

IN IC AND ABOVE IC MEMS FOR MILLIMETERWAVE COMMUNICATIONS

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Abstract: The paper proposes to make an overview of the MEMS technologies and architectures that will be involved in advanced micro and millimeterwave applications. It will be presented the concept of MEMS IC that features very attractive capabilities both in term of sensitivity, power handling, reconfigurability and flexibility through the concept of System in Package. Different options will be assessed consisting of tailoring directly the SiGe chip, grafting some MEMS processes on silicon based chip or assembling the IC chip on a MEMS substrate.

Keywords: 3D MEMS, Above IC, IN IC, SiGe, Reconfigurability

1. INTRODUCTION

It is now understood that the future of communications will be driven by the improvement of performances, the increase of fonctionnality and compactness. This motivates research at materials, technology, devices, circuits, systems and software level. This paper relates on the research at the materials, technological process development and advanced devices, circuits and systems that will be used in the next generation of wireless communications. Among the different orientations, it is propose to investigate the potentialities offered by the silicon based technologies through the concept of MEMS IC. This concept aims to associate MEMS devices with advanced integrated circuit in order to produce high compactness systems featuring added functionalities. This concept will be investigated here through two ways. The first one deals with an above IC approach that consists to graft additional devices on top of SiGe HBT integrated circuit. The second approach deals with an In IC approach that consists to tailor using appropriate micromachining techniques the integrated circuits to speed up their performances and/or to create new components. Finally, it is proposed an approach referred to as System In Package where a full smart system will be integrated using both In IC and above IC MEMS techniques. The paper is organized into three main sections that will trace the different options that could be considered for the realization of smart microsystems at RF and millimeterwave range.

Section II will address the technological development of the above IC process. Section III will present the In IC approach when section IV presents the heterogeneous system integration.

2. ABOVE IC MEMS

The development of a MEMS technology compatible with an integrated circuit has to face with the following requirements :

- A compatible thermal budget
- An appropriate control of the strain in the different layers
- An appropriate use of the micromachining technologies

In order to combine these requirements with a very important issue when a high performance RF circuit is considered deals with the minimization of the losses. The solution we are preconizing deals with the use of the Benzo-Cyclo-Butene (BCB) technology that is featuring very low loss and that is easily compatible with IC technology. Figure 1 is showing different solutions we have experimented in order to minimize the losses. The BCB layer is spun out and baked at 200°C. The thicknesses are ranging from 5µm to 20µm.

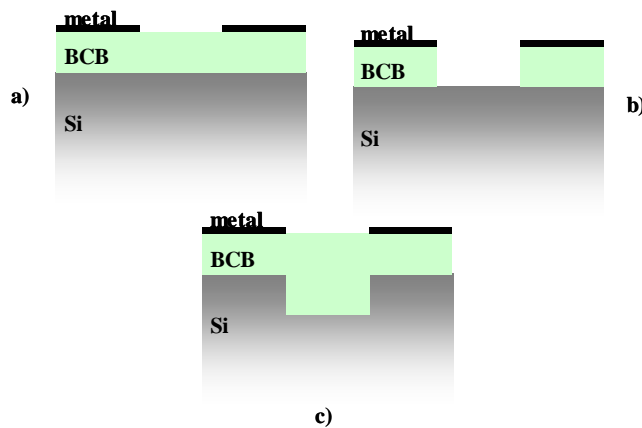


Fig1 : Different MEMS solutions to minimize the insertion losses

Figure 2 is showing the measurements that have been performed on the different topology of Coplanar Wave Guide (CPW) and the results indicate that combining the surface micromachining and the BCB deposition of 10 µm thickness is the best suited topology to minimize the insertion losses up to the millimeterwave.

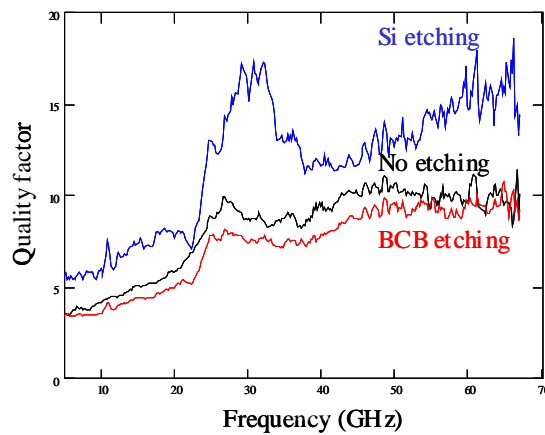


Fig 2 : Measurement of the transmission coefficient for the different topology of CPW

The second technological process that has been developed deals with a 3D process consisting of depositing of two layers of BCB featuring 10 μ m thickness each separated by a metal level.

