RF Pad Optimization for a 140 GHz RF–MEMS Switch

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Abstract. RF pads are designed based on IHPs 0.13 µm SiGe BiCMOS technology and measured in D–band (110–170 GHz). Using the optimized RF pad helps to eliminate the loss which is introduced by the coupling of the RF signal to the Metal1 (M1) ground shields. The extracted capacitance of the optimized RF pad shows a drop of 7 fF at 140 GHz. The goal of the RF pad optimization is to combine the new RF pad with a 140 GHz RF–MEMS switch in order to avoid the pad de–embedding procedure. The fabricated RF–MEMS switch with the optimized RF pads shows a low insertion loss of 0.68 dB at 140 GHz with an improvement of 0.45 dB compared to the same RF–MEMS switch with the not optimized standard RF pads.

Key words: RF–MEMS; BiCMOS; mm–wave; EM modeling; GSG; RF–pad

1. Introduction

SiGe technologies have become more attractive with the high performance of heterojunction bipolar transistors (HBTs) for millimeter–wave frequency applications [1]. The RF–MEMS switch integration into IHPs 0.13 µm SiGe BiCMOS process technology gives the opportunity to use low insertion loss and high isolation RF–MEMS switches together with high performance HBTs. This provides circuits with low attenuation, to be used in antenna switching matrices and phase shifters [2]. RF–MEMS switches in mm–wave circuits are lately realized and demonstrated for 94 GHz passive imaging systems and 140 GHz active radar systems [3].

RF pads are the essential elements to characterize RF– MEMS switches or any other RF–circuits, since they provide the direct access to the DUTs (device under test). The RF performance of the DUT should not be affected by the de–embedding of the RF pads; however accurate de–embedding of the RF pads is critical in the mm–wave frequency range [4]. Therefore the electromagnetic (EM) optimization of the RF pads itself is inevitable [5].

In this work, EM optimizations of RF pads for a 140 GHz targeted RF–MEMS switch are presented. The EM simulations are performed for standard and optimized RF pads and also both devices are fabricated, measured and the measurement results are compared. The switch, including the optimized RF pads, is monolithically integrated into IHP`s 0.13 µm SiGe BiCMOS process technology and provides 0.68 dB insertion loss and isolation of 32 dB at 140 GHz.

2. RF–MEMS Switch in 0.13 µm BICMOS Technology

IHPs RF–MEMS switch technology is embedded into the Back–end–of–line (BEOL) of the 0.13 µm SiGe BiCMOS technology. The developed RF–MEMS switch [6] consists of Metal4 (M4) high–voltage electrodes, a Metal5 (M5) RF–signal line, a TopMetal1 (TM1) movable membrane, and a TopMetal2 (TM2) plate with releasing holes. The TM2 plate is placed on top of the RF–MEMS switches to provide a wafer–level encapsulation packaging process. With this approach, no additional package will be required for the RF–MEMS switches as the devices will be encapsulated during the standard BEOL process. In this paper, the presented results of the RF-MEMS switches are in case of the uncovered encapsulation holes.

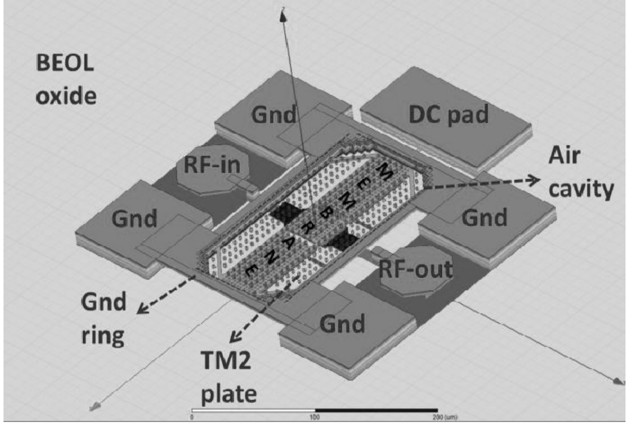

Fig. 1. EM model of a 140 GHz targeted RF–MEMS switch with its patterned TM2 plate, including standard RF pads.

3. RF–PAD Optimization

In order to optimize the GSG (Ground–Signal– Ground) pads of a 140 GHz targeted RF–MEMS switch, EM models were built up in Ansoft HFSS 3D FEM (Finite–Element–Method) solver. The goal of the RF pad optimization was not to have a necessity to perform de – embedding since the performance including the pads will not be significantly different compared to a switch without RF pads. In the standard GSG pad configuration, Metal1 (M1) layer was patterned underneath the pads as a ground shield and the ground pads were connected to each other with metal and via stacks from M1 up to TM2 (Fig. 2–a). To achieve a minimum parasitic capacitance introduced by the RF pads, the optimized GSG pad (Fig. 2b) was designed only in TM2 layer. The optimized pad is created as a coplanar waveguide (CPW), with an 80 µm wide signal pad and 7 µm gap to the ground pads.

