MEMS/NEMS TECHNOLOGIES FOR AMBIENT INTELLIGENCE

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This paper presents an overview of the potentialities of MEMS/NEMS technologies to develop smart miniaturized systems for ambient intelligence. They allow the development of devices featuring enhanced capabilities in term of sensitivity, flexibility, reconfigurability and testability. Some issues are still opened related to the reliability, 3D packaging, IC interface, hardware/software interface.

Keywords: MEMS/NEMS, Miniaturized sensors, 3D integration, wireless sensor

1. INTRODUCTION

For the last ten years, we have observed a real revolution concerning the impact of information and communication technologies on society and industrial sectors through a new concept called ambient intelligence. This concept aims to be able to develop miniaturized Microsystems that :

- will sense different quantities in different places,
- will process the data and to send the information through appropriate network architectures.

It is obvious that this concept will translate to a convergence between complexity and miniaturization. Figure 1 shows an example of possible scenario of ambient intelligence where, we can see that it will find applications in many industrial sectors as well as in day to day life.

Figure 1 : Some examples of scenarios concerning AMI

From the scenarios displayed in figure 1, it is understood that it will be important to investigate different technologies issues as well as architecture issues in order to be able to fulfill the requirements. It has to be outlined that in order to be exhaustive, the sensors will have to be deployed in a very smart architecture in order to provide a very efficient and very robust mesh. Figure 2 is presenting an example of architecture that is commonly in the field of wireless network sensors.

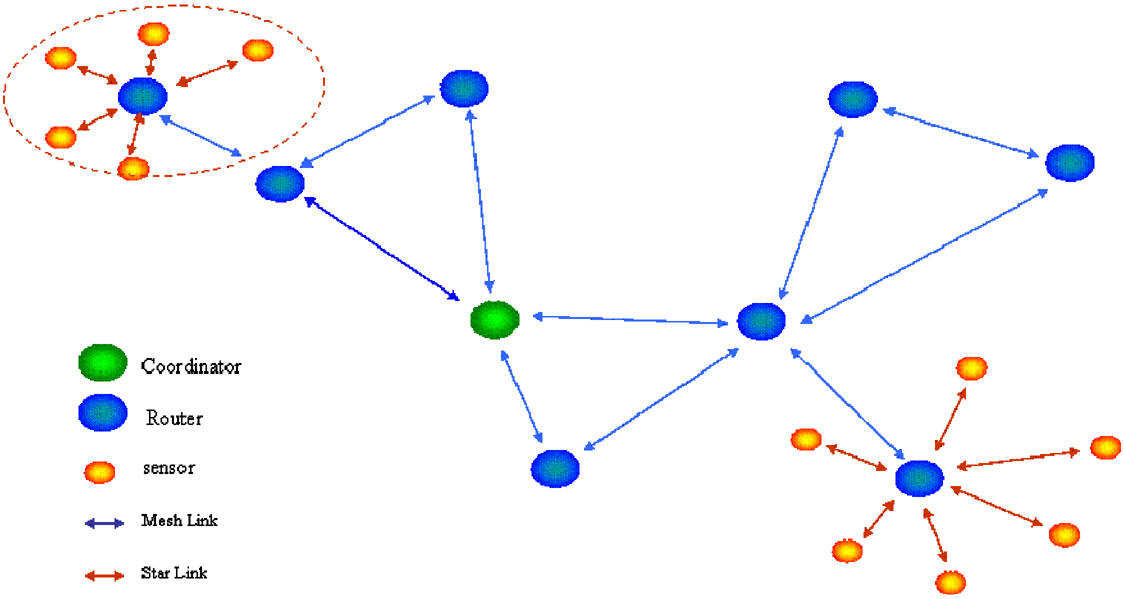

Figure 2 : Typical architecture for a wireless sensors network

In this paper, we will present the potentialities exhibited by MEMS/NEMS technologies and their association with other technologies to develop miniaturized smart systems for ambient intelligence.

2. MEMS/NEMS TECHNOLOGIES

It is understood that ambient intelligence will necessitate new devices for sensors, actuators and for the connectivity between the different nodes. We have chosen to explore the potentialities of the MEMS/NEMS technologies as they feature very attractive capabilities as follows :

- Possibility to exploit the electrical/mechanical coupling
- Opportunity to make some strain engineering
- Collective fabrication techniques
- High degree of genericity
- Fabricate simultaneously sensors, actuators and wireless components
- To be silicon based

The basics of MEMS/NEMS involve different materials (dielectric, metal, piezoelectric material, magnetic material, polymer), conventional growing, deposition techniques and photolithography. The most important issue deals with the micromachining techniques that are used to define the sensitive area. Figure 3 shows the two main techniques that are used today referred to as bulk micromachining and surface micromachining.

