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► To cite this version:

Julien Pagazani, Pierre Nicole, Lionel Rousseau, Frederic Marty, Gaelle Bazin Lissorgues. An Original Rotational RF MEMS Based on Multi-Varactors on a Chip. *Procedia Engineering*, 2011, 25, pp.1581-1584. 10.1016/j.proeng.2011.12.391 . hal-02439824

HAL Id: hal-02439824

<https://hal.science/hal-02439824>

Submitted on 28 Feb 2020

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Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

An original rotational RF MEMS based on multi-varactors on a chip

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Abstract

The design studied is an innovative MEMS rotational structure dedicated to RF applications around 10GHz. The originality relies on the integration of several tunable micro-capacitors on a single chip. The rotational structure offers the possibility to obtain high displacement in the structure outskirts (over 200µm) for actuation voltage around 40V (with extremely low current thanks to electrostatic actuation). Design, fabrication and measurements are presented in this paper.

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Keywords: RF MEMS; tunable capacitor; varactors; rotational MEMS; curved combdrives; pullin

1. Introduction

The domain of application of tunable capacitors [1] is large, especially in the Radio Frequency (RF) domain. Agile filter [2] is one of the favorite applications because of its use in the multiband or wideband transceivers [3]. Another field concerns the resonator circuits [4] that are used in Voltage Controlled Oscillators [5] and mixers [6]. Adaptation circuits for antenna [7] or for power amplifiers [8] are also a subject of interest.

Among solutions to tune a capacitor, most of the published RF MEMS capacitors are using the double air gap variation. Another existing solution to get capacitance tunability uses surface variation mostly based on comb-drives with high capacitance ratio [9]. The interest of our work is to develop a novel design of wideband, tunable RF MEMS capacitor for VCO applications.

Our tunable capacitor is based on the same structure as for a MEMS gyroscope [10] for the mechanical part, which is composed of a central anchor acting as a pivot to ensure an angular movement

The suspension beams linked to this anchor allow the mobility of the ring. Eight rigid arms are connected to this ring to support the fingers of curved comb-drives. At the extremity of each arm is attached a mass supporting the mobile electrode (100x350 µm), see Fig.1.a.

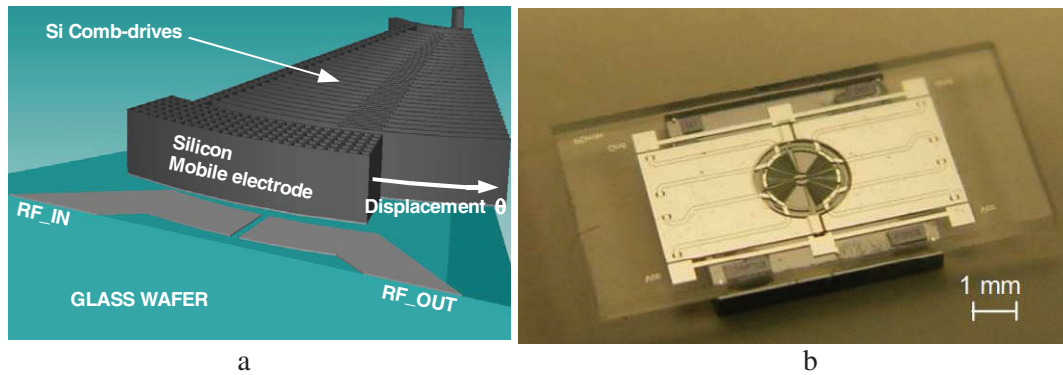


Fig. 1. (a) Schematic 3D view of the tunable capacitor. (b) Picture of a completed RUN1 device after dicing.

A glass PCB is placed underneath supporting the fixed electrodes which form the tunable capacitor, the coplanar RF access and the DC polarization pads. There are different configurations for the mechanical and RF parts of the design. The capacitor values are between 40 and 320 fF, which is relatively small due to a limited electrode surface ($15000\mu\text{m}^2$) but which is also related to the high frequency operation (over 10GHz). The current design is following a previous realization, RUN1, [11] which has shown an issue of Pull-in during actuation (a dicing chip of RUN1 can be seen on Fig.1.b). After a thorough study of this effect through a measurement campaign on the first run, it was found that the longest fingers were unbalanced.

