研 究 解 説

Microsystem for Telecommunication

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1. INTRODUCTION

Nowadays intensive research activities are performed to introduce Micro Electro Mechanical Systems (MEMS) into many industrial products. And, as a result, successful technology transfer have been already obtained for the mass production of ink jet head[1] and image projection system[2], for example. Motivated by these convincing successes, the communication system companies (hardware) are showing a growing interest in these micro-technologies. Two main domains are foreseen with different motivations: the first one concerns the radio-frequency (RF: 0.8-2.5 Ghz) wireless communication system such as portable phones and the second one is related to microwave or millimeter wave (> 2.5 Ghz) equipments such antenna switch, attenuators and filters.

For the RF mobile communication[3], the main goal is to reduce the assembling cost of the mobile phone handset by decreasing the number of off-chip components (up to 100) by the use of integrated electromechanical devices, such as variable capacitors, reconfiguration switches, filters and resonator. As a direct consequence, replacing the conventional bulky off-chip components by tiny integrated ones will lower the coupling capacitance, and so the power consumption and will lead to an improved autonomy. The challenge is here to reach discrete component characteristics with MEMS counterparts that can be directly co-integrated with CMOS technology.

For microwave applications[4], the motivations are different. With frequencies increase around 10Ghz and above, the characteristics of semiconductor components show drastic degradations, as for example, the insertion loss of PIN diode for commutation purpose. In that case, the MEMS components can represent a real alternative way to realize the same function with better characteristics. So the research is strongly motivated by the development of new electromechanical devices that overcome semiconductor components in terms of insertion losses, isolation and power consumption. Current investigations concern the microwave guide commutation, programmable attenuator, filter and transmission lines with very low losses.

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MEMS based components for both RF and microwave applications are overviewed in the following sections.

2. RF wireless communication

The figure 1 shows the schematic principle of the front-end part of a mobile phone handset[5].

This configuration is based on the widely spread superheterodyne architecture that uses an intermediate frequency in both receiving and transmitting paths. Unfortunately, although some blocks like low noise amplifiers, mixers or modulators are already integrated in CMOS technology, resonating circuits for voltage controlled oscillators, matching networks and rejection filters cannot be achieved without off-chip passive components like inductances, varactors, ceramic and SAW filters.

Recent studies have demonstrated the ability to replace each of the off-chip function by MEMS counterparts making the ultimate goal of a single-chip transceiver feasible[3]:

– Micromechanical switches have already been implemented, with transmission losses lower than 0.1dB, high linearity and no DC consumption[6] to enable receive/transmit mode and antenna switching.

– Micromachined voltage tunable mobile capacitance in conjunction with integrated inductances have exhibited quality factors around 30 and large tuning range[7–9], sufficient for use as VCO tank and matching networks.

