EXTRACTION OF PARASITIC PARAMETERS OF DUMMY DEVICES ON DIFFERENT SILICON SUBSTRATES

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ABSTRACT

S-parameters of dummy devices fabricated on Si substrates with different resistivities are measured and analyzed to study the effects of substrate resistivity on the microwave characteristics. An equivalent parasitic circuit model is proposed and the extraction procedure also developed. The substrate resistivity effects can be well explained by the proposed model.

INTRODUCTION

For wireless communication applications, the developments of silicon based high frequency devices and circuits are becoming another attractive research topic in low cost VLSI technologies. However, the poor high frequency performance and parasitic substrate loss due to the semiconducting substrates used to fabricate Si IC have made some limitations on the growing of this area. In order to get better high frequency performance, shrinkage of the device dimension is the most importantant for Si IC used in high frequency applications. Therefore, the “de-embed” process of the device under test to get precise high frequency characteristics and device model parameters is necessary. The dummy device with open pads is widely used to perform the “de-embed” process. However, there is not any report on the silicon substrate resistivity effects on the high frequency characteristics of the dummy devices. We report some original technical results relating to this topic in this paper.

EXPERIMENTAL

Dummy devices were fabricated on the Si substrates with four different resistivities. The values of the resistivities are illustrated in Table 1. A standard CMOS technology is used to fabricate the dummy devices. An oxide layer with 500 nm was grown on Si substrate. Then a metal layer with Ti/TiN/Al-Cu/TiN structure was applied. Dummy devices were then defined by dry etching process. Two port S-parameters were measured with a HP 8510C network analyzer and Cascade microtech RF probe station. The Smith charts with measured S-parameters of dummy devices on different resistivities Si substrates are shown in Fig. 1. We can find that the S-parameters of the dummy devices have a strong dependence on the substrate resistivity.

RESULTS AND DISCUSSIONS

Based on the analysis of measured S-parameters, we propose an equivalent parasitic circuit model which is composed of passive components to explain the above results and the circuit model is shown in Fig. 2. R_1 and R_2 are the series resistances from the outputs of the bias networks to the inputs of the dummy device and can be extracted by measuring the S-parameters of the standard short device. R_3 is the series resistance connecting to ground and its value is dependent on the substrate resistivity. C_1 and C_2 are the capacitances under port 1 and port 2 dummy pads which are dependent on the oxide thickness and substrate concentration. C_{12} is the coupling capacitance between port 1 and port 2 dummy pads. R_{1B} and R_{2B} is the parallel parasitic resistance under port 1 and port 2 dummy pads. As usual, C_{12} is much smaller than C_1 and C_2 and can be neglected in parasitis resistances extraction as an approximation. Therefore the equivalent parasitic circuit model in high frequency range (>10 GHz) can be simplified and shown in Fig. 3. The equivalent circuit in Fig. 3 can expressed by the following Z parameters:

$$Z_{11h} = (R_1 + R_{1B}) + R_3 \quad (1)$$
$$Z_{12h} = R_3 = Z_{21h} \quad (2)$$
$$Z_{22h} = (R_2 + R_{2B}) + R_3 \quad (3)$$

As described previously, the extracted values of R_1 and R_2 are 545 mΩ and 360 mΩ, respectively. Based on the analysis in Eq.(1)~(3), R_{1B}, R_{2B} and R_3 will be extracted by the Z-parameters analysis in high frequency range. The values of R_{1B}, R_{2B} and R_3 are strongly dependent on the substrate resistivity. With the knowledge of the series resistances, the parallel parasitic circuit model can be "de-embed" as following,

$$Z_{11p} = Z_{11} - (R_1 + R_3) \quad (4)$$
$$Z_{12p} = Z_{21} - R_3 \quad (5)$$
$$Z_{22p} = Z_{22} - (R_2 + R_3) \quad (6)$$