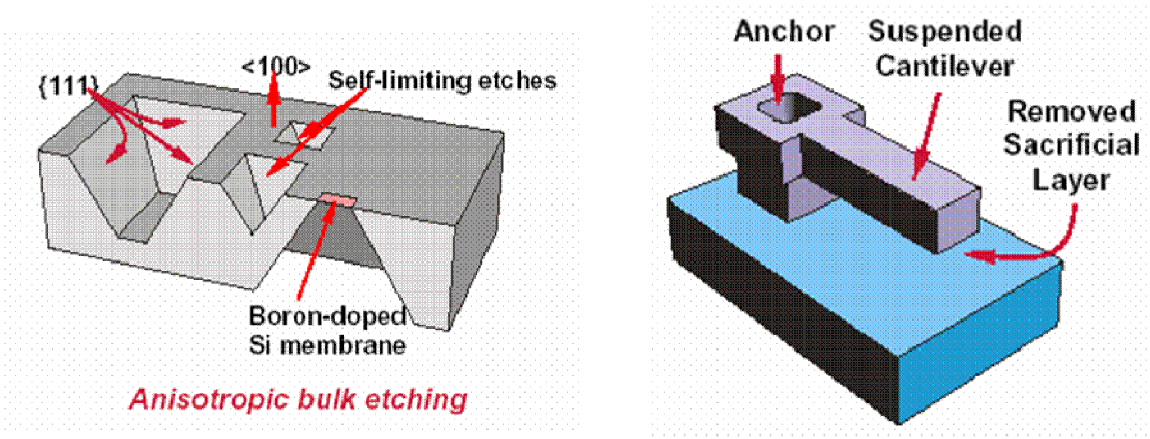

Figure 3 : Main micromachining techniques involved in MEMS/NEMS technologies

It has to be outlined that the behavior of the components will be mainly driven by the strain that exists inside each component and it will be very important to be able to determine the material properties with a very high accuracy. In table 1, we have reported some techniques that are used to investigate the material properties.

Measurement technique	Test structure	Material	Properties	Loading	Deformation
Wafer curvature	Full wafer	All*	σ	*****	Profiler
Cantilever curvature	Cantilever	Au	$\Delta\sigma$, σ**	*****	Optical profiler
Nano indentation	Full wafer	SiNx , Au , Cu	E , σ	Nano indentor	Nano indentor
Ponctual loading	Bridge	Au	E , σ	Nano indentor	Nano indentor
Ponctual loading	Membrane	SiNx , Au	E, σ, σ_r	Nano indentor	Nano indentor
Bulge test	Membrane	SiNx , Au	E , σ, σ_r	Pressure	Optical profiler
Vibrometry	Bridge	Au,PZT	E , σ	Piezoelectric	Optical profiler
Vibrometry	Membrane	Au, PZT	E , σ	Piezoelectric	Optical profiler
Electrostatic actuation	Cantilever	Au	E (T) , σ	Voltage	Optical profiler
Electrostatic actuation	Bridge	Au, PZT	E (T) , σ	Voltage	Optical profiler

Table 1 : summary of the different techniques to investigate the material properties [1]

The MEMS/NEMS technologies are allowing today the fabrication of a large panel of devices as [2].

- Pressure sensors
- Gauge strain
- Temperature sensors
- Chemical sensors
- Micro and Nanoresonator
- Miniaturized antenna…

The next section will assess the association of the MEMS/NEMS technologies with the integrated circuits in order to introduce some intelligence within the device and to be able to pre-process the data at the node level.

3. MEMS IC CONCEPT

As it has been outlined in a previous section, MEMS/NEMS technologies have already demonstrated very attractive performances and the future will be related to their association with the integrated circuit through different schemes. It has to be outlined that the integration can be 2D and we will speak about systems on chip or 3D and we will refer it as System in Package.

Figure 4 shows on example of the MEMS/NEMS IC vision that could be investigated to fabricated smart systems.

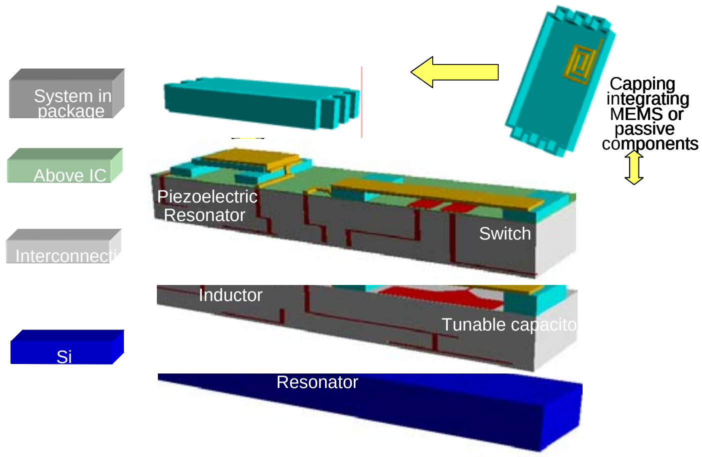

Figure 4 : example of MEMS/NEMS IC architecture from [3]

It has to be outlined that using such complex integration scheme will necessitate significant efforts concerning the compatibility between the different process. This is referred to as "heterogeneous integration" and that represents a major step in the smart system field. Concerning the integrated circuit, for process compatibility issues they will be silicon based (SiGe HBT or CMOS or even CMOS SOI). Figure 5 shows an example of the different components that could be integrated in order to fabricate a smart miniaturized system for ambient intelligence application.

