Short Communication Polymer Sciences 2020
Vol.6 No.2

Nano Congress 2017-A Study on the Characteristics of Ni-Cr-Mn-Y-Dy Thin Film Resistors Using High Entropy Method - Ying-Chieh Lee - National Pingtung University of Science & Technology.

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A Ni-Cr-Mn-Y-Nb resistive thin film was prepared in this study using DC and RF magnetron co-sputteringfrom $Ni_{0.45}$-$Cr_{0.27}$-$Mn_{0.13}$-$Y_{0.16}$ cast alloy and niobium targets. The electrical properties and microstruc-tures of Ni-Cr-Mn-Y films with Nb addition under various annealing temperatures were investigated. Thephase evolution, microstructure and composition of Ni-Cr-Mn-Y and Ni-Cr-Mn-Y-Nb films were char-acterized using X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), field-emission transmission electron microscopy (HRTEM). All Ni-Cr-Mn-Y-Nb films annealed at 300^{o}Cexhibited an amorphous structure. The $Ni_{17}Y_{12}$crystalline phase was observed in Ni-Cr-Mn-Y-Nb filmswith or without lower Nb content when annealed at 400^{o}C. When the annealing temperature was set to300^{o}C, the Ni-Cr-Mn-Y films exhibited a resistivity ~480mU-cm with the temperature coefficient ofresistance (TCR)at þ30 ppm/^{o}C. However, Ni-Cr-Mn-Y films with 14 at.% Nb exhibited the smallesttemperature coefficient of resistance (þ5 ppm/^{o}C) with the resistivity ~585mU-cm after annealing at300 C in air.

Introduction

The rapid development and improvement of information andtelecommunication technologies as well as the expansion of digitalindustries are based to a substantial degree on high precision,reliable, integrated, low noise and low power consuming electricalcomponents . The resistor is one of the fundamental componentsused primarily in electronic circuits. The demand for thin film re-sistors with low temperature coefficients of resistance (TCR) andhigh precision has dramatically increased in recent years. An important technical parameter of thin film resistors is thetemperature coefficient of resistance (TCR). A high TCR will result inthe resistance value drifting, influencing the resistor accuracy asthe temperature changes . The main factors influencing TCRinclude the film composition, sputtering process and annealingtemperature. The film composition plays a decisive role amongthese three factors. Therefore, employing an appropriate methodfor depositing a suitable film composition is essential to obtaininghigh-resistance resistors with a low TCR.Extensive rapid development in high entropy alloy (HEA) filmwere obtained recent years by Yeh . High entropy alloys aremulticomponent systems composed of elements displaying anearly equiatomic configuration with contents ranging between 5and 35 at.% . It was generally found that high entropy alloys formsimple solid solution structures (rather than manycomplex phases)at elevated temperatures because of their large mixing entropies.However, it is possible to enhance the resistivity of alloy films usingthe high entropy alloy method. According to Matthiessen's rule:

ρ̇totat= ρ̇defects + ρ̇rimpuritie + ρ̇rthermal.

2. Experimental procedure

2.1. Ni-Cr-Mn-Y thin filmNickel (Ni), Chromium (Cr), Manganese (Mn), and Yttrium (Y)powders, as the main raw materials, were chosen to smelt thetarget for high-resistance thin film resistors. Alloy films weredeposited onto polished alumina (Al_2O_3) substrates. These aluminasubstrate were scribed for the TCR measurement into 1.6 ×0.8 mmcell sizes using a laser. Glass and Si wafers were used as substratesfor the sheet-resistance measurements and thin film thickness,respectively. These substrates were cleaned using a D.I. water-cleaning procedure and dried in nitrogen before loading into thesputtering chamber.Ni-Cr-Mn-Y thin films that were 80 nm in thickness weredeposited onto the substrates using a DC magnetron sputteringsystem. A $Ni_{0.45}$-$Cr_{0.27}$-$Mn_{0.13}$-$Y_{0.16}$ alloy with a diameter

This work is partly presented at 19th Nano Congress for Next Generation August 31-01, 2017 Brussels, Belgium

76.2 mmwas used as targets. The DC power was fixed at 50 W. The sput-tering chamber was evacuated to a background pressure of 5 $\times 10^{-7}$torr using a cryo-pump. Sputtering was performed using argon gaswith a purity of 99.999% at flow of 60 sccm using mass flow con-trollers at a working pressure of 3 $\times 10^{-3}$torr for gas introductioninto the chamber.

2.2. Ni-Cr-Mn-Y-Nb thin filmThe niobium target was made from Nb powders, which ishelpful to improved TCR and stabled film structure. Ni-Cr-Mn-Y-Nb thin films 80 nm in thickness were deposited onto the substratesusing a DC and RF magnetron co-sputtering system. A $Ni_{0.45}$-$Cr_{0.27}$-$Mn_{0.13}$-$Y_{0.16}$ alloy and niobium with a diameter 76.2 mm were usedas targets. The Ni-Cr-Mn-Y alloy target was set at the DC position.The niobium target with a diameter 76.2 mm was set at the RFposition. To obtain different niobium contents in the Ni-Cr-Mn-Yfilm, the DC power was fixed at 50 W and the RF power waschanged from 20 W to 120 W. The sputtering chamber was evac-uated to a background pressure of 5 $\times 10^{-7}$torr using a cryo-pump.Sputtering argon gas with a purity of 99.999% at flow of 60 sccmwas performed using mass flow controllers with a working pres-sure of 3 $*10^{-3}$torr.

