Thin Solid Films xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Thin Solid Films

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

A study on the NiCrMnZr thin film resistors prepared using the magnetron sputtering technique

Cheng-Hsien Lin[a], Ho-Yun Lee[b], Yaw-Teng Tseng[a], Ying-Chieh Lee[c,*]

[a] Department of Applied Physic, National Pingtung University, Pingtung 90003, Taiwan
[b] Department of Resources Engineering, National Cheng Kung University, Tainan 70101, Taiwan
[c] Department of Materials Engineering, National Pingtung University of Science &Technology, Pingtung 91201, Taiwan

ARTICLE INFO

Keywords:
NiCrMnZr
Thin film resistors
Resistivity
Temperature coefficient of resistance

ABSTRACT

We prepared two types of thin film, a NiCrMn resistive thin film was prepared using direct current and radio frequency magnetron co-sputtering from $Ni_{0.6}Cr_{0.4}$ casting alloy and manganese targets. A NiCrMnZr resistive thin film was prepared based on the optimum NiCrMn film composition, which was made using direct current and radio frequency magnetron co-sputtering from NiCrMn casting alloy and zirconium targets. The electrical properties and microstructures of the resistive films under different annealing temperatures were investigated. The results indicated that the NiCr film resistivity can be enhanced by adding manganese. When the annealing temperature was set to 300 °C, the NiCrMn films exhibited a resistivity ~400 μΩ-cm with the smallest temperature coefficient of resistance of −6.6 ppm/°C. For NiCrMnZr films, there are some Ni_7Zr_2 Nano crystalline phases observed when the annealing temperature was set to 400 °C. However, the NiCrMnZr film annealed at 300 °C still has an amorphous structure by transmission electron microscopy analysis. NiCrMn films with 16.7 at.% Zr exhibited the smallest temperature coefficient of resistance (+53 ppm/°C) with the resistivity ~510 μΩ-cm after annealing at 300 °C in air.

1. Introduction

NiCr alloy has been widely used as resistance or heating material due to its good oxidization resistance and corrosion properties [1,2]. NiCr thin film has a low temperature coefficient of resistance (*TCR*) and high resistivity, it will increase in importance and technical applications as a resistor in the electronic industry field [3–5]. Several works have been reported on NiCr resistive film deposition using radio frequency (RF) sputtering and thermal evaporation [6–9]. However, the evaporation method has difficulty controlling the composition of such films because of the large differences in Ni and Cr vapor pressures [10].

The key technical thin film resistor parameter is the temperature coefficient of resistance. A high *TCR* will induce resistance drifting, influencing the precision of resistors as the temperature changes [11]. The main *TCR* parameters include the film composition, sputtering process and annealing temperature, whereas the film composition plays a decisive role among these three factors. However, developing suitable film composition is a key to obtaining high-resistance resistors with a low *TCR*.

Several papers have reported on *TCR* and resistivity control in NiCr resistors by doping the films with different elements. Silicon can help improve thin *TCR* film, since Si is semiconductor. When the Si element was added to NiCr alloys, the NiCrSi thin film exhibited very low resistivity temperature coefficients, but the resistivity values were not increased significantly [12]. In our previous study [13], when Al was added to NiCrSi alloy films, the NiCrSiAl thin film resistivity value was higher than that of NiCrSi films annealed at ≤400 °C. However, NiCrSiAl thin film *TCR* values are not easy to control within ± 25 ppm/°C after annealing. The tantalum has the characteristics of a small thermal expansion coefficient, strong tenacity and good ductility. The NiCrSiAlTa thin films exhibited a high resistivity of 2215 μΩ-cm with a temperature coefficient of resistance of −10 ppm/°C [14]. However, aluminum and tantalum metals had a lower oxidation threshold, which perhaps is not good for film stability when the heat treatment is at higher temperatures.

Mn was found to form a uniform barrier layer about 2 nm thick with excellent reliability in a dual damascene interconnect structure [15]. Lee and Shin investigated NiCr-based alloy thin film resistors with precision characteristics using a material comprised of Ni (75 wt%), Cr (20 wt%) Al (3 wt%), Mn (4 wt%), and Si (1 wt%) as the target. The resistance and *TCR* of the thin films resistor increased more remarkably for samples annealed in ambient air [16]. Zirconium was chosen as the

* Corresponding author.
E-mail address: YCLee@mail.npust.edu.tw (Y.-C. Lee).

https://doi.org/10.1016/j.tsf.2018.04.015
Received 16 December 2017; Received in revised form 14 April 2018; Accepted 15 April 2018

Table 1
Surface compositions of NiCrMn thin films prepared at DC 50 W with different RF powers sputtered on cooper sheet by XPS analysis.

DC	RF	Film compositions (at.%)		
(W)		Ni	Cr	Mn
50	0	61.0	39.0	0
50	40	59.5	38.1	2.4
50	50	56.2	34.8	8.8
50	60	49.5	27.5	22.9

Table 2
Surface compositions of NiCrMnZr thin films prepared at DC 50 W with different RF powers sputtered on cooper sheet by XPS analysis.