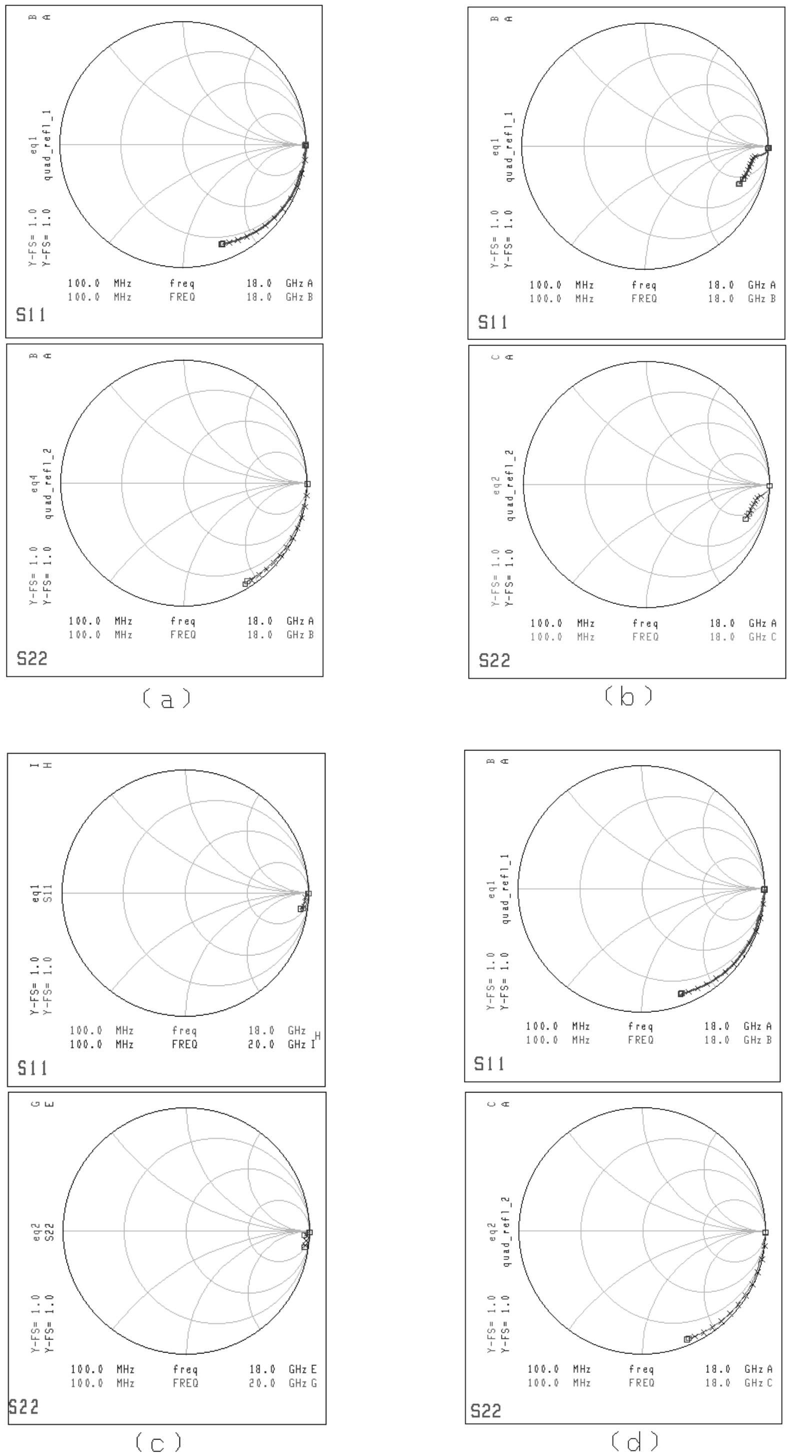
Where $\mathbf{Z_p}$ is the Z-parameters of the parallel parasitic circuit . The Y-parameter of the parallel parasitic circuit can be obtained by $\mathbf{Y_p} = 1/\mathbf{Z_p}$ and the $\mathbf{Y_p}$-parameters can be expressed as following,

$$Y_{11p} = [j\omega C_1/(1+j\omega R_{1B}C_1)] + j\omega C_{12} \quad (7)$$
$$Y_{12p} = - j\omega C_1 = Y_{21p} \quad (8)$$
$$Y_{22p} = [j\omega C_2/(1+j\omega R_{2B}C_2)] + j\omega C_{12} \quad (9)$$

C_1, C_2 and C_{12} can be easily extracted by the above method and the values are also illustrated in Table 1. After the parasitic parameters extraction, ICCAP is used to do the optimization and the final parameters are also expressed in Table 1. The simulated S-parameters of the dummy devices are also illustrated in Fig. 1. The results show well consistence between measured and simulated data.

