BiCMOS Embedded RF-MEMS Technologies

S. Tolunay Wipf [1], A. Göritz [1], M. Wietstruck [1], C. Wipf [1] and M. Kaynak [1, 2]
[1] IHP, Germany
[2] Sabanci University, Turkey

Introduction

Novel communication system technologies demand not only miniaturization but also multifunctionality. From this perspective, RF-MEMS devices are promising candidates to add functionality into future RF systems. With their good RF performances, there is a growing need and interest in RF-MEMS switches for both RF and mm-wave applications in the recent years. This need is expected to increase tremendously in the near future with more applications operating at mm-wave frequencies.

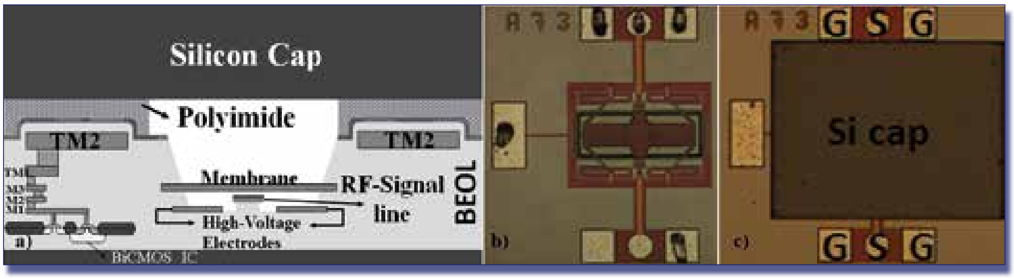

Fig. 1: The generic cross section of the packaged 0.25 µm BiCMOS technology RF-MEMS switches (a) and the micrograph of K-band RF-MEMS switches before (b) and after Si cap (c) [3].

IHP has developed two BiCMOS embedded RF-MEMS switch technologies for two different technology lines, namely the 0.25 µm and the 0.13 µm SiGe BiCMOS. In both technologies, RF-MEMS Single-Pole Single-Throw (SPST) and Single-Pole Double-Throw (SPDT) switches are realized for mm-wave applications. The technologies offer two different packaging technologies for the RF-MEMS switches, namely Silicon cap packaging and thin film wafer-level encapsulation.

Technologies

0.25 µm SiGe BiCMOS

The RF-MEMS switch module is initially embedded into IHP`s 0.25 µm SiGe BiCMOS technology using the Back-End-Of-Line (BEOL) metallization layers [1]. The 0.25 µm SiGe BiCMOS technology has 5 aluminum metallization layers in BEOL. The high-voltage electrodes of the switch are formed using M1 while M2 is used as the RF-signal line. A thin Si_3N_4/TiN stack, which is part of the BiCMOS metal-insulator-metal (MIM) capacitor, forms the contact region and provides DC isolation between movable membrane (M3) and the RF-signal line. After the MEMS releasing process, the RF-MEMS cavities are sealed with the silicon (Si) caps at wafer-level [2] - [3]. Fig. 1(a) shows the generic cross section of the packaged RF-MEMS switch in 0.25 µm BiCMOS technology [3].

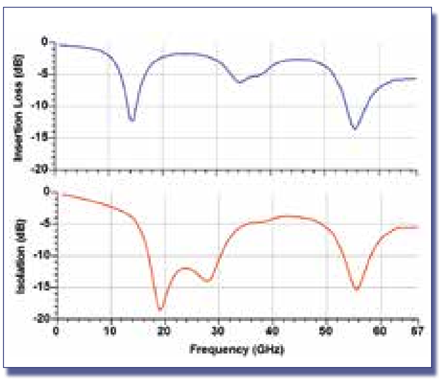

Fig. 2: The measured S-parameters of the K-band RF-MEMS SPDT switch in 0.25 µm SiGe BiCMOS technology.

Based on the 0.25 µm SiGe BiCMOS technology RF-MEMS module, RF-MEMS switches for K-band (18 – 27 GHz) are designed, fabricated and packaged. The micrograph of K-band RF-MEMS switches are shown in Fig. 1 (b,c) before and after the Si cap packaging [3]. Furthermore, the developed K-band RF-MEMS switch is used as a standard building block for an RF-MEMS SPDT switch [4]. The S-parameter measurement results of the fabricated SPDT switch are shown in Fig. 2 and show an insertion loss of 1.8 dB and an isolation of 12.4 dB at 25.5 GHz.

0.13 µm SiGe BiCMOS

The second integration of RF-MEMS module is done in the IHP`s 0.13 µm SiGe BiCMOS process. IHP`s 0.13 µm SiGe BiCMOS process represents one of the fastest currently available SiGe heterojunction bipolar transistor (HBT) technology with peak f_T/ f_{max} values of 505 GHz/720 GHz [5]; thus opening potential markets for SiGe BiCMOS technologies (i.e. imaging systems at 94 and 140 GHz, THz spectroscopic systems at 240 GHz and beyond).

