Sensors and Actuators A 247 (2016) 75–82

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

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

High temperature sensors fabricated on Al_2O_3 ceramic and nickel-based superalloy substrates

Yanlei Wang[a,c], Congchun Zhang[a,c,*], Di Niu[a,c], Guifu Ding[a,c], Li Duan[b,c]

[a] National Key Laboratory of Science and Technology on Micro/Nano Fabrication, PR China
[b] Key Laboratory for Thin Film and Micro fabrication of the Ministry of Education, PR China
[c] Department of Micro/Nano Electronics, Shanghai Jiao Tong University, Shanghai 200240, PR China

ARTICLE INFO

Article history:
Received 5 February 2016
Received in revised form 26 April 2016
Accepted 31 May 2016
Available online 2 June 2016

Keywords:
Resistance temperature sensors
Al_2O_3 thin films
High temperature insulators
Electrical properties
Sputtering

ABSTRACT

The main purpose of this study is to develop resistance temperature sensors which can work at high temperature. A 2 μm thick Al_2O_3 thin film was deposited as an electrical insulating film on Pt-coated Al_2O_3 ceramic substrates and nickel-based superalloy substrates by Dual Ion Beam Sputtering Deposition (DIBSD). The results of atomic force microscopy (AFM), scanning electron microscopy (SEM), and X-ray photon electron spectroscopy (XPS) analyses reveal that the Al_2O_3 films were dense, smooth and pinholes free with roughness around 3 nm. The vertical electrical resistance of thin films deposited on Pt-coated Al_2O_3 ceramic substrates was more than 2 GΩ at room temperature and 100 kΩ even at around 800 °C. Both resistance temperature sensors (RTSs) fabricated on Al_2O_3 ceramic substrate and that on nickel-based superalloy substrates showed a linear relation up to 1000 °C. The RTS on the ceramic substrates showed stable after 4 thermal cycles while RTS on the superalloy substrates showed a good repeatability of heating and cooling curves even after experiencing a high temperature environment as high as 1000 °C.

1. Introduction

To validate the design code of jet aircraft and space-based engines, a range of sensors are needed to monitor strain, temperature and heat flux in a harsh environment with high pressure, high temperature and high gas flow. Thin film sensors are thought to be a superior choice compared to conventional wire and foil sensors since they are directly deposited onto the test part with a micrometers scale, which minimized the disturbance of the operating propulsion system [1–3]. Considering turbine engine blades and vanes are usually made of conductive nickel-based superalloy, a high quality insulator between the substrate and the sensor, which provides good insulation at high temperature are required. Among a variety of candidate insulating materials, Al_2O_3 shows excellent insulation property at high temperature. Flame-sprayed Al_2O_3 insulator provides good insulating capability, but the thickness of 300 μm or greater of the coating lessens the advantage of the thin film sensors [4]. As a result, a thermal oxidation on MCrAlY coating followed by a 5–8 μm sputtered or e-beam evaporated Al_2O_3 is usually served as insulation layer since a single Al_2O_3 layer indicated a short at room temperature because of grain boundaries and defects [5,6].

Dual Ion Beam Sputtering Deposition (DIBSD) system has been used in film deposition for years. Compared with traditional deposition methods such as RF magnetron sputtering, DC reactive magnetron sputtering and e-beam evaporation, the films deposited by DIBSD system show an excellent adhesion to the substrate since a wide atomic intermixed zone could be set up at the film/substrate interface by ion-assisted dynamic mixing [7]. What's more, the DIBSD sputtered Al_2O_3 films are amorphous and relatively stable compared to reactive sputtered alumina films, where partial formation of crystalline Al_2O_3 phases were observed. In particular, amorphous Al_2O_3 shows better electrical properties since the formation of crystalline phase in the amorphous matrix might introduce defects and trap states into the alumina films [8]. The DIBSD sputtered Al_2O_3 thin film preformed high density, pin holes free and amorphous structure, which are significant for the electrical insulation at high temperature. In this work, Al_2O_3 thin film insulator was prepared by DIBSD on metal layer. The microstructure was examined by XPS, AFM and SEM. Moreover, resistance temperature sensors on ceramic and nickel-based superalloy substrates were investigated with DIBSD sputtered Al_2O_3 thin films as insulator layers. The electrical insulation was evaluated at high temperature up to 1000 °C.

---

* Corresponding author at: National Key Laboratory of Science and Technology on Micro/Nano Fabrication, PR China.
E-mail addresses: zhcc@sjtu.edu.cn, zhccgw@gmail.com (C. Zhang).