– For reference oscillators and highly selective filters, extensive

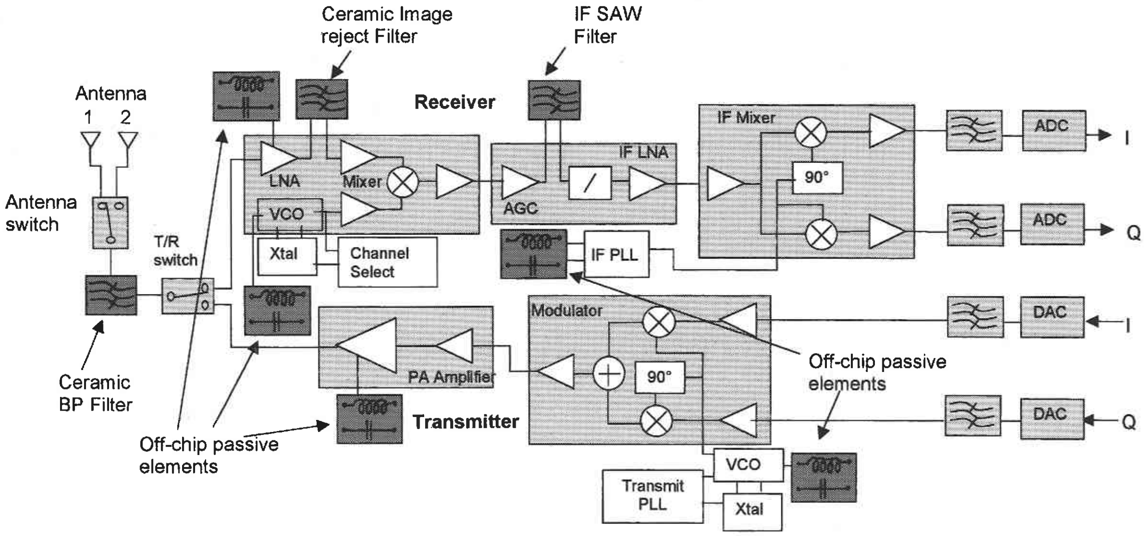

Fig. 1　System-level schematic of a superheterodyne transceiver front-end architecture[5].

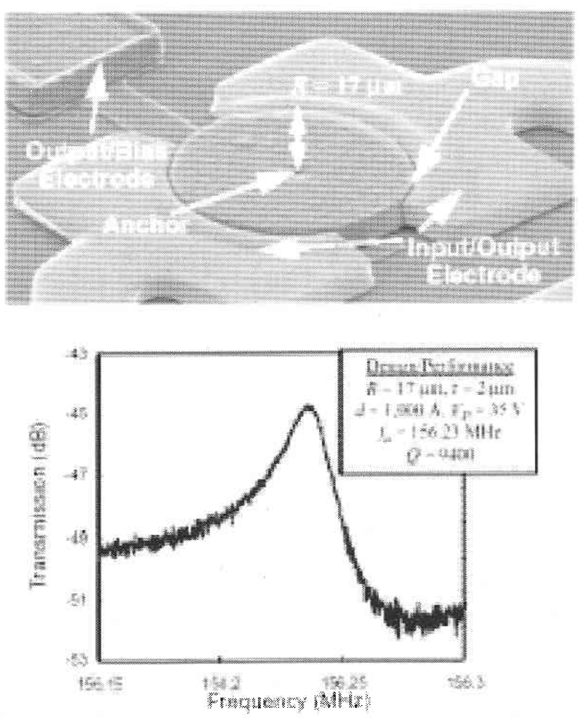

Fig. 2　Contour mode electromechanical resonator[14]. (a) SEM view (b) Transmission spectrum.

studies have been undertaken to show that resonating surface micromachined structures with Q factors higher than 10,000 provided a excellent solution for frequency ranging from a few kHz to a hundred of Mhz[10–14].

An electromechanical RF filter is displayed in Fig. 2. By electrostatic coupling, the central disk is put in vibration through the signal of the input port. At the resonance frequency of the disk, maximum vibration amplitude is sensed by the output port. So, the