This 3D technology features via holes which dimensions have been optimized in order to minimize the insertion losses up to the millimeterwave range. Figure 3 shows the process flow that has been developed.

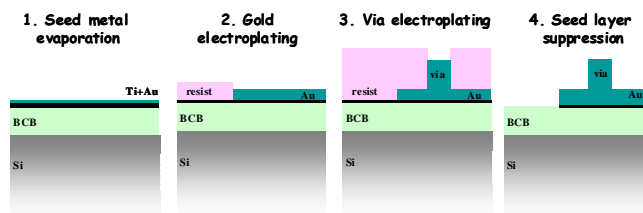


Fig.3 : Process flow for the 2.5D above IC process

Filters have been fabricated at 24 GHz et 60 GHz featuring respectively 1 dB and 6 dB insertion loss. Figure 4 shows a photography of the band pass filter that has been fabricated [1].

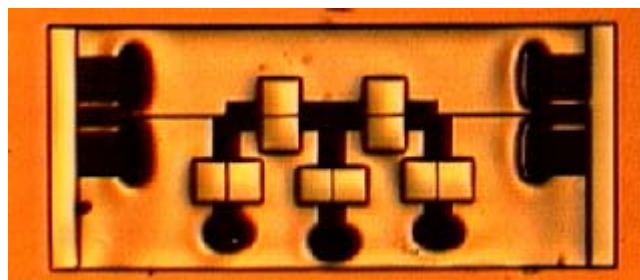


Fig.4 : photography of a 3D BCB based filter at 24 GHz designed by LEST Laboratory

This process has been implemented on a SiGe HBT process developed by ATMEL and we do not have observed any degradation of the electrical properties of the active devices. Figure 5 shows a BCB layer grafted on top of a millimeter wave

integrated circuit [2]. We will come back later on in this paper on the system demonstrators.

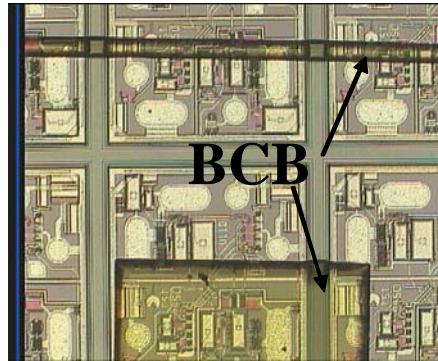


Fig.5 : BCB layer grafted over a millimeterwave integrated circuit

Finally, the process has been extended toward the fabrication of capacitive switch featuring 0.2 dB insertion loss, 20dB isolation and actuation voltage in the 30-40 volts range. These data compare well with already published works [3,4].

3. IN IC MEMS

The process we are reporting here deals with the integrated circuit tailoring to modify the characteristic of the device (essentially passive) and to create additional device like filter and/or miniaturized antenna. Figure 6 shows the process flow that has been developed.

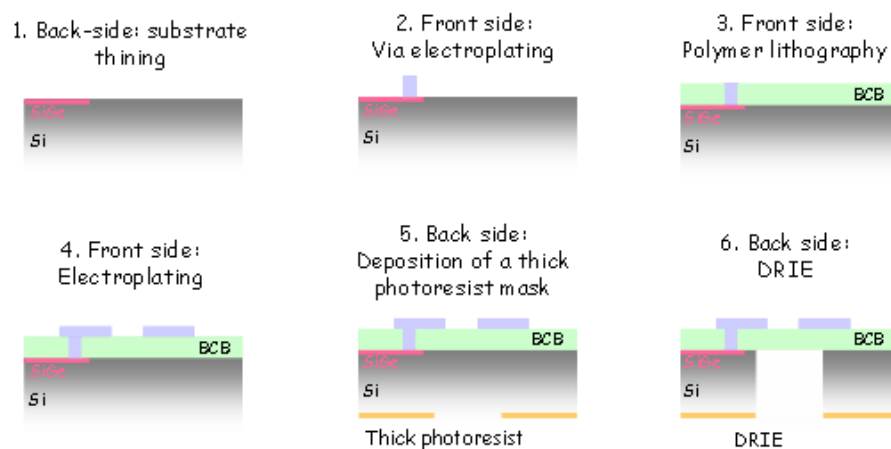


Fig.5 : Process flow for In IC MEMS device

The process involves both front side and back side lithography. The process uses a BCB layer to protect the integrated layer and to be able to re-process as it is very important for future heterogenous integration. We will come back later on on this issue.