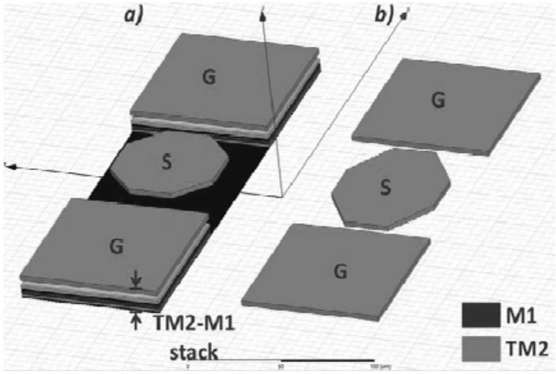

Fig. 2. RF GSG pad of the 140 GHz RF–MEMS switch (a) before and (b) after optimization.

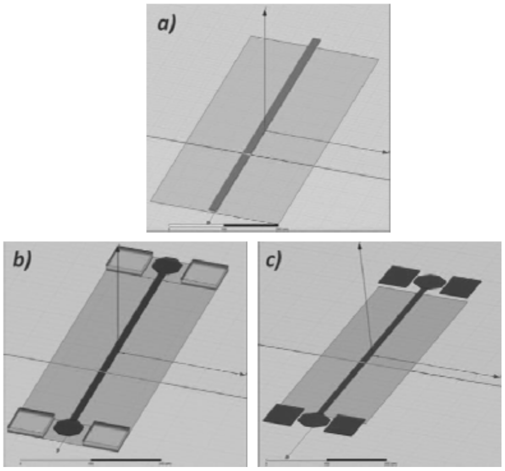

Fig. 3. EM simulations of a 50 ohm matched microstrip line (a) without RF pads, (b) with the standard RF pads and (c) the optimized RF pads.

During the EM optimization of the RF pad, different pad configurations were combined with a 50 Ω matched microstrip line and simulated (Fig. 3).

The designed microstrip line which consists of TM2 signal line and M1 ground shield, has a width of 15 µm, and a length of 730 µm. The EM simulation gives a loss of 0.47 dB at 140 GHz (Fig. 4–a). EM simulations also show that the impedance matching of the microstrip line significantly deviates by the standard RF pads (Fig. 4–b, c). With the standard RF pads, the impedance of the microstrip line decreases from 50.6 Ω to 20.8 Ω (Fig. 4–d). As a result of this mismatch, transmission line with the standard RF– pads shows 1.62 dB loss. On the other hand with the optimized GSG pads, the impedance of the microstrip line changes slightly, 3 Ω deviation at 140 GHz. The loss of the transmission line with the optimized RF–pads is 0.63 dB, which is only 0.15 dB higher than the transmission line loss without RF pads.

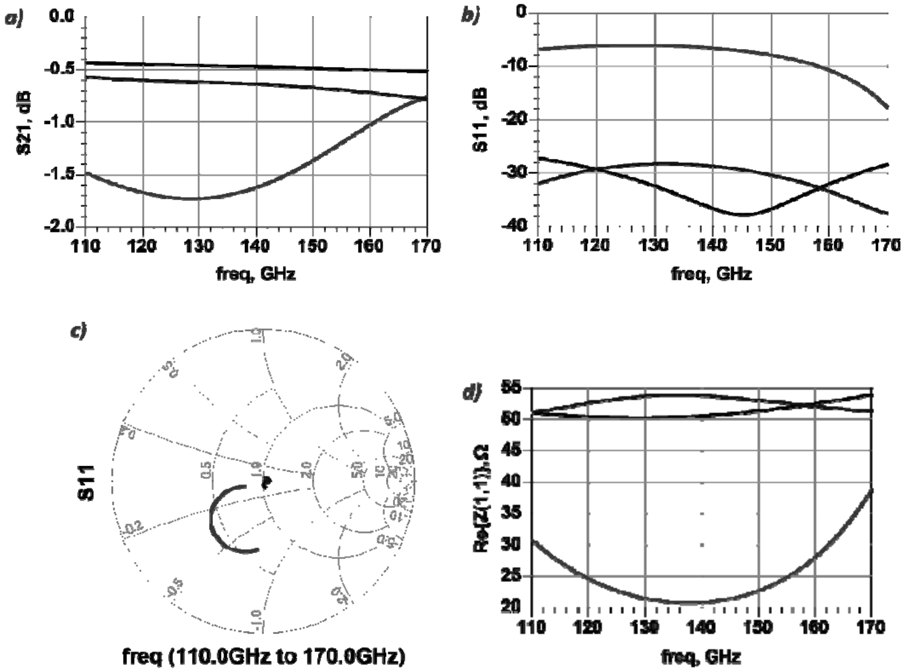

Fig. 4. S parameter (a, b, c) and characteristic impedance (d) comparisons of the 50 Ω matched microstrip line without RF pads (black), with the standard RF pads (red) and the optimized RF pads (blue).

