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RF-MEMS technology as an enabler of 5G: Low-loss ohmic switch tested up to 110 GHz

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A B S T R A C T

Microsystems for Radio Frequency (RF) passive elements, known as RF-MEMS, have been attracting the attention of academic and industrial research since their first discussion, thanks to the remarkable performance they can trigger. Despite the flattering premises, RF-MEMS technology did not score consistent spread into mass-market applications, yet, as technical issues still needed to be managed, but also because consumer products did not use to really need such pronounced characteristics. Nowadays, the application scenarios of 5G (i.e. 5th generation of mobile communications and networks) and of the Internet of Things (IoT), highlight a growing need for cutting edge performance that RF-MEMS are capable of addressing. Given such a context, this short communication discusses an RF-MEMS series ohmic micro-switch, electrostatically driven and fabricated in a surface micromachining process, exhibiting good characteristics up to 110 GHz. In brief details, the micro-relay shows isolation (when OPEN) better than −15 dB and loss (when CLOSE) better than −1 dB up to 40 GHz. The actuation voltage is around 50 V, although it can be lowered acting on the release step temperature. Despite the design concept admits margins for improvement, the characteristics of the micro-switch reported in the following are already quite interesting in the discussion of next generation of RF passive components for 5G and IoT.

1. Introduction

The field of MicroElectroMechanical-Systems (MEMS) for Radio Frequency (RF) applications, known as RF-MEMS, has been gathering interest since the early discussions in the scientific literature, about two decades ago [1,2]. The unprecedented performance of Microsystem-based RF passive components, conjugated to relative ease of manufacturing in planar microfabrication technologies (e.g. surface micromachining), triggered intense research activities (mainly within academic sector) around their demonstration, as well as concerning possible market exploitations [3,4], i.e. mainly pursuing a *technology push* approach. As a matter of fact, the variety and diversity of functionalities enabled by RF-MEMS is remarkable, as it ranges from very-simple components, like switches and varactors (variable capacitors), to complex networks, like reconfigurable filters, phase shifters, impedance matching tuners, programmable step attenuators, and so on [5–9].

In spite of such favourable premises, RF-MEMS did not spread into the consumer market segment as it was forecasted, for more than one decade, starting from the first years of the 2000s. The reasons for such a limited success are multiple. From the point of view of technology, RF-MEMS suffer from a wide range of mechanical-related reliability issues, exposing them to failure mechanisms (both reversible and irreversible), which need to be properly accounted for at design, fabrication and operation level [10–12]. Also important, fabrication of Microsystems is typically incompatible with standard active technologies (i.e. CMOS). Therefore, packaging and integration solutions must be developed in order to enable integration of RF-MEMS with the rest of the system or subsystem [13–16], thus increasing technical complexity and cost of manufacturing. If, on one side, all these issues have been solved at research and engineering level, on the other hand, potential killer applications paving the way for a robust spread of RF-MEMS technology into the market have started to peek out just in very recent years.

In this respect, the emerging field of 5G (i.e. 5th generation of mobile communications and networks), along with the comprehensive reference scenario of the Internet of Things (IoT), seems to be a very suitable context for benchmarking and testing the potentialities of RF-MEMS solutions [17–19]. Also interestingly, IIIV technologies are being discussed against 5 G applications, and they exhibit, at the same time, significant potential for integration with RF-MEMS with respect to standard technologies, thus opening

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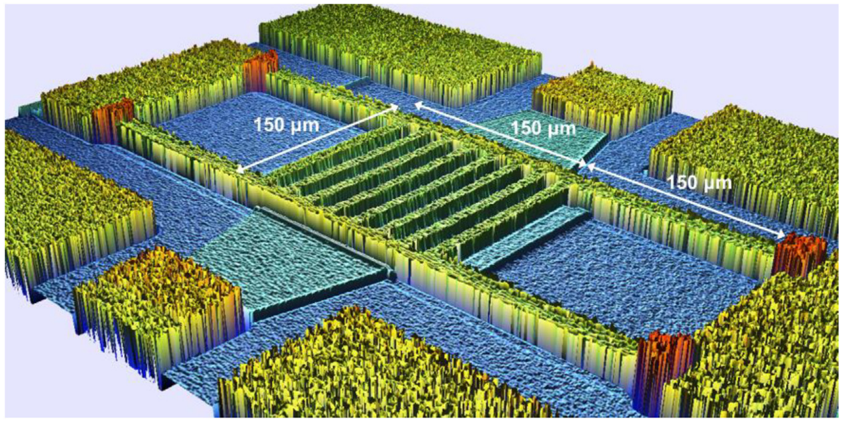

Fig. 1. 3D measured topology of the RF-MEMS clamped-clamped ohmic switch, acquired by means of a profiling system based on optical interferometry.

