Microelectronics Journal 39 (2008) 1560–1563

Contents lists available at ScienceDirect

Microelectronics Journal

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

RTD characteristics for micro-thermal sensors

Gwiy-Sang Chung *, Chael-Han Kim

School of Electrical Engineering, University of Ulsan, San 29, Mugeodong, Namgu, Ulsan 680-749, Republic of Korea

ARTICLE INFO

Article history:
Received 9 January 2008
Accepted 25 February 2008
Available online 15 April 2008

Keywords:
Pt-RTD
Thermal sensor
MgO
TCR

ABSTRACT

The physical and electrical characteristics of MgO (medium layer) and Pt (sensor material) thin films deposited by a reactive RF sputtering method and a magnetron sputtering method, respectively, were analyzed as a function of the annealing temperature and time by using a four-point probe, SEM, and XRD. After being annealed at 1000 °C for 2 h, the MgO layer showed good adhesive properties on both layers (Pt and SiO_2 layers) without any chemical reactions, and the surface resistivity and the resistivity of the Pt thin film were 0.1288 Ω/□ and 12.88 μΩ cm, respectively. Pt resistance patterns were made on $MgO/SiO_2/Si$ substrates by the lift-off method, and Pt resistance thermometer devices (RTDs) for micro-thermal sensor applications were fabricated by using Pt-wire, Pt-paste, and spin-on-glass (SOG). From the Pt RTD samples having a Pt thin film thickness of 1.0 μm, we obtained a temperature coefficient of resistor (TCR) value of 3927 ppm/°C, which is close to the Pt bulk value, and the ratio variation of the resistance value was highly linear in the temperature range of 25–400 °C.

1. Introduction

Many studies of MEMS, which can be mass produced at a low price using Si micro-processing technology to be small and lightweight and have a high-speed response and easy integration, have been conducted recently [1–3]. Recently, Pt thin film-type resistance thermometer devices (RTDs) have been fabricated on Al_2O_3 substrate. The RTD, however, should be fabricated on Si wafers, because the integration of a temperature sensor with an electrical circuit or other sensors on Si wafers is needed in many applications for micro-thermal sensors. In particular, the working temperature of micro-thermal sensors (such as gas, mass, flow, and vacuum applications) is very important in order to optimize characteristics such as sensitivity, selectivity, and response properties of the sensors [4]. Accordingly, the development of temperature sensors with the following properties is necessary: low power consumption, high output, low thermal capacity, excellent linearity, ease of application of arrays, and integration with other devices. Studies of temperature sensors for micro-thermal sensors have been achieved by using pn-junction diodes [5] and Pt thin films [6]. The pn-junction diodes have low linearity of output with variations of temperature in spite of the merit of using the standard CMOS process. With Pt thin films, it is possible to precisely control temperature due to the high temperature coefficient of resistor (TCR) value, excellent linear output, and superior thermal and chemical characteristics of Pt material within a wide temperature range. Because of the poor adhesive property between Pt thin films and SiO_2 layers, studies on the structure using a medium layer such as $Pt/Cr/SiO_2/Si$ [7] or $Pt/Al_2O_3/SiO_2/Si$ [8] have been conducted.

However, in the high-temperature annealing process used for the crystallization of Pt thin films, the metal used as the medium layer causes deterioration of the inherent Pt characteristics as well as its adhesion by reacting with Pt. Pt has a considerably high point of fusion (~1780 °C), and Pt thin films must be annealed at temperatures over 1000 °C [9]. In this sense, it is more stable to use a dielectric substance as a medium layer rather than a metal in order to improve the adhesion and eliminate reaction with Pt at high temperatures.

In this work, an MgO thin film, which is an ionic oxidation film, was used as a medium layer that possesses superior heatproof characteristics and excellent insulation properties in addition to improved adhesion to Pt thin films without any chemical reactions at high temperatures. Moreover, we fabricated low-cost thin film RTDs by using Pt material and analyzed the properties of the RTDs. The RTDs were thermally and chemically stable.

