Study of a tunable MEMS capacitor: influence of fluids

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Study of a tunable MEMS capacitor: influence of fluids

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In this letter we evaluate the effect of a dielectric liquid on the tunability of capacitor operating in RF domains. The RF measurement shows a high variations of the resonant frequency accompanied with a low insertion loss. Moreover, the fluid positions between electrodes modifies the capacitance value up to $Tr = 6660\%$ at 600MHz. The quality factor decreases in response of water filling from $Q_{max} = 51.9$ when it is empty to $Q_{min} = 1.49$ when it is fully filled. According to the FEM analysis, the change of the dielectric permittivity influences the capacitor performances. Essentially, the tuning range of the capacitance and the quality factor could reach respectively: $Tr = 7660\%$ and $Q_{min} = 35$.

-/ Introduction: The RF MEMS capacitors present many advantages comparatively to the conventional varactors. To enhance their performances or to introduce some agility in their operating mode, several actuation techniques have been proposed [1-3]. Three setting parameters are highlighted: capacitance tuning range, quality factor, and resonant frequency. Many microwave circuits or components have used microfluidic as a powerful tool to reconfigure or to upgrade some RF circuits [4-6].

The presence of deionized water (DI) in microwave structure could increase the effective permittivity of the capacitor, giving hence an adaptable enlargement of the corresponding electrical length. The practical result can be expressed as a semi-continuous capacitance variations or a smooth shift of the resonant frequency with a stable insertion loss.

In this work we present some results about the performances of a microfluidically tunable microwave capacitor actionable by DI water. This fluid is inserted in microchannels and it can occupy different positions between the metallic electrodes of the MEMS structure. The resulting permittivity modifications impact the device performances, particularly its electrical and frequency characteristics.

We study the impact of the fluid presence by investigating the capacitance variations, insertion loss, quality factor and the resonant frequency.

Structure design: The spiral electrodes are completely doubled by fluidic channels which would increase their capacitance variations as shown in Fig. 1. They are made with gold layer due to its good resistance to water corrosion and to its high electrical conductivity. The fluidic parts are structured by using the SU-8 photoresist: on the one hand, this material allows having high aspect ratio for fluidic structures and on the other hand it presents some interesting microwave properties used to tune specific components and circuits [7-8]. The substrate BR33 glass is lossless dielectric and presents a good candidate to be used as a mechanical/electrical support. The physical characteristics of these different materials are summarized in Table 1.
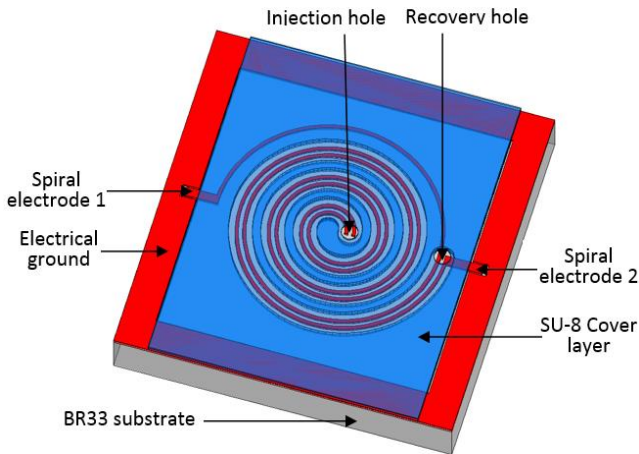

Fig. 1 *3D view of the projected capacitor structure.*

Table 1: physical characteristics of the different materials used for the MEMS capacitor.

Material	Relative Permittivity	Dielectric loss	Bulk Conductivity S.m^{-1}	Relative permeability
Br33	4.6	0.0037	0	1
Au	1	0	41E6	0.99996
Di water	80	0.01	0.002	1
SU-8	2.9	0.04	0	1

Fabrication process: The realized capacitor is presented in Fig. 2. The fabrication process can be divided into two important parts: fabrication of electrodes and structuration of the SU8 photoresist to obtain fluidic channels.

At the first part, we patterned a layer of positive photoresist (AZ4562) by using photolithography techniques in order to realize a mold for the capacitor structure. Thereafter, by using an electrolysis process we obtain metallic electrodes (Au) having a typical thickness of 7 µm, and 15 µm of width. Finally, the photoresist layer is removed to let the dual circular electrodes with typical dimensions: separating distance 20 µm, inner diameter close to 200 µm.

