Thermal stability of tantalum nitride based thin film resistors

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Abstract. Tantalum nitride thin films were deposited on Al2O3 substrates by the dc-magnetron sputtering technique. The nitrogen content in the argon/nitrogen flow varied from 5 to 50%. Structural properties were studied using X-ray diffraction. The ratio of Ar:N2 was 4:1; the ratio of Ta:N became 1:1. Sheet resistance depends on thickness and is in the range of 20 – 80 Ω/□ due to thickness 100 – 50 nm. The TaN films deposited at a nitrogen/argon ratio of 20% show the thermal stability of the resistance in the 25–400°C temperature range. Sheet resistance degradation was ~ 5%. The TCR value was determined in the range of 25 – 300 C and was equal to -21 ppm/K.

1. Introduction
To create compatible components of microwave electronics materials with unique properties, CMOS technology is required. Tantalum nitride may serve as an example of such a material [1]. It is chemically inert, resists corrosion and has a near-zero temperature coefficient of resistivity [2].

The difference in stoichiometry is quite a common feature of tantalum nitride films because of their defective structure [3]. Thus, microstructure, electrical properties, etc. will vary depending on the conditions of film formation. Typically, tantalum nitride films are made by CVD [4,5] and PVD [6-12] methods.

In this paper, we studied the thermal stability of tantalum nitride thin films. Electrical and structural properties were observed using sheet resistivity and X-Ray diffraction. Thermal stability was tested in the temperature range 300 – 600°C by measurement of sheet resistance. In addition, we measured IVT and defined TCR.

2. Experiment
Tantalum nitride films were deposited by reactive magnetron sputtering of the installation Kurt J. Lescker PVD 250. The ratio of nitrogen / argon was varied in a range from 10 to 30%. Al2O3 was used as a substrate. The operating pressure in the installation was 8.4 e- Torr. Sputtering was conducted for power stabilization mode, power is maintained equal to the value of 200 watts. The surface resistance was measured by 4-probe method on Jandel RM-3000. The phase composition of the films was determined by the X-ray diffraction method on Rikagu Ultima IV. Temperature stability was tested in the temperature range 200 - 600°C in an atmosphere of air on Modular RTP-600S.

The temperature coefficient of resistance was determined by using IVT measurements on the installation Agilent B1500 [13]. For this test, the films with TLM pattern were formed; Ti films (250
nm) were used as ohmic contact. Resistance measurements were carried out in the temperature range of 25 - 300 °C. The resulting dependence was approximated by the least squares method.

3. Results and Discussion

3.1 Structural properties
The films were deposited by reactive magnetron sputtering. Al₂O₃ was used as a substrate. To a nitrogen concentration of 5% and 10% of the total flow of the carrier gas, irreproducible parameters of the film were achieved. This can be explained by the poor stoichiometry and phase instability of the film composition [11]. The ratio of nitrogen atoms to atoms of tantalum in the film was 1:4 and 1:2, which are 5% and 10% of the total nitrogen carrier gas flow, respectively. For 20% of the content of total nitrogen carrier gas flow, the ratio of nitrogen and tantalum atoms of approximately 1:1 was obtained. The X-ray diffraction measurements are shown in Figure 1.

![Figure 1. X-ray diffraction spectrum (20 scan mode)](image)

3.2 Electrical properties
For TaN films obtained from the ratio of Ta: N = 1:1, the dependence of the surface resistance of the thickness (Figure 2) was obtained.
Figure 2. The experimental dependence of the surface resistance of the thickness

For TCR measurements of solid tantalum nitride film, the TLM test was formed by photolithography followed by chemical etching. The ohmic contacts to the resulting structures were formed with the Ti (200) electron beam evaporation. On the obtained test, specimens of current-voltage characteristics were measured at temperatures of 25-300 °C (in steps of 50 °C). The obtained data was fitted by the least squares method and was calculated with TCR. Its value was -21 ppm / K, which is the best result for a given thickness and application method according to [2].

3.3 Thermal stability
To determine the thermal stability in the annealing furnace, rapid thermal annealing was carried out in air at temperatures of 200-600 °C with increments of 100 °C for 2 minutes. With increasing the annealing temperature, resistance is also increased. At 400 °C, annealing temperature resistance did not increase exceeding 5%, whereas increase to 500 °C changed resistance by 10%, and after 600 °C the resistance value dramatically increased by 64%. Thus, it is possible to conclude that the resistors are stable when used in normal conditions.

4. Conclusion
Thin films of tantalum nitride were deposited by reactive magnetron sputtering with different ratios of nitrogen and argon flow. By X-ray diffraction, the composition of Ta films was determined: N = 1:1. Temperature coefficient of resistance was determined, which is equal to -21 ppm / K. The resulting value corresponds to the best results for a given method of obtaining films [2]. In addition, the thermal stability of the films was tested during an annealing temperature of 500 °C with an increase in resistance not higher than 10%.

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