MgO thin films as medium layers and Pt thin films were deposited by a reactive RF sputtering method and a magnetron sputtering method, respectively. The electrical and physical characteristics of the Pt thin films were analyzed by four-point probe, α-step, SEM, and XRD as a function of annealing conditions. After fabricating thin film Pt RTDs on SiO_2/Si and Al_2O_3 substrates, the TCR values and the resistance variation ratios were compared and evaluated with each other as a function of increasing temperature.

* Corresponding author. Tel.: +82 52 259 1248; fax: +82 52 259 1686.
E-mail address: gschung@ulsan.ac.kr (G.-S. Chung).

0026-2692/$ - see front matter
doi:10.1016/j.mejo.2008.02.028

2. Experiments

In this study, Si (P(1 0 0), 530 μm, 4–5 Ω cm) wafers were used after applying the standard cleaning process and removing native oxides followed by growing a thermal oxidation layer 3000 Å thick. Also, Al_2O_3 substrates (luminous intensity analysis: 2°) produced by KYOTO SERAMIC Co. were used. MgO thin films, which were deposited with a thickness of about 1000 Å by keeping the distance between the target and substrate at 7 cm by a reactive R.F. sputtering method, were used as a medium layer in order to improve the adhesive property of the Pt thin films. Sensor material Pt was deposited with a thickness of 1 μm by a magnetron sputtering method [6]. After the annealing process using a quartz tube furnace under an N_2 atmosphere, the properties of the MgO thin films and the effects of annealing between the Pt thin films and the MgO thin films were analyzed by a four-point probe, α-step, SEM, and XRD. A thin film-type Pt RTD was fabricated on an $MgO/SiO_2/Si$ wafer by a photolithography process and a lift-off method. The RTD was annealed at 1000 °C for 2 h in N_2, and its properties were analyzed. Table 1 shows the deposition and annealing conditions of the Pt and MgO thin films, respectively.

Fig. 1 shows a surface photograph of the thin film Pt RTD fabricated on a $MgO/SiO_2/Si$ substrate under the optimal deposition and annealing conditions. The thin film Pt RTD in Fig. 1 was designed and fabricated to have a resistance of 100 Ω at 0 °C with consideration of the resistivity of the thin film, which is 13.0 μΩ/cm. The minimum width was 30 μm, and the entire cell size was $2.5 \times 4\,mm^2$. The characteristics of the fabricated thin film Pt RTD were analyzed after bonding Pt wire onto the cell by using Pt paste and passivation in a closed system without air convection effects since the atmospheric gas and vacuum were controlled.

Table 1
The deposition and annealing conditions of MgO and Pt thin films

Deposited thin film	MgO thin film	Pt thin film
Target (2 in diameter)	MgO	Pt
Substrate temp. (°C)	Room temp.	Room temp.
Sputtering gas (sccm)	Ar: 72	Ar: 80
Flow rate (sccm)	O_2: 8	
Initial vacuum (Torr)	Below 1×10^{-6}	Below 1×10^{-6}
Working vacuum (mTorr)	20	5
Input power density (W)	150	90
Post-annealing (2 h in N_2) (°C)	1000	1000

