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Characterization and Reliability of Thin Film Resistors for MMICs Application Based on AlGaN/GaN HEMTs*

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Abstract: Tantalum nitride (TaN) and nichrome (NiCr) are the two most common materials used as thin film resistors (TFR) for monolithic microwave integrated circuits (MMIC) based on AlGaN/GaN high electron mobility transistors (HEMTs). In this study, we compare the reliability of the two materials used as TFRs on a semi-insulation 4H SiC substrate. Through the comparison between NiCr and TaN thin-film resistor materials, we find the square resistor (R_s) of TaN TFR increases as the annealing temperature increases. However, the R_s of NiCr TFR shows the opposite trend. We also find the change of the TaN R_s and contacted resistor (R_C) is smaller than the NiCr. After O_2 plasma exposure in RIE, the TaN R_s only decreases 0.7Ω, or about 2.56%, and R_C increases 0.1Ω, or about 6.6%, at an annealing temperature of 400℃. In contrast, the NiCr R_s and R_C show large changes at different annealing temperatures after O_2 plasma exposure. In conclusion, TaN is more stable during plasma exposure after 400℃ annealing in N_2 ambient.

Key words: TaN; NiCr; TFR; reliability; MMIC
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1 Introduction

As IC technology advances, circuits require the precise resistors across a broad range of use conditions. NiCr and TaN are the two most common materials used as TFR material for MMICs. NiCr resistors are routinely used for hybrid circuit manufacturing since they are simple to fabricate using standard life-off techniques[1,2]. TaN resistors have been used extensively in Si technology for many years due to their chemical stability, high resistance, and small temperature coefficient of resistance (TCR)[3~5]. Both are implied in MMIC based on the AlGaN/GaN HEMTs. However, the AlGaN/GaN HEMTs are always used in high power amplifiers (HPA), so the low temperature coefficient of resistivity and the sensitivity to oxidation become important in the use of the TFR. In this study, we perform a comparison between NiCr and TaN thin-film resistor materials for use with our AlGaN/GaN HEMTs technology. We compare the fabrication procedures required for both resistor materials, the sheet resistance stability of each for O_2 plasma exposure, and the annealing temperature from 200 to 400℃ in N_2 ambient.

2 Experiment

The TFR was fabricated using standard passive device fabrication techniques in the MMIC based on AlGaN/GaN HEMTs. Sputter deposition of TaN was performed using a 99.99% pure Ta target in an Alliance DP650 system. A deposition rate of 16.5nm/min was obtained at DC power of 600W, $N_2/Ar = 1:11$ with a pressure of 500Pa. With a deposition rate of 11nm/min, NiCr sputter deposition was performed using a Ni : Cr (80 : 20 atomic%) alloy target in a SP_3 system, obtained at 240W DC power, 300Pa pressure, and using Ar gas at a flow of 80sccm. Both the TaN and NiCr films were deposited at room temperature. For deposition rate measurements, lift-off patterns were laid on the samples, and step height was measured after lift-off using a Dektak 6M system. For resistance measurements, a Ti/Au (20nm/400nm) by e-beam evaporation was patterned on the samples prior to the appropriate TFR lift-off pattern. In addition to the long-term stability enhancement[6], a 300nm SiN, which was deposited using a PECVD system coating simultaneously, serves as a capacitor dielectric and transistor passivation for the MMICs. Transmission lines of 3μm electroplated gold were used to contact the resistors. Resistances were measured on rectangular shaped TRFs using a DC probe station and an HP 4155 semiconductor parameter analyzer. Figure 1 shows the picture of the TFR on a semi-insulating 4H-SiC substrate.

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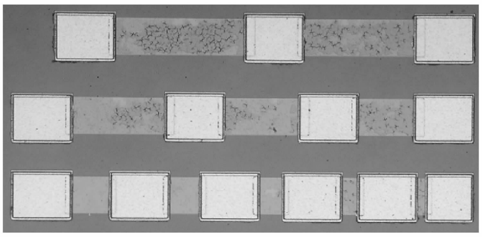

Fig. 1　Picture of the TFR on a semi-insulating 4H SiC substrate

3　Results and discussion

In this study, we compare the reliability of two materials used as TFR on a semi-insulating 4H-SiC substrate. For the different anneal temperatures, each wafer was separated into four segments. The four segments were annealed at four different temperatures: 200, 250, 300, and 400℃. 103 ± 2nm TaN and 25.0 ± 0.5nm NiCr were measured after lift-off using a Dektak 6M system. We use the transmission line measurement (TLM) to calculate the square resistor (R_s) and the contacted resistor (R_C). The NiCr and TaN TFR were both measured before and after the same processing environment: O_2 plasma exposure in a parallel plate reactive ion etch (RIE) system at 50W and 20sccm for 1min before a 300nm SiN deposition using PECVD. Table 1 shows the characterization of the NiCr and TaN TFR at various environments, including annealing at 200, 250, 300, and 400℃ in N_2 ambient, and before and after O_2 plasma exposure. Figure 2 shows the characterization of the NiCr and TaN TFR before and after annealing at 400℃. Figure 2 shows that it has a marked barrier between the NiCr (or TaN) thin film to Ti/Au surface before the annealing. However, after the annealing, the barrier disappeared. This may be due to alloy formation with the thin film. Table 1 demonstrates that the contacted resistor (R_C) decreases as the annealing temperature increases. From Table 1, we find the R_s of TaN TFR increases as the annealing temperature increases. However the R_s of NiCr TFR shows the opposite trend. Furthermore, the TaN R_s increases about 5.3Ω and R_C decreases about 1Ω with the annealing temperature. It is smaller than the change of the NiCr R_s and R_C. The increase of TaN R_s may be primarily due to a loss in N_2 in the film, since the film was annealed in N_2 ambient. After O_2 plasma exposure in a parallel plate reactive ion etch (RIE), the TaN R_s only decreases 0.7Ω, or about 2.56%, and R_C increases 0.1Ω or about 6.6%, at an annealing temperature of 400℃. But the NiCr R_s and R_C changed greatly at different annealing temperatures after O_2 plasma exposure. This is most likely due to preferential oxidation of the Cr in the film. The comparison between NiCr and TaN thin-film resistor materials under different conditions reveals that TaN is more stable during plasma exposure after 400℃ annealing.

