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On the reflectivity and antibacterial/antifungal responses of Al-Ni-Y optical thin film metallic glass composites

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ABSTRACT

It has been demonstrated that the Al-Ni-Y based thin film metallic glass composites (TFMGCs) can provide high optical reflectivity, especially over the UV regime, suitable for various optical devices such as optical coating or as functional layer. When such optical devices are applied in humid environment which is sensitive to bacteria or fungus, the antibacterial or antifungal capability needs to be explored. In this study, the microstructural evolution, surface roughness, hardness, optical reflectivity, and antimicrobial/antifungal responses of the Al-Ni-Y based films are overall reported. It is demonstrated that the current Al-Ni-Y TFMGCs can exhibit satisfactory UV reflection, as well as highly promising antibacterial or antifungal capability.

1. Introduction

In the past years, various bulk metallic glasses (BMGs) have been widely researched as potential structure materials in various filed [1]. Recently, thin film metallic glasses (TFMGs) and their composites (TFMGCs) have also been developed for functional applications, such as optical films, biomaterial coating or special layer in micro-electro-mechanical-system (MEMS) devices [2–4]. Especially, for TFMGCs, with nanocrystalline phases, lead to different properties than the conventional material [5]. Selected application examples utilizing such TFMGs or TFMGCs have been reported lately, including Zr-Cu-Ag TFMG for antibacterial purpose [6], Ag-Al-Mg TFMG for optoelectronic devices [7], Al or Ag based TFMGCs for UV LED lamp [8], or Ag/Al based TFMGCs for surgery shadowless lamp [9].

Metallic coating on various substrates could provide quite high reflectivity over a broad wavelength range, including common lighting and other solar energy applications. For the latter case, there are two primarily paths to harvest solar energy. One is directly converting solar energy into thermal energy and another is to transfer it to useful electricity. In the case of solar to thermal energy conversion, the metallic-coated reflectors are widely used, to collect abundant solar energy. However, there are some environmental issues needed be take into consideration when a reflector is in use. For instance, thermal stability, corrosion, wear resistance and oxidation [10–12] are some aging problems. Furthermore, when the above devices are applied in humid environment or room sensitive to bacterial or fungus, it also gradually alter the surface condition and change the performance of the reflector [13–15]. Thus, there is indeed need to explore the anti-bacterial and anti-fungus capability of such optical films. There is basically no report along this line in literature.

In previous work [16], it revealed that a series reflectance of Al-Ni-Y-X (X = Cu, Ta, Zr) as-deposited composite/amorphous film via magnetron co-sputtering. Though it shows the 70% up reflectance, there is still room for improvement. It is well known that the optical and electricity properties of thin films can be improved through annealing [17–19]. For TFMGs, literature reported that sub-T_g or above-T_g annealing, where T_g is the glass transition temperature, could upgrade the as-deposited films for both their structure and the properties [20–22]. But the detailed happening for such annealing treatments and the optimum annealing conditions in terms of resulting structure and optical property in the Al-Ni-Y system are still not completely known. In this study, the structural evolution, optical reflectivity, and anti-bacterial and anti-fungus response of the fully amorphous and partially amorphous Al-based TFMG and TFMGC films are presented.

2. Experimental details

2.1. Sample preparation

The three films, $Al_{95}Ni_2Y_3$, $Al_{92}Ni_5Y_3$, and $Al_{68}Ni_{18}Y_{14}$, were all deposited on optical glass by magnetron sputtering. Metallic targets, 50.8 mm in diameter, were used under a working pressure of 3

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$\times 10^{-3}$ Torr in Ar atmosphere. The chamber was initially evacuated to the pressure of 3.0×10^{-7} Torr before being backfilled with highly pure Ar gas. During deposition, the substrate was rotated with an average speed of 15 rpm and the working distance was 120 mm. Different nominal composition (all in atomic percent) of Al-based films is prepared by DC co-sputtering.

2.2. Basic characterization

The glassy nature of the films was characterized by X-ray diffraction (XRD, Bruker D8) with a monochromatic Cu-K_a radiation ($\lambda = 0.15406$ nm), operated at 40 kV and 40 mA, and equipped with a 0.01 mm graphite monochromator. The film morphology and composition were examined by scanning electron microscopy (SEM, JEOL 6330) with energy dispersive X-ray spectrometry (EDS). The cross-section TEM foils were fabricated using the dual-focus ion beam (FIB, SEIKO SMI3050) system. Phase identification was checked by transmission electron microscopy (TEM, FEG Tecnai G2 F20). The glass transition temperature was firstly determined to be ~320 ± 5 °C by differentiate scanning calorimetry (DSC), as shown in Fig. 1. Thermal treatment was conducted in rapid thermal annealing (RTA) system for 5 min for different temperatures from 300 to 390 °C. The thicknesses were measured by 3D alpha-step profilometer. Then, the optical reflectance was measured by n & κ analyzer 1280 with a light wavelength range from 190 to 1000 nm. The average surface roughness (Ra) was measured by atomic force microscopy (AFM) under the tapping mode, and the elastic modulus and hardness were measured by MTS nanoindenter XP equipped with a standard Berkovich tip, under the continuous stiffness measurement mode. The sheet resistance R_s was measured by four-point probe, and the electrical resistivity ρ was subsequently calculated by the multiplication of R_s and thin film thickness d. The hardness readings of the resulting films are all measured by nanoindentation.

