System packaging & integration for a swallowable capsule using a direct access sensor

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Abstract

Technological developments in biomedical microsystems are opening up new opportunities to improve healthcare procedures. Swallowable diagnostic capsules are an example of this. In this paper, a diagnostic capsule technology is described based on direct-access sensing of the Gastro Intestinal (GI) fluids throughout the GI tract.

The objective of this paper is two-fold: i) develop a packaging method for a direct access sensor, ii) develop an encapsulation method to protect the system electronics. The integrity of the interconnection after sensor packaging and encapsulation is correlated to its reliability and thus of importance. The zero level packaging of the sensor was achieved by using a so called Flip Chip Over Hole (FCOH) method. This allowed the fluidic sensing media to interface with the sensor, while the rest of the chip including the electrical connections can be insulated effectively. Initial tests using Anisotropic Conductive Adhesive (ACA) interconnect for the FCOH demonstrated good electrical connections and functionality of the sensor chip. Also a preliminary encapsulation trial of the flip chipped sensor on a flexible test substrate has been carried out and showed that silicone encapsulation of the system is a viable option.

Key words: Flip chip over hole, direct-access sensor, flexible substrate, ACA, polysiloxane.

Introduction

The Human gastro-intestinal (GI) tract is prone to various distressing and fatal disorders which have dramatic effect on health and quality of life of people. As an example each year, around 3 million people in the US are hospitalized from gastrointestinal (GI) related disease [1]. No suitable reason or cause was ever found in more than one third of the cases.

The conventional method used to investigate suspected pathology employs an endoscope which is inserted through patient's mouth, nose (gastroscopy) or anus (colonoscopy). These procedures provide some information on the state of the GI tract: gastroscopy provides data about the oesophagus and the stomach while colonoscopy helps investigate the large intestine. These procedures are not only unpleasant for the patients but are also unable to provide any information on the condition of the small intestine.

With recent advances in electronics, wireless communication and microelectronic miniaturisation the limitation of endoscopy can be overcome by using a swallowable electronic capsule. The swallowable capsules can be classified into families of imaging (PillCam [2], Olympus Optical [1]), drug delivery systems (Enterion, ipill) and sensing capsules (Smart [3], Bravo device, IDEA [4], [5], ipill [6]. In none of these sensing capsules is the sensor interconnection achieved through Flip Chip (FC) and in particular Flip Chip Over Hole (FCOH) technology.

FCOH interconnection involves attaching a sensor chip's bond pads face down on to a substrate with an opening in it. This allows interaction between a sensor die and the medium to be sensed. FCOH is particularly suitable for low I/O count applications such as few I/O sensors [7]-[9] because it provides:

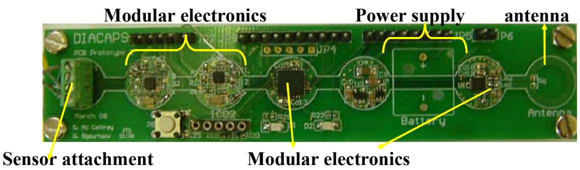
- Rugged connections;
- Requires low processing temperature (which results in low thermal stress during processing);
- Dual function, ACA interconnect vertical electrical conduction and liquid insulation around the substrate hole perimeter;
- Mask free process; potentially no post clean step.

This paper presents the zero level packaging and priliminary encapsulation trials of the flip chipped sensor. In the next section, a detailed review of the chip, test substrate, the FCOH packaging and the preliminary encapsulation trials will be presented with the results and discussion.

System Schematic

The electronic system is complex consisting of many elements, see figure 1. The sensor is interfaced to analogue circuitry for signal conditioning. A power supply is placed centrally along with a single lithium ion cell. A processing unit, or microcontroller, controls the measurement and communication process. An ultra low power wireless communication system is added, which provides the transfer of measured data to an external receiver module. This receiver has been developed to acquire the data and interface it to a PC end-user.

The latest system prototype implements the instrumentation in a modular fashion on circular PCB disks which are interconnected with a flexible polyimide core. In this way the disks can be folded for encapsulation and the flexible core provides a reliable interconnect between them.