CONCLUSIONS

From the above results, we can find that R_{1B} and R_{2B} are the most important components that affect the high frequency characteristics of the dummy devices. The values of R_{1B} and R_{2B} increase with the increase of the substrate resistivity. The results also show that the lower substrate resistivity causes serious parasitic effect. In conclusion, we proposed an equivalent parasitic circuit model to well expxplain the substrate effects on the high frequency characteristics of the dummy device. The more serious parasitic effect of the dummy devices on lower resistivity substrates is due to the smaller parallel parasitic resistance R_{1B} and R_{2B}. This paper can provide a design reference for the microwave devices with coplanar pad to avoid parasitic effect and get precise "de-embed" results.



——— measured data xxxxx simulated data

Fig. 1 Measured and simulated S-parameters of dummy devices on Si substrates with different resistivities (a) 0.01~0.025 Ω-cm B-doped Si (b) 10~20 Ω-cm B-doped Si (c) 1K~2K Ω-cm B-doped Si (d) 0.008~0.025 Ω-cm Sb-doped Si

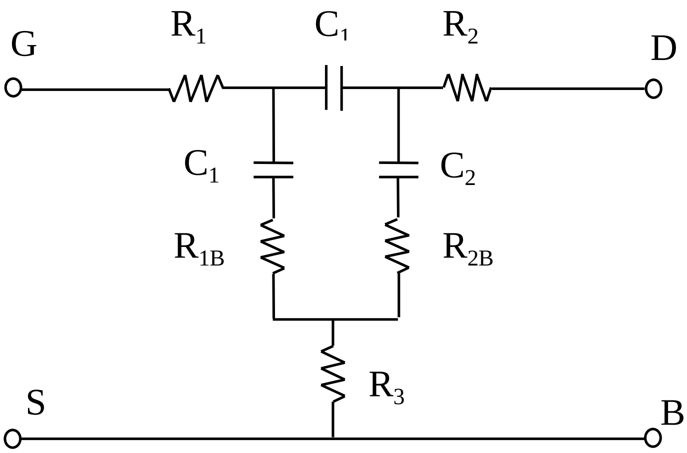


Fig. 2 Equivalent parasitic circuit model of the dummy device.

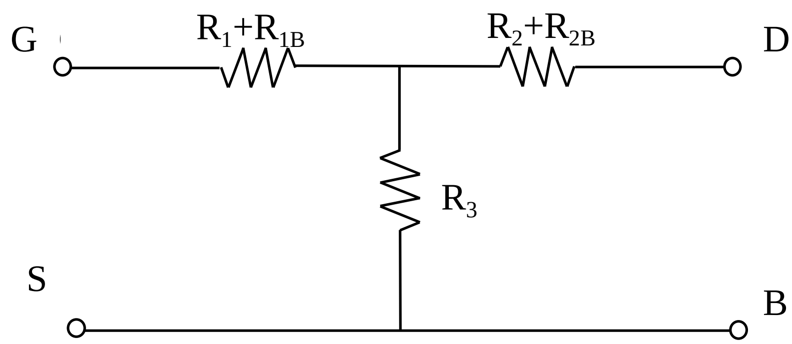


Fig. 3 Equivalent parasitic circuit model of the dummy device in high frequency range.

Wafer #	**Substrates Resistivity (Ω-cm)**	**R_1 (Ω)**	**R_2 (Ω)**	**R_3 (Ω)**	**R_{1B} (Ω)**	**R_{2B} (Ω)**	**C_1 (F)**	**C_2 (F)**	**C_{12} (F)**
D3-1	**P^+(Boron)** 0.01 ~ 0.025	545m	360.1m	1u	13.27	4.547	107.7f	84.25f	16.27f
D3-3	**P(Boron)** 10~20	545m	360.1m	11	730	850	220f	100f	29f
D3-4	**P(Boron)** 1k~2k	545m	360.1m	936.9	3k	3.5k	90f	96f	12f
D3-6	**N^+(sb)** 0.008~ 0.025	545m	360.1m	1u	7.796	3.849	104.3f	99.51f	20.39f

Table 1 Parasitic circuit model parameters of dummy devices on different substrates