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Characterization and Modeling of Charging Effects in Dielectrics for the Actuation of RF MEMS Ohmic Series and Capacitive Shunt Switches

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1. Introduction

Charge accumulation in dielectrics solicited by an applied voltage, and the associated temperature and time dependencies are well known in scientific literature since a number of years [1]. The potential utilization of materials being part of a device useful for space applications is a serious issue because of the harsh environmental conditions and the necessity of long term predictions about aging, out-gassing, charging and other characteristic responses [2], [3]. Micro-mechanical Systems (MEMS) for RF applications have been considered for sensor applications as well as for high frequency signal processing during more than one decade [4], [5], [6], [7], [8], [9]. In this framework, RF MEMS switches are micro-mechanical devices utilizing, preferably, a DC bias voltage for controlling the collapse of metalized beams [8]. Magnetic [10], thermal [11] and piezoelectric [12] actuations have been also evaluated, but the electrostatic one seems to be until now preferred for no current flowing, i.e. a virtual zero power consumption, less complicated manufacturing processes and more promising reliable devices [13]. During the last few years, several research activities started to release the feasibility of RF MEMS switches also for Space Applications [14], [15], [16]. The electrostatic actuation of clamped-clamped bridges or cantilevers determines the ON and OFF states depending on the chosen configuration. As well established, RF MEMS switches are widely investigated for providing low insertion loss [8], no or negligible distortion [17], [18] and somehow power handling capabilities [19], [20], [21], [22] for a huge number of structures already utilizing PIN diodes for high frequency signal processing. Actually, redundancy switches as well as single pole multiple throw (SPMT) configurations, [23], [24], matrices [25] true time delay lines (TTDL) [26], [27] and phase shifters [28], [29] for beam forming networks in antenna systems could benefit from their characteristics. On the

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other hand, the reliability of this technology has been not yet fully assessed, because of the limitations introduced by: (i) the mechanical response of the single switches [30], (ii) the necessary optimization of the packaging [31], and (iii) the charging mechanisms. In particular, the charging effect is due to the presence of both the dielectric material used for the realization of lateral actuation pads, deposited to control the collapse of bridges and cantilevers far from the RF path, and the dielectric used for the capacitance in the case of shunt connected microstrip and coplanar configurations. Presently, there is a wide literature about the onset of the mechanism [32], [33], [34] and its control by means of uni-polar and bi-polar actuation voltage schemes [35], [36], [37]. Some results give evidence also for the substrate contribution to charging effects [39] and those related to packaging [38]. Specifically, electromagnetic radiation is a serious issue for space applications [40], [41]. Electrostatic discharge has been discussed in [42], and it is clearly influenced by the deposition process [43]. Besides structural dependence of the charging [44], solutions considering the absence of the dielectric material is also considered, giving evidence for a decrease but not for a complete disappearance for such a contribution [45], [46]. Specific aging schemes based on the temperature are also proposed for long term evaluation of the devices [47]. Advanced studies have been also performed by means of the Kelvin Probe Microscopy, for improving the surface resolution of the charging effect detection [48]. Ohmic contact problems have been evaluated in [49]. Different kind of charging mechanisms can influence the reliability of the MEMS devices, as it has been assessed after the study published in [50].

In this chapter, it will be presented the characterization of two configurations of RF MEMS switches, to demonstrate how the actuation voltage is modified by using a uni-polar bias voltage and how it is under control and stable, at least for a limited number of consecutive actuations, if an inversion in the bias voltage is provided. In particular, the measurements recorded for an ohmic series and for a shunt capacitive configuration will be presented and discussed, considering the main source of charging for both devices. Moreover, experiments performed in both MIM and MEMS reveal that the charging process is strongly affected by the temperature [51]. MIM capacitors have been used to assess the material bulk properties with the aid of Thermally Stimulated Depolarization Current (TSDC) method. The charge storage was found to increase exponentially with temperature in both MIM capacitors and MEMS switches. In particular, in the high temperature range the activation energies in MEMS switches were found to have close values with respect to MIMs, and from TSDC experiments in MIM capacitors they have been found to be rather small. Equivalent circuits accounting for the above charging effects can be used as an effective lumped model, useful for circuitual simulations of feeding lines and actuation pads [52].

2. Technology

Suspended bridges have been manufactured in coplanar waveguide (CPW) configuration. The series ohmic switch has been obtained by means of a bridge isolated with respect to the lateral ground planes, closing a capacitive in-plane gap when the proper bias voltage is provided by means of lateral poly-silicon pads. In such a case the bridge is collapsed and the switch passes from the OFF to the ON state. Vice versa, the shunt capacitive switch is composed by a metal bridge connecting the lateral ground planes and by a dielectric layer providing a capacitive contribution when the bridge is collapsed. In this case, when the switch is actuated by means of a DC bias voltage, it passes from the ON state to the OFF


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The advances of microelectromechanical systems (MEMS) and devices have been instrumental in the demonstration of new devices and applications, and even in the creation of new fields of research and development: bioMEMS, actuators, microfluidic devices, RF and optical MEMS. Experience indicates a need for MEMS book covering these materials as well as the most important process steps in bulk micro-machining and modeling. We are very pleased to present this book that contains 18 chapters, written by the experts in the field of MEMS. These chapters are grouped into four broad sections of BioMEMS Devices, MEMS characterization and micromachining, RF and Optical MEMS, and MEMS based Actuators. The book starts with the emerging field of bioMEMS, including MEMS coil for retinal prostheses, DNA extraction by micro/biofluidics devices and acoustic biosensors. MEMS characterization, micromachining, macromodels, RF and Optical MEMS switches are discussed in next sections. The book concludes with the emphasis on MEMS based actuators.

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