Effect of substrate choosing process on the structures and radiation-proof properties of Al films

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Al thin films used as radiation-proof materials on textile fabrics were prepared by magnetron DC-sputtering. In the deposition, different substrate materials (Polyester, Cotton and Aramid) were chosen, resulting in different structures, morphologies and radication-proof properties. It was found that substrate choosing process was the key deposition parameter influencing the Al film phase change from cubic to tetragonal structure. Moreover, the surface roughness and grain sizes were slightly different in the films on different substrates. Finally, the optical measurements suggest that the radiation-proof properties were affected by the grain density and lattice match on the various substrates.

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For the last decade, aluminum has been intensively investigated as a protective coating material in a wide variety of application due to its high mechanical hardness and good corrosion resistance [1]. Previous attention has been focused on its applications in the mechanical and microelectronic industries. However, it may be of potential value in radiation-proof applications on textile fabrics [2,3]. Among some protective films, Al film is one of the suitable candidates for the production of radiation-proof materials due to its good light reflection, heat radiation performance, high conductivity, the shielding effect of the microwave and anti-static properties [4], which make it extensive application in the military, civilian and other fields [5].

Al thin films have been prepared by various techniques such as DC-magnetron sputtering [6], flash evaporation [7], chemical spray [8] and electro-deposition [9]. Enormous amount of work has been already reported on structure, optical properties of Al thin films [10]. However, still it requires further investigation to optimize the optical properties of Al films to use as a suitable candidate for radiation-proof applications.

It is reported that the change of substrate materials is effective to enhance the reflection properties of Al films because the formation of a dense protective surface layer on the textile fabrics [11,12]. Until now, only a few research groups, however, focused on promising enhanced radiation-proof properties of Al films according to the deposition parameters [13,14]. The main aim of this paper is to determine and characterize the influence of the choosing substrate processes on the structures and on the radiation-proof properties of Al films.

1. Experiment

1.1 Synthesis of Al thin films

Thin films of Al were deposited by DC-sputtering in argon gas atmosphere on different substrates (polyester, cotton and aramid). Substrates were cleaned ultrasonically and chemically in organic solvents. A thin Al film was deposited by an Al target of 60 mm diameter. No changes in target composition where observed with time. All films were deposited at the room temperature 25 ^{o}C, at a working gas pressure of 0.7 Pa and a sputtering time of 20 min. The samples were deposited at a sputtering power of 30 W. The process parameters of Al films used in DC magnetron sputtering are shown in Table 1.

Table 1. Sputtering parameters of Al films.

Sample	Substrate	Sputtering power / (W)	Sputtering time / (min)
a	Polyester	30	20
b	Cotton	30	20
c	Aramid	30	20

1.2 Characterizations of Al films

Optical properties of the Al thin films were measured at normal incidence using a double-beam UV-VIS-NIR spectrophotometer (type Lambda 35 from Perkin Elmer) of optical transmittance in the photon energy range of 1.1- 6.6 eV. The resistivity calculated from the sheet resistance measured by a four-point probe. Coupled θ-2θ X-ray diffraction (XRD) scans in the simple mode were performed in the range of $2\theta=5^o$-90^o by using of the Cu Kα1 line of the X-ray source (type Rigaku D/max2550) to investigate crystallographic properties of the films. The surface morphology of each film was examined by scanning electron microscopy (SEM-3400-N, type Hitachi).

2. Results and discussion

2.1 Structural studies of Al films

Fig. 1 shows the XRD patterns of Al films deposited on different substrates at room temperature by magnetron CD-sputtering. The Al films deposited on polyester and aramid substrates are almost amorphous or nano-scale grain size. The film deposited on cotton has a clear though wide diffraction peak of Al (311), indicating that the grain size of this phase in the largest. The crystallinity of the films can be improved by the substrate choosing process. The different substrates will lead to different crystal lattice mismatch between substrates and Al films, and the crystal lattice mismatch will cause different growth model in the films [15].

