MEMS SiGe Technologies for Advanced Wireless Communications

J.P.Busquére[1,2], N.Do[1], F.Bougriha[1], P.Pons[1], K.Grenier[1], D.Dubuc[1], A.Boukabache[1], H.Schumacher[3], P.Abele[3], A.Rydberg[4], E.Ojefors[4], P.Ancey[2], G.Bouche[2] and R.Plana[1]

[1] LAAS-CNRS 7 Av du Colonel Roche 31077 Toulouse France
[2] STM 850 rue Jean Monnet, 38926 Crolles, France
[3] Dept of Electron Devices and Circuits University of Ulm, Albert Einstein Allee 45, D-89081 Ulm, Germany
[4] Dept of Material Science Uppsala University, PO Box 528, SE-751 20, Uppsala, Sweden

Abstract :**This paper shows the potentialities of merging the MEMS and micromachining with SiGe technologies in order to speed up the performances of next generation of front end in term of flexibility, reconfigurability and adaptability. MEMS technologies are presented based on BCB materials and BAW materials. Special attention is paid to ensure a full compatibility between IC and MEMS. We have shown that very innovative functions could be considered by using this MEMSIC concept.**

Index terms : **MEMS, Above IC, SiGe HBT, Microsystem, BIST RF**

I INTRODUCTION

The information age is leading to a tremendous increase of the number of wireless applications devoted to personal and mobile communications, satellite communications, automotive applications, health control and survey environment. This results to a spectrum overcrowding that is overcome by increasing the allocated frequency for wireless communication. Today, the wireless applications have frequency operation ranging from 1GHz to 100 GHz. Another issue deals with the improvement of the performance of the RF and the microwave modules in term of noise, linearity and power consumption which cannot be assessed by conventionnal approach and that could be solved by using the MEMS technology. For some applications, it will be necessary to feature additional functionality in order to satisfy the customer requirements. Among these functionalities, we can outline the multi standard operation, the reconfigurability with respect to the environmement conditions (i.e by varying the DC power consumption, or by changing the RF performances when it is needed) and the facility of tuning and reparing in order to feature some intelligence and to present an improved reliability behavior. The last requirement deals with the cost reduction of the RF modules which has motivated a tendency to have a higher degree of integration with more embedded devices.

During the last ten years, silicon based technologies has become more attractive due to the use of its micromachining capabilities, mechanical capabilities defining the MEMS technologies and also due to the emergence of the Silicon Germanium based technology that make possible the fabrication of device featuring cut-off frequency larger than 100 GHz with very attractive noise behavior [1,2]. We are convinced that in the future, there is a need for integrating MEMS technologies with IC SiGe technologies in order to develop the concept of Microsystem for RF and millimeterwave communications. In this communication, we will present the potentialities that could be considered by using this concept of MEMS SiGe.

The first section of the paper will present the MEMS technology that could be of interest. Section II will address some words concerning some results featured by SiGe based HBT technology. Section III will outline the different advanced circuits that could be realized using the MEMS SiGe concept when conclusions will be presented in the last section.

II MEMS TECHNOLOGY

It has been already published a lot of works concerning the MEMS technology the last ten years but most of the works are related to "stand alone" devices. Here we will present MEMS technologies that are compatible with integrated circuit through a grafting process. The first 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 BCB technology that is featuring very low loss and that is easily compatible with IC technology. Figure 1 is showing different solutions we have experienced in order to minimize the losses. The BCB layer is spun out and baked at 200°C. The thickness are ranging from 5µm to 20µm.

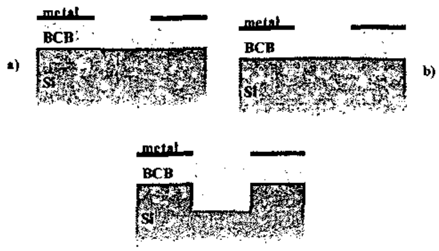

Fig1 : Different MEMS solutions to minimize the insertion losses

Figure 2 is showing the measurements that have been performed on the different topology of 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.

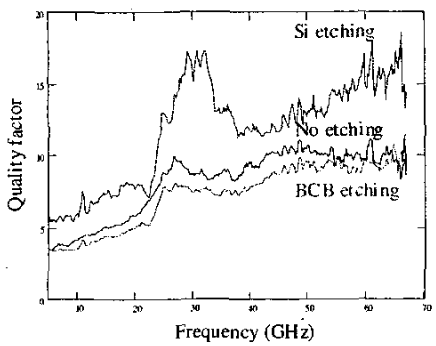

Fig 2 : Measurement of the transmission coefficient for the different topology of CPW

The second technological process that has been developped deals with a 2.5 D process consisting of depositing of two layers of BCB featuring 10µm thickness each separated by a metal level. This technological process will be used to fabricate filter, coupler or combiner. Figure 3 is showing the topology of an inductive and capacitive microstrip line that could be realized using this two layers of polymer. This will be used to fabricate filter up to the millimeterwave range.

