## Conclusion

This paper has shown some important EMC test methods for the compliance of electromagnetic compatibility at vehicle level, component level and semiconductor level. These test methods were developed or proposed by the EMC research of the Westsächsische Hochschule Zwickau (FH) - University of Applied Sciences.

Especially the new measuring method of inductive coupling for conductive interferences and the Tubular Wave Coupler as a laboratory measuring method for interferences by mobile radio services should be accentuated.

The DPI measuring method, which is used for transceiver tests at data bus systems, was described specifically at the semiconductor level.

The results were reached in close cooperation with the automotive manufacturers Volkswagen and Audi as well as leading manufacturers of semiconductors.

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# THE NEW DEVELOPMENTS IN ASSEMBLY TECHNOLOGY FOR THE SENSORS BASED ON SILICON STRUCTURES

**Sensor manufacturing process uses various technologies and various materials, but the sensors based on silicon structure became a dominant group of these devices.**

**In the paper are given the last developments in assembly technique for silicon sensors. The results of our research concerning assembly technology for silicon humidity sensors and silicon gas sensors will be presented.**

**Applied assembly processes are based on flip chip technology which plays the most important role in sensor packaging technology.**

## 1. Introduction

Over the last years a great progress has been made in sensors packaging technology. New silicon sensor designs have been appeared which created new challenges for sensors assembly processes.

For silicon sensors one of the most essential problem concerns how the silicon chip will be electrically and mechanically connected to the sensor package, what comprises assembly process. This process is responsible for reliable, free stresses mechanical and electrical connection.

The new demands which were put for electronic industry which concern first of all integration of different functions into one unit reduction of devices sizes and lowest costs have activated the development of new assembly solution i.e. SiP (system in package [1], [2] .SiP is a new alternative for multi chip modules (MCM) and system on chip (SiC).

Flip chip technology in these new assembly solutions plays pivotal role. After forty years of development of flip chip technology, this assembly techniques become a standard mounting technology and with success this technology also entered in sensor area. It especially concerns of silicon sensors, since this technology offers high joint reliability, the best electrical characteristics and significant package size reduction.

For new design silicon sensors based on 3-D silicon structure, flip chip technology also composes very good alternative.

Flip chip technology is a good choice as well for polymer substrates very often used in sensor packaging. With flex substrates there is the additional factor, since flex substrates are not particularly suitable for wire bonding because some problems occur during assembly process [5}. And that is why in our researches the main attention was put on flip chip technology, which was applied in two versions with gold bumps, with solder bumps and using adhesive bonding, solder bonding and thermocompression bonding.

When flip chip technology is realized on polymer substrates, then serious problems connected with flip chip joints reliability will appear. Due to great mismatch of thermal expansion between bonded materials, high stresses are induced in the flip chip solder and adhesive joints, during power up/down thermal cycling or environmental changes. The reliability of flip chip joints can be considerably enhanced through the use of underfilling process in which underfill encapsulant is inserted in the gap between silicon chip and polymer substrate. This underfiller reduces the possibility of stresses concentration, stiffness of bonded construction and prevents flip chip joints against humidity penetration.

The researches with silicon sensors were carried out with silicon humidity sensors and silicon gas sensor based on 3-D silicon structure.

## 2. Experimental procedure

Silicon humidity sensor was designed in the Institute of Electronic Systems of Warsaw University of Technology.{7}, as the sensor for medical applications. Health of the human skin and condition of mucous membrane can give important information of various disorder.

Cross section of silicon humidity sensor is shown at the fig.1.

Heater and thermometer are placed on the first level while detector on the second level of gold metalization. Layout of the heater and thermorezistor were designed in this manner to assure uniform temperature distribution. Since the surface of the sensor detector ought to be in direct contact with human skin during humidity sensor, humidity sensor was designed on the flex substrate with the using of flip chip technology. Only flip chip bonding can assure direct contact of sensor detector with human skin, while the wire bonding doesn't fulfil these requirements.

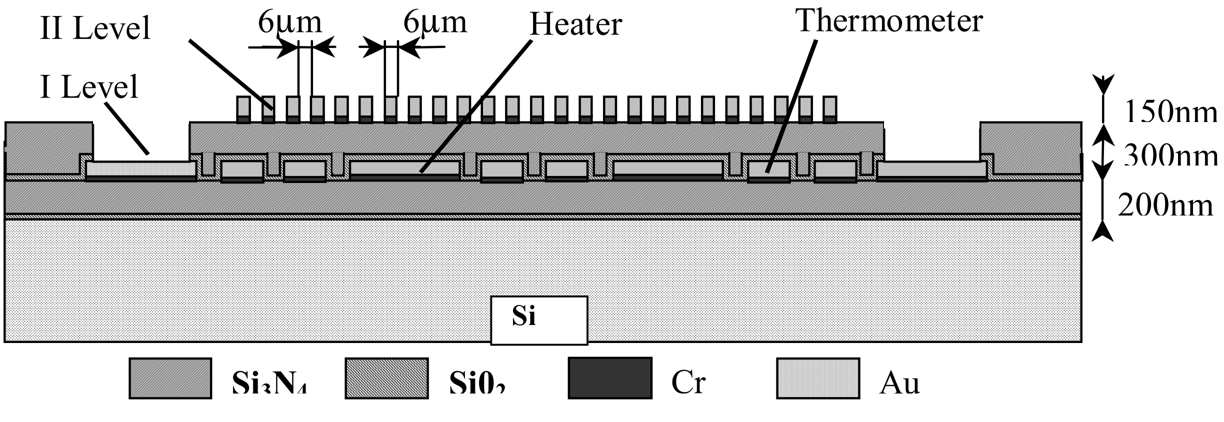

*Fig. 1. Cross section of humidity sensor*

In humidity sensor assembly process two bonding technologies have been applied : flip chip adhesive bonding and flip chip solder bonding. Adhesive flip chip connection, like: low process temperature, low thermo-mechanical fatigue, low number of process steps und usability with low bump pitches, But on the other hand, there are disadvantages such as higher electrical and thermal resistance, higher placement accuracy during bonding process, since there is not self-aliment effect and low mechanical stability.

Silicon gold stud bumped structure was connected to the substrate bond pads by means of adhesive bonding. The conductive adhesive was stencil printing on substrate bond pads and silicon sensor chip with gold bumps was placed on the substrate pads with adhesive. After adhesive curing, to enhance the reliability of adhesive joints, in the last step underfilling process has been applied.

The second flip chip assembly approach was realizes with gold bumped structure using flip chip soldering, where on the substrate bond pads, solder paste was stencil printed. The best results were achieved in last assembly approach, in which solder balls with diameter of 250μm were placed on the pre-fluxed gold plated copper substrate pads and reflowed on a hot plate. Then silicon sensor chip was aligned and placed on the solder bumps and soldering process was exacted. (fig.2)

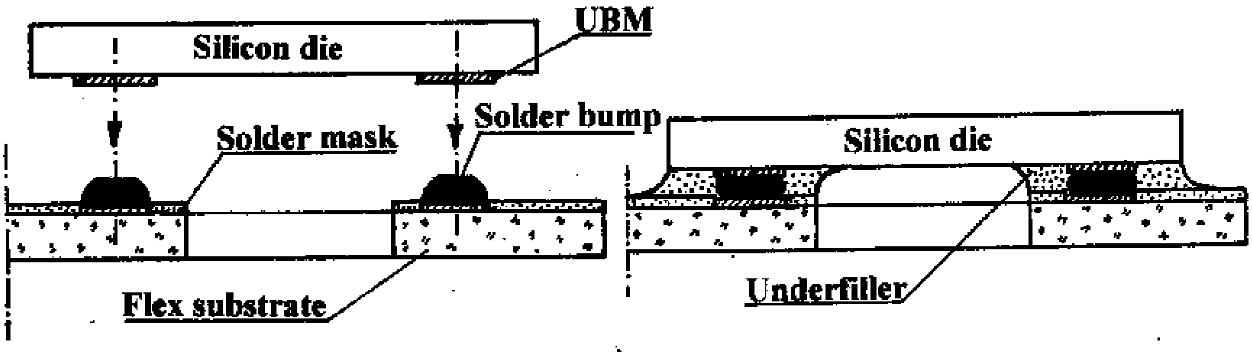

*Fig. 2. Flip chip bonding with bumped substrate band pads*

Mentioned processes at beginning realized on FR-4 substrate and final process was performed on the flex substrate of polyamide fail (Kapton) with the thickness of 120μm. Such substrate allows better contact on measured surface to ensure.

The detailed specification of the presented assembly process is shown in table 1.

The next part of our researches comprised silicon gas sensor based on 3-D silicon structure. The essential part of silicon gas sensor is silicon membrane and polysilicon heater integrated with the membrane (fig.3)

In such construction all bonding pads are situated at the bottom side of the silicon structure in a form so called „Backside contacts". Such design simplifies the vacuum deposition process of gas sensitive layer and assures minimal thermal capacity of silicon structure and good thermal isolation. But on the other hand such sensor construction creates additional difficulties connected with assembly process.

Presented silicon gas sensor construction was designed and manufacturing within cooperation of laboratories from Institute of Electron Technology in Warsaw and Department of Electronic at University of Mining and Metallurgy in Cracow.[8]

Since the temperature under the gas sensitive layer exceeds 350°C, the choice of assembly technique is limited. A few approaches have been undertaken, to make the connections between the backside contacts and sensor package.

Specification of applied materials and processes for silicon humidity sensor.

*Table 1*

**Applied materials and processes for silicon humidity sensor and gas sensor**

| Applied processes | Applied materials |
|---|---|
| **Silicon humidity sensor**<br>chip size: 4 x 4 mm; chip thickness: 380μm, gold bond pads: 250 x 200μm | |
| Gold stud bumping on silicon chip | gold wire diameter: 50μm<br>gold ball size: ~ 180μm<br>gold ball height:: ~ 80μm<br>(after flattening) |
| Solder bumping on substrate bond pads | Sn95 Ag5 solder ball: 200μm diameter<br>Kapton polyamide flex with the thickness of 120μm;<br>Substrate bond pads Cu-Ni / Au |
| Stencil printing of solder paste | Heraeus solder paste F369 (Sn95,5Ag4Cu0,5)<br>FR-4 glass epoxy laminate<br>Substrate bond pads: Cu-Ni / Au |
| Reflow soldering on a hot plate | Soldering temperature: 230°C<br>Time - 20s |
| Adhesive bonding | Loctite adhesive 3888<br>Curing temperature: 125°C<br>Curing time: 1h |
| Underfiling | Underfiller with capillary action<br>U - 300 from Epoxy Technology<br>substrate preheating: 80°C<br>Curing: 150°C<br>Time: 5 min. |
| *Average contact resistance of flip chip joints*<br>Solder flip chip joint – 3 ÷5 mΩ<br>Adhesive flip chip joint – 12 ÷ 15 mΩ | |

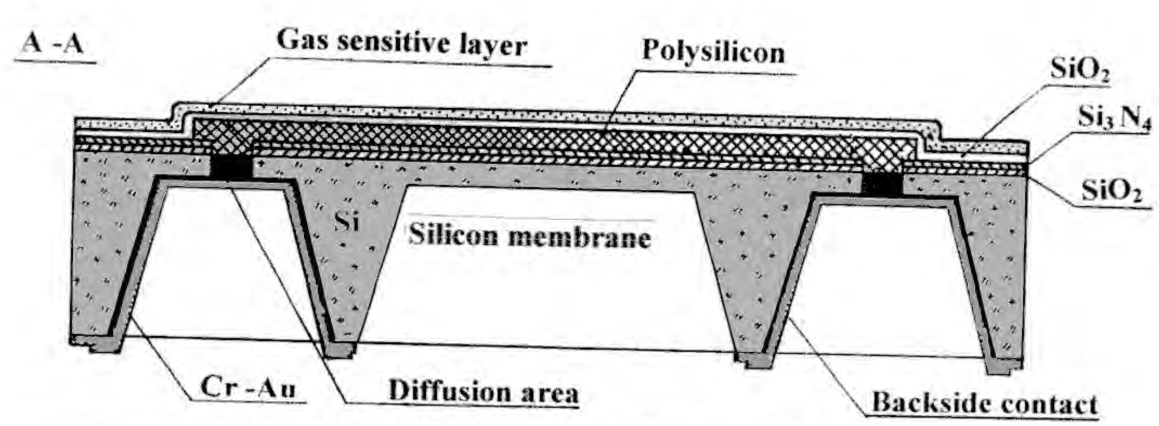

*Fig. 3. Cross section of the silicon gas sensor*

The first one concerned adhesive bonding taking into account the high temperature (above 350°C) in the area of silicon membrane, the special adhesive Loctite P-1011 based on polyamide matrix with high thermal resistance has been chosen. But such solution gives connection with high contact resistance (above 12mΩ) and low thermal stability. And therefore the main attention was concentrated on thermocompression bonding process which gives high reliability connections with very low contact resistance.

First gold wire connection was prepared in such way, to achieve gold ball an the end of wire connection adequate diameter, corresponding with the size of backside cavity. It needs pre- formation of gold wire before flame of cutting wire.

Such prepared gold wire connection in the second step are bonded to gold metalization of the backside contacts, using thermocompresion bonding.

The scheme of this process is shown at. Fig.4.

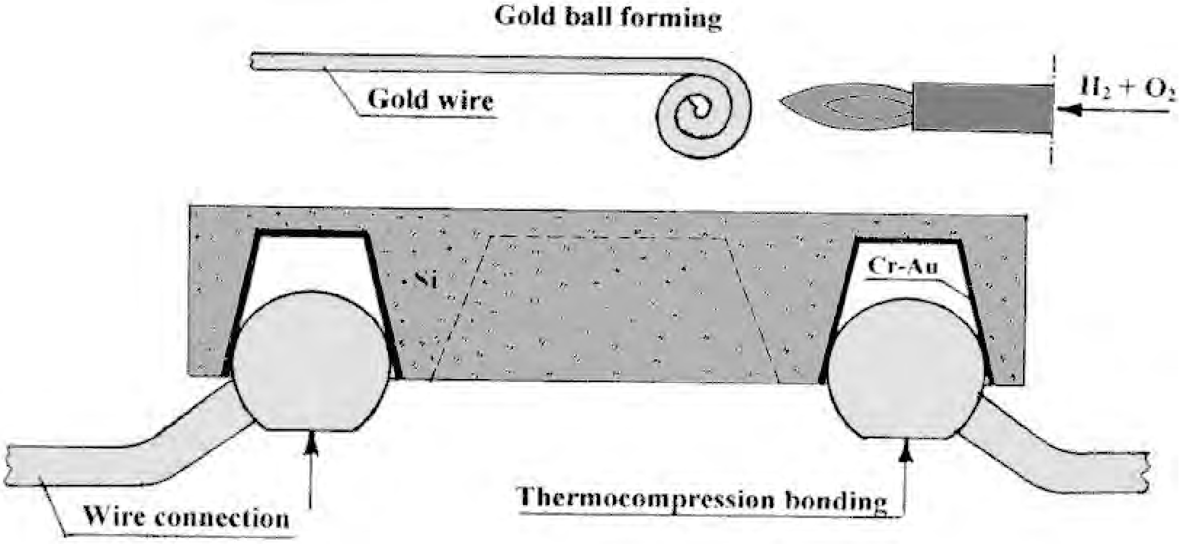

*Fig. 4. Thermocompression bonding of wire connections to backside contacts*

When adequate sensor package is available, then silicon sensor chip is directly bonded to the sensor package by means of backside contacts with thermocomression gold balls bonded.

Detailed specification concerning silicon gas sensor assembly processes and materials is presented in table 2

*Table 2*

**Applied materials and processes for silicon gas sensor**

| **Silicon gas sensor with backside contacts**<br>chip size: 4 x 4mm; chip thickness: 400μm | |
|---|---|
| Adhesive bonding of wire connection with gold ball | P - 1011 adhesive from Epoxy Technology<br>(silver-filled polyamide)<br>curing: 150°C; time: 1h |
| Thermocompression bonding of wire connection with gold ball | Gold wire diameter: 100μm<br>Gold ball diameter: ~ 700μm |
| Gold ball formation with flame of system | |
| **Average flip chip contact resistance value**<br>adhesive joints: 12 -15mΩ<br>thermocompression joint: 2 - 3 mΩ | |

## 3. Conclusions

The great progress in assembly techniques that is observed during the last years, also to sensor packaging entered, what enabled new sensor design to create and reliability of manufacturing devices to increase.

Flip chop technology is one of the dominant technologies in sensor packaging which offers new possibilities and plays the most important role in sensor packaging technology.

This especially concerns such sensors and such applications, when sensor detector ought to be in direct contact with measured surface, what is very often found in medical applications.

From among flip chip processes for humidity silicon sensor, flip chip solder bonding seems to be the best solution. For silicon gas sensor with backside contacts, thermocompression bonding process is the most suitable since enables, as well thermocompression wire bonded connections to produce as wireless connections i.e. thermocompression flip chip bonding to realize. For the sensors on flex substrate packed, the underfilling process is needed to relieve the thermal mismatch between bonding materials and reliability of flip chip joints to enhance.

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# ANALYSIS OF PIEZORESISTORS ARRANGEMENTS ON THE SURFACE OF CIRCULAR MEMBRANE IN PRESSURE SENSORS

**A theoretical analysis concerning metrological properties of thick film piezoresistors placed on circular edge-clamped membrane is described. The change of resistance of a thick film piezoresistor, caused by the deflection of the membrane, related to the distance from the membrane centre and the width of the piezoresistor, is evaluated. Analytical expressions for different piezoresistors arrangements are presented and discussed.**

## 1. Introduction

About 1940 the construction of pressure sensor with etch-foil metal resistors glued on circular membrane was elaborated. In 1970s this construction was adopted in miniaturized silicon pressure sensors: the membrane was etched in silicon monocrystal and metal-foil resistors were replaced with diffused semiconductor piezoresistors which gauge factor GF is about hundred times greater than for metals. The output signal increased because of an immense change in the resistivity of strained semiconductor – whereas in metals GF is related with so called “geometrical piezoresistivity” caused by change of dimensions.