2. Improvement of the tunable RF capacitor design in the RUN2

The expression of the Pull-in voltage was determined in the case of a curved comb drive actuator. The formula (1) enhanced the most critical physical values i.e. the finger rigidity (that are depending on length, width and thickness of finger) and the inter finger gap. To push this effect beyond the operating voltage, different solutions were simulated. One is to draw curved comb-drives with a variable gap (g) between the interdigitated fingers. The gap increases with the radius (r), which reduces the attractive forces on the longest fingers. Another is to vary the widths of the fingers according to their length, increasing their rigidity (K_{finger}).

$$V_{\text{pullin}} = \sqrt{\frac{K_{\text{finger}}}{\epsilon \times \text{thickness} \times \text{overlap}}} (2/3 g)^3 \quad (1)$$

Considering the problem of unbalanced comb drives, new designs were realized within a second run, called RUN2. The major improvement is localized on the actuation part. The comb drives that were 6 on the previous RUN were increased to 8 for better attraction and lower actuated voltage. The structure of the curved comb drive was modified, according to 4 different configurations. The common comb drive has 4 main parameters, the finger width, the finger thickness, the gap between fingers and the number of fingers. As RUN1 was based on usual comb drives, with gap equal to finger width, the new structure of RUN2 proposes either different gaps and finger widths or different widths for the fixed and movable fingers. Another innovative aspect is the unfixed value of gap and finger width, indeed the gap value is increasing with the radius (from 2 to 3 μm for reference “2x2”), as for the finger width (from 2 to 3 μm , in case of references “x2x”).

Those configurations offer the same final impact on the pull-in voltage, allowing increasing the range of actuation. Six MEMS structures were designed for the RUN2, with associated RF part of 1, 2, 4 or 8 capacitors (on each device). The capacitance values are between 40 and 320 femto Farad. The RUN2 has a total of more than 24 different devices. The maximal displacement of $200\mu\text{m}$ can be reached with an actuation voltage around 40V Fig.4.a.

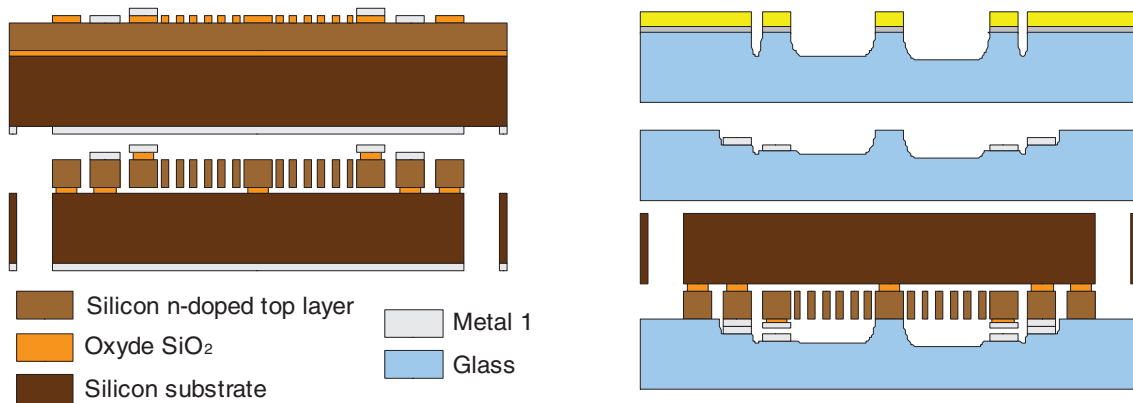


Fig. 2. Simplified micro-fabrication process

3. Fabrication and measurements

The micromachining process consists of two 4" wafers: a glass wafer for the fixed part and access and a SOI wafer for the MEMS part. The simplified process is shown on Fig.2.

The SOI wafer is oxidized, followed by a patterning of the top oxide, the back side oxide is completely etched and an aluminum deposition on both sides is done.

The top aluminum is etched to create the contact pads and mobile electrodes metallization. The back side aluminum is etched to open the handle silicon for contact access. The SOI wafer is etched on both sides by DRIE for $20\mu\text{m}$ on top and $500\mu\text{m}$ on back. The wafer is finally released with gaseous HF. One of the devices can be seen on the SEM view on Fig.3a. The glass wafer is etched 3 times to create 3 depths: first $10\mu\text{m}$ etch in HF with Cr/Au as masking layer, second $1\mu\text{m}$ etch in buffer HF for contact recovery, and the last $2\mu\text{m}$ etch in buffer HF for the gap creation between mobile et fixed electrodes. An aluminum deposition and patterning is performed for RF part creation, a completed glass part device can be seen on Fig.3.b. The two wafers are finally unified by anodic bonding. This process requires 7 mask levels and the chip size is $8000 \times 5000 \times 1020 \mu\text{m}$ after dicing.