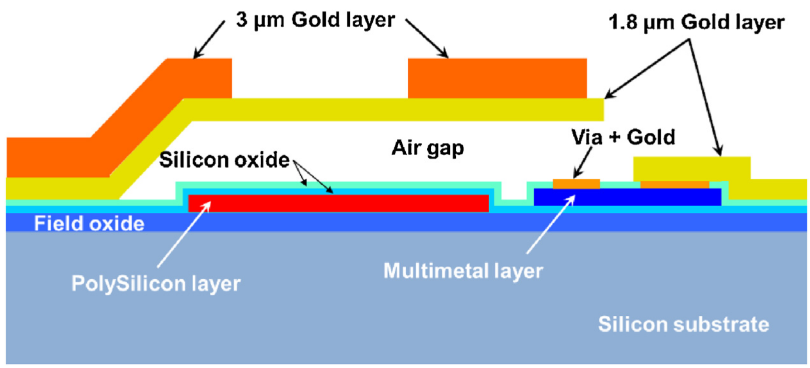

Fig. 2. Schematic cross-section of the RF-MEMS technology available at the Center for Materials and Microsystems (CMM) of Fondazione Bruno Kessler (FBK), in Italy.

up interesting opportunities of hybridisation with Microsystems [20–24].

Despite the discussion against system-level characteristics and functionalities is still hectic and, above all, open, it is possible identifying target performance to be complied by RF passive components, in order to enable and sustain 5G and IoT high-level requirements [17]. Among them certainly stand frequency wideband operability (e.g. from a few GHz up to 60–70 GHz), low-losses, very-limited cross-talk, good isolation, etc.

The focus of this short communication is spent around the crucial building block of high-performance RF-MEMS passive devices and networks, i.e. micro-switches. A novel relay design is introduced, along with the discussion of its measured performance up to 110 GHz.

2. Micro-switch design and working principles

The discussed RF-MEMS micro-relay is implemented by a clamped-clamped suspended Gold membrane, electrostatically driven in order to open/close ohmic contact between the input/output RF terminations. The movable membrane is framed within a Coplanar Waveguide (CPW) structure, suitable both for on-wafer probe measurements, as well as for wire-bonding and Surface Mount Technologies (SMTs). The measured 3D topology of the series ohmic switch was acquired with an optical profilometer and is shown in Fig. 1.

The suspended Gold membrane is 2 μm thick and underneath it a fixed counter-electrode is placed in order to drive it, along with Gold contacts to connect the input/output terminations when the MEMS is pulled-in. Straight flexible suspensions are 15 μm wide and 150 μm long. The central square plate size is 150 μm and has 10 μm wide strip openings, in order to ease the release of the suspended structure, when the sacrificial layer is removed. The micro-fabrication process is based on surface micromachining technique performed on 6 inch Silicon wafer [25,26]. The whole technology platform is available at the Center for Materials and Microsystems (CMM) of Fondazione Bruno Kessler (FBK), in Italy. A schematic cross-section of the process is depicted in Fig. 2.

The process flow features two buried layers, namely Polycrystalline Silicon (PolySilicon) and Aluminium Multimetal layer, for DC biasing lines/electrodes and RF underpass, respectively. MEMS membranes are realised in electroplated Gold and airgaps are defined by photoresist sacrificial layer patterning [27,28].

The switch is equipped with an active mechanism in order to improve its reliability in case of stiction (i.e. missed release of the membrane when the bias is zeroed) induced by charge accumulation and/or micro-welding. It is based on a micro-heater, embedded underneath the anchoring MEMS areas, and is not further discussed here, as it was previously reported in literature [31,32]. In the following, the experimental characterisation of the RF-MEMS micro-switch is discussed.

3. Experiments and discussion

The experimental testing of the RF-MEMS physical samples was performed according both to the electromechanical and electromagnetic (RF) characteristics. Concerning the former, the experimental pull-in curve was observed by means of input/output DC current versus applied bias (I-V) measurements, compared against simulated results obtained in Ansys Workbench [16]. Differently, in the latter case, S-parameters onwafer measurements