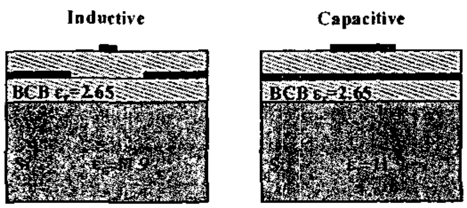

Fig 3 : Inductive and capacitive microstrip line

This 2.5D technology features via holes which dimensions have been optimized in order to minimize the insertion losses up to the millimeterwave range.

The third technological process that has been developped derives from the others and deals with the fabrication of capacitive switch based on the BCB technology. The devices are featuring 40 Volts actuation voltage, 0.2 dB insertion loss and 15 dB isolation. Special attention has been paid to improve the reliability behavior. More details will be given at the conference.

Finally, these BCB MEMS processes have been experienced on SiGe Wafer provided by ATMEL in Germany as plotted in figure 4.

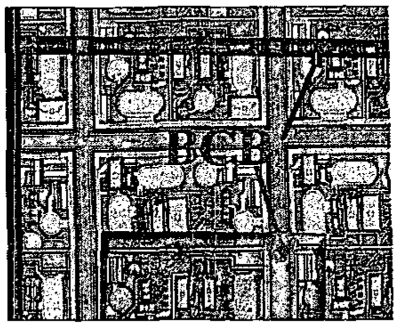

Fig4 : Picture showing a 10µm thick BCB layer grafted on a SiGe wafer provided by Atmel (Germany)

In order to verify the compatibility, we have performed microwave measurements and low frequency noise measurements before and after the grafting process and we have observed no degradation of the active performance validating our approach.

In order to assess the microsystem concept, it is important to demonstrate the compatibility of the micromachining techniques with a SiGe process.

Figure 5 shows one approach we have developped which consists to fabricate the passive and/or the antenna suspended on a BCB membrane connected to the active devices.

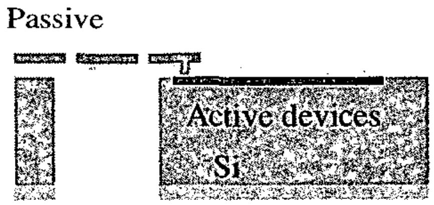

Fig 5 : First architecture of the above IC microsystem integration

The approach presented in figure 5 is featuring very attractive performance as it will be shown in the extended version of the paper and at the conference but the main drawback deals with the large space of silicon occupied. In order to overcome this problem, it is proposed an alternative approach displayed in figure 6 where the passive are now surrounding the active devices saving a lot of space and then resulting to a significant cost reduction.

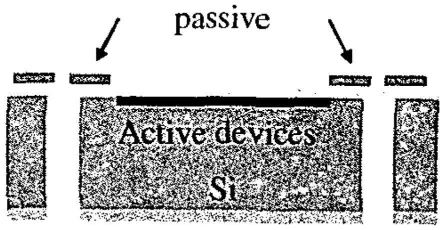

Fig 6 : Alternative solution for microsystem integration

In this topology, of course the antenna performance will be a little bit inferior to the previous one. Another issue deals with the micromachining process closer to the active devices that could turn out to higher strain that could result to some degradation of the performance of the active devices.

In order to confirm these assumptions, we have done an exhaustive investigation of the compatibility of the micromachining process (wet and dry) with the integrated circuit. The investigation has been supported mainly by RF measurements, DC measurements and low frequency noise characterization as it is well understood that 1/f noise behavior is a very efficient signature of some microscopic degradation. The investigation has been carried out on a set of 5 devices and it has been observed that some design rules have to be respected in order to have a complete compatibility of the micromachining process with the IC. The results will be presented at the conference and will show that it is possible to machine an IC in order to speed up some performances which is to our knowledge the first time such a demonstration is done.

Another MEMS technology that is very important deals with the exploitation of the transverse accoustic wave to fabricate high Q filter. This process has been developped by CSEM [3,4] and is compatible with an above IC integration with a SiGeBiCMOS process developped by ST Microelectronics. Using this technology, it could be possible to have front end filter having very attractive performance as the quality factor obtained are in the range of 500. It could be used also for low phase noise VCO and for advanced front end architecture for 3G and 4G applications. These points will be discussed later in this paper. We have to outline that this piezoelectric process could be used to develop switches with very low actuation voltage. More details will be given at the conference.

