Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp82-83

Radio Frequency Characteristics in Tantalum Nitride Thin Film Resistor

Soon Hyeong Kwon[1], Minwoo Nam[1], Areum Kim[1], Keunwon Kang[1], Su Jin Chae[1], Seon Jea Lee[1], , Woo Suk Sul[2], and Sung Gyu Pyo[1,*]

[1] School of Integrative Engineering,Chung-Ang University.
84, Heukseok-ro Dongjak-gu , Seoul 156-756, KOREA
Phone: +82-2-820-5781 E-mail: sgpyo@cau.ac.kr
[2] National NanoFab Center (NNFC).
Daejeon 205-806, KOREA

Abstract

This study reports the analysis results of radio frequency characteristics according to the size, area and shape of TaN thin-film resistor -formed layers. As the TFR size increased, its characteristics were degraded with increasing frequency due to the increased capacitive parasitic components. The effective resistance decreased to about 12.5%, 16.4%, and 37.8% when the resistor widths and lengths were 0.5×20, 1×40, and 2 µm×80 µm, respectively. To secure this RF isolation, methods for minimizing the effect of lossy Si-substrates need to be introduced by using TFR with a smaller area or by forming a patterned ground shield (PGS)

1. Introduction

Along with the rapid advancement of portable wireless communication devices, radio frequency (RF) devices must satisfy various indispensable requisites including high performance, miniaturization, light-weight, and low power and cost. Many studies are continuously being conducted on integrated circuit-based elements to satisfy these requirements [1-3]. Resistors, one the leading passive elements, are widely used for various purposes including the termination, attenuation, matching, isolation, and stabilization of RFIC. Resistors have precision resistance with a smaller error margin compared to polysilicon resistors, diffusion resistors, and well resistors, and can be processed at low temperatures, particularly for securing precise resistance.

Thus, TFR is commonly used in BEOL(back end of line) process due to its applicability. However, such a resistor is unable to maintain the original resistance properties due to the influences of parasitic capacitance and parasitic inductance components as the frequency increases. The impedance changes over TFR frequency with 500Ω. The ideal resistor characteristic was observed in the range below about 10MHz and, subsequently, a decrease in impedance was exhibited up to about 10GHz due to the effect of parasitic capacitance components. However, an increase in impedance was followed due to the effect of parasitic inductance components at the higher frequencies. Analysis of the RF model is essential to examine the causes affecting the RF characteristics. Figure 1 shows the equivalent circuit of the RF model of modified TFR by taking the effects of the substrate into consideration in the equivalent circuit of the RF model of ordinary TFR. The circuit is composed of combined parasitic capacitance (C_{Sub}) and parasitic resistance (R_{Sub}) components using parasitic capacitance (C_{OX}) and Si substrates by parasitic inductance (LS) components and parallel dielectric in two sides vertically generated at resistance (Rs), which is the substantial section of the resistor.

The study analyzed the effect of the parasitic element in inhibiting the RF characteristics of TFR by applying various design and manufacturing methods of TFR. Tantalum nitride (TaN)-based TFR was used in the design because of its outstanding temperature coefficient of resistance (TCR) . The analysis aimed to improve the shortcomings of the RF characteristics in conventional TFR.

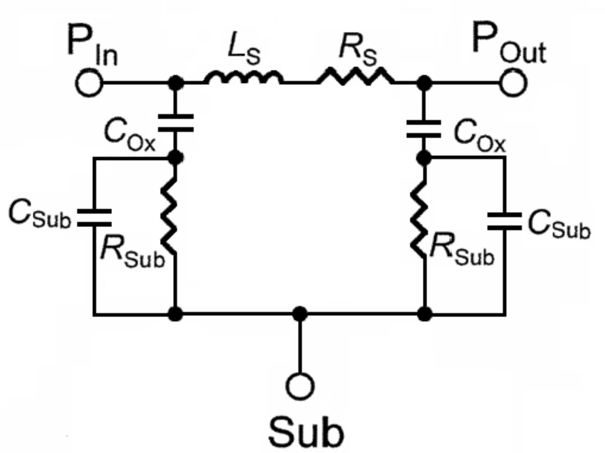

Figure 1. Equivalent Circuit of the RF Model of Thin Film Resistor (TFR)

2. Experimental Results

The TFR used in the study was manufactured based on 0.18µm standard CMOS process. The deposition condition of TaN TFR determines the compositions with the optimum characteristics. Therefore, we identified the sheet resistance (Rs), TCR, and voltage coefficient of resistance along with the changes in gas flow (N2 flow in fixed Ar flow) during sputtering the TaN film. A 500Å thick TaN TFR film was manufactured using the TaN film acquired through the above process.

The structure of the ground-signal-ground pad was used to assess the on-wafer of the TFR test pattern using an 8510C microwave vector network analyzer of Agilent Technologies. Moreover, two-step de-embedding for open and short was applied to exclude the effects of the additionally inserted pad, and interconnection, other than the actual TFR.

