Characteristics of tantalum nitride thin film resistors deposited on SiO_2/Si substrate using D.C-magnetron sputtering

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Abstract: The structural and electrical properties of the films are investigated as a function of nitrogen/argon ratio at room temperature and at various deposition temperatures. The phase changes as Ta_2N or TaN in the films were observed as nitrogen/argon ratio increases from 3% to 25%. The phase changes were associated with a change in the resistivity and TCR (temperature coefficient of resistance) of the films. TCR values of the films deposited at room temperature and different nitrogen contents were negative, and strongly decreased with the increase in nitrogen/argon ratio. The Ta_2N films deposited at nitrogen/argon ratio of 3% show improved TCR values and thermal stability with increasing deposition temperature. The Ta_2N films grown at nitrogen/argon ratio of 3% and the temperature of 200°C showed a TCR value of -47 ppm/°C, which is close to near-zero TCR in the range of deposition temperature.

Key Words: TCR, TaN, Resistor

1. Introduction

Tantalum nitride has been widely used in many industrial applications such as barrier layer between Cu and Si or SiO_2 [1], thin film resistor [2] because of some attractive properties of its including chemical inertness, hard material, corrosion resistance, thermal stability, and high resistivity [3]. Low temperature coefficient of resistance (TCR) is required in microelectronics, especially in portable terminal and telecommunication devices for the purpose of high reliability. Temperature coefficient of resistance of tantalum nitride thin film depends strongly on the composition, microstructure of the films, and substrate. In this study we focus on synthesizing tantalum nitride material on oxidized silicon substrate at high deposition temperature for the purpose of improving TCR.

The influences of nitrogen/argon ratio on phase composition, resistivity, and TCR of the films deposited at room temperature were investigated in detail. In order to improve the TCR value, samples were deposited at the temperatures in the range of (100°C-400°C).

2. Experimental procedure

The tantalum nitride films were deposited by reactive DC-magnetron sputtering with tantalum target. Oxidized silicon wafer of (100) orientation with an oxide thickness of 600nm were used as substrate. The detailed deposition conditions of tantalum nitride film were summarized in the table 1. The crystal structure and morphology of the film were characterized by X-ray diffraction, AFM. The thickness of the film was determined by alpha-step machine. The sheet resistance was measured at room temperature using the standard four-probe technique. The tantalum thin film for measurement of TCR was patterned using a shadow mask stabilized during deposition. TCR of the sample was measured in the range of temperature of (25-120 °C).

Table 1: Deposition conditions of tantalum nitride

Substrates	SiO_2 (600nm)/ Si (100)
Target material	Tantalum
Base pressure	$1.2x10^{-5}$ torr
Working pressure	$5 x10^{-3}$ torr
D.C power of Ta target	100 w
Ar + N_2 gas flow rate	10 sccm
$N_2/(Ar+N_2)$ flow ratios	0~25%
Deposition temperature	Room temperature ~ 400 °C

3. Results and discussion

The change of phase structure is observed clearly from Ta (N) to Ta_2N, and then TaN phase when nitrogen-argon flow ratio was increased from 1% to 25% as shown in fig.1.

In the range of nitrogen/argon ratio of (3%-5%), the resistivity of the film is constant (see fig. 2a). The resistivity gradually increased with the increasing in nitrogen/argon ratio to 10%. In the range of

nitrogen/argon ratio of 10%-20%, the resistivity of the film remains a constant. The rms roughness of the film deposited at various N_2/Ar ratios is below 3.5nm (see fig. 2b) implying that the surface morphology of the films is quite smooth.

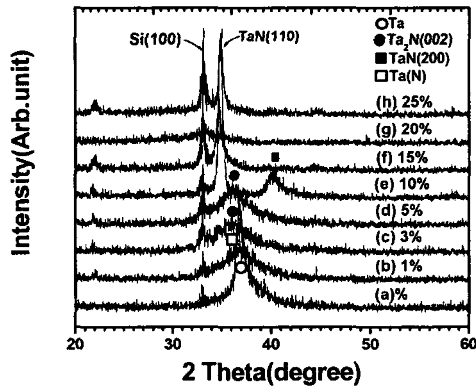

Fig.1. XRD pattern of tantalum nitride thin films deposited at various nitrogen-argon flow ratios.

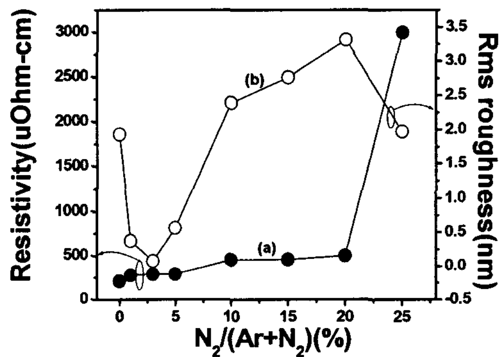

Fig.2. resistivity and Rms roughness of tantalum nitride thin films deposited at various nitrogen-argon flow ratios.

Fig. 3 shows temperature coefficient of resistance (TCR) as a function of nitrogen/argon ratio. All TCR value obtained to be negative, and depend strongly on nitrogen/argon ratio. The best TCR value of the film deposited at room temperature and nitrogen/argon ratio of 3% is -140ppm/^{0}C.

In order to improve TCR value for the tantalum nitride film at nitrogen/argon ratio of 3%, the samples were deposited at high temperature of 100°C, 200°C, 300°C and 400°C. The sample deposited at 200^{0}C exhibited the best TCR of approximately -47ppm/^{0}C.

Fig.4 shows AES depth profiles of Ta_2N thin film deposited at 200°C. There is no elemental diffusion between tantalum nitride and SiO_2/Si substrate, resulting in an excellent thermal stability.

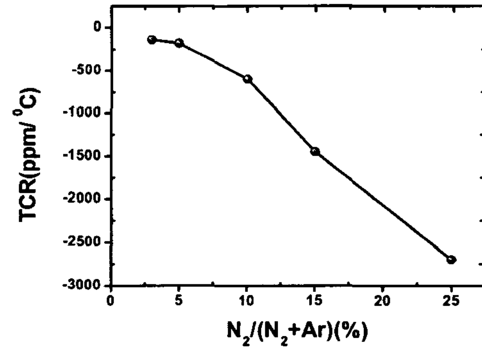

Fig.3. TCR of tantalum film as a function of nitrogen/argon ratio

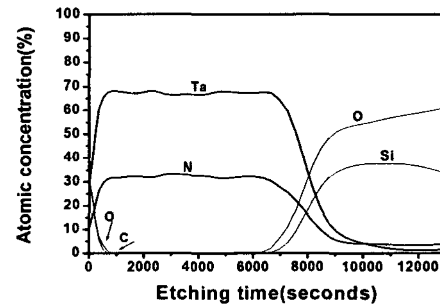

Fig.4. AES depth profiles of Ta_2N thin film deposited at 200°C.

4. Conclusion

The optimal TCR value showing about -47ppm/^{0}C was obtained at nitrogen-argon flow ratio of 3% and deposition temperature of 200^{0}C, respectively. The change of phase structure was observed clearly when nitrogen content was increased. The TCR value strongly depends on nitrogen-flow ratio as well as deposition temperature.

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