2.3. Antibacterial activity

The antibacterial activity is investigated by the American Association of Textile Chemists and Colorists 100 (AATCC 100) code. In order to determine the antimicrobial activities, the *P. aeruginosa*, *E. coli* and *S. aureus* were selected. All the specimens are wiped by 99.9% alcohol and placed into a dish. The test microorganism is prepared by growth in a liquid culture medium. The suspension of test microorganism is standardized by dilution in a nutrient broth. Since all these bacterial grow fast under such cultured environments, the current samples are only incubated at 37 °C in humid environment for 24 h.

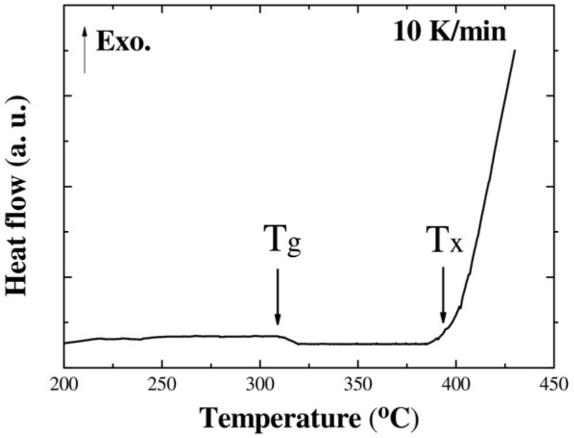

Fig. 1. Representative DSC curve of the $Al_{95}Ni_2Y_3$ thin film with a heat rate of 10 K/min.

2.4. Antifungal activity

The antifungal activity is determined by the American Society for Testing and Materials G21 (ASTM G21) method. *A. brasiliensis*, which is among the most common species of the genus *Aspergillus* and contaminant for the human living and most optical device environments, is selected for the antifungal study. All the specimens are wiped by 99.9% alcohol and placed into a dish. The fungi for test are prepared by growing in a liquid culture medium. After inoculation, the bacteria on the blank control are separated from the sample surface and microbial concentrations are determined at "time zero" by elution followed by dilution and plating. Since the fungus typically grows much slower, the current samples are designed to be incubated at 30 °C and 85% relative humidity for 28 days.

3. Results and discussion

3.1. Basic characterization

All of the sputtered film thicknesses were measured to be about 300 nm. The XRD diffraction patterns of the three representative as-deposited Al-based films are presented in Fig. 2(a). There is no crystalline peak for the $Al_{68}Ni_{18}Y_{14}$ TFMG films, but there is a single peak at about 39° for the $Al_{92}Ni_5Y_3$ and $Al_{95}Ni_2Y_3$ TFMGC films. This peak is indexed as the textured Al-(111) planes, revealing a nanocrystalline pure Al face centered cubic (FCC) phase embedded in the amorphous matrix, forming a composite structure.

Systematical TEM characterization has been done on the as-deposited fully amorphous TFMGs and partially amorphous composite TFMGC films, as presented in Fig. 3. The TEM selected area electron diffraction (SAED) patterns from the as-deposited partially amorphous composite

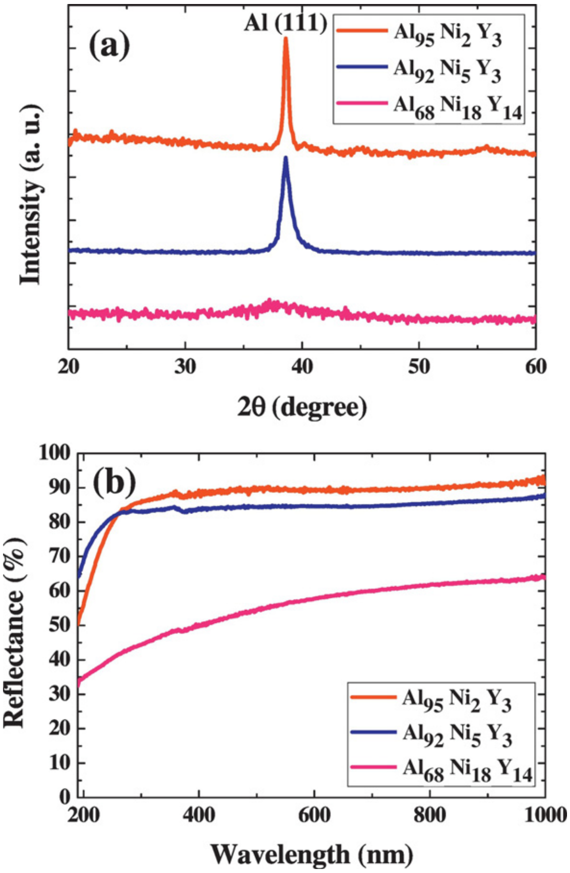

Fig. 2. (a) XRD patterns of various Al-based TFMGCs and TFMGs. (b) Reflectance versus wavelength of various Al-based TFMGCs and TFMGs.