THIN FILM INTEGRATED RC-NETWORKS WITH COMPENSATED TEMPERATURE COEFFICIENTS OF R AND C

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Thin film integrated RC-networks can be prepared from two non reactively sputtered TaAl films, the properties and optimum compositions of which have been found. Temperature compensation of the integrated resistors and capacitors is achieved by adjusting the temperature coefficient of capacitance. A duplex dielectric capacitor structure is used with anodically formed TaAl-oxide and a sputtered SiO₂ layer. Temperature coefficient of capacitance, dielectric loss and capacitance density have been measured vs. SiO₂ thickness. Because of almost linear dependences on temperature of both the TaAl resistors and the TaAl-oxide/SiO₂-capacitors, such RC-networks show temperature compensation over a wide temperature range, the TCC being +110 ppm/K and the TCR –110 ppm/K.

1. INTRODUCTION

Thin film integrated resistor- and capacitor-networks are expanding into the electronic market because of a high standard of miniaturization, high stability and high precision. Important applications are active filters with temperature compensation. Temperature compensation, i.e. matching of TCR and TCC is usually achieved by altering the resistive film properties. In the well known β -Ta/Ta₂N technology,¹ the TCR of the highly stable Ta₂N, which is about –70 ppm/K, is lowered by reactive sputtering of Ta with both oxygen and nitrogen to give a TCR of –200 ppm/K, which compensates for the positive TCC of β -Ta oxide capacitors. A possible way of decreasing the TCC of β -Ta oxide is to use a sandwich dielectric structure, consisting of anodic β -Ta oxide and sputtered SiO₂. An improvement of capacitor yield and long term stability and a reduction of capacitance density, as compared to β -Ta oxide capacitors, have been reported.²

This paper will be concerned on temperature compensated TaAl thin film RC-networks.

2. TaAl RC-NETWORKS

Thin film integrated resistors and capacitors can be prepared from a single TaAl film or from two TaAl layers with different alloy compositions. RC-networks made of a single TaAl film cannot be fabricated with

higher sheet resistivities. A TaAl double layer technique has to be applied then for RC-fabrication, where the resistors are made of a high resistivity TaAl alloy, whereas TaAl oxide capacitors are prepared from a low resistivity TaAl alloy.³ In this case both high resistance values of the resistors and a low series resistance of the capacitor base electrode can be achieved.

To account for temperature compensation either reactive sputtering means or duplex dielectric capacitors have also to be introduced into this technology. Adjustment of the TCR in a similar way as in conventional Ta-technology is possible, but will not be discussed in this paper, since we did not want to lose the main advantage of TaAl technology, i.e. the non reactive sputtering process. We have investigated TaAl oxide/SiO₂ duplex dielectric capacitors with respect to temperature compensation and their compatibility with a TaAl-RC-fabrication process, where the TaAl films can be sputtered without using reactive gases.

The optimum compositions of the TaAl double layer have been found out, also the conditions necessary for temperature compensation, when TaAl oxide/SiO₂ capacitors are used.

2.1. TaAl Resistors

TaAl films with Al contents from 8 to 98 at. % have been investigated. They were sputtered in an a.c. rod sputtering system.⁴ The sputtering parameters were:

argon pressure 10^{-2} Torr, a.c. voltage 3,5 kV, a.c. current 0,45A, sputtering rate 25–30 nm/min. Some results are given in Figures 1 to 4. In the far Ta-region a tetragonal structure has been found, similar to that of β -Ta, with high resistivities and a low film density, which can be attributed to the relatively low sputtering voltage. This region is not very interesting for resistor fabrication using these sputtering conditions, since the ρ -values decrease with film thickness. This is not the case for the amorphous TaAl films above 30 at. % Al. Their resistivities and TCR's are, moreover, almost insensitive to Al content between 30 and 65 at. % Al, as seen in Figures 1 and 2. Figure 3 shows the

FIGURE 1 Resistivity of TaAl.