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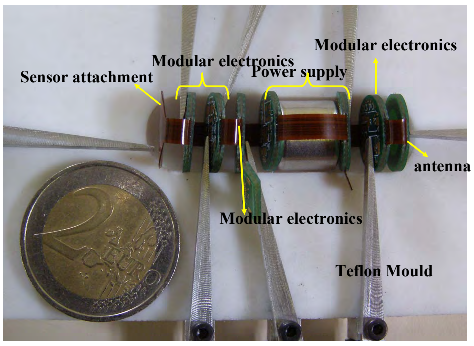


b)

Fig 1. a) PCB electronic system and b) system in serpentine form awaiting encapsulation.

System Components

Sensor Chip

The sensing chip was fabricated using silicon multi-layer process and photolithography techniques. Gold and platinum were deposited on the chip sensing area. The sensing chip had an I/O count of 5 300µm square pads, which were positioned on the periphery of a 6x6mm^2 die as shown in figure 2. The microelectronic sensor comprised of four gold working electrodes (WE) of 1 mm diameter and a platinum counter electrode (CE) of 2mm diameter. The distance between centers of counter electrode and the working electrode was set at 0.5mm.

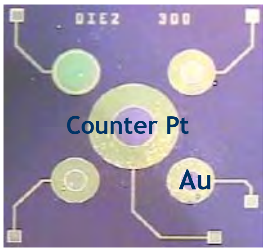


Fig 2. The Sensing Chip

Test Substrate

A thin subsrate with thickness 0.025mm was fabricated[1]. The board pad metallization scheme consists of 15µm Cu, 5µm Ni and 0.05µm of electroplated flash gold. Using a laser, a square window of 4.4mm was cut from the centre of the board to expose the chip to external conditions, see figure 3

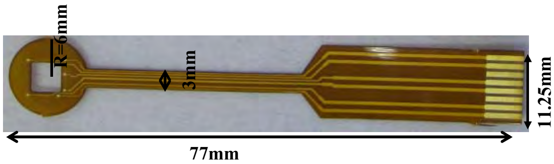


Fig 3. Flexible Polyimide FCOH sensor test substrate.

Assembly Process

A pre-cleaning procedure was carried out separately on both the chip and the substrate. This involved placing the chips and the substrates into a barrel type chamber of a March Plasmod system and exposing them to an oxygen plasma for 40sec at 150 watts. This was followed by IPA immersion in a bench top ultraware ultrasonic precision cleaner for 5 min followed by a DI water rinse. The samples were then dried in a conventional Heraeus vacuum oven at 150˚C for an hour.

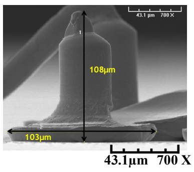
Gold stud bumps were formed on the die pads using a Kulicke and Soffa ball wedge gold bonder. The bumps had a mean diameter of 103 microns and a mean height of 108 microns, see figure 4a. This was followed by coining the gold stud bump on to a glass substrate using Finetech Fineplace 96 Lambda flip chip bonder. The main purpose of the gold bumps was to provide an under bump metallurgy so that a standoff would be provided when assembling the device onto to the substrate. The gold stud bump was coined at 11.7N at a coining temperature of 180ºC for 20 sec, see figure 4b.

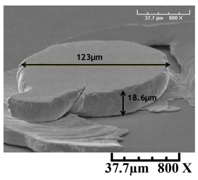
Bonding

ACA material from Loctite was dispensed on the test board using a CAM/ALOT 1414 liquid dispense system. A brown viscous epoxy paste with gold coated nickel filler particles of 7µm was used.

[1] Trulon printed circuits – UK.

The alignment of the chip/substrate was done using the Finetech Flip-Chip bonder. Bonding was carried out at 180°C and a bonding pressure of 10N for 8 sec. Figure 4c provides an overview of the assembly process.





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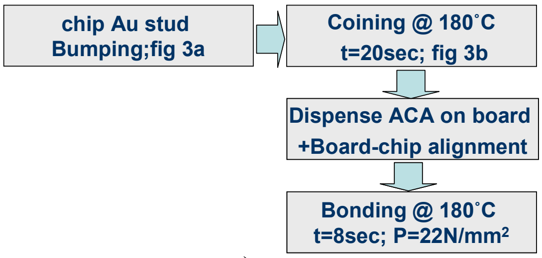


c)

Fig 4. (a) SEM image of a gold stud bump; (b) SEM image of a coined bump and (c) Flow diagram of assembly process.