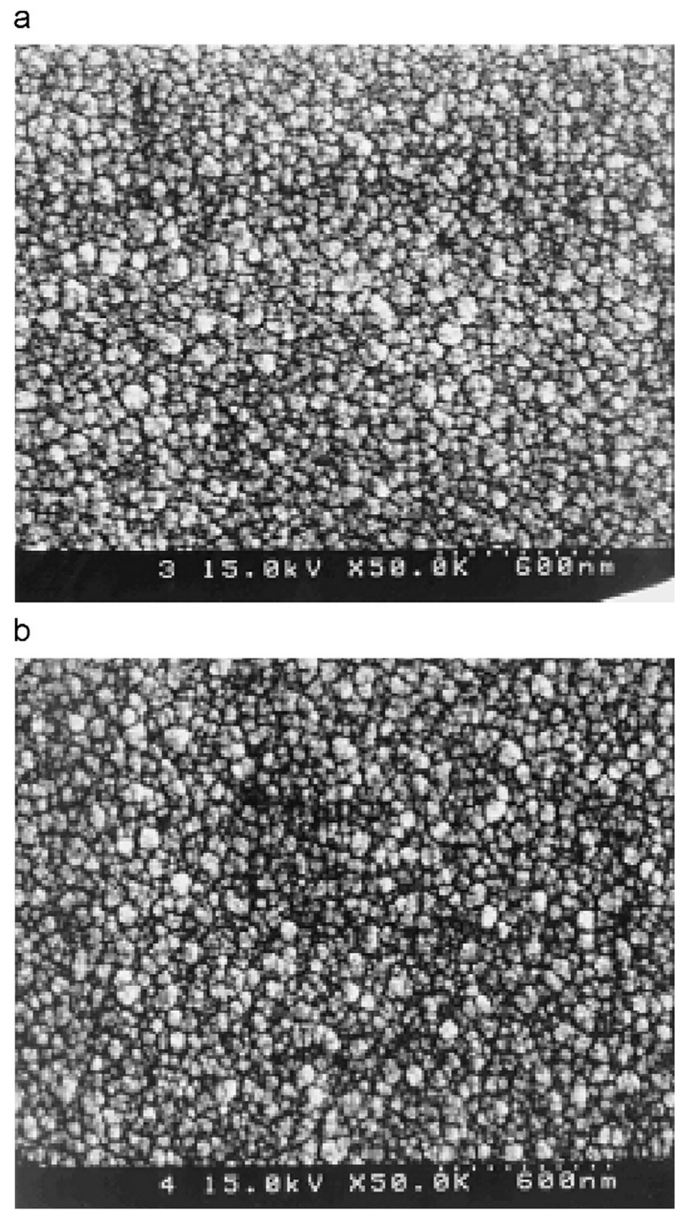

Fig. 2. SEM pictures of MgO thin films (a) without annealing and (b) with annealing at 1000 °C for 2 h.

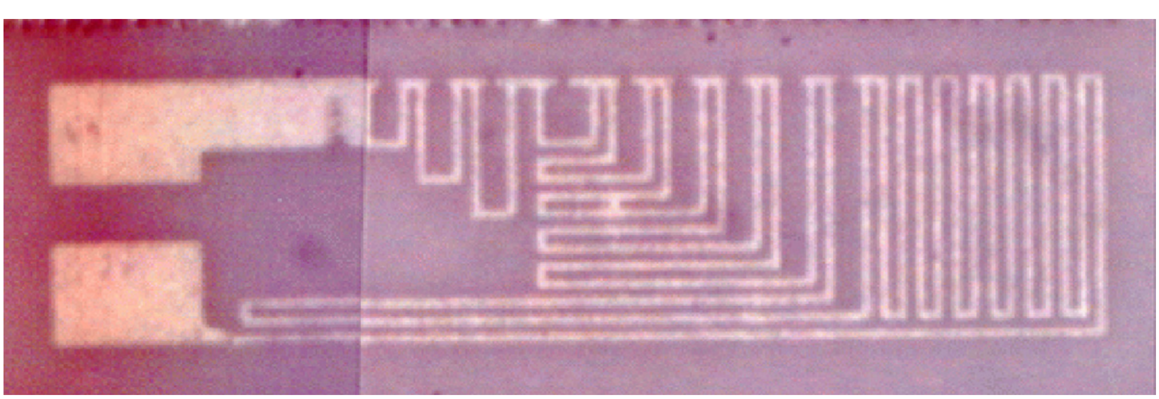

Fig. 1. A surface photomicrograph of a thin film Pt RTD fabricated on an $MgO/SiO_2/Si$ substrate.