FIGURE 2 TCR of TaAl.

resistivity and the TCR vs. film thickness for a 60 at. % Ta/40 at. % Al alloy film. Taking into account also the excellent ageing behaviour, which is shown in Figure 4 for the whole TaAl system, we have chosen this composition as best suited resistor material. Its resistivity is $250 \pm 10 \mu\Omega \text{ cm}$ and its TCR is $-110 \pm 10 \text{ ppm/K}$ for film thicknesses between 25 and 500 nm. A Al-rich TaAl alloy with 7 at. % Ta/93 at. % Al

is used as capacitor base electrode material, because of its low resistivity, which is about $50 \mu\Omega \text{ cm}$ and its good capacitor properties reported elsewhere.⁵ The capacitance density of 200 V anodized films of this compositions is 34 nF/cm^2 , their TCC is about $+500 \text{ ppm/K}$.

FIGURE 3 TCR and ρ (resistivity) of TaAl 60/40.

FIGURE 4 Resistance change of TaAl.

2.2 TaAl-Oxide/SiO₂ Capacitors

For temperature compensation a SiO₂ layer is sputtered on top of the anodically formed TaAl oxide dielectric by r.f. sputtering from a quartz target. Typical sputtering parameters are: argon pressure 10^{-2} Torr, r.f. power 500W, r.f. voltage 1,5 kV, sputtering rate 9 nm/min. The influence of SiO₂ thickness on the TCC, the dielectric loss and the capacitance density can be seen in Figures 5 and 6. Temperature compensation with the integrated resistors is achieved with a 230 nm thick SiO₂ layer. The TCC of such a duplex dielectric capacitor is $+110 \pm 10 \text{ ppm/K}$, the tangent δ is 0,10% and its capacitance density is $8,5 \text{ nF/cm}^2$, if a 200V-TaAl-oxide is used as the first dielectric layer.

FIGURE 5 TCC and tangent δ vs. SiO_2 thickness. FIGURE 6 Capacitance density vs. SiO_2 thickness.

3. TEMPERATURE COMPENSATED TaAl/ SiO_2 RC-NETWORKS

The duplex dielectric TaAl-oxide/ SiO_2 capacitor can be easily integrated into the fabrication process of TaAl R-networks.^{6,7} A schematical view of the RC-structure is given in Figure 7.

Temperature compensation in TaAl/ SiO_2 technology is easier to achieve than in conventional Ta-technology mainly for three reasons: the more simple non reactive sputtering process itself, the lower absolute value of the temperature coefficients of the components and, as a consequence, a better linearity of resistance and capacitance with temperature. We have examined the temperature compensation of TaAl/ SiO_2 RC-networks in a broad temperature range between -55°C and $+125^\circ\text{C}$ (Figure 8). Both resistance and capacitance are almost linearly dependent on temperature. Taking into account the

FIGURE 7 TaAl/ SiO_2 RC structure. FIGURE 8 $\frac{\Delta R}{R}$, $\frac{\Delta C}{C}$ and $\frac{\Delta RC}{RC}$ vs. temperature.

measuring accuracy of ± 5 ppm/K, the RC-product, the relative change of which is also delineated in the figure, is nearly constant over the whole temperature interval. Another advantage of RC technology is good reproducibility, since non reactive sputtering processes only are applied. Because of weak dependences of the TCR and the TCC on film thicknesses (see Figures 3 and 5) both sheet resistivity and capacitance density can be varied to some extent without giving up temperature compensation.

4. CONCLUSION

Integrated RC-networks have been prepared, using a non reactively sputtered TaAl double layer and r.f. sputtered SiO_2 . The TaAl oxide/ SiO_2 duplex dielectric capacitor structure shows low tangent δ values and a TCC, which compensates for the TCR of the 60 at. % Ta/40 at. % Al alloy film in a broad temperature range. Together with the simple fabrication process the TaAl/ SiO_2 technology is a real alternative to the more sophisticated β -Ta/ Ta_2N technology.

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