DC	RF	Film compositions (at.%)			
(W)		Ni	Cr	Mn	Zr
50	0	57.2	35.5	7.3	0
50	5	54.5	29.3	10.1	5.9
50	30	47.8	26.9	9.5	16.7
50	50	45.7	22.6	7.3	28.5

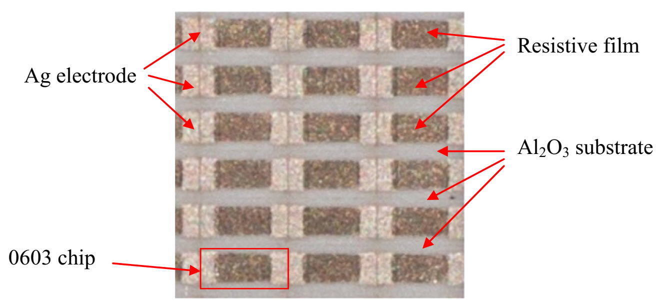

Fig. 1. Commercially available Al_2O_3 substrates were printed Ag electrodes on surface.

Table 3
Surface compositions of NiCrMn thin films with different RF powers and annealing temperatures using XPS analysis.

Annealing (°C)	RF power							
	40 W				60 W			
	Ni	Cr	Mn	O	Ni	Cr	Mn	O
250	57.6	33.1	1.5	7.8	43.2	26.8	19.3	10.7
300	55.9	31.8	1.1	11.2	42.3	25	17.4	15.3
400	49.8	28.7	0.9	20.6	39.9	20.7	14.3	25.1

dopant in the current work due to its high thermal stability, which may be beneficial for resistive thin film thermal stability.

Zirconium with a high melting point (1855 °C) was introduced in this study to investigate NiCrMnZr compositions as resistive film. The zirconium content and annealing temperature effects on the phases, microstructural and electrical properties of NiCrMnZr thin films were investigated.

2. Experimental procedure

The alloy thin films were deposited using a DC and RF magnetron sputtering (Creating Nano Technologies Inc.) under various conditions, which are listed in Tables 1 and 2.

2.1. NiCrMn thin film

A NiCrMn thin film with a thickness of 80 nm was deposited onto substrates using a DC and RF magnetron co-sputtering system. A $Ni_{0.6}Cr_{0.4}$ alloy and manganese plates with a diameter of 76.2 mm were used as the targets. The $Ni_{0.6}Cr_{0.4}$ alloy target was set at the DC position. The manganese target was set at the RF position. To obtain different Mn contents in the NiCr film, the DC power was fixed at 50 W and the RF power was changed from 40 W to 60 W. The sputtering chamber was evacuated to a background pressure of 6.6×10^{-5} Pa using a cryo-pump. Argon gas with a purity of 99.999% at flow of 60 sccm was introduced into the chamber using mass flow controllers. The working pressure was 0.4 Pa. The deposited films on substrate were set at room temperature (25 °C). The as-deposited films were annealed at 250 °C to 400 °C for 2 h, with a heating rate of 5 °C/min in air.

2.2. NiCrMnZr thin film

NiCrMnZr thin films that were 80 nm in thickness were deposited onto the substrates using a DC and RF magnetron co-sputtering system. A $Ni_{0.56}Cr_{0.35}Mn_{0.09}$ alloy and zirconium plates with a diameter 76.2 mm were used as the targets. The NiCrMn alloy target was set at the DC position. The zirconium target was set at the RF position. To obtain different zirconium contents in the NiCrMn film, the DC power was fixed at 50 W and the RF power was changed from 40 W to 65 W. In the deposition parameters the background pressure, argon flow, working pressure and substrate temperature were set the same as in Section 2.1. The annealing conditions are also the same as in Section 2.1.

2.3. Analysis

Two kinds of samples were prepared in this study. The first one is thin film deposited onto glass plates for Transmission Electron microscopy (TEM), Field-Emission Scanning Electron Microscope (FE-SEM) and X-ray diffraction (XRD) analysis. The second one is thin films deposited onto Al_2O_3 substrates (size: 400 mm^2) for resistivity and *TCR* measurements. The Al_2O_3 substrates had Ag electrodes printed on the surface, as shown in Fig. 1. This substrate is a general commodity with polycrystalline structure produced by LEATEC Fine Ceramics Co., Ltd. (Taiwan).

The NiCrMn and NiCrMnZr thin-film resistor resistances were measured using the four-point probe method. The thickness *t* of the films was measured using FE-SEM (cross-section). The resistivity was calculated with the measured resistance and alloy thin film thickness, according to Eq. (1):

$$R = \rho \times l/A \quad (1)$$

where R is the resistance, ρ is the resistivity, A is the area of the resistor, and l is the length of the resistor.

The *TCR* values of the thin films were measured on thin long strips cleaved from the substrate. Electrical contacts at the two ends of the resistive strips were obtained by selectively coating the ends with sputtered silver. The DC resistance of the strips was measured on a digit multimeter (HP 34401A) at different temperatures (25 °C and 125 °C). The measured temperatures were 25, 50, 75, 100, 125 °C, where the