For the second part, the walls of the channel are obtained by spin coating 4 ml of SU-8 3050 on a glass substrate (BR33), and structured by photolithography. The realized channels are separated within 100 µm with 50 µm of height, and 180 µm of width. The cover layer is constituted by an SU-8 dry film having a thickness of 20 µm: it is laminated on the top of the channels network. The last step to finalize the device is to open the access holes allowing thereafter to introduce fluids in the device.
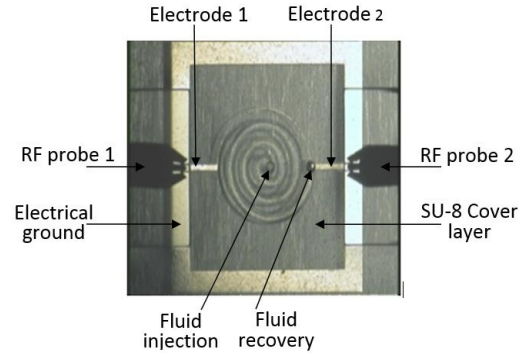

Fig. 2 *Photography of the finalized MEMS device.*

Experimental and theoretical analysis: We have characterized the microwave capacitor by using Agilent 8510 and GSG probes. We have evaluated its performances for the six DI water positions illustrated in Fig. 3 by varying the frequency between 10 MHz and 4 GHz.
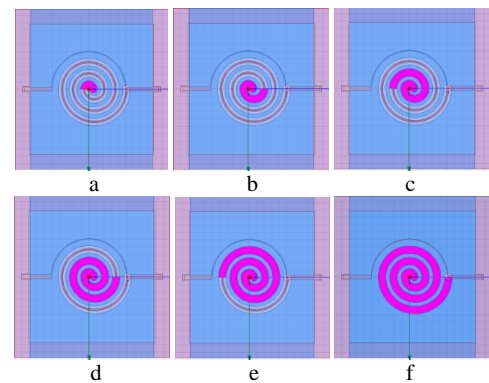

Fig. 3 *Illustration of the six water positions in microchannels*
a: POS1, b : POS2, c : POS3, d : POS4, e : POS5, f : POS6.

To evaluate the influence of the DI water on the RF responses we have used the S-parameters to extract the resonant frequency and the insertion loss. Their variations according to the six water positions are represented in Fig. 4(a): the resonant frequency decreases continuously with the water penetration on the microchannels while the insertion loss presents a good stability. When the capacitor is empty the resonant frequency present a maximal value Fres = 3 GHz and reaches a minimal value Fres = 690 MHz when it is fully filled. Globally, these results show an important variation of the resonance frequency up to $Tr = 330\%$ accompanied with an insertion loss lower than -1 dB.
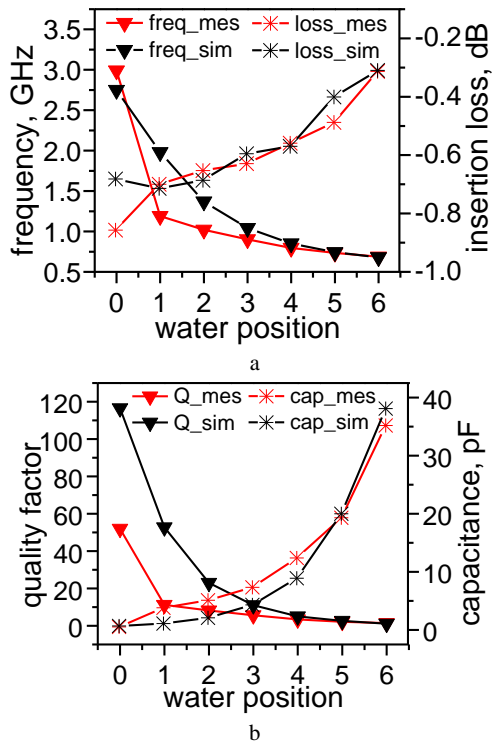
Fig. 4 *Regrouped results of the measurements and simulations realized for the six DI water positions in microchannels*
a: resonant frequency and insertion loss
b: capacitance and quality factor at 600 MHz

On Fig. 4(b) we have reported the capacitance measurements and the quality factor for six DI water positions at 600 MHz. As it can be observed, the capacitance value increases according to the water positions in microchannels. When the last are empty C_{min} = 0.52 pF and it can reach the maximal value Cmax = 35.2 pF when they are fully filled. Hence, we obtain a high tuning range of the order of Tr = 6660%. This result could be explained by the increase of the capacitance value of the device by the presence of a high permittivity liquid between its electrodes. Furthermore, the quality factor decreases from Q_{max} = 51.9 when the capacitor is empty to Q_{min} = 1.49 when the channel is full.

To complete our experimental approach, we have used a finite element method tool (HFSS) to simulate this tunable device for the six DI water positions in channels. The simulation results reported on Fig. 4(a-b) show that the global behavior matches correctly with that obtained from experiments; the difference between measurements and simulations is essentially related to the permittivity value of the global structure instead that of DI water.