Direct Access sensor testing

The electrical connection and the robustness of the packaging as well as the functionality of the sensor were tested using cyclic voltammetry of the three electrode sell comprising of WE and CE on the designed sensing chip and a standard Ag/AgCl electrode which was used as the reference electrode. Elecrochemical reactions occurring at the interface between the WE and the solution were monitored by a CH instruments 620B computer controlled potentiostat The fabricated test assemblies were dipped into a solution of 0.5M of H_2SO_4 and cyclic voltammetry test at a scan rate of 0.2V/sec was applied to the electrode system. The chemical reactions that occured at the gold WE in this solution is well documented [10] so any change in the performance of ACA or the component will be identified at this stage.

The measured voltammograms for different assemblies are presented in figure 5. Each voltammogram showed a similar response. A peak was obtained at 1.4V during the positive voltage sweep from 0 to 1.5V, and a corresponding peak was obtained at 0.9V during the negative voltage sweep. These gold peaks were due to gold oxide formation and reduction, and they illustrated the correct function of the sensor and interconnect.

Encapsulation of the direct access sensor.

The test assemblies were then encapsulated with silicone. The encapsulation process consisted from a number of steps: the first step involved dispensing silicone on the perimeter of the window using CAM/A LOT and cured in the oven at 80° for 3hrs. The cured silicone acted as a dam around the window. Then the protection of the sensor was carried out via AZ photoresist – Diazonnaphthoquinones (AZ Electronic Materials GmbH). The photoresist was applied using the pendant drop method - 6 drops of AZ on the sensor area - and cured at 80°C for 1 hr. It had a height of around 596.7µm and acted as a plug covering the exposed area of 19.36mm^2. Once the dam and the plug were ready, the assembly was inserted into a gelatin glycerin capsule (33mm*13mm) and secured in place. The fixed assembly was then filled with silicone and cured at room temperature for 24-48 hrs. This was followed by immersing the capsule in warm water (50°) for 10-15 min. to dissolve the glycerin capsule. The sensor was exposed by dissolving the AZ photoresist in acetone for 5-10 min, as shown in figure 6.

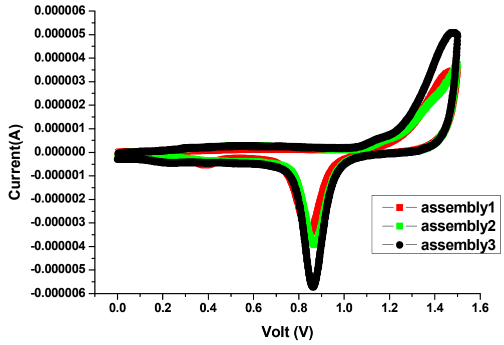


Fig 5. Cyclic current-voltage curve of the Au WE of 3 different chips with the same assembly method

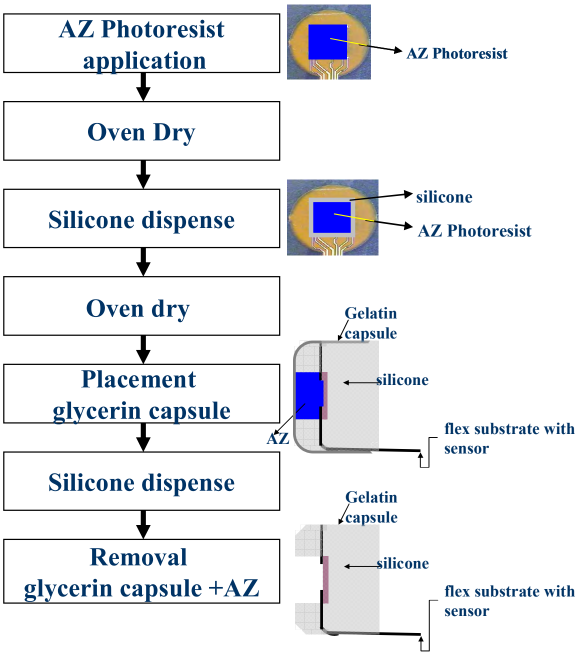
To prove a quality of the encapsulation process the cyclic voltammetry test was carried out on both an unencapsulated sensor and an encapsulated sensor. The derived voltammograms are shown in figure 7. A similar response was obtained for both of the tested sensors. Oxidation and reduction peaks were obtained at 1.4V and 0.9V for both sensors; minor changes in the shape of the voltammogramms can be related to a standard voltagramm dispersion as a result of difference between surface of the WE on the sensing chips and decreasing of the leakage current in case of encapsulated sensor. Thus this test results allows the conclusion that the assembly process for the sensor encapsulation did not affect the sensor operation.