It will be presented also a RF Switch having a thermal electrostatic actuation compatible with a SiGe BiCMOS process developped by ST Microelectronics [5].

The next section will present some circuits that could be done using a SiGe technology.

III SiGe TECHNOLOGY

Different SiGe HBT technologies are existing today. Some are pure bipolar devices and usually could feature aggressive Ge shape in order to reach very hich frequency range when other solutions prefer to have a SiGe BiCMOS process that is featuring more functionality due to the MOS devices.

In addition to the active device performance, large progress have been achieved concerning the quality factors of the passives and there is a lot of demonstration in the litterature of SiGe HBT based circuits featuring very attractive performance.

For instance, we have realized recently a 10 GHz VCO featuring -100 dBc/Hz phase noise at 100 kHz offset which at the state of the art. We have to note that this IP block has been associated with divider by two, by four and with a tripler to generate low phase noise signal from 2 GHz to 30 GHz.

LNA have been realized both in the 5-6 GHz range [6] and up to the millimeterwave range [7,8]. Finally a fully integrated 24 GHz have been presented by E Sonmez et al [9] demonstrating the tremendous potentialities of the SiGe HBT technology.

In the next section, we will present some microsystem application that could be done in order to push out the performances of silicon based circuits.

III MICROSYSTEM APPLICATIONS

In figure 7, we are presenting a typical heterodyne architecture where it is shown where some simplification could be achieve using some MEMS devices. The added value of the association between MEMS and SiGe deals with the fact that for instance the SP3T and the tunable filter could be integrated together with the SiGe based mixer and eventually the VCO. Concerning the filter, they could be realized using either the BAW technology or the 2.5D BCB process. The antenna could also be realized directly above IC using the two topologies presented in the previous section. Concerning the transmitter section, if moderate power is needed, the architecture could be strongly simplified by associated input and output impedance synthesizer in order to cover the desired frequency band or to give some degree of intelligence to the transmitter.

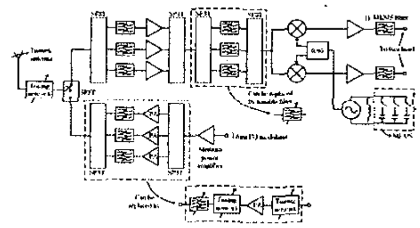

Fig 7: Multistandard architecture

In figure 8, we are presenting a typical dual band architecture with MEMS.

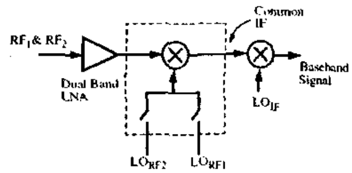

Fig 8 : MEMS based dual band architecture

In this configuration, all the front end could be integrated on a same chip. The dual band LNA could be realized by changing the input and output impedance in oder to cover the two frequency bands. We can note that in this case the design is done globally which is more simple. The mixer could be designed having a broad band range and the two bands are addressed through a 2P1T together with the two VCO. The architecture could be more simplified by choosing a very low IF or Zero IF architecture.

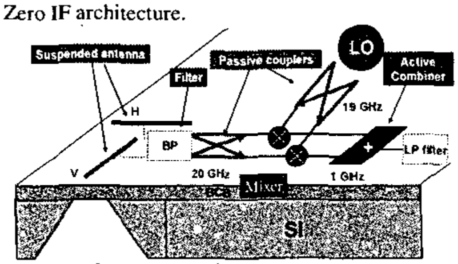

Fig9 : Generic view of a microsystem for RF and microwave communication

Figure 9 is showing a generic view of the potentialities given by the combination of BCB, micromachining and SiGe technology in order to have a high integrated circuit operating up to millimeterwave range.

Finally, another potentiality is possible by merging MEMS and SiGe which consists to the fabrication of simple and miniaturized RF and microwave test bench that could be used to simply test the next generation of RF and microwave modules. It is understood now that the RF modules are becoming more and more complicated with more devices embedded within a system and then it becomes more and more difficult to asses their RF behavior. MEMSIC is providing the opportunity to consider some system having testing and/or reparing fonctionalities re-using the Built in self test concept (BIST) for RF modules. We will present more details on that at the conference.

IV CONCLUSION

This paper presents an overview of the potentialities of merging MEMS technologies and SiGe technologies to fabricate smart microsystem that will have reconfigurability, flexibility adaptatbility functionalities. The concept we are defending is the above IC concept where additional layer are grafted on an IC to emphasize its performance. We have shown that the compatibility of MEMS with IC could be achieved and that it could turn out to the fabrication of very innovative function like miniaturized RF test bench or BIST RF.

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