In general, resistors of various sizes are designed and inserted to satisfy the different resistance values used in circuits. However, the resistors inserted through this process exhibited various undesirable frequency properties depending on their different sizes. The capacitive parasitic components of the resistor, in particular, were mainly applied as the parasitic characteristics exhibited by TFR itself. The capacitive parasitic components became proportional to the total area of TRF. Figure 2 shows the characteristics of the measured frequency of TFR of various sizes having identical effective resistance. The effective capacitances of the resistors with widths and lengths of 0.5 μm × 20 μm, 1 μm × 40 μm, and 2 μm × 80 μm were decreased by about 12.5%, 16.4%, and 37.8%, respectively, as the frequency was increased from 1MHz to 10GHz.

The characteristics of TFR were degraded as the frequency was increased due to the increase in undesirable capacitive parasitic components with increasing TFR size. The aspect of frequency was favorable with narrower resistors forming the square of resistor in the case of having the identical effective resistance for the above reason. However, the problems of increasing resistance variation generally arise due to increased errors in the manufacturing process as the resistor becomes narrower. Likewise, the resistance variation depending on the resistor area forms a trade-off relationship with the frequency characteristics. Hence, the resistance variation needs to be minimized by selecting the resistor width that ensures the required margin of sufficient process when acquiring accurate resistance, regardless of the frequency in the circuit composition. Moreover, using a small resistor is more desirable as it is less influenced by parasitic components in the circuit area where precise resistance needs to be secured at high frequency. Minimizing the parasitic capacitor is thought to be a useful method for preventing a relative deterioration of RF characteristics by diversifying resistor widths instead of changing resistor lengths when the resistance of the inserted resistor varies. In general, the patterns of TFR are mainly designed into dog-bone type and bar type. TFR with wide resistors is designed in bar type to secure sufficient area size forming via for the electrical connection of TFR. In contrast, TFR with narrow resistors is unavoidably designed in dog-bone type since the area size forming via is not sufficiently secured. Table 1 compares the assessed average Rs of the dog-bone and bar types having the identical unit effective resistance. Excluding the effect of parasitic components over frequency, the measured frequency was set at 100 MHz to solely analyze the influence of the shape of the test pattern. The measured effective resistance aligned with that of the bar type compared to the outcome of the dog-bone type, which was attributed to the corner effect in the TFR production process where it is much harder to form accurate patterns in the dog-bone type than in the bar type. Therefore, the bar type is recommended in the design of TFR with accurate resistance. However, the insertion of a guard pattern is considered essential to minimize the corner effect when the dog-bone type is inevitably used in the design.

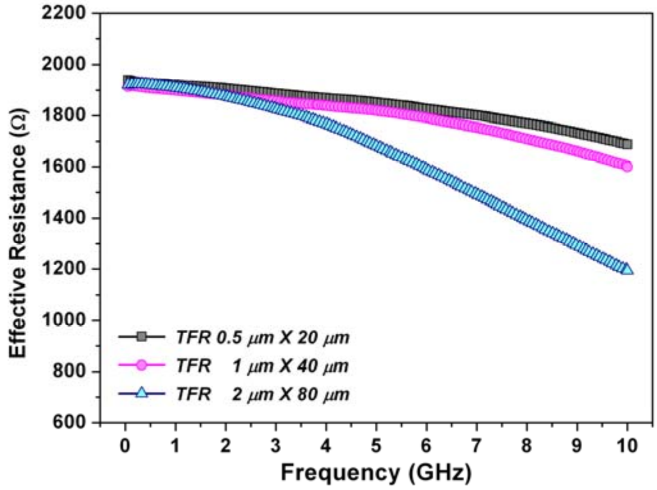

Figure 2. Frequency Characteristics of Various Sizes of Thin Film Resistor (TFR) Having the Identical Effective Resistance

	TFR Size	TFR Shape Type	Designed Average Sheet Resistance	Measured Average Sheet Resistance	3 × Sigma (Ω / □)
TFR 1	1 μm × 20 μm	Dog-bone Type	50 Ω / □	46.17 Ω / □	11.4
TFR 2	2 μm × 40 μm	Dog-bone Type	50 Ω / □	48.06 Ω / □	5.73
TFR 3	4 μm × 80 μm	Bar Type	50 Ω / □	49.77 Ω / □	3.48

Table 1. Measured Average Sheet Resistance of Dog-bone Type and Bar Type TFR

3. Conclusions

This study proposed a method for improving the RF characteristics by applying various design and manufacturing methods of TaN-based TFR, one of the leading resistors among high frequency passive elements, by analyzing the characteristics of area, pattern, and layer location. To assess the effect of TFR formation, the effects of dog-bone type and bar type formations were evaluated. The insertion of a guard pattern was considered essential to minimize the corner effect due to the greater difficulty in forming a precise pattern in the dog-bone type due to the corner effect. Securing RF isolation is crucial for optimizing the high frequency TFR performance.

References

[1] Jr-Wei Lin, C. C. Chen, and Y.-T. Cheng, *IEEE Trans. Electron Devices*, vol 52, pp. 1489-1496, July. 2005.

[2] H. L. Kao, A. Chin, C. C. Liao, C. C. Chen, S.-P. McAlister, and C. C. Chi, *IEEE Trans. Electron Devices*, vol 53, pp. 636-642, April. 2006.

[3] J. G. Fiorenza, and A. Del Alamo, *IEEE Trans. Electron Devices*, vol. 49, pp. 687-692, April.2002