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Corrosion resistance of the NdFeB coated with AlN/SiC bilayer thin films by magnetron sputtering under different environments

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ABSTRACT

The AlN/SiC bilayer and SiC monolayer thin films were deposited on sintered NdFeB by RF magnetron sputtering to improve the corrosion resistance. Their structures and morphologies were studied by XRD and AFM and SEM. The corrosion behaviors of AlN/SiC and SiC-coated NdFeB in 3.5 wt% NaCl, 20 wt% NaOH and 0.1 mol/L H_2SO_4 solutions were characterized with potentiodynamic polarization curves. The results show that AlN/SiC and SiC thin films can evidently improve the corrosion resistance of NdFeB, and the AlN/SiC films have the better resistance than the SiC film.

1. Introduction

NdFeB permanent magnets have the outstanding magnetic properties and have been widely used in voice coil motors, hard disk drives, medical instruments, automotive applications, industrial motors and generators, etc. However, the poor corrosion resistance prevents its further developments [1–4]. There are $Nd_2Fe_{14}B$ main phase, Nd-rich phase and B-rich phases in NdFeB magnets. The Nd-rich phase distributed on the grain boundaries of $Nd_2Fe_{14}B$ is the most active and the B-rich phase comes second. The Nd-rich and B-rich phases are easy to be corroded under corrosion media, which will result NdFeB magnets into powder-like, non-usable product [5,6]. Many efforts have been made to improve the corrosion resistance of the NdFeB, including adding alloy elements [7] and preparing protective coatings [8,9]. The alloying elements can improve the intrinsic corrosion resistance of NdFeB at the expense of magnetic properties, whereas the surface coating can improve the corrosion resistance of NdFeB and does not damage its magnetic properties obviously [10,11]. The electroplating is widely used for the NdFeB protective coatings in industry, however, there is the environmental pollution and the magnetic damage of the NdFeB. Magnetic sputtering coating technique is the low temperature and friendly environment, so it can replace the electroplating for preparing NdFeB protective coating. Al, Ti/Al and Ni/Al coatings have been deposited on NdFeB by thermal evaporation [12,13], however, it has not been reported that AlN/SiC bilayer films are prepared on NdFeB by magnetron sputtering. AlN has the excellent mechanical properties and thermostability, and its lattice constant and thermal expansion coefficient are between the NdFeB and SiC, so it can improve the

Table 1
NdFeB magnet composition.

NdFeB (48 M)	Pr,Nd	B	Dy	Fe	Others
wt%	29.0–30.0	1.0–1.1	1.5–2.0	65–66	0.5–3.0

Table 2
The preparing parameters of AlN/SiC bilayer thin films.

Film	Parameters			
	Working pressure (Pa)	RF power (W)	N_2/Ar (sccm)	Depositing time (min)
SiC	0.5	150	0:60	90
AlN	0.5	100	10:20	60

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adhesion strength between the SiC film and the NdFeB substrate. SiC can prevent the radiation and high temperature oxidation, at the same time, it has wear-resistance, corrosion resistance and optoelectronic properties [14,15]. The AlN/SiC-coated NdFeB is a promising way to improve the corrosion resistance.

In this report, the AlN/SiC bilayer thin films were deposited on sintered NdFeB by radio frequency (RF) magnetron sputtering. The structures, morphologies and corrosion resistances of AlN/SiC and SiC-coated NdFeB are investigated.

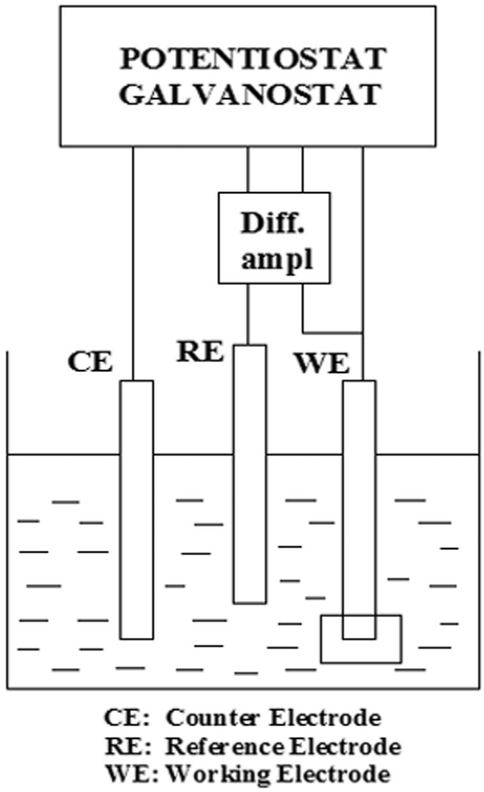

Fig. 1. The schematic diagram of three electrode cell testing system.