It also can be observed in Fig. 1 that two structures phase occurred in cotton-sub film. The cubic structure is mainly confirmed by the (2 0 0) and（2 2 0) diffraction peaks at 2 theta = 44.5°and 65.8°, which followed by a tetragonal structure confirmed by (1 1 1) and (3 1 1) peaks at 2 theta = 36.2° and 78.4° [16]. However, when the materials (Aramid, Polyester) are used to be substrates, only two characteristic peaks (2 0 0) and（2 2 0) are displayed in these samples, indicating that single phase (Cubic structure) appeared in these films. It can be interrupted by that the role of the substrate in its influence on the growth direction, like generally for epitaxy, will be unquestionably determinant in the initial stages of growth during the nucleation stage [17].

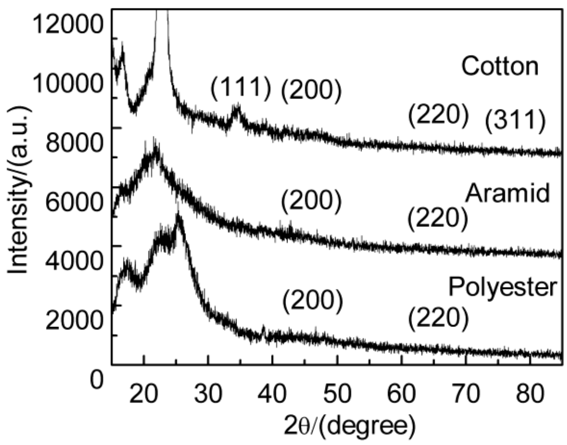

Fig. 1. XRD patterns of Al films prepared on various substrates.

2.2 Morphological studies of Al films

Fig. 2 (a-c) shows the Low multiples (×1k) of SEM images of the Al films on different substrates. It can be seen from Fig. 2 that the surface of fiber texture on Polyester was smoother and the grains seemed to be rather compact and dense than that of Cotton and Aramid. It shows that the microstructures and surface morphologies of the films could be improved by the chose of substrate material. This could be attributed to the thorough diffusion and better growth of the Al grains as the increase of sputtering particles on the smoother fiber texture on the Polyester than the rougher ones on Cotton and Aramid [17].

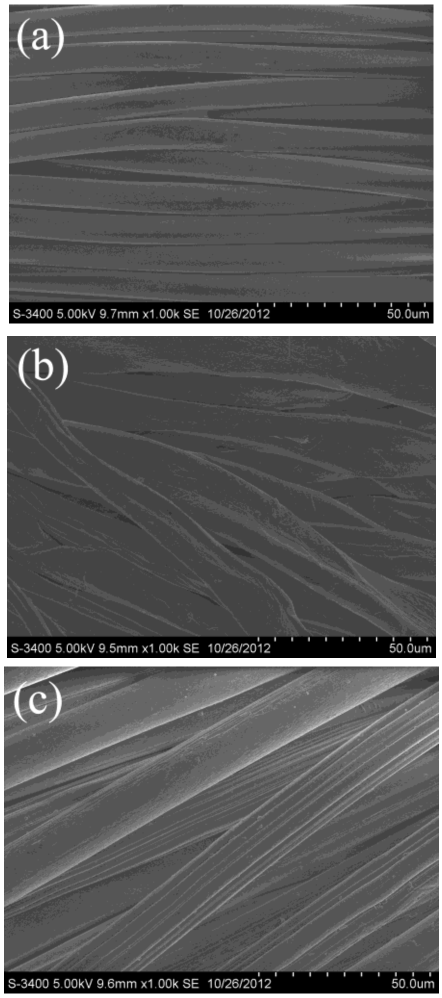

Fig. 2. Low multiples (×1k) of SEM images of Al films deposited on various substrates: (a) Polyester, (b) Cotton and (c) Aramid.

Fig. 2. (a-c) is the high multiples (×30k) of of SEM images of the Al films at the different substrates. It can be found in Fig. 3 (a) that the Al film deposited on polyester has grows in two dimensions and a domain structure is formed. This domain has many micrograins that gathered in the same orientation. Also, the mobility of the atoms on the surface of cotton is larger than that of the atoms on the Cot-

ton and Aramid substrates. Thus, the density of the crystalline grains deposited on cotton is more compact than that on the other substrates.

Al film on cotton crystallizes in three-dimensional manner, and a granular crystalline structure is formed. In addition, the Al film surface has many crystalline grains with cubic and tetragonal structures, and its surface roughness is larger than that of the film deposited on the other substrates. Also, the grains show an oval structure and the film has better crystalline grains with a clear grain boundary, and the fluctuation of the film surface is big.

