Smart sensors for all over industrial application niches

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1 INTRODUCTION

For many years, the University of Liege is involved in microelectronics and microsystem modeling, design and integration. Recently, the University of Liege has received the opportunity to build a brand new infrastructure (clean rooms – ISO 7) with specific equipments for packaging and MEMS characterization. This new facility (clean rooms and equipments) enables to the University to be very well positioned in the nano/micro-electronics modeling, analysis and packaging world and is now able to answer to specific research and industrial needs. The two main research activities presented in this paper are, on the one hand, the design, analysis, tests of MEMS for simulation calibration, and on the other hand, the design, interconnection, encapsulation, in situ test and characterization of microsystems for industrial applications. Both laboratories are described hereafter.

1.2 MICROSYS – Packaging laboratory

The aims of MICROSYS are to increase industrial awareness and help industrials to develop innovative prototypes of microsystems for all kind application niches.The Microsys facility involves 200 m² of clean rooms available for the interconnection and packaging activities for research and industrial prototyping in the field of microsystem. The interconnection and packaging of microsystems of course need the use of equipments and software of a high level technology. These tools allow us to design and assemble microsystems in agreement with a wide range of norms and harsh environment.

All the equipments available are manual and versatile to allow the largest and innovative capabilities for packaging application.

Figure 1 : Clean rooms

In summary, this facility allow to assemble, interconnect, encapsulate and characterize a wide range of microsystems, i.e. : wafer scribing (till 6''), plasma cleaning and activation, pick and place (die attach, flip chip), ultrasonic wire bonding (ball, wedge and bump), tests (wire pull, ball & die shear test), microsystem encapsulation (potting, globe top, hermetic seam sealing), PCB gold plating, PCB machining and package decapsulation.

1.3 MEMS laboratory

The laboratory of « Structural Dynamics Research Group » has recently purchased new instruments: a laser vibrometer Polytec and a vacuum cryogenic chamber, Janis. With this equipment we will be able to characterize the dynamic behaviour of microsystems and perform measurements in vacuum until around 10^{-6} Torr at different temperatures from 8K to 450K.

Figure 2 : Laser vibrometer

2 PACKAGING FOR NICHE APPLICATION

Industrial applications induce several constraints on the choice and the assembly of Components Off The Self (COTS) (packaged and bare die). These constraints depend on the application and are often located in a harsh environment. Most of the cases, we need to integrate the microsystem in an existing system and that induces a lot of constraints like dimensions, power supply, … The choice of the right COTS is leading by some criteria:

Functionality : This means how the component is responding to the specifications. Most of the time, the first components to choose are the sensor and/or the actuator. When this choice is made, we can identify the other electronic components needed to perform the correct measurements (frequency, threshold identification…), signal processing, power supply and communication with the "outside world".

Resistance to environment : The choice of these components is also leaded by their ability to withstand the environmental constraints. Industrial applications are often located in a harsh environment: high/low temperature, vibrations, shock, chemical resistance, high pressure,… In most of the cases, all the components of the microsystem will not individually withstand all the environmental constraints. These components must be integrated in a dedicated "package". The role of this package is to protect the components against the environment and allow the requested measurement. Each time we design a package, each time we need to find innovative solution. As an example we can take a environment with many vibrations. This has an impact on MEMS components and on the interconnection of any type of components. A good example is a MEMS in bare die form, interconnected with wire bonds. The wires are free to move laterally within a certain range (wire sweep). To avoid contact between wires and short circuits, we usually encapsulate them with an epoxy (it also strengthen the bonds). But in case of high vibration level, simulations tell us that the epoxy does not move in the same way as the die and wires, inducing stress on the bonds. An elegant and safe way to avoid unexpected wire displacement is to use the flip-chip process, with or without under fill. The different simulations around the MEMS and also the interconnections are detailed later in this paper.

Costs : Usually, people think that the components are the main factor of cost in a package. But in fact, the packaging represents 30 up to 75% of the global cost of a microsystem. Awfully, we can say that 13/15 components projects failed because nobody had foreseen the packaging. For a new component development “benchmark”, we must take into account the associated costs of the development, packaging and assembly. That means that most of the time, it is not the best choice to take the cheapest component.

Power consumption :For autonomous microsystems, the power consumption is one of the most important constrain and become a challenge when using an associated energy harvesting system. This has an impact on the choice of the components, but not on the package. An example is given in the next paragraph.

3 DYNAMICS BEHAVIOUR OF MEMS IN HARSH ENVIRONMENT

One of the research topics of the laboratory of « Structural Dynamics Research Group » is the study of static and dynamic behaviours of MEMS actuated by electrostatic forces. The main applications are microresonators and RF switches, which consist in suspended structures on which a voltage is applied. Then a potential difference appears between this device and the substrate, and produces electrostatic forces attracting both electrodes together. These strongly nonlinear forces affect the behaviour of the device.
To study numerically the behaviour of these structures, new finite element formulation has been developed and several simulation tools are available in 2D and 3D using the commercial finite element code Oofelie from Open Engineering. With the new equipment of our laboratory, dynamic response of MEMS may be measured and allows to validate our models or to test new microdevices. The goal of this research and collaboration with the Microsys laboratory is to study the behaviour of the MEMS and its package in harsh environment such as high external vibration level.

