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Design of Anti-Sticking Membrane for RF MEMS Tunable Capacitor

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Abstract

The paper describes a radio frequency microelectromechanical (RF MEMS) tunable capacitor with electrostatic actuation and an anti-sticking membrane. The varactor capacitance changes from 0.3 pF to 3.5 pF with |S(1,1)| > -0.25 db at 10 GHz. Actuation voltage is 18 V.

Keywords: RF MEMS Tunable Capacitor, Membrane Sticking, RF MEMS Reliability.

INTRODUCTION

RF-MEMS switches have been widely studied in the last decade because of their excellent RF properties, such as low insertion loss, high isolation, high linearity and low power consumption [1]. In spite of their promising performance, reliability issues are still preventing a broad exploitation of RF MEMS devices [2, 3].

The reliability of RF MEMS capacitors is dominated by stiction between the dielectric layer and the metal due to the large contact area of the switch [4].

In this paper, the development and design of an anti-sticking membrane in RF MEMS tunable capacitor is presented. The key feature of the structure is an additional control electrode, which, under the applied voltage, causes the membrane return to its initial position.

DESIGN AND MODELLING

An RF MEMS tunable capacitor (varactor) has been designed and modelled. The capacitor topology is presented in Fig. 1. It is implemented as a single-port CPW structure, where the membrane is connected to RF ground and hangs over the CPW central line, which is covered with the dielectric layer Si_3N_4.

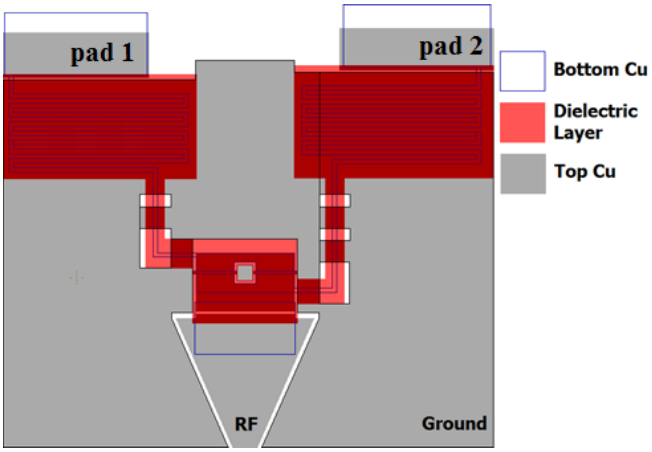

Figure 1: Topology of RF MEMS capacitor.

The membrane is implemented according to the seesaw principle with two separate electrodes. With the application of actuation voltage to the contact pad 2, the membrane is actuated by being pulled down to the lower electrode. Thus changes the gap between the capacitor plates, and consequently the capacitance. Contact pad 1 is placed opposite to the pad 2. In the case of membrane stiction, the application of actuation voltage to the pad 2 brings the membrane back to its initial position. Such a principle allows to avoid membrane stiction - one of the main challenges in RF MEMS operation.

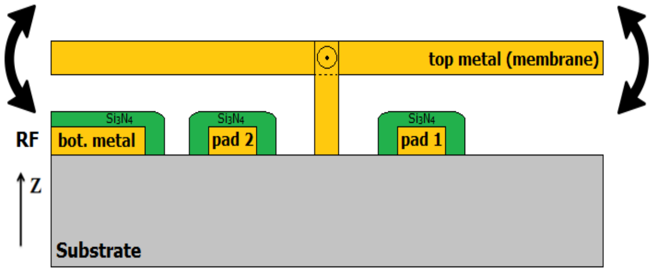

Figure 2: Seesaw membrane principle (not scaled).

Finite elements modelling has been used to simulate the varactor structure. The geometry of the membrane and the control electrode allowed to obtain a low actuation voltage of 18 V.

At a frequency of 10 GHz the following values have been obtained: |S(1,1)on|= -0.22 db, |S(1,1)off|= -0.1 db (Fig.3). Thick top metallization ensures low loss.

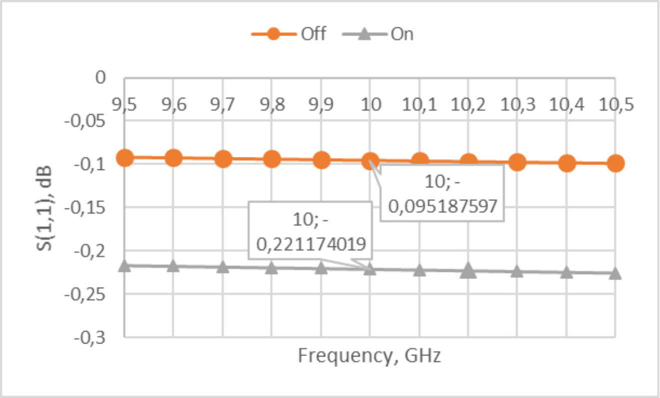

Figure 3: Modelled S-parameters.

