Transactions of the Materials Research Society of Japan 28 [4] 1149-1152 (2003)

Measurement of Specific Contact Resistivity of TaN_x Resistor Films Deposited by Reactive Sputtering

Motoki Obata, Teruyuki Sakuda*, Katsuya Abe*, Rinpei Hayashibe* and Kiichi Kamimura*
Cimeo Precision Co., Ltd. 4107 - 5 Miyota-Machi, Kitasaku-Gun, Nagano 389-0295 Japan
Fax: 81-267-31-1184, e-mail: motozo@cimeo.co.jp
*Department of Electric and Electronic Engineering, Shinshu University, 4 - 17 - 1 Wakasato, Nagano, 380-8553 Japan
Fax: 81-26-223-2174, e-mail: kamimur@gipwc.shinshu-u.ac.jp

Tantalum nitride films were deposited on insulating substrates by reactive sputtering to fabricate thin film resistors. Electrodes were formed on the resistor films by sputter deposition of Au. An interfacial layer was implemented between the resistor film and the Au electrodes. Mechanical strength of the electrode was improved using the interfacial layer. The thickness of the interfacial layer was less than 30 nm. Specific contact resistivity was determined by Transmission Line Model (TLM) method. The value of specific contact resistivity depended on the properties of interfacial layer, and was less than $5 \times 10^{-8}\ \Omega m^2$.

Key words: TaN_x, Contact, Specific contact resistance, Thin film resistor

1. INTRODUCTION

Tantalum nitride films have been investigated because of its high stability, high reliability and proper value of reisitivity for thin film resistor application. As the results of recent development in microelectronic packaging, higher performance has been required in specification of the thin film resistors. The contact resistance between electrode and resistor film is one of the important factors for designing and fabricating packaging modules. The temperature coefficient of resistance (TCR) of thin film resistor is determined not only by the TCR of the film but also by the contact resistance between electrode and resistor film.

There have been many works about preparation of the thin film resistors made from TaN_x film [1]. Another promising application of the TaN_x film was a barrier layer between Si and Cu conduction lines [2]. But no paper has reported about contact resistance between TaN_x film and electrode. In this work, specific contact resistivity at the interface of electrode and TaN_x film was determined by using TLM method. The TLM sample was used to estimate the TCR of TaN_x film itself and that of electrode, separately. The data were also used to estimate the temperature dependence of specific contact resistivity.

2. EXPERIMENTAL

Tantalum nitride films were deposited by RF magnetron sputtering. The sputtering target was pure Ta disk of 150 mm in diameter. The target was sputtered with Ar. The N_2 gas was used as a reactive gas. Before the deposition, the sputtering chamber was evacuated with conventional oil diffusion pump system to about 1×10^{-4} Pa. The flow rate of the gases was controlled by mass flow controller. The flow rate of Ar was 20 sccm and that of N_2 was changed from 0 to 5 sccm. The sputtering power was 4 W/cm^2. The substrate was heated to 300 °C with irradiation from a W lamp. The substrate was Si wafer, glass or AlN ceramic plate. The thickness of the TaN_x film was controlled to 0.35 μm by *in situ* monitoring system. The properties of the TaN films were characterized by using X-ray diffraction, Auger electron spectroscopy and SEM observation.

The Au electrodes were deposited on the TaN_x layer to measure the electrical characteristics of TaN thin film resistor. The interfacial layer was inserted between the Au electrodes and the TaN_x layer in order to make tight contact. Without the interfacial layer, the Au film was easily removed from the TaN_x layer or the substrate. The interfacial layer was formed by sputter deposition of Ta., Ti or Cr with thickness of 30 nm. The Ti layer is widely used as an interface material between AlN substrate and Au, and the Cr layer is used for oxide substrate.

The Transmission Line Model (TLM) was used to determine the specific contact resistivity [3]. Figure 1 shows the schematic view of TLM sample.

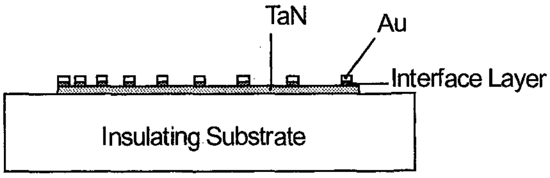

Fig. 1 Schematic view of TLM sample

Each electrode has same square shape of 2 x 2 mm. The distance between electrodes was changed from 1 to 8 mm. The width of TaN_x film was 1 mm. Resistance and its temperature dependence were measured between nearest two electrodes. The resistance of electrode and that of TaN_x layer itself were determined from the relation between the resistance and spacing between electrodes. The specific contact resistivity was estimated using TLM method.