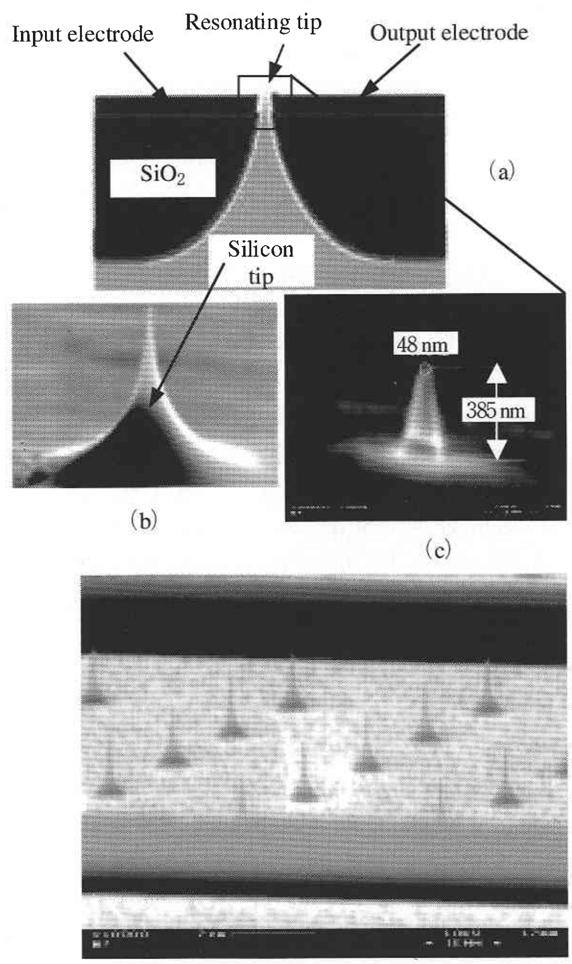

Fig. 3　RF electromechanical resonator based on vibrating tips[24]. (a) Principle. (b) Sharpened silicon tip. (c) resonating tip apex after inter-tip area filled with SiO_2. (d) Array of tips before SiO_2 filling.

input signal is filtered by the mechanical frequency response of the resonating element. With up to date technology, maximum achievable resonance frequencies are in the 100 Mhz range, as shown by the transmission spectrum of Fig. 2.

The next challenge is to directly filter the RF input signal in the 0.8-2.6 Ghz, so, new mechanical structures have to be investigated. It is nowadays the goal of our own current research with mechanical architecture based on arrays of resonating tips, as shown in Fig. 3.

3. Microwave applications

Above 5 Ghz signal frequency, usual Gallium Arsenide (GaAs) based components, Field Effect Transistor or PIN diode exhibit poor performance like 1-2 dB insertion loss in the pass-through state and reduced electrical isolation like-20 db in the blocking state[4]. So, for microwave and millimetre wave applications, a lot of efforts are put on the development on MEMS based switches as an alternative approach. At these frequencies, signal are transmitted along microwave guides, usually with coplanar structure in which the signal line runs between two grounded lines. So, two architectures are possible[4], serial and shunt switch, as shown in Fig. 4.

In the case of serial configuration, the switch directly touches the signal line using metal/metal contact[15–16]. But, for shunt architecture[17–18], the signal line is isolated or grounded through a variable capacitance, that can reach very low impedance at microwave frequencies. In both configurations, the switches are usually actuated with electrostatic forces.

An example of capacitive coupling shunt switch is shown in Fig. 5. The switch consists of a grounded thin aluminium membrane suspended over a dielectric film deposited on top of the bottom electrode. In the membrane up state, most of the signal passes through the coplanar waveguide (pass-through state). When an electrostatic voltage (typically 50V) is applied between the membrane and the bottom (signal) electrode, the membrane is pulled down onto the dielectric layer. The coupling capacitance between the signal line and the grounded membrane increases (impedance to ground decreases)and thus blocks the RF signal from passing through to the other side of the signal line.

Typical parallel plate electrostatic actuator, like those of Fig. 5, shows well-known hysteresis in its deflection/voltage characteristics. The difference between the pull-in and the pull-out voltages requires additional treatments at the system control level. In order to simplify the command, our current activities concern the design of new switch architecture in which hysteresis is avoided and actuation voltage decreased. The schematic view of the device is plotted in Fig. 6 with simulated characteristics and first technological realization.

At microwave and millimetre wave frequencies, substrat losses become significant and seriously limit the possibility of circuit integration. So active research are also carried out to develop MEMS based element in which lossy substrate is locally removed around the microwave components. Thanks to microtechnology development, a wide range of process capabilities is now available for that purpose such as bulk micromachining,

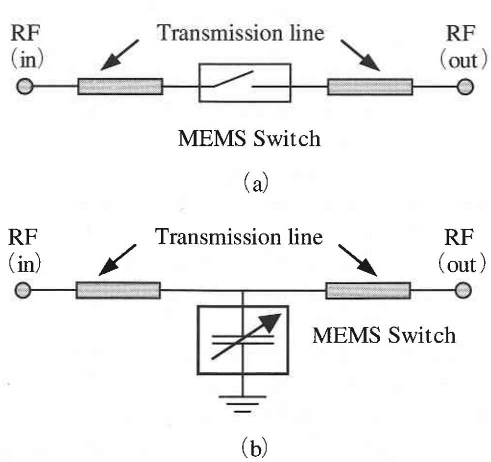

Fig. 4 Schematic illustration of (a) a serial switch configuration, (b) a shunt switch.

