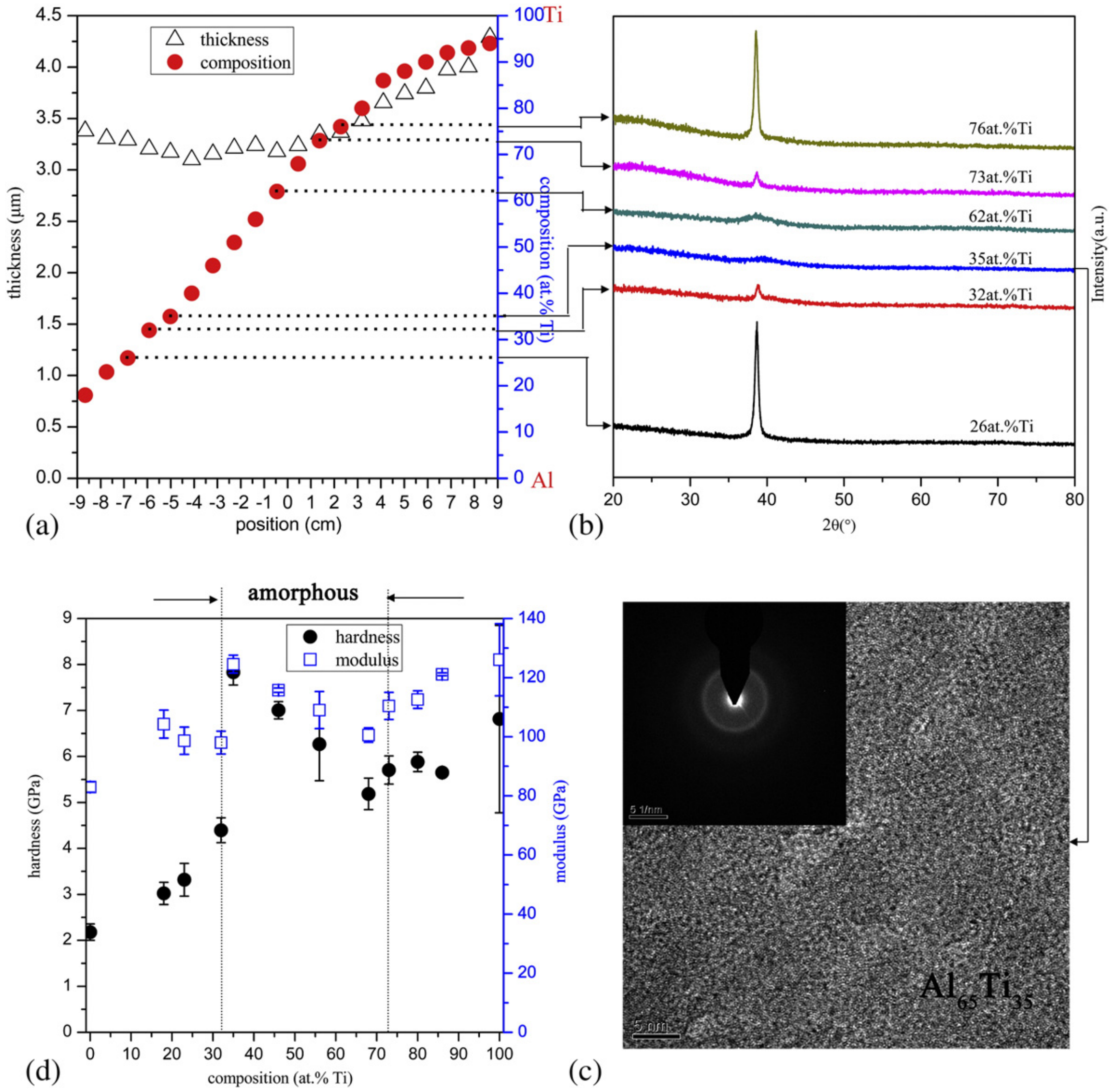

Fig. 2. (a) Thickness and composition against position and (b) XRD results for Al–Ti alloys. (c) TEM results for $Al_{65}Ti_{35}$ coating. (d) Nanoindentation results for Al–Ti alloys.