2.3. Analysis

Thin films deposited onto glass plates at room temperature weresubjected to transmission electron microscopy (TEM) and X-raydiffraction (XRD) studies, Thin films deposited onto Al_2O_3sub-strates (size: 400 mm2) were used to measure the electrical prop-erties. The substrate temperature was 25^{o}C. The as-deposited filmswere annealed at 250-400^{o}C for 2 h, at a heating rate of 5^{o}C/minin air.The sheet resistance Rsof the films was measured using thefour-point probe technique. The thickness tof the films wasmeasured using FE-SEM (cross-section). The resistivity measuredusing the four-probe method was consistent with the resistivityobtained by the Rsand tsamples. The TCR values of the thin filmswere measured using thin long strips cleaved from the substrate.Electrical contacts at the two ends of the resistive strips were ob-tained by selectively coating the ends with sputtered silver. The DCresistance of the strips was measured using a digital multimeter(HP 34401A) at different temperatures (25^{o}C and 125^{o}C). The TCRof the thin films was measured using the following equation

TCR ¼[(DR/DT) 1/R] $*10^{6}$ppm/K

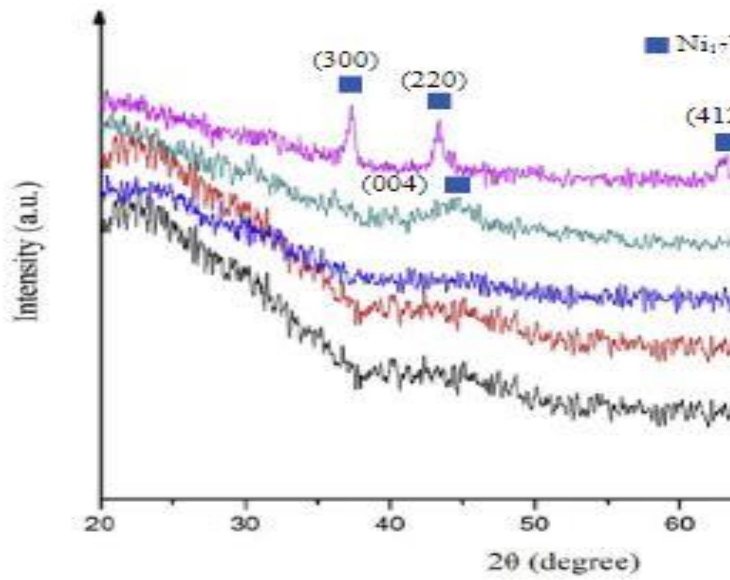

Fig. 1. X-ray diffraction patterns of Ni-Cr-Mn-Y thin fil temperatures.

Conclusion:

This study investigated thin films fabricated for the purpose ofpreparing high resistivity with low-TCR thin film resistors. Thedependencies of the Ni-Cr-Mn-Y-Nb thin film electrical propertieson the annealing temperatures and the film compositions were alsoinvestigated. Our conclusions are summarized as follows:A Ni-Cr-Mn-Y resistive thin film was prepared using DCmagnetron sputtering from $Ni_{0.45}$-$Cr_{0.27}$-$Mn_{0.13}$-$Y_{0.16}$cast alloy tar-gets. When the annealing temperature was set to 400^{o}C, Ni-Cr-Mn-Yfilms with some amounts of $Ni_{17}Y_{12}$nanocrystalline phases wereobserved. The Ni-Cr-Mn-Y film annealed at 300^{o}C presented anamorphous structure using TEM analysis. The Ni-Cr-Mn-Y filmsannealed at 300^{o}C exhibited the smallest temperature coefficientof resistance (þ30 ppm/^{o}C) with a resistivity of ~480mU-cm.A Ni-Cr-

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Mn-Y-Nb resistive thin film was prepared using DC andRF magnetron co-sputtering from $Ni_{0.45}$-$Cr_{0.27}$-$Mn_{0.13}$-$Y_{0.16}$ castalloy and niobium targets. All of the Ni-Cr-Mn-Y-Nb films annealedat $^{O}400^{O}C$ exhibited an amorphous structure, except for speci-mens with 0% and 6.3% Nb addition at $400^{o}C$. Ni-Cr-Mn-Y filmswith 6.3 at.% Nb annealed at $400^{o}C$ presented amount of $Ni_{17}Y_{12}$crystalline phase. Amorphous structures were obtained for Ni-Cr-Mn-Y films with higher Nb content (□14 at.%), which is attributedto the high entropy alloy effect. The TCR values gradually shiftedfrom positive to negative with increasing in niobium content. Asthe annealing temperature was increased, the TCR shifted fromnegative to close to zero. This shift is attributed to the crystallineand oxidation. The TCR of Ni-Cr-Mn-Y-Nb thin films could beadjusted to close to zero using the annealing process and adding Nbcontent. The oxidation layer thickness in the films was increasedsignificantly from 8 nm at 14 at.% Nb to 11 nm at 31.6 at.% Nb. Thisresult indicates that the film surface oxidation becomes thickerwith more added Nb. The electrical properties indicated that Ni-Cr-Mn-Y films with 14% Nb addition annealed at $300^{o}C$ exhibited thesmallest temperature coefficient of resistance (þ5 ppm/^{o}C) with aresistivity of ~585mU-cm. For practical purposes, it is importantthat films with a small TCR possess high resistivity water-based binders modified with nanoparticles materials and its application in the leather finishing.

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