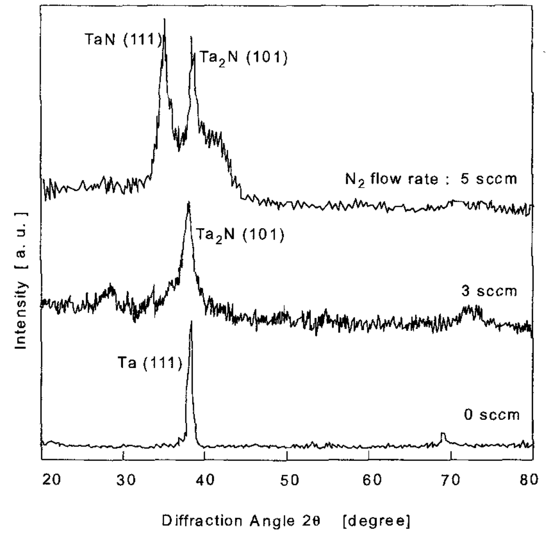

Fig.2 X-ray diffraction patterns of TaN_x films.

2. RESULTS AND DISCUSSION

2.1 Structure of the films

The property of TaN_x film was depended on the N_2 partial pressure during deposition. Figure 2 shows the X-ray diffraction patterns of TaN_x films deposited at different N_2 flow rate.

The peaks corresponding to Ta were observed in the diffraction pattern of the film deposited without N_2. The main peak changed from Ta_2N to TaN when the N_2 flow rate increased from 3 sccm to 5 sccm. The main diffraction peak of the sample deposited with N_2 flow rate of 3 sccm seemed to consist of the diffractions from Ta and Ta_2N, because the peak corresponding to Ta (111) diffraction is very close to that from Ta_2N (101). Auger spectroscopy measurement suggested that films consisted of Ta and its nitride when the film was deposited at N_2 flow rate of 3 or 5 sccm.

2.2 Sheet resistance and contact resistance

The resistance of the electrode and that of TaN_x film were estimated separately by measuring the resistance between two electrodes, which have different spacing between them. Figures 3 and 4 show the resistance as a function of spacing.

The resistance increased linearly to the spacing of electrodes. The slope of the straight line indicates the sheet resistance of TaN_x film. The slopes were almost the same for samples deposited under the same N_2 flow rate. This indicated that the resistivity of TaN_x film was determined mainly by the concentration of N_2 flow rate with enough reproducibility.

The resistance R was no zero at zero spacing (d=0) because of the resistance of the electrode. The resistance R can be expressed with the distance between electrodes d as,

$$R = R_s d + 2R_e \qquad (1),$$

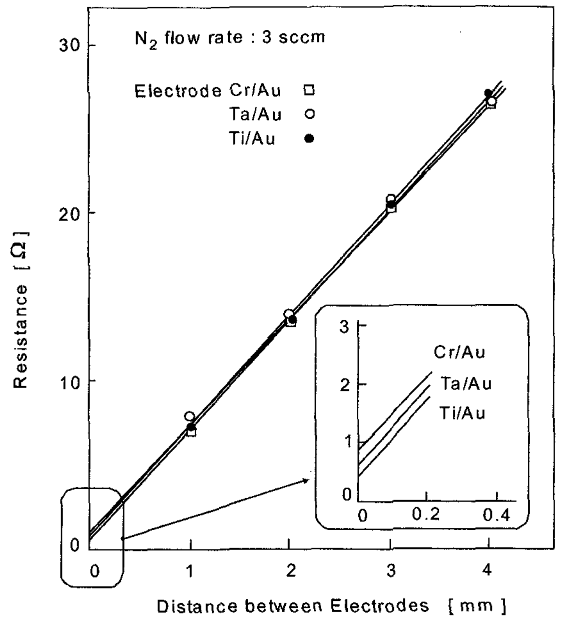

Fig.3 Relation between resistance and distance between electrodes. Films were deposited at N_2 flow rate of 3 sccm.