The main issue deals with the fact that the MEMS fabrication could degrade the behavior of the active devices (i.e SiGe HBT). In order to control that, it has been decided to use the investigation of the low frequency noise behavior of the devices that are a good signature of microscopic degradation. Fig.7 presents the low frequency noise behavior of SiGe HBT when different processes are applied. It is

shown that temperature is a very critical process when the situation for the micromachining process is a little bit different. We have shown that the micromachining process has to be done with some design rules in order to be not too close to the active devices. This effect has been attributed to strain related to the technological process (etching) that could damage the active devices. We demonstrated that making the micromachining process at at least 50 μm distance from the active devices do not degrade their electrical and physical characteristic. Other types of stress have been investigated (etching, chemical cleaning) that have been proved the compatibility of the process developed with respect to the integrated circuit. The results will be detailed during the conference.

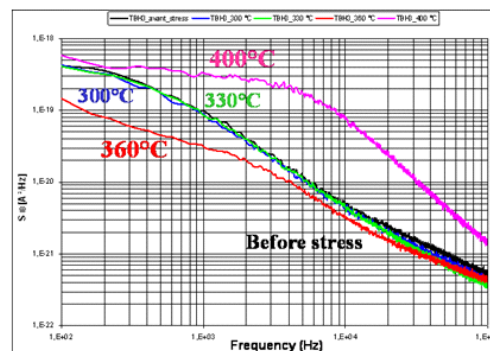


Fig.7 : Low frequency noise behavior of active devices with different thermal processes

This process has been experimented on a 24 GHz receiver on which we have fabricated a miniaturized antenna as reported in figure 8.

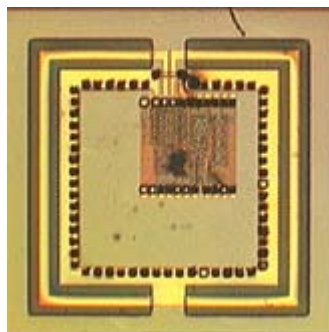


Fig.8 : Photography of the miniaturized antenna surrounding the SiGe based transceiver

Additional miniaturized antennas have been fabricated and measured that have confirmed the IN IC approach for millimeterwave range [5,6].

The nex section will address the different demonstrators that have been realized and tested using the above IC and In IC MEMS approach.

4. HETEROGENEOUS MEMS IC INTEGRATION

This section will present the heterogeneous MEMS IC integration approach we are developing to tackle the realization of smart microsystems for RF and

millimeterwave range. Figure 9 shows the global vision that conducts us up to the system integration.

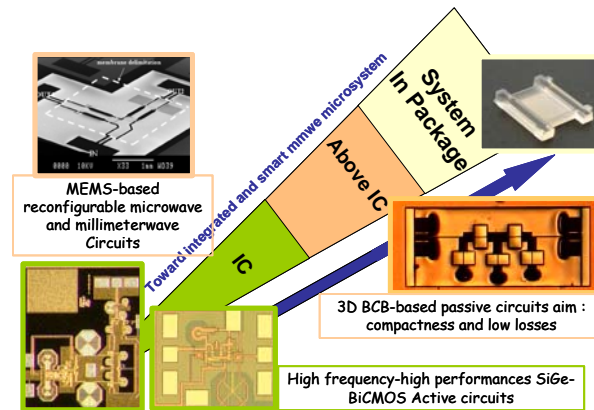


Fig.9 : General vision for smart microsystem integration

In order to validate this approach, we have worked on a certain number of building blocks. The first one deals with a MEMS based reconfigurable Low noise amplifier that is able to switch from 2.5 to 5.5 GHz with a noise figure lower than 2.5 dB. Another building block has been done concerning a MEMS based VCO at 10 GHz featuring improved performance in term of phase noise. Finally, a miniaturized micromixer at 20 GHz has been designed and fabricated with above IC transformer and combiner that translates to improved characteristics. More details will be given concerning the results that have been obtained in the extended version of the paper and at the conference.

5. CONCLUSION

This paper relates the technological development of above IC and IN IC MEMS for RF and millimeterwave range. The technological processes have been developed with respect to temperature, materials and strain compatibility. The processes have been validated on RF and millimeterwave demonstrators and we have also proposed the convergence between above IC and In IC MEMS in order to explore the future architecture of smart microsystems for advanced communications.

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