Conclusion

These preliminary results show that FCOH can be used for direct-access sensor packaging and integration. Futrhermore ACA can be used as a suitable material for applications with few relatively large bond pads and particularly in relation to measurements in the fluidic environment when the sensing area needs to be sealed off from the electronics.

Electrical tests after system encapsulation with silicone showed that electronic functionality and chemical sensing performance wasn't compromised.

Future work will incorporate the study of leakage and impedance of the encapsulated assembly.



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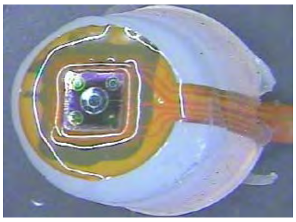

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Fig 6. (a) Encapsulation assembly process and (b) picture of an encapsulated assembly.

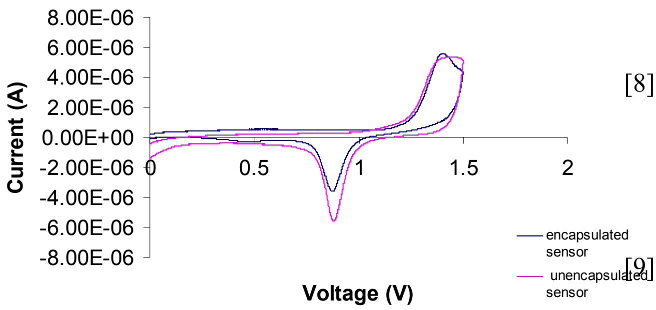

Fig 7. Voltammetric responses of an unencapsulated sensor and an encapsulated sensor

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References

[1] Colm Mc Caffrey, Olivier Chevalerias, Cian O'Mathuna, and Karen Twomey, "Swallowable-Capsule Technology", IEEE Pervasive Computing, Vol. 7, No. 1, pp. 23-29, January-March, 2008.

[2] Guido Costamagna, Saumil K. Shah, Maria Elena Riccioni, Francesca Foschia, Massimiliano Mutignani, Vincenzo Perri, Amorino Vecchioli, Maria Gabriella Brizi, Aurelio Picciocchi, and Pasquale Marano, "A Prospective Trial Comparing Small Bowel Radiographs and Video Capsule Endoscopy for Suspected Small Bowel Disease", Gastroentrology, pp. 999-1005, 2002.

[3] Roger Allan, "Smart Pill goes on a Fantastic Voyage", Electronic Design, Vol. 54, No. 27, pp. 66, December 2006.

[4] Erik A. Johannessen, Lei Wang, Li Cui, Tong Boon Tang, Mansour Ahmadian, Alexander Astaras, Stuart W. J. Reid, Philippa S. Yam, Alan F. Murray, Brian W. Flynn, Steve P. Beaumont, David R. S. Cumming, and Jonathan M. Cooper, "Implementation of Multichannel Senosrs for Remote Biomedical Measurements in a Microsystems Format", IEEE Transsactions on Biomedical Engineering, Vol. 51, No. 3, pp. 525-535, March 2004.

[5] K. Twomey, J. Marchesi, "Swallowable Capsule Technology: current perspectives and future directions", Endoscopy, vol. 41, pp. 357-361, 2009.

[6] http://technologyreview.coverleaf.com/technologyreview/200902/?pg=80.

[7] Francesca Campabadal, Josep Lluís Carreras, Enric Cabruja, "Flip-Chip packaging of piezoresistive pressure sensors", Sensors and Actuators, A 132, pp. 415-419, 2006.

[8] Jun Karasawa, Masao Segawa, Yasukazu Kishimoto, Makoto Aoki, Tomoyuki Sasaki, "Flip Chip Interconnection Method Applied to Small Camera Module", IEEE Electronic Components and Technology Conference, pp. 1024-1028, 2001.

[9] R. Briegel, M. Ashauer, H. Ashauer, H. Sandmaier, W. Lang, "Anisotropic conductive adhesion of microsensors applied in the instance of a low pressure sensor", Sensors and Actuators A: Physical, Vol. 97-98, pp. 323-328, April 2002.

[10] L. D. Burke, B. H. Lee, "An investigation of the electrocatalytic behaviour of gold in aqueous media", Journal of electroanalytical chemistry, pp. 637-661, 1992.