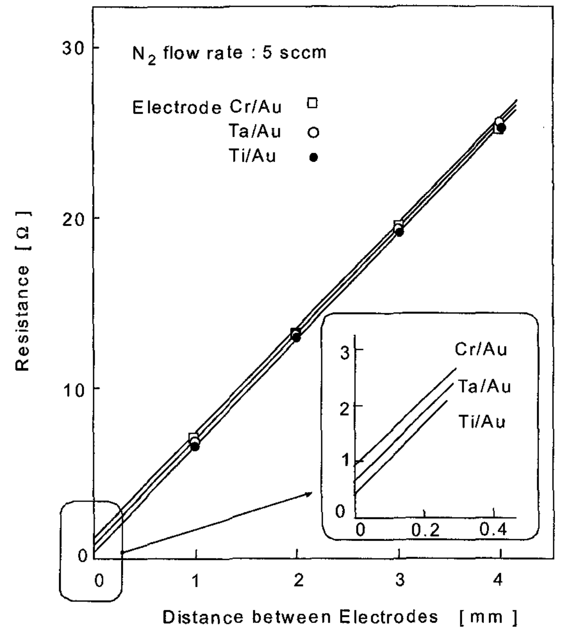

Fig.4 Relation between resistance and distance between electrodes. Films were deposited at N_2 flow rate of 5 sccm.

where, R_s is sheet resistance of TaN_x film, R_e is resistance of electrode. The term $2R_e$ means that two electrode contributed to the measured value of resistance. The zero spacing resistance corresponds to the resistance of two electrodes.

The values of R_s and $2R_e$ were estimated from Figs 3 and 4 by least mean square method. These values are listed on Table I. The sheet resistance of the films deposited at the N_2 flow rate of 5 sccm was lower than that of the sample deposited at the N_2 flow rate of 3 sccm. The reason seemed to be that the film deposited at 5 sccm was slightly thicker than the sample deposited at 3 sccm, though the thickness was monitored during the deposition.

The resistance of electrode was larger than 10% of the sheet resistance. These results indicate that the resistance of electrode is an important factor for designing thin film resistor.

Table I Sheet resistance and resistance of electrode.

N_2 (sccm)	Interface	R_s [Ω]	$2R_e$ [Ω]
3	Ta	6.40	0.87
3	Ti	6.48	0.72
3	Cr	6.52	0.93
5	Ta	6.10	0.86
5	Ti	6.14	0.73
5	Cr	6.04	0.91

2.3 Temperature coefficient of resistance

Temperature coefficient of resistance (TCR) is one of the most important parameters for designing resistor. The TCR of TaN_x film depended on N concentration in the film. The lowest value was obtained for the film deposited at N_2 flow rate of 3 sccm.

Figure 5 shows the TCR of TaN_x thin film resistor as a function of temperature. The distance between electrodes was 1 mm.

All TCR values were lower than 100 ppm/°C, when the TaN_x films were deposited at N_2 flow rate of 3 sccm. The TCR value depended on the interfacial material of electrode. The lowest TCR was obtained for the sample prepared with the interfacial layer of Ti.

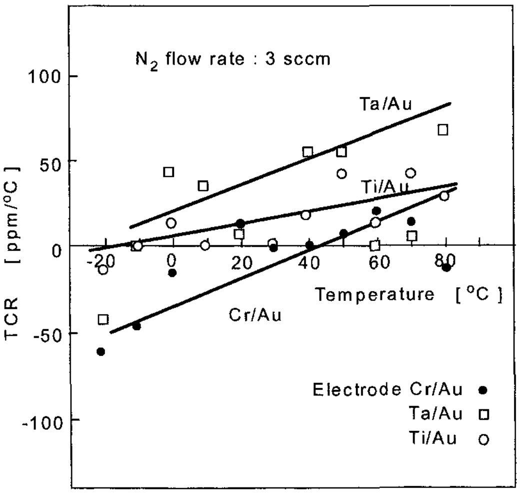

Fig.5 TCR of TaN_x thin film resistor. The TaN_x layer was deposited at N_2 flow rate of 3 sccm. The distance between electrodes was 1 mm.

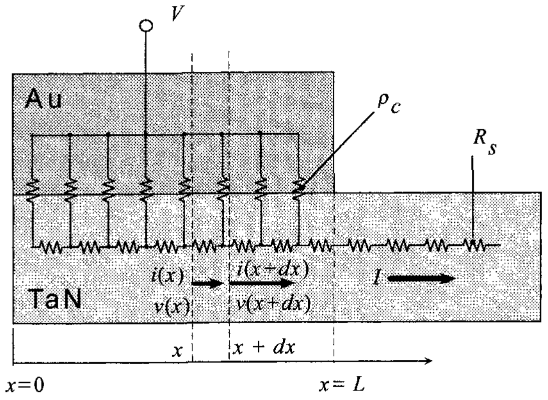

Fig.6 Transmission line model of the contact

2.4 Specific contact resistivity

The specific contact resistivity was the most convenient value to express the contact performance. Figure 6 shows the transmission line model of the contact between electrode and TaN_x film. The electrode itself assumed to have zero resistance. The contact property is expressed by specific contact resistivity, which is defined as a resistance at the interface per unit area. Resistance of electrode is expressed as a function of specific contact resistivity and sheet resistance of TaN_x layer.