Permittivity effect: In this part we have used the same FEM tool (HFSS) to investigate the influence of the global permittivity variations including those of the fluid and the substrate on capacitor performances. We have modified the substrate permittivity from 3 to 5 and that of the liquid from 10 to 80. The obtained results are reported in Fig. 5 for the case where the channels are fully filled with a fluid.
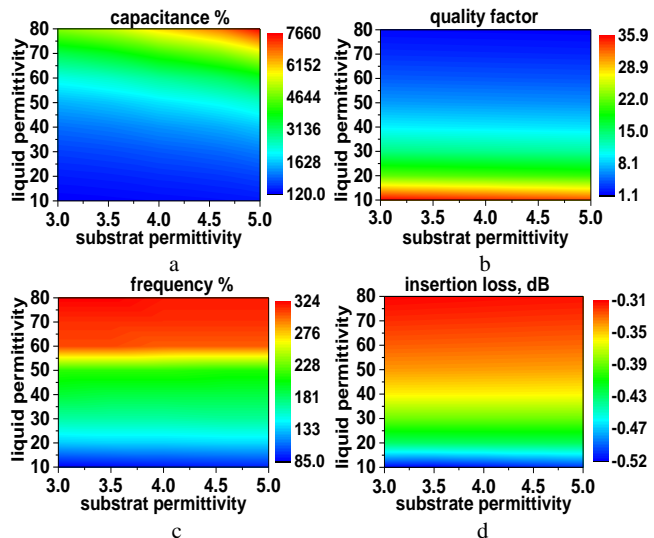

a

b

c

d

Fig. 5 *Maps showing of the influence of the global variations of permittivity on the capacitor characteristics*
a: tuning range, b: quality factor, c: frequency resonant
d: insertion loss

The first color map (Fig. 5(a)) presents the effect of the permittivity value on the capacitance tuning range. The red area indicates that the variation is maximal for higher permittivity value of fluid and substrate, giving a tuning range from Tr = 120% to Tr = 7660%, i.e. sixty times. However, the second color map (Fig. 5(b)) shows that the quality factor is inversely proportional to the permittivity of dielectrics materials when the microchannels are full. The quality factor decreases from Q = 35.9 when the fluid permittivity is minimal to Q = 1.1 for higher permittivity, i.e thirty times.

The third color map (Fig. 5(c)) shows that the variation of the resonant frequency has a strong permittivity dependence from 85% to 338%. The maximal variation of the resonant frequency is reached for a higher fluidic permittivity upper than ε = 60. The insertion loss variation is showed in Fig. 5(d): it value decreases when permittivity rises, varying from -0.52 dB to -0.31 dB. It is obvious to remark that the RF performances are less influenced than the electrical one by medium permittivity change.

Conclusion: A widely tunable microwave capacitor using microfluidically actuation has been fabricated and analyzed. The measurement and simulation results have a quasi-concordance, showing very high capacitance and resonant frequency variations when the DI water occupies different positions in the channels. Nevertheless, these advantages are accompanied by quality factor degradation.

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References
1 Pu, S. H., Darbyshire, D. A., Wright, R. V., Kirby, P. B., Rotaru, M. D., Holmes, A. S., Yeatman, E. M.: 'RF MEMS Zipping Varactor With High Quality Factor and Very Large Tuning Range', *IEEE Electron Device Lett,* 2016, **37**, (10), pp. 1340–1343, doi:10.1109/led.2016.2600264.
2 Pulskamp, J. S., Bedair, S. S., Polcawich, R. G., Meyer, C. D., Kierzewski, I., Maack, B.: 'High-Q and Capacitance Ratio Multilayer Metal-on-Piezoelectric RF MEMS Varactors', *IEEE Electron Device Lett.,* 2014, **35**, (8), pp. 871–873, doi:10.1109/led.2014.2327611.
3 Elshurafa, A., Ho, P., Salama, K.: 'Low voltage RF MEMS variable capacitor with linear C-V response', *Electron Lett*, 2012, **48**, (7), pp. 392–393, doi:10.1049/el.2011.3340.
4 Zhou, W. J., Chen, J. X.: 'Novel microfluidically tunable bandpass filter with precisely-controlled passband frequency', *Electron Lett*, 2016, **52**, (14), pp. 1235–1236, doi: 10.1049/el.2016.1298.
5 Morishita, A., Kitamura, C., Shiroma, W., Ohta, A.: 'Two-octave tunable liquid-metal monopole antenna', *Electron Lett*, 2014, **50**, (1), pp. 19–20, doi:10.1049/el.2013.2971.
6 Fayad, H., Record, P.: 'Broadband liquid antenna', *Electron Lett,* 2006, **42**, (3), pp. 133–134, doi:10.1049/el:20063633.
7 Gmati, I. E., Calmon, P. F., Boukabache, A., Pons, P., Boussetta, H., Kallala, M. A., Besbes, K.: 'RF MEMS continuous reversible variable inductor based on a microfluidic network', *Microsyst Technol,* 2013, **20**, (6), pp. 1085–1091, doi:10.1007/s00542-013-1787-y.
8 Pinon, S., Diedhiou, D. L., Gue, A., Fabre, N., Prigent, G., Conedera, V., Boukabache, A.: 'Development of a microsystem based on a microfluidic network to tune and reconfigure RF circuits', *J. Micromech. Microeng.,* 2012, **22**, (7), pp. 074005, doi:10.1088/0960-1317/22/7/074005.