Microwave Laminate PCB Compatible RF MEMS Technology for Wireless Communication Systems

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Abstract: This paper introduces state of the art microwave laminate printed circuit board (PCB) compatible RF MEMS technology for wireless communication systems. This technology is novel in that RF MEMS components, particularly RF MEM switches, can be fabricated on *any* PCB substrate and they can be monolithically integrated with antenna elements on the same substrate offering adaptability and reconfigurbility features to the communication systems. The advantages of this technology in terms of overcoming critical drawbacks of the existing RF MEMS technology are described. A three-element diversity antenna monolithically integrated with RF MEM switches on RT/Duroid5880 PCB is provided to establish a proof of concept for this technology. Results are presented and discussed.

I. Introduction: RF MEMS technology is a new emerging sub area of MEMS technology that is revolutionizing and making a big impact to today's RF and microwave applications. In particular, RF MEM switches [1] have been the device of choice for reconfigurable communications applications due to their superior switching performances such as very low insertion loss, high isolation, and ultra-low power requirement when compared to existing semiconductor switches (e.g. P-I-N diode, FETs). Various systems such as variable capacitors, phase shifters, tunable RF matching circuits/filters, and integrated reconfigurable antennas employing RF MEM switches as basic building blocks have been demonstrated with superior performance over conventional semiconductor devices [2], [3], [4].

One drawback, however, has been the limited choice of substrates for these switches and systems using them as building blocks. Particularly microwave laminate substrates with desired electrical characteristics for antenna applications cannot be used by the current RF MEM technology. This has prevented MEMS reconfigurable multi-element antennas operating at microwave frequencies from achieving excellent system level performance, as that offered by low cost RF MEMS. In the current MEMS technology, a typical MEMS reconfigurable antenna consists of antenna elements integrated with discretely packaged RF MEM switches. RF MEM switches are fabricated on substrates such as silicon, GaAs, quartz and glass with the antenna elements being constructed on a different substrate (typically laminated PCB substrate), for low dielectric constant/loss to ensure good radiation and impedance characteristics. Discretely packaged RF MEM switches are then attached to PCB substrate and wire bonded to the antenna elements. Matching circuits are also required to preserve the VSWR of the system. However, this approach does not permit the exploitation of the most striking benefit of MEMS technology, which is the *monolithic integration* capability, over to IC technology. It is expensive due to the individual packaging of the MEM switches; wirebonds and matching circuits also increase complexity and loss. On the other hand, the breakthrough advantage of microwave laminate PCB-compatible RF MEMS technology [5] lies in making possible RF MEM switches on *any* PCB substrate, plus monolithically integrating either two- or three-dimensional antenna elements with switches on this same substrate. System level packaging then allows for reduced cost and, by eliminating all

0-7803-7846-6/03/$17.00 ©2003 IEEE

wirebonds and most of the matching circuits, reduced loss, complexity, and size. It should be noted here that three-dimensional antennas are extremely difficult, if not impossible, to be employed by the current MEMS technology due to the limitations of the deep etching process for the substrate such as GaAs, quartz, and glass. On the other hand, three-dimensional structure of an antenna is key to size reduction and allows exploiting performance limits of small size antennas [6].

This MEMS technology calls for two novel process techniques, low-temperature (90-170 ^{o}C) high-density inductively coupled plasma chemical vapor deposition (HDICP CVD) and compressive molding planarization (COMP) developed within the authors' group [5]. Due to the maximum allowable processing temperature of many PCBs generally being below 200 ^{o}C, depending on the time of exposure, the commonly used plasma enhanced chemical vapor deposition (PECVD) SiN_x process at 250-400 ^{o}C cannot be employed for microwave laminate PCB substrates. Instead of PECVD, we use HDICP CVD to deposit SiN_x dielectric material, which is used as an insulating layer in RF MEM switch structure [1], at low temperatures in order to be compatible with typical operation temperatures (150-200 ^{o}C) of PCBs. COMP is the second key process step for this technology. Prior to the formation for the bridge membrane, it is performed to planarize uneven surfaces of sacrificial photoresist layer to ensure mechanical integrity of deposited metallic membrane. Measured *s*-parameters of RF MEM switches fabricated on RO4003-FR4 PCB [7] showed excellent RF characteristics similar to those of switches fabricated on semiconductor substrates [8]. A more detailed discussion on this fabrication technology and its use for monolithically integrating RF MEM switches with three-dimensional antenna elements on a PCB substrate are given in [8] and [9] respectively.

II. Diversity Antenna Integrated with RF MEM Switches: The antenna element, so called cactus antenna, used in this work has previously been introduced [10]. It is a CPW fed compact broadband antenna with 50% impedance bandwidth covering the frequency band from 4GHz to 6 GHz. This band was deliberately chosen to be compatible for the next generation wireless communications standards.

A three-element cactus antenna monolithically integrated with RF MEM switches was built on a microwave laminate PCB substrate to establish an application example for the microwave laminate PCB compatible RF MEMS technology (See Fig.1). RT/Duroid 5880 microwave laminate [7] was used as a substrate since it offers high performance for antenna applications due to its very low loss property (ε_r=2.2, tanδ=0.0004). We specifically aimed at creating a diversity antenna suitable to implement switch combining through RF MEM switches. Three RF MEM switches located on CPW feed lines can be operated to select only one of the three diversity branches at a given time in order to maximize the signal-to-noise-ratio (SNR) of the diversity signal available to the receiver. More specifically either "switch and examine" or "switch and stay combining" schemes are suitable to be implemented by this MEM integrated antenna. In the switch and examine technique, the receiver switches to another diversity branch if the signal strength drops below a predetermined threshold value for the current diversity branch. For the switch and stay scheme, switching is not performed unless received signal's SNR crosses the threshold value from high to low.