In the case of the Al grains grow on the Aramid substrate, a more or less uneven surface morphology is observed. Also, the worst lattice match is obtained while the lowest crystallinity is detected for films on Aramid substrate. Importantly, the surface of Al film on Aramid is significantly rougher than the others and it shows a much higher defect density compared to the other films. This clearly indicates that during depositing in the Aramid substrate, the Al thin films have partially obtained different growth orientation of the formed particles [18].

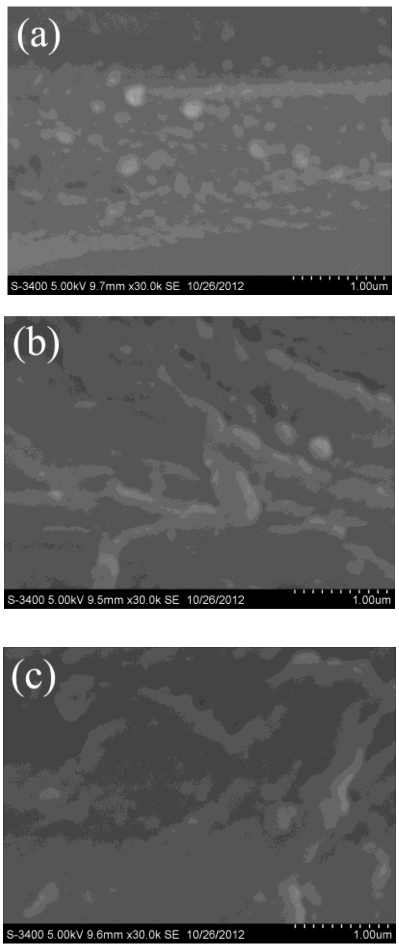

Fig. 3. High multiples (×30 k) of SEM images of Al films deposited on various substrates: (a) Polyester, (b) Cotton and (c) Aramid.

2.3 Radiation-proof properties of Al films

Fig. 4 shows the spectra curves of Al films on different electrodes in the wavelength range 200-1100 nm. It can be found in Fig. 4 that the optical transmittance spectra of the Polyester-sub films exhibit worse transmission in the visible region compared with the others (Cotton and Aramid films), which indicates that the Al film on the Polyester has the best radiation-proof properties. This result may be attributed to the fact that the particle distribution on the smoother Polyester surface can be improved by the best lattice match than the others.

Further, it can be clearly observed that the optical transmittance of the Al film on aramid (ranged from 6% to 6.3%) is much higher than the others (ranged from 0% to 1.3%). This is attributed to the increase in grain gaps due to lattice defects and lattice mismatch, which can decrease the reflection and enhance the transmission in the visible light wave [19].

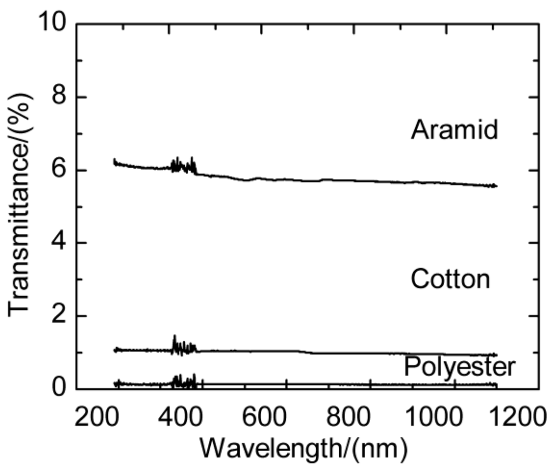

Fig. 4. Transmittance spectra curves of Al_2 films deposited on various substrates.

3. Conclusions

1) The XRD patterns show that the Al films on Polyester substrate were found to exhibit cubic and tetragonal structures while that on substrates (Cotton, Aramid) appear single phase (cubic structure).

2) The result of SEM morphologies indicated that surface of fiber texture on Polyester was smoother and the grains seemed to be rather compact and dense than that of Cotton and Aramid. However, the Al film on Cotton shows an oval structure and the film has better crystalline grains.

3) The optical transmittance spectra suggest that the Polyester-sub films exhibited better optical properties than the other electrodes. It is concluded that not only the better grain density but also lattice match affected the optical properties of Al films.

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