The relation between current and voltage was,

$$\frac{dv(x)}{dx} = -\frac{R_s}{w} i(x) \quad (2),$$

$$\frac{di(x)}{dx} = \frac{w}{\rho_c} v(x) \quad (3),$$

where, ρ_c is specific contact resistivity, w is width of electrode and R_s is sheet resistance of TaN_x layer. The resistance of electrode R_e is,

$$R_e = \frac{V - v(L)}{I} = \frac{1}{w}\sqrt{R_s \rho_c} \coth \frac{L}{\sqrt{R_s \rho_c}} \quad (4)$$

where, L is length of electrode, V is applied voltage, I is total current. When L is lager enough, coth is approximately 1 and,

$$\rho_c \fallingdotseq \frac{R_e^2 w^2}{R_s} \quad (5).$$

R_e and R_s were determined from the relation between resistance and spacing of electrodes.

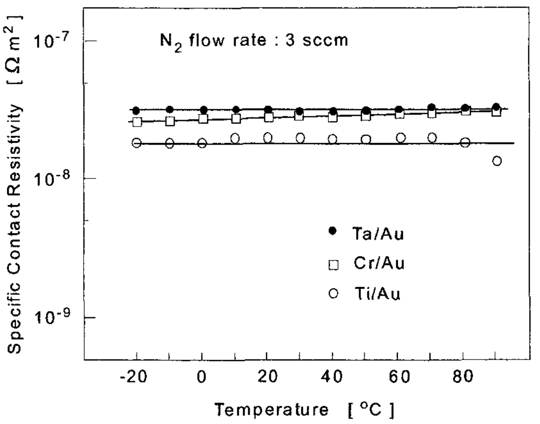

Fig. 7 Temperature dependence of specific contact resistivity. The TaN_x film was deposited at N_2 flow rate of 3 sccm.

The specific contact reisitivity was determined from the data listed in Table I, using eq.(5). The values of specific contact resistivity were less than 5 x 10^{-8} Ωm^2 for all samples prepared in this work. The value of R_s was about 6 Ω as listed on Table I. The value of $\coth(L/(R_s\rho_c)^{1/2})$ becomes about 0.95, when R_s is 6 Ω and ρ_c is 5×10^{-8} Ωm^2. This means that the approximation using Eq.(5) is reasonable for samples in this work. It may be necessary to use Eq.(4) for the samples with shorter electrodes or higher specific contact reisitivity than the samples listed on Table I. The errors caused from current distribution in the film are small enough because the width of the electrodes was larger than that of the resistor film and the reisistivity of the film was very low as compared to that of semiconductors[3].

Figure 7 shows the temperature dependence of specific contact resistivity determined using TLM model.

Specific contact resistivity was less than 5x 10^{-8} Ωm^2. The lowest value was obtained for the sample with interfacial layer of Ti. Schottky barrier model was used to explain the specific contact resistivity of ohmic contact in a semiconductor device [4]. In the case of Cr, oxygen was detected near the interface between Au and Cr by Auger analysis.

3. CONCLUSION

The tantalum nitride films were deposited on the insulating substrates by reactive sputtering to form thin film resistors. The resistance of the electrode was determined from the resistance measurements of the samples with different length. The resistance of the electrode was more than 10 % of the sheet resistance of TaN_x film. The specific contact resistivity was determined by Transmission Line Model (TLM) method. The value of specific contact resistivity depended on the properties of interfacial layer, and was less than 5 x 10^{-8} Ωm^2.

RFERENCES

[1] T. Riekkinen, J. Molarius, T. Laurila, A. Nurmela, I. Suni and J. K. Kivilauhti, *Microelectronic Engineering*, **64**, 289 - 297 (2002).
[2] T. Laurila, K. K. Zeng, J. K. Kivilahti, J. Molarius, T. Riekkinen and I. Suni, *Microelectronic Engineering*, **60**, 71 - 80 (2002).
[3] H. H. Berger, *Solid-State Electronics*, **15**, 145 - 158 (1972).
[4] M. Wermer, C. Johnston, P. R. Chalker, S. Romani and I. M. Buckley-Golder, *J. Appl. Phys.*, **79**, 2535 - 2541 (1996).

(Received February 5, 2003; Accepted June 30, 2003)