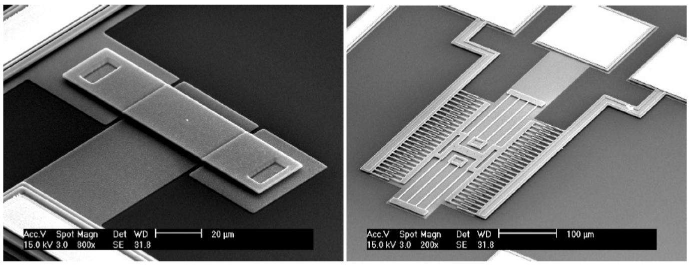

Figure 3 : Examples of MEMS beams

Two effects are described in this paper. The effect on the microdevices and on the package:

- Effect on the microdevice :

External vibrations will have an effect on the dynamic of structure. Indeed, when electrostatic forces are used to actuate the device, due to this dynamic perturbation, the device may reach earlier the unstable zone and collapse to the ground which may cause damages. To avoid or predict this behaviour, simulations and experimental test has to be done.

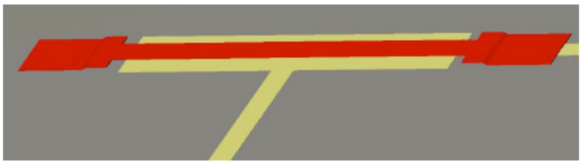

Figure 4: Simulation of a MEMS beam

- Effect on package.

Electrical connections around the device itself are also affected by external vibration, as explain previously. In the case of wire bonds, they are used to apply a voltage to the device and thus are electrically charged. During their external excitation, they may touch each together and create short circuit. Moreover, electrostatic forces appear also on these cables and attract them together. To avoid this, simulations have to be performed in order to estimate the acceptable distance between the cables and their thicknesses. An elegant packaging solution will be to connect by flip-chip process, this cable behaviour is then removed. But this method will damp the vibrations felt by the microdevice and a complete model of the structure and its packaging has to be realized.

4 SOME GENERIC APPLICATIONS

Since the launch of activities in the Microsys laboratory, several major industrial actors have expressed their needs in applications requiring microsystem and miniaturization of existing products. Domains of application are various, going from smart sensor used on a continuous production line, where it’s usual to find a harsh environment, to ensure intelligent manufacturing, to domotics microsystems communicating each other to monitor health of your house where we usually trade with a less aggressive environment but for which sensors must be roughly invisible. As explain previously, the packaging is therefore a critical point of the development and must be considered as soon as possible when a research is started. An example of our realizations was dedicated to a cement ball mil from which the system had to harvest energy. In this application, the challenge was to find a solution supplying enough electrical power to the system in such a way that this one monitors several parameters of the milling process. Since the location of the system and due to the extremely harsh environment, there was a lot of constraint, among others vibrations, rotation, heat, dust, shock and so on. However, the research led to a design and a packaging allowing to take benefit of some of these constraints and to supply the required power.Other types of design touched on the health monitoring. There are numerous fields for which microsystems can be used for this end (building, aircraft structure and engine, …). In particular, we realized research on the health monitoring applied to the walls of a house. In this case, the environment is less aggressive than for industrial applications; however the challenge here lied in the design of low cost, very thin and easy to use microsystems making them roughly invisible once placed and very attractive for the general public. This has been achieved by designing specific package and interconnections.A third kind of application developed in our laboratory take place in the clothing field. Using microsystems from this perspective allows to create intelligent clothes fitted with numerous sensors and processing units. The prospects of this technology are notably very promising in medical and sports domain. Once again, the constraints encountered here led to focus the design on specifics package and interconnections to make these sensors as imperceptible as possible.

5 CONCLUSIONS

For all kind of researches (design of a new electronic component or integration of microelectronic in a industrial application) packaging and simulation are very important. In particular, we showed in this paper that when using MEMS in a harsh environment, it is fundamental to take into account the interconnection and the package (microsystem) where the MEMS is integrated. So simulation must be done on the MEMS and on the whole microsystem to understand the influence of the package and interconnection on the MEMS. These simulations need then to be correlated with measurements on a real microsystem. We also showed that a lot of industrial processes or products need a specific packaging approach to reach success in the final solution (product with microsystem integrated in it). As a general conclusion, most of the developed microsystems are used in harsh environment, hard to access location or maximization of the user comfort. Therefore, a particular effort has to be done in the design of their package.

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