http://dx.doi.org/10.1016/j.sna.2016.05.048
0924-4247/

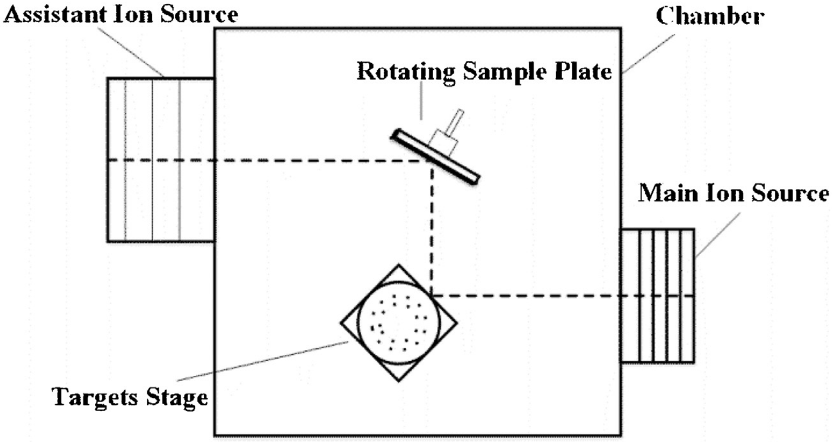

Fig. 1. The schematic diagram of the DIBSD system applied for the deposition of Al_2O_3 thin film.

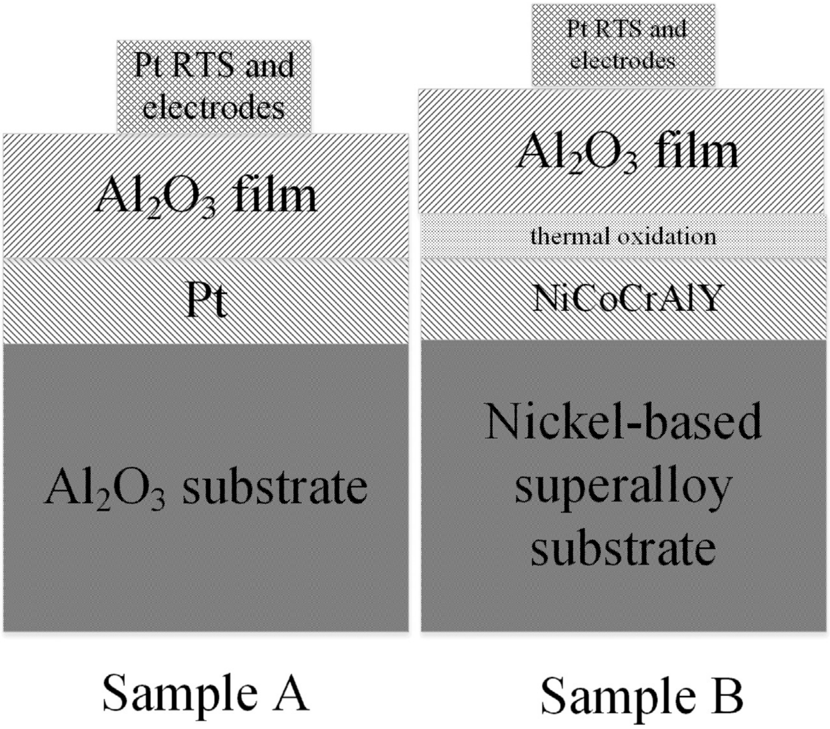

Fig. 2. Schematic cross section of specimens.

2. Experimental

Al_2O_3 thin film was deposited on both Pt-coated Al_2O_3 ceramic substrates (30 mm × 20 mm × 0.8 mm) and nickel-based suuperalloy substrates (20 × 20 mm × 1 mm) by a Dual Ion Beam Sputtering Deposition (DIBSD) system at room temperature. A 99.99% sapphire target was used. The Al_2O_3 ceramic substrates were ultrasonically cleaned to remove organics and other impurities. Prior to Al_2O_3 thin films deposition, a Cr/Pt layer was sputtered on the Al_2O_3 ceramic substrates as a bottom electrode for the later tests, where Cr layer was applied as intermediate layer between the Pt layer and the substrate. For the superalloy substrate, 20 μm NiCoCrAlY coating was first deposited onto the substrate by RF magnetron sputtering system. Then the samples were heat treated to grow thermal oxides on the surface of the NiCoCrAlY coatings. The Dual Ion Beam Sputtering Deposition (DIBSD) system, which consists of two ion sources-the main ion source (MIS) and the assisted ion source (AIS) were applied for Al_2O_3 insulation films deposition. Fig. 1 shows a schematic diagram of the DIBSD system. The MIS bombards the high-purity sapphire target with inter Ar^+ beams at an angle of incidence of 45° from the target normal while the AIS sputters the sample at the same time with Ar^+ beams in an incidence angle of 60° from the sample normal [9]. The chamber was first evacuated to a base pressure of 5×10^{-4} Pa and the work pressure was 2.9×10^{-2} Pa. Oxygen was admitted as an additional O source to offset the loss of O atoms during the depositing process. The oxygen partial pressure was 10%–18%. The energy and current for MIS was 900 eV and 85 mA, respectively, and that for AIS was 80 eV and 20 mA. The sputtered Al_2O_3 thin films were around 2 μm thick. Prior to Al_2O_3 deposition, a pre-bombardment of target with MIS for 3 min was carried out to remove the thin contamination layer on the surface of the pure sapphire target. And the samples were cleaned with AIS for 2 min, which not only can clean the sample, but also enhanced the samples' affinity for target composition.