After the optimization of the RF pads, both the standard and the optimized RF pads are fabricated in IHPs SG13 BEOL technology for further characterization. All two port on–wafer S–parameter measurements are performed with a setup from Rohde & Schwarz, consisting of a 4 port ZVA24 as VNA / system controller and two ZVA170 Millimeter–Wave Converters from 110 to 170 GHz. Pad capacitances are extracted from equation (1) with conversion of the measured S parameters into Z parameters. With the new GSG pad configuration, the pad capacitance is reduced from 15 fF to 8 fF (Fig. 5), which is a reduction of ~45%.

$$C_{pad} = \frac{-1}{\left(2\pi f \cdot \mathrm{im}\left(Z\left(1,1\right)\right)\right)} \tag{1}$$

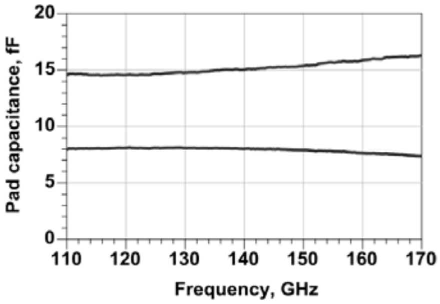

Fig. 5. Extracted capacitances of the standard (red) and optimized (blue) RF pads from S-parameter measurements.

Moreover to the RF–pad fabrications, the 140 GHz targeted RF–MEMS switch was simulated and fabricated together with the standard (Fig. 6a) and the optimized RF pads (Fig. 6b). The comparison of the simulated and measured RF–MEMS switches with both GSG pad configurations is shown in Fig. 7 with the apparent improvement of the insertion loss in the up–state. The measured S–parameter results of the RF–MEMS switch including the optimized RF pads provide 0.68 dB insertion loss and 32 dB isolation at 140 GHz.

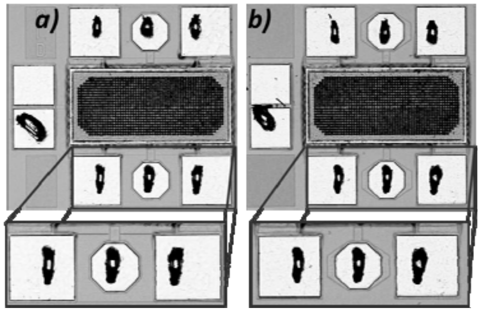

Fig. 6. The 140 GHz RF–MEMS switch with (a) the standard and (b) the optimized RF pads.

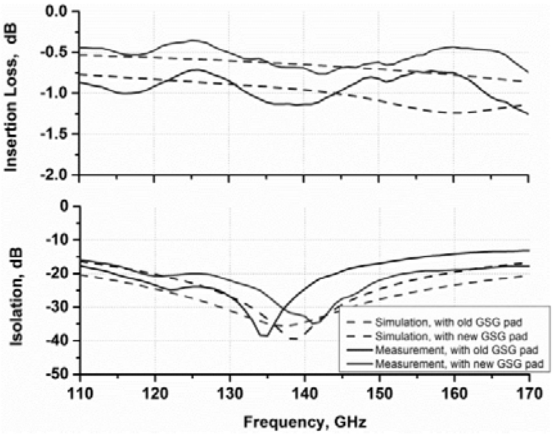

Fig. 7. EM simulation and S-parameter measurement comparisons of the RF-MEMS switch with the standard (blue) and optimized (red) GSG pad configurations.

4. Conclusion

An EM optimized RF–pad is designed and simulated together with a 50 Ω impedance matched microstrip line using Ansoft HFSS 3D FEM (Finite–Element–Method) solver. The optimized RF–pad shows ~45% reduction of the extracted pad capacitance compared to the standard RF pad with M1 ground shield. Finally, both the standard and the optimized RF–pads are combined with a 140 GHz RF–MEMS switch. The insertion loss of the 140 GHz RF–MEMS switch including the optimized RF pads is 0.68 dB at 140 GHz, which shows an improvement of 0.45 dB compared to the switch with the standard RF pads.

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