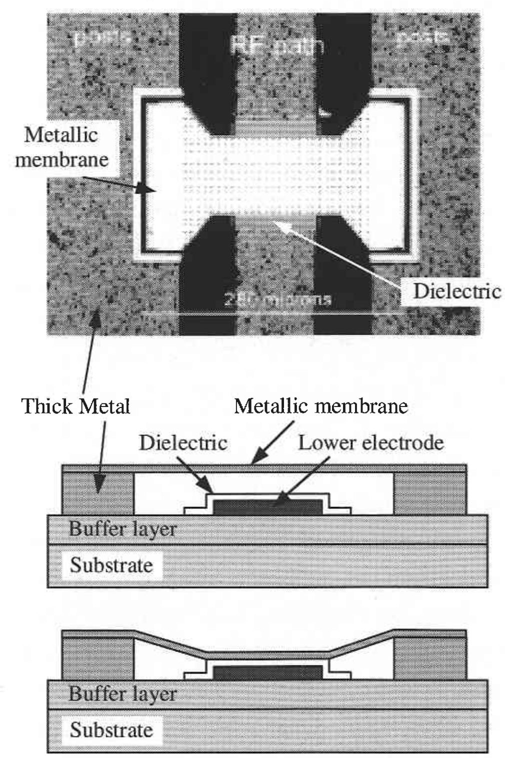

Fig. 5 Capacitive coupling switch developed by Raytheon/Texas Instrument[17–18]. (a) Micrograph. (b) Schematic cross sectional view.

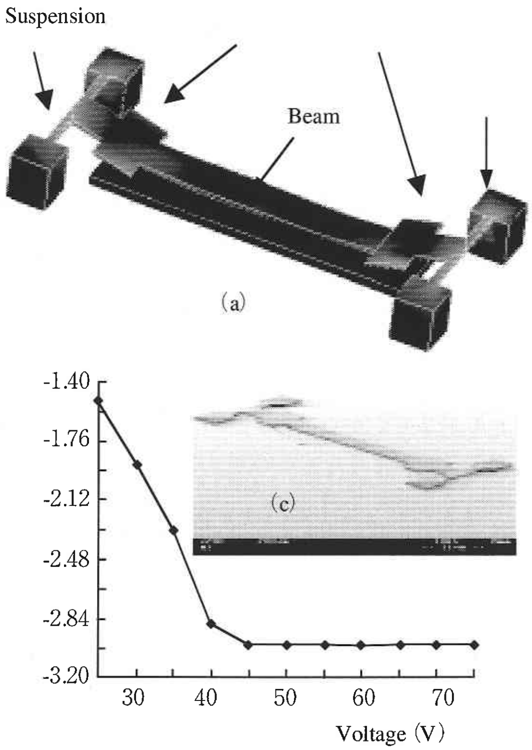

Fig. 6 IEMN Switch with reduced voltage actuation.. (a) Schematic view during actuation. (b) Simulated displacement/voltage characteristic. (c) SEM view of first prototypes.

wafer bonding and deep reactive ion etching.

Demonstrations have already be performed with microwave devices enclosed in a metallic cavity realized by silicon wet bulk micromachining[19], or by multiple wafers stack[20]. Interdigitated bandpass filter20, Lange coupler and mixers[21], stripline resonator, and other low pass and bandpass filters[22] and distributed MEMS distributed phase shifters[23] are been also developed.

4. Conclusions

As it has been demonstrated in this review, a big effort is produced worldwide to introduce MEMS technology and components in communication systems. Two domains are mostly investigated, RF wireless equipments such as phone handset to foresee a full monolithic integration of the receiver and microwave system when MEMS components have already exhibited better characteristics than semiconductor counterparts. But still a lot of work have to be done. For RF wireless applications, MEMS based component characteristics have to be improved such as the maximum reachable frequency of electromechanical resonator or co-integration capabilities with CMOS circuitry. For microwave products, reliability issues are of prime importance to validate the MEMS approach.

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