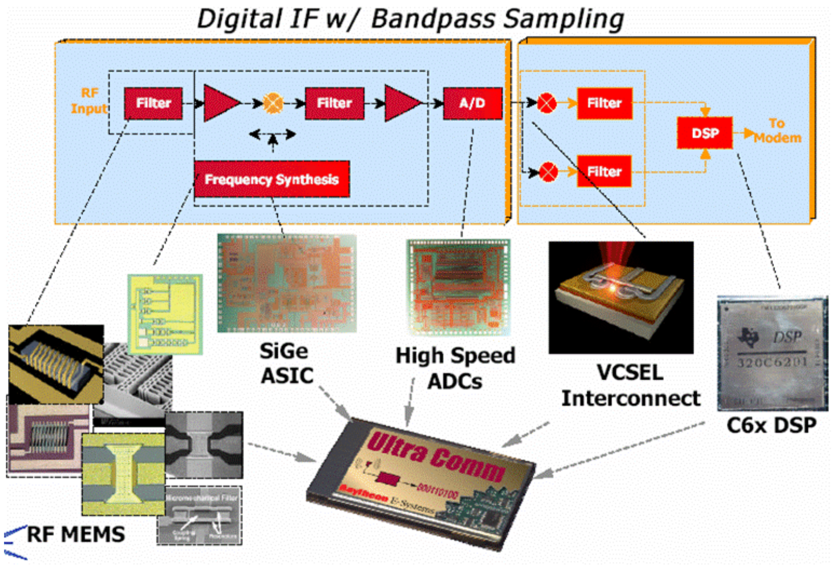

Figure 5 : example of the different components that could be integrated for an AMI microsystem

It has to be emphasized that for most of the applications, it will be important to limit the power consumption at the node level, interface level and wireless level in order to safe some energy but also to make the wireless sensor network transparent with respect to interference with other equipment. These power consumption requirements will motivate research concerning architectures but also protocol of communications and processing techniques.

4. WIRELESS SENSOR NETWORK ARCHITECTURE

This section will aim with the architectures that will be needed to support the concept of miniaturized sensor networks. The first point deals with the wireless medium. There is frequency allocation ranging from 1 GHz to 100 GHz following the type of application targeted. In the RF range (1 GHz-6 GHz) it has to be emphasized that due to the spectrum overcrowding there is strong need concerning the interferer minimization that makes the design architecture very complicated. In order to overcome this problem, one way consists to use millimeter wave frequency range where the linearity issues are less important. It has to be pointed out that going to millimeterwave is also very interesting for some applications necessitating high bit rate. We also have to highlight that millimeterwave range turns out to very confined radiation pattern that allows the saving of electromagnetic energy. In this context, it is important to ensure a full coverage of the communication medium. The other important issue is related to the application scenario that is tackled by the sensors network as it will impact the requirements in term of protocol of communication and signal processing techniques.

We can distinguish two main categories of applications. The first category where the data do not have to monitor at a very high duty cycle and then it means that the wireless duty cycle is quite small that will have a significant impact on the architecture and on the energy management process. As an example, the wireless network can be turned off most of the time and turned on only when the data is needed. This type of architecture is commonly used and fully compatible with the MEMS/NEMS technologies. The only issue that has to be carefully checked deals with the number of nodes that have to be connected simultaneously and that could impact the overall bit rate of the network. One solution is related to the use of TDMA modulation scheme in order to diminish the overall bit rate. In this case, the price to pay is related to the duty cycle that will be longer and then the energy budget will be affected.

The second category deals with applications at high duty cycle where the data are monitor at a very high sampling rate leading to a wireless network always turned on. In this category, the energy to manage the network operation will be the main issue.

Finally, it has to be emphasized that the wireless architecture has to support the MEMS technologies. More precisely, the MEMS technologies will allow the realization of tunable antenna or beam steering antenna that have to be integrated into the algorithm of the protocol of communication.

5. CONCLUSIONS

This paper outlines the capabilities of MEMS/NEMS technologies for ambient intelligence. It is shown in the first section that the future challenges for Microsystems are related to a convergence between miniaturization and complexity. Concerning the technologies, both bulk and surface micromachining techniques allow the fabrication of very sensitive and very versatile components. It is also shown that these technologies necessitate a very deep knowledge at a material level and at a process level. The generic character of MEMS/NEMS will make possible the development of the MEMS based FPGA that could opened new innovative ways for microsystem architecture. A second section is presenting the necessity to have a MEMS IC integration in order to have a full microsystem and some requirements and issues are given. Finally, the last section deals with the wireless architecture, the protocol of communication and signal processing techniques that have to be compatible with the MEMS based front end.

6. REFERENCES

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