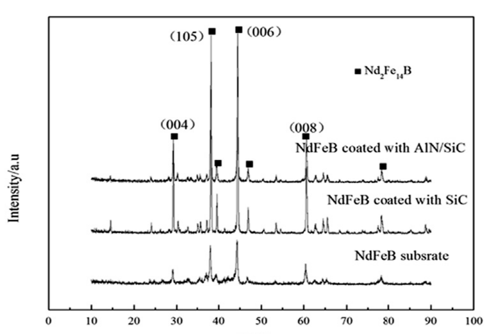

Fig. 2. XRD patterns of NdFeB substrate and SiC and AlN/SiC-coated NdFeB.

2. Experimental details

The SiC and AlN thin films were sputtered on sintered NdFeB commercial substrates ($10.5 \times 6.5 \times 1.2$ mm^3) with a FJL560B1 Ultra-High Vacuum Magnetron and an Ion Beam Sputtering Equipment. The NdFeB compositions are in Table 1, and these substrates were successively grinded with SiC abrasive paper from 400# to 800# and polished, then cleaned in acetone and alcohol about 10 min, finally blew-dry. The sintered SiC (purity 99.5%) and metal Al (purity 99.99%) targets were used. The original vacuum was 1.0×10^{-4} Pa and high purity Ar and N_2 were entered. SiC film was sputtered under Ar gas of 0.5 Pa for 90 min and the AlN film was sputtered under Ar and N_2 mixed gases of 0.5 Pa for 60 min at room temperature. The preparing process parameters of the thin films are listed in Table 2.

The thickness, crystal structure, surface and cross-sectional morphologies of the AlN/SiC thin films were measured with a Step Apparatus (XP-1), X-ray diffraction (CuKα1, λ=0.15406 nm) (Rigaku18kW D/Max 2500 V), an atomic force microscope (AFM, CSPM5500A) and a scanning electron microscope (SEM, SU8020). The magnetic properties of NdFeB coated with AlN/SiC (remanence, coercivity and maximum energy product) were measured by a ultra-high coercivity permanent magnet pulse tester (PFM12).

The electrochemical corrosion behaviors of the specimens in 3.5 wt% NaCl, 20 wt% NaOH and 0.1 mol/L H_2SO_4 solutions were evaluated by potentiodynamic polarization test with a CHI650D electrochemical analyzer (Shanghai Chenhua, China) at 25 °C. A three-electrode cell testing system was showed in Fig. 1. Ag/AgCl was a reference electrode (RE), a platinum sheet was a counter electrode (CE) and the specimen was the working electrode (WE). The exposed surface area of the working electrode was 0.67 cm^2 and all electrodes were kept in solutions for 1 h to stabilize the stationary potential. Polarization curves were measured at a

Table 3
The AFM data of SiC and SiC/AlN thin films coated on NdFeB.

Specimen	The average grain diameter (nm)	The average roughness (nm)
NdFeB/SiC	212	6.17
NdFeB/AlN/SiC	181	3.07

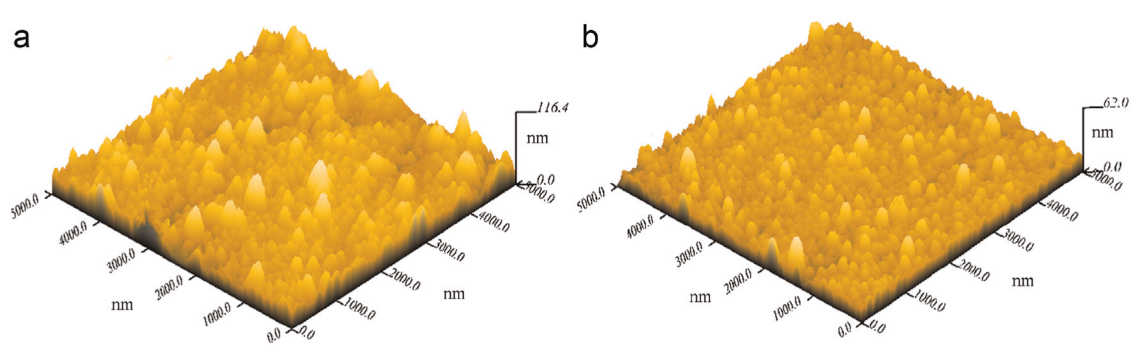

Fig. 3. The surface morphologies of SiC and AlN/SiC thin films coated on NdFeB. (a) SiC monolayer film and (b) AlN/SiC bilayer films.