The fabrication process flow of the MEM-switched antenna is illustrated in Fig.2. It starts with via hole formation, that is a well established standard PCB process, to be used as part of switches' bias circuitry. This vertical via holes (see Fig.1) run from one side of the RT/Duroid 5880 PCB substrate to the other side connecting central electrode of each switches to the dc power supply. It is worth noting that using vertical vias, which are not possible for most of the semiconductor substrates employed by current MEMS technology, allows bias circuitry to be fabricated to the opposite side of the substrate where the MEM switches and antennas are located. This in turn results in more real estate available for housing more antenna elements, which is critical for capacity enhancement in wireless communication systems. Next, antenna structures, dc blocks, CPW feed lines both for antennas and MEM switches are simply formed by wet etching process. After this structure is obtained, we fabricate RF MEM switches following the process flow shown in Fig. 2(b) – (e). We refer the reader to [8] and [9] for the details of the fabrication process.

By selecting the ON and OFF states of the switches we can either activate a particular single antenna (A1, A2 or A3) or create a superposition radiation pattern by activating more than one antenna. Fig.3 illustrates the measured x-y plane co-polar radiation patterns corresponding to the sequential individual activation of the three single antennas. As a result of the inter-element 45° rotation angle, radiation patterns with 45° rotation can be clearly distinguished in the figure. With appropriate activation angular or polarization discrimination of a useful weak signal from an unwanted strong interference can be performed in multipath scenarios. For example the axis of the active element can be oriented to the direction of the strong interference.

III. Conclusions: The intent of this study is to introduce a novel MEMS technology, that is the microwave laminate PCB- compatible RF MEMS technology, for building low cost and high performance wireless communication systems with adaptability and reconfigurability features. Its key advantages over existing MEMS technology are described. A three-element diversity antenna monolithically integrated with RF MEM switches fabricated by using this technology is provided as a proof of concept. Although in this example we use only three RF MEM switches located on CPW feed network, this technology is capable of employing many RF MEM switches, due to its monolithic integration capability, within antenna structure to enhance reconfigurability and adaptability features of the system. Current and future wireless communication systems are highly likely to benefit from this RF MEM technology.

Acknowledgment: The authors would like to express their sincere gratitude to Professor N. G. Alexopoulous, University of California,Irvine, CA, USA, for his invaluable guidance in our research endeavors.

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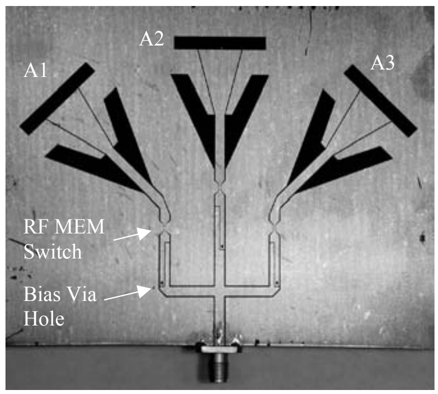

Fig.1 Photograph of the diversity antenna integrated with RF MEM switches.

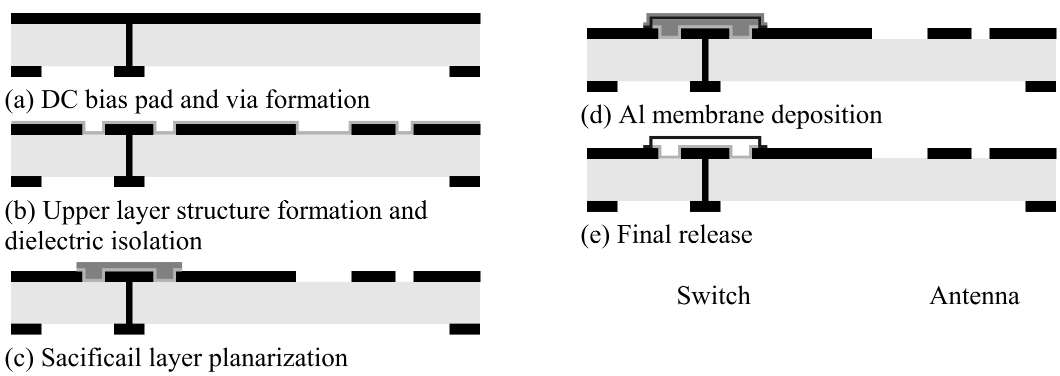

Fig.2 Fabrication sequence of monolithically fabricated RF MEM switched diversity antenna on RT/Duroid 5880 PCB.

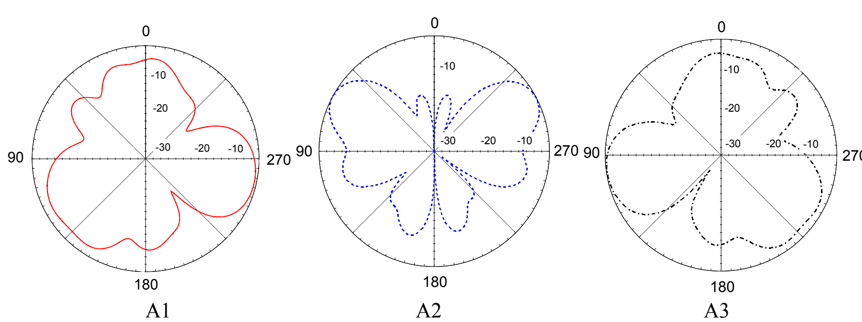

Fig.3 Measured co-pol radiation patterns from each antenna element in the x-y plane when the three switches are sequentially activated.