The fabricated devices were tested in DC and static RF. The DC measurements shown on Fig.4.a are according to the simulation and the pullin issue doesn't appear for now. One measure shows a displacement of $25\mu\text{m}$ for an actuation voltage of 11V. The RF part of the device were tested under a VNA Agilent 8722ES in static mode (without actuation). The RF measurements of Fig.4.b correspond to one design with four capacitors of 80fF. The capacitance value was extracted from the S-parameters measurement giving a capacitance value of 143fF and a resonance frequency over 25GHz.

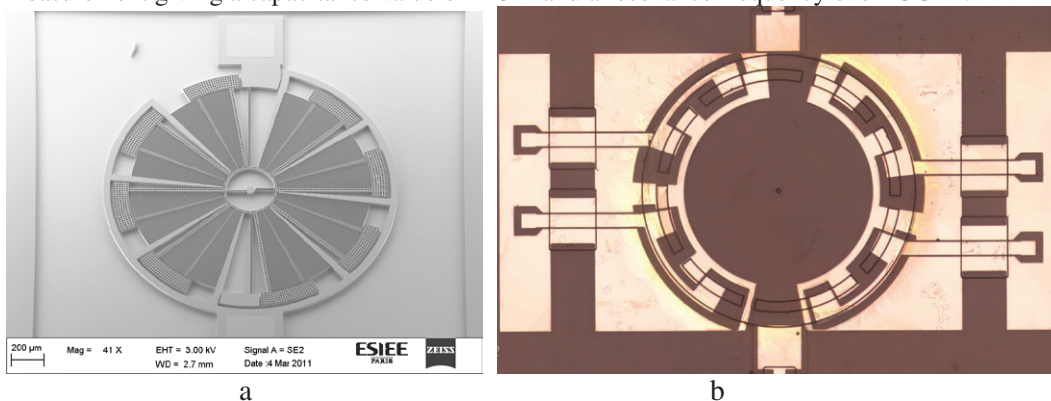


Fig. 3. (a) SEM view of fabricated devices. (b) Picture of one RF configuration with 4 RF capacitors on the chip.

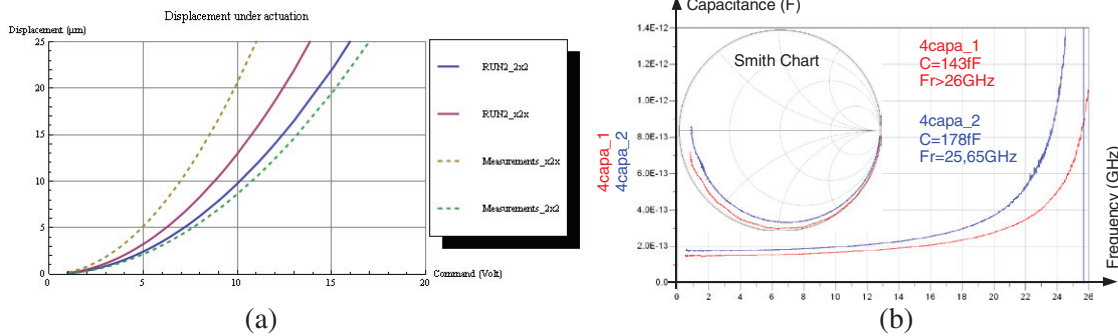


Fig. 4. Displacement under DC actuation. (b) Measurement of the capacitance value versus frequency.

The measure is quite far from the theoretical value; however some critical steps of the process can explain this variation, mainly the gap etching step that is directly linked to the capacitance value, or the accuracy of the access line dimensions that can produced high parasitic capacitance.

Conclusion and prospects

We presented here a novel design of original tunable MEMS capacitor based on curved combdrives for applications in RF wideband systems. The fabrication process involving 7 mask levels is now approved and will lead to individual diced chips. This second RUN has shown an improvement of the displacement and a reduction of the pullin effect compared to the first RUN. A next axis of research will be to increase the maximal capacitance value to address larger frequency values.

The device is intended to be included in the realization of a VCO, as a frequency tunable element, but may be applied to agile filters or tunable phase shifters in the GHz range.

Acknowledgements

The authors gratefully acknowledge THALES Airborne Systems for partial funding of this work and PhD grant, and the Service of Microelectronics and Microsystems of ESIEE for the advices in micro fabrication.

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