SelinTolunay Wipf

Alexander Göritz

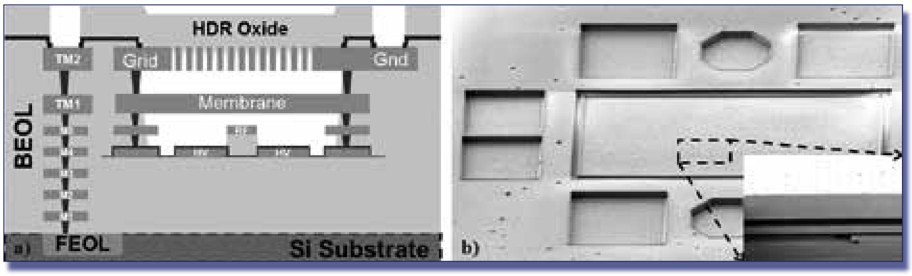

Fig. 3: The schematic cross section (a) and SEM image (b) of the WLE RF-MEMS switch [6].

Compared to the 0.25 µm SiGe BiCMOS technology, the BEOL metallization stack of the 0.13 µm SiGe BiCMOS technology includes 7 metal layers instead of 5; hence a different integration scheme is used (Fig. 3(a)). The RF-MEMS switch in 0.13 µm SiGe BiCMOS technology consists of high-voltage electrodes (M4), RF-signal line (M5) and a movable membrane (TM1). For the packaging, a thin film wafer-level encapsulation approach is developed using the standard BiCMOS fabrication steps. Fig. 3(b) shows the fabricated wafer-level encapsulated (WLE) RF-MEMS switch in the 0.13 µm SiGe BiCMOS process, developed for the D-Band (110 – 170 GHz) applications [6]. By using the developed 0.13 µm SiGe BiCMOS embedded RF-MEMS switch technology, a 140 GHz center frequency SPDT is designed with a tee junction that is connected to two RF–MEMS switches with each side λ/4 microstrip lines. The D-band RF-MEMS based SPDT switch has been successfully demonstrated, with its measured 1.42 dB insertion loss (IL) and 54.5 dB isolation at 140 GHz (Fig. 4) [7].

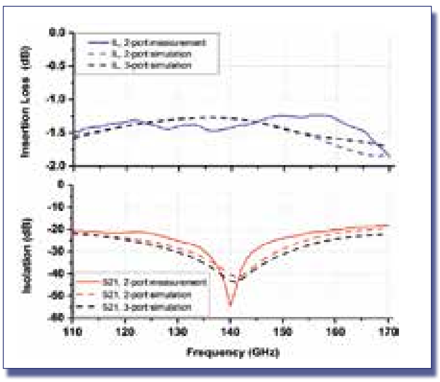

Fig. 4: Comparison of the measured and simulated S-parameters of the D-band RF-MEMS based SPDT switch in 0.13 µm SiGe BiCMOS technology [7].

Conclusion

IHP has developed BiCMOS embedded RF-MEMS switch technologies for both 0.25 µm and the 0.13 µm SiGe BiCMOS lines. Each technology has applied different packaging techniques; namely, Si cap packaging and wafer-level encapsulation. In both technologies, RF-MEMS SPST and SPDT switches for mm-wave applications are successfully realized.

Acknowledgment

The authors would like to thank to Fraunhofer IZM, Berlin, for the Si cap packaging.

References

[1] M. Kaynak et al., “BEOL embedded RF-MEMS switch for mm-wave applications,” in 2009 IEEE International Electron Devices Meeting (IEDM), Dec 2009, pp. 1-4.

[2] K. Zoschke et al., “Capping technologies for wafer level MEMS packaging based on permanent and temporary wafer bonding,” in 2014 IEEE 64th Electronic Components and Technology Conference (ECTC), May 2014, pp. 1204-1211.

[3] S. Tolunay Wipf et al., “Effect of wafer-level silicon cap packaging on BiCMOS embedded RF-MEMS switch per-formance,” 2017 IMAPS Nordic Conference on Microelectronics Packaging (NordPac), Gothenburg, Sweden, 2017, pp. 31-34.

[4] S. Tolunay Wipf et al., “Packaged BiCMOS Embedded RF-MEMS Test Vehicles For Space Applications,” in 2017 47th European Microwave Conference (EuMC), Oct 2017, pp. 320-323.

[5] B. Heinemann et al., “SiGe HBT with fx/fmax of 505 GHz/720 GHz,” 2016 IEEE International Electron Devices Meeting (IEDM), San Francisco, CA, 2016, pp. 3.1.1-3.1.4.

[6] S. Tolunay Wipf et al., “Thin film wafer level encapsulated RF-MEMS switch for D-band applications,” in 2016 46th European Microwave Conference (EuMC), Oct 2016, pp. 1381-1384.

[7] S. Tolunay Wipf et al., “D-Band RF-MEMS SPDT Switch in a 0.13 µm SiGe BiCMOS Technology,” IEEE Micro-wave and Wireless Components Letters, vol. 26, no. 12, pp. 1002-1004, Dec 2016.

M.Sc. Selin Tolunay Wipf
IHP GmbH
Leibniz-Institut
für innovative Mikroelektronik
Im Technologiepark 25
15236 Frankfurt (Oder)
Germany
Phone +49 (0)335 - 5625 - 487
Fax +49 (0)335 - 5625 - 327
Mail tolunay@ihp-microelectronics.com
Web www.ihp-microelectronics.com