The calculated capacitance of the varactor changes from Cmin = 0.3 pF to Cmax = 3.2 pF, which ensures the contact ratio k= Cmax/ Cmin ≈ 10 (Fig.4).

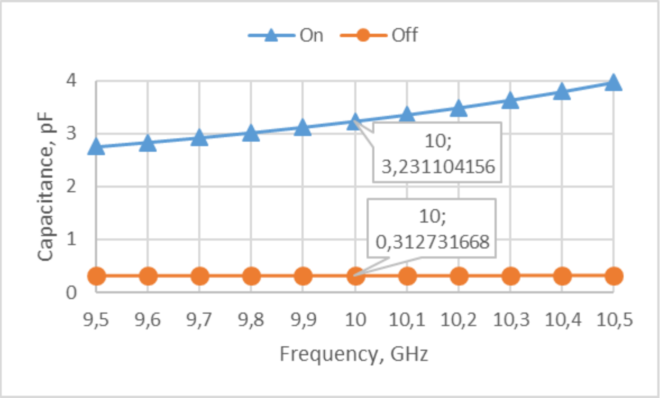

Figure 4: Modelled capacitance.

FABRICATION

To fabricate the tunable capacitor, sapphire substrates have been used. Sapphire, being a true dielectric, ensures the required isolation between the separate structural elements. In the fabrication, a 3-lithography process has been used.

The first mask defines the topology of the lower metal layer forming control electrodes and lower capacitor coating. Cu is used as a main structural metal due to its high conductivity. The lower metal layer is deposited using magnetron sputtering.

The second mask forms the topology of dielectric and sacrificial layers, which are deposited during a single PECVD process. Silicon nitride Si_3N_4 is used as a dielectric layer and silicon oxide SiO_2 is used as a sacrificial layer.

The third mask forms the movable element – membrane which is fabricated using electroplating of Cu above the sacrificial layer. After that, the sacrificial layer is etched out.

Table 1 contains the measured thicknesses of the fabricated RF MEMS capacitor in comparison with the target values.

Table 1: RF MEMS capacitor layer thicknesses.

Layer	Target thickness, um	Measured thickness, um
Lower metal (Cu)	0.2	0.19 – 0.22
Si3N4	0.2	0.18 – 0.2
Sacrificial layer SiO2	1	1 – 1.1
Membrane (Top metal, Cu)	2	2.0 – 2.3

Fig.5-6 presents the fabricated RF MEMS tunable capacitors.

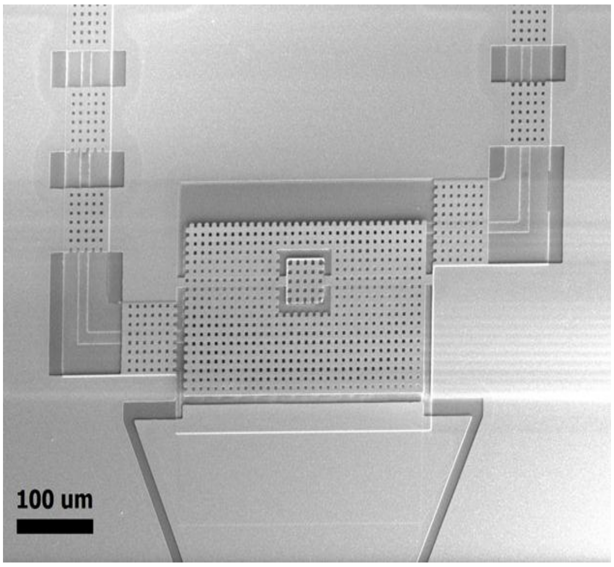

Figure 5: Anti-sticking membrane of RF MEMS capacitor.

