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Mechanical assessment of an anisotropic conductive adhesive joint of a direct access sensor on a flexible substrate for a swallowable capsule application

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ABSTRACT

Sensor interconnection achieved with Flip Chip (FC) technology and most particularly with Anisotropic Conductive Adhesive (ACA) is a very attractive technique, in achieving a Direct Access Sensor (DