Advanced Assembly Techniques For Silicon Sensors

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Abstract

Some assembly approaches which were carried out with silicon gas sensor and silicon humidity sensor are presented and described in this paper. Some of these sensors were based on silicon 3-D structures with so called "backside contacts'' which need special assembly solutions. Flip chip solder and adhesive bonding were used for silicon humidity sensor. Experimental specifications concerning applied assembly solutions and obtained results are presented and described.

Key words

backside contacts, flip chip bonding, silicon sensors, underfilling

1. Introduction

During the past few years, great progress in electronic packaging technology has been made. It was forced by electronic industry which significantly moved forwards in reducing package size from dual in line package to ball grid array and chip scale package. On the other hand new demands from the electronic market to integrate various functions into one unit with smallest sizes and lowest costs activated development of new assembly solutions i.e. SiP (system in package) [1], [2]. SiP is a new alternative for MCM (multi chip modules) and SoC (system on chip).

In mentioned assembly solutions flip chip assembly technique became a standard mounting technology. These assembly solutions were introduced in sensor packaging. It especially concerns silicon sensors where new construction based on 3-D silicon structure appeared [3], [4]. Sensor manufacturing process uses various materials and various processes but sensors based on silicon structures are becoming more and more popular.

For silicon sensors one of the most essential problems is how the silicon chip will be electrically and mechanically connected to the sensor package, that is namely assembly process. This process is responsible for the reliable, stresses-free mechanical and electrical connection. Flip chip technology is very good alternative for silicon sensors, since this technology offers high joint reliability, the best electrical characteristics and possibility of package size reduction.

When flip chip assembly process is realized on polymer substrate, then underfilling process is necessary to decrease thermal expansion mismatch between the bonded materials. Underfill encapsulant inserted into the gap between silicon chip and polymer substrate stiffens bonded construction, reduces the possibility of stress concentration and protects the adhesive joints against humidity penetration. The research was concentrated on silicon humidity sensor and silicon gas sensor. The main purpose of this research was to develop a reliable mechanical and electrical connection between the silicon structure and the sensor package.

2. Experimental procedure

Silicon humidity sensor for medical applications was designed at the Institute of Electronic Systems at Warsaw University of Technology [5]. Health of the human skin and the state of mucous membrane can give important information about various disorders. Humidity is one of the most important factors of human skin and mucous membrane. Cross section of silicon humidity sensor is shown in Fig. 1.

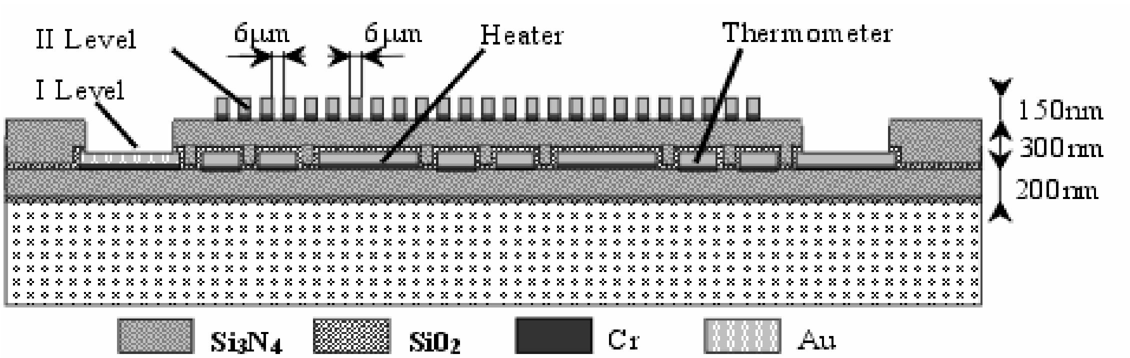

Fig. 1. Cross section of Humidity Sensor.

Heater and thermometer are placed on the first level and detector on the second level. These elements are made of gold layer. Detector impedance is dependent on humidity of the object that is in contact with the surface of the sensor.

Since the sensor detector surface ought to be in direct contact with human skin during humidity measurement, humidity sensor was designed on the flexible substrate using flip chip technology. Only flip chip bonding can assure direct contact with measured surface, while wire bonding does not fulfill this requirement.

In humidity sensor assembly process some assembly approaches have been undertaken: flip chip adhesive bonding and flip chip solder bonding with the use of gold bumps and solder bumps. The scheme of flip chip adhesive bonding is shown in Fig. 2.

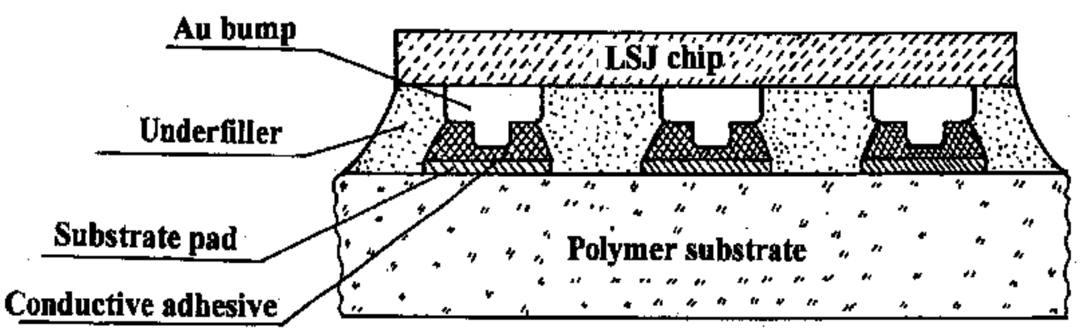

Fig. 2. The scheme of flip chip adhesive bonding.

Silicon gold stud bumped structure was connected to the substrate bond pads by means of adhesive bonding. The conductive adhesive (Loctite 3880) was stencil printed on FR-4 laminate bond pads. To enhance the reliability of the adhesive joints and the mechanical bond strength, the underfilling process used Epoxy Technology U-300 underfiller. Using the same FR-4 substrate and the same gold bumped structure the other approach was executed using flip chip soldering, where solder paste Sn 95.5 Ag 4 Cu 0.5 (Heraeus F 369) was stencil printed on the substrate bond pads. Then after silicon chip placement, reflow soldering was accomplished in IR oven.

The last assembly solution was realized on the flexible substrate of polyimide foil (Kapton). Such substrate allows ensuring better contact with measured surface (e.g. human skin). On the pre-fluxed gold plated copper traces Sn 95 Ag 5 solder balls of diameter 250 µm were placed and reflowed on a hot plate. Then silicon sensor chip with solderable gold bond pads was aligned and placed on the solder bumps and soldering process was realized (Fig. 3). In this assembly solution underbump metallization (UBM) on the chip was changed, Cr-Ni-Au was used instead of Cr-Au.

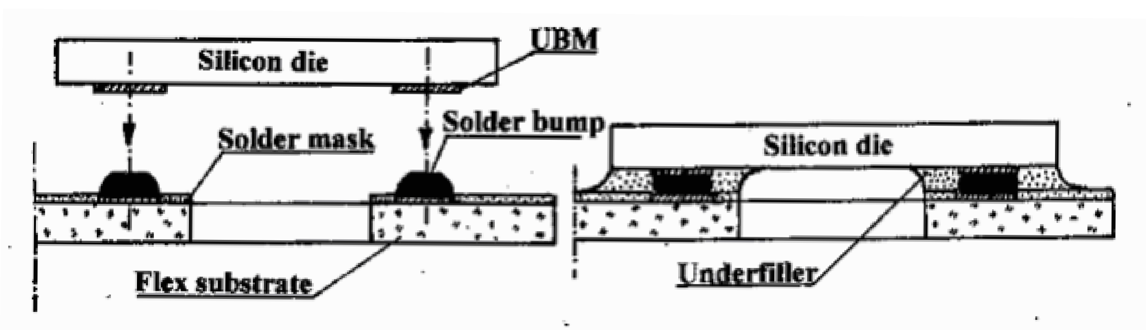

Fig. 3. Silicon humidity sensor chip assembly on the flex substrate.

In the last step underfilling process was carried out which on the flexible substrate plays particular role, taking into account its significant deformation during the contact with the measured surface i.e. human skin.

From among mentioned processes, the last assembly approach seems to be the best solution, taking into account the contact resistance value. The detailed specification of the presented assembly processes is shown in Table 1.

The next part of our research comprised silicon gas sensor based on 3-D silicon structure (Fig. 4). The essential parts of silicon gas sensor are silicon membrane, polysilicon heater and gas sensitive layer which are integrated with the silicon membrane.

APPLIED PROCESS	APPLIED MATERIALS
Silicon Humidity Sensor 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 gold ball size: ~ 180μm gold ball height (after flattening): ~ 80μm
Solder bumping on substrate bond pads	Sn95 Ag5 solder ball: 200μm diameter Kapton polyimide flex with the thickness of 120μm; Substrate bondpads Cu-Ni / Au
Stencil printing of solder paste	Heraeus solder paste F369 (Sn95.5 Ag4 Cu0.5) FR-4 glass epoxy laminate Substrate bondpads: Cu - Ni / Au
Reflow soldering on a hot plate	Soldering temperature: 240°C Time: 20s
Adhesive bonding	Loctite adhesive 3888 Curing temperature: 125°C Curing time: 1h
Underfilling	Underfiller with capillary action U-300 from Epoxy Technology Substrate preheating: 80°C Curing: 150°C Time: 5min
Silicon gas sensor with backside contacts chip size: 4 x 4mm; chip thickness: 400μm	
Adhesive bonding of wire connection with gold ball	P - 1011 adhesive from Epoxy Technology (silver filled polyimide) Curing: 150°C; Time: 1h
Thermocompression bonding of wire connection with gold ball----- Gold ball formation with flame of system	Gold wire diameter: 100μm Gold ball diameter: ~ 700μm
Average flip chip contact resistance value adhesive joints: 12 - 15mΩ solder joints: 3 -5mΩ thermocompression joint: 2 - 3mΩ	

Table 1. Specification of applied materials and processes

In such a sensor all bonding pads are placed at the bottom side of the silicon structure. They are 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 construction creates additional difficulties connected with assembly process.

The presented silicon gas sensor construction was designed and manufactured in cooperation of laboratories from Institute of Electron Technology in Warsaw and Department of Electronics of University of Mining and Metallurgy in Krakow [6].

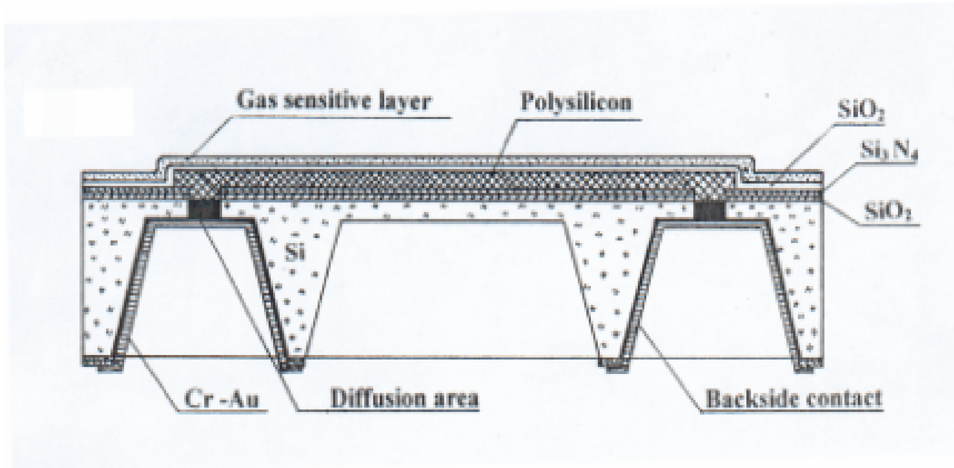

Fig. 4. Cross section of the silicon gas sensor.

Since the temperature under the gas-sensitive layer exceeds 350°C, the choice of assembly technique is limited. Two bonding technologies of making connections between backside contacts and sensor package were taken into consideration: adhesive bonding and thermocompression bonding. To fulfill temperature requirements, conductive adhesive based on polyimide matrix with operating temperature of 350°C was selected (P-1011 Epoxy Technology adhesive). Maximum temperature resistance in a short temperature cycle for this adhesive reaches 500°C. At the end of wire connection gold ball was formed to increase the adhesive joint surface and bond strength (Fig. 5).

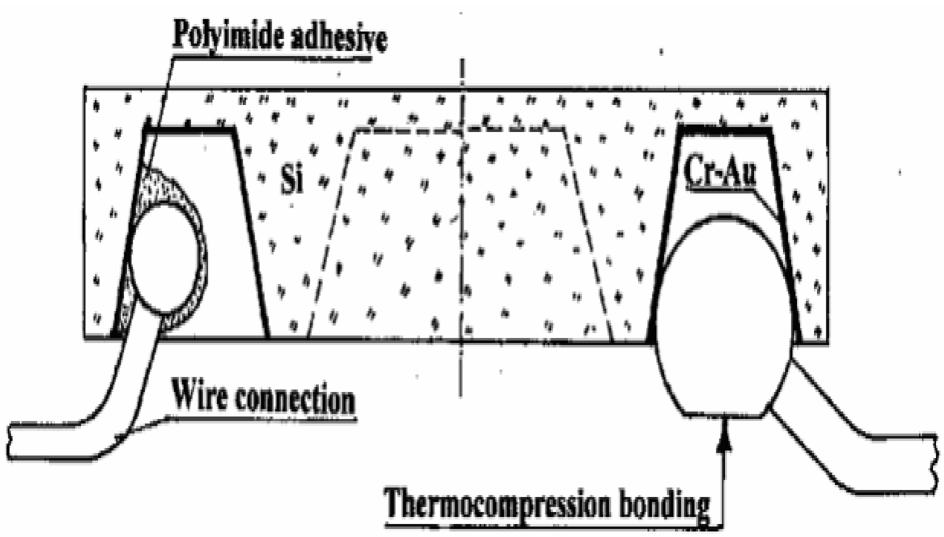

Fig 5. Adhesive and thermocompression bonding of wire connections.

The other assembly solution is based on thermocompression bonding process. To achieve large diameter gold ball at the end of wire connection , which is adequate to backside contact cavity sizes, the special forming method with the use of flame system was applied [Fig.6].

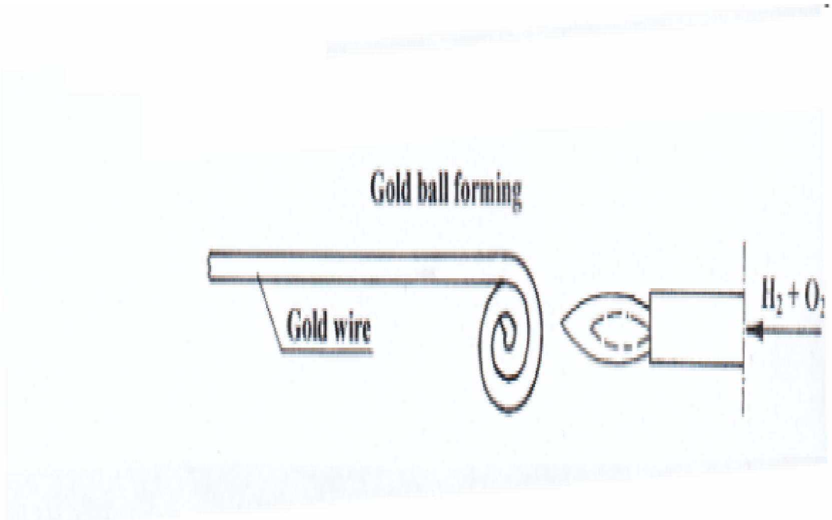

Fig. 6. The scheme of large gold ball forming.

When the flip chip sensor package is available, then all bonding processes can be accomplished by means of flip chip thermocompression bonding, where gold balls are directly connected to the backside contacts and package leads.

3. Conclusions

The great progress in assembly techniques that has been observed during the last years is also visible in area of sensor packaging which enabled the creation of new, more reliable sensors. Flip chip 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 which is very often found in medical applications.

For the 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 this process allows achieving the lowest contact resistance and high joint reliability. For the sensors mounted on flexible substrate, the underfilling process is necessary to relieve the thermal expansion mismatch between bonding materials.

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