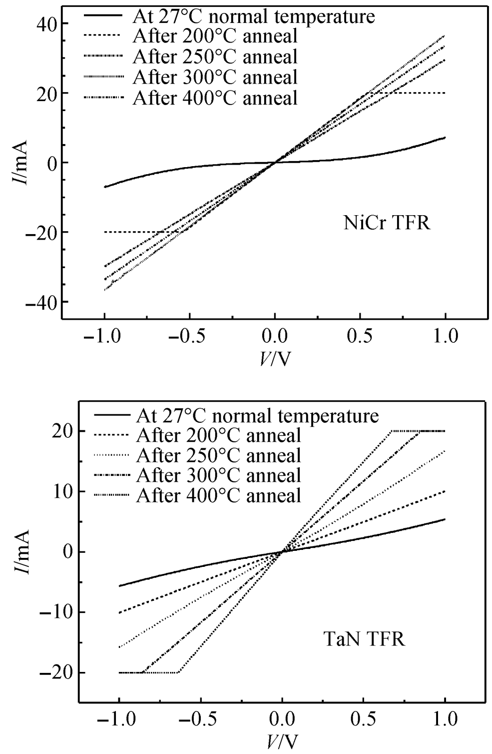

Fig. 2　Characterization of the NiCr and TaN TFR before and after annealing at 400℃

4　Conclusion

The aim of this work has been to establish a stable process for the fabrication of TFR. Through the comparison between NiCr and TaN thin-film resistor materials under different conditions, we find the R_s of TaN TFR increases as the annealing temperature increases. However the R_s of NiCr TFR shows the opposite trend. We also find the change of the TaN R_s and R_C is smaller than the NiCr. After O_2 plasma exposure in RIE, the TaN R_s only decreases 0.7Ω, or about 2.56%, and R_C increases 0.1Ω, or about 6.6%, at an annealing temperature of 400℃. But the NiCr R_s and R_C changed greatly at different annealing

Table 1　Characterization of the NiCr and TaN TFR under different conditions (different anneal temperatures, and before and after O_2 plasma exposure)　Unit: Ω

Annealing temperature and time	TaN(103nm) TFR				NiCr(25nm) TFR			
	Before O_2 plasma		After O_2 plasma		Before O_2 plasma		After O_2 plasma	
	R_s	R_C	R_s	R_C	R_s	R_C	R_s	R_C
200℃, 10min	22	2.5	19.1	8.6	74	17	56.9	16.3
250℃, 10min	23.2	2.14	21.7	8.1	39.4	11	42.9	14.5
300℃, 5min	25.6	1.9	24.2	7.6	26	8.7	24.3	10.3
400℃, 3min	27.3	1.5	26.6	1.6	23.4	4.3	24.1	5.8

temperatures after O_2 plasma exposure. In conclusion, TaN is more stable during plasma exposure after 400℃ annealing. Thus, we establish it as a standard TFR fabrication process in the MMIC based on AlGaN/GaN HEMTs.

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应用于 AlGaN/GaN HEMTs MMIC 薄膜电阻的特性与可靠性*

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摘要: TaN 和 NiCr 是 AlGaN/GaN HEMTs 微波集成电路中薄膜电阻最为常用的两种材料. 文中对比了在 SiC 衬底上生长的这两种材料的薄膜电阻的可靠性. 通过 TaN 和 NiCr 薄膜电阻的对比,发现 TaN 薄膜电阻的方块电阻(R_s)随着退火温度的上升而增大,然而 NiCr 薄膜电阻的 R_s 却出现相反的趋势. 同时发现随着退火温度的上升 TaN 薄膜电阻的 R_s 和接触电阻(R_C)的变化远远小于 NiCr 薄膜电阻的变化. 在 400℃退火及等离子刻蚀机的氧等离子暴露后,TaN 薄膜电阻的 R_s 只下降了 0.7Ω,大概 2.56% ,并且 R_C 上升了 0.1Ω,大概 6.6%. 但是 NiCr 薄膜电阻的 R_s 和 R_C 在不同的退火条件下经过氧等离子暴露后发生了很大的变化. 因此,TaN 薄膜电阻在氮气保护下经过 400℃退火后在氧等离子暴露下更为稳定.

关键词: TaN; NiCr; 薄膜电阻; 可靠性; 微波集成电路
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