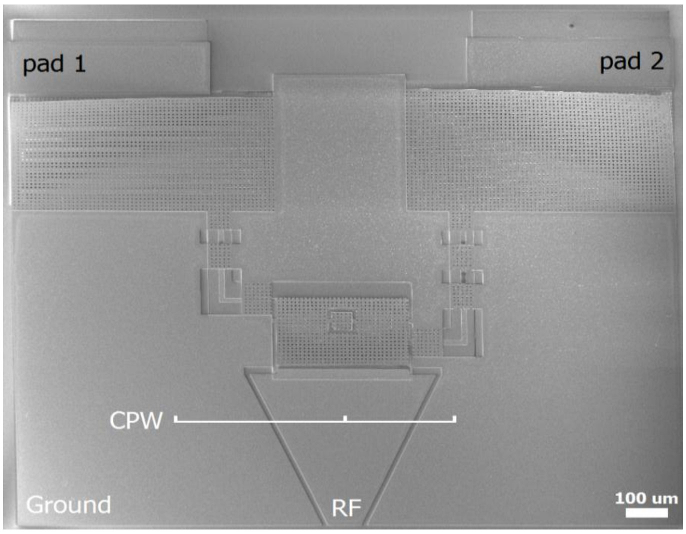

Figure 6: RF MEMS tunable capacitor.

Performance and Analysis

The fabricated capacitor has been measured using a wideband one-port measurement system in 9.5 GHz – 10.5 GHz frequency range, comprising a vector network analyzer, a probe station for on-wafer tests and a waveform generator.

The measured value of the actuation voltage has been found to be 18 V, as modeled.

Fig.7 presents the measured |S(1,1)on| = -0,22 dB at 10 GHz, and |S(1,1)off| = -0.16 dB at 10 GHz.

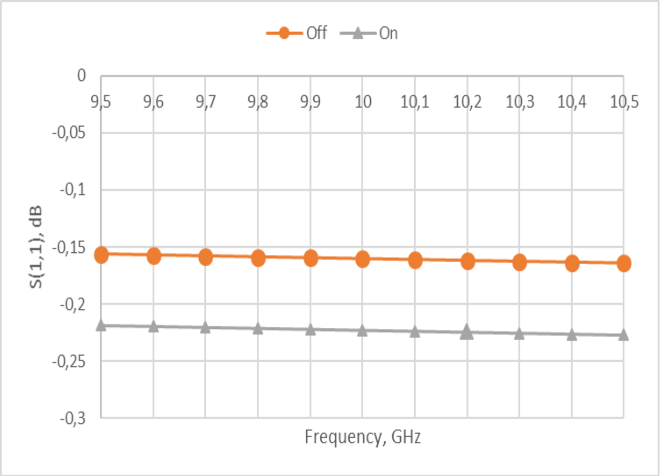

Figure 7: Measured S-parameters.

Measured varactor capacitance changes from Cmin = 0.3 pF to Cmax = 3.5 pF, ensuring a contact ratio k= Cmax/ Cmin ≈ 11 (Fig. 8).

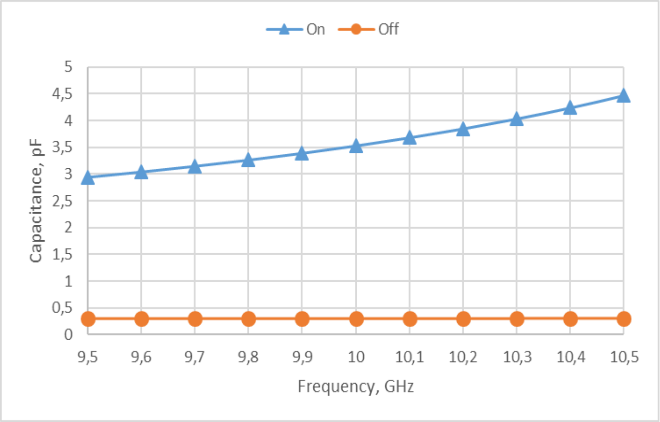

Figure 8: Measured S-parameters.

There is a dependence of the capacitance value on frequency due to parasitic effects. The measurement results are in good accordance with the simulation. It should be noted that the presence of two separate control electrodes together with the developed seesaw membrane geometry allow to handle the membrane stiction problem and thus extend a lifetime of RF MEMS capacitor.

CONCLUSION

RF MEMS tunable capacitor (varactor) has been designed and manufactured with a seesaw-type membrane and two separate actuation electrodes. The proposed structure allows to bring the membrane back in the case of stiction, leading to a longer lifetime of the varactor.

The developed and manufactured varactor has been measured with the loss better than 0.25 dB at 10 GHz, the capacitance range from Cmin = 0.3 pF to Cmax = 3.5 pF at the actuation voltage of 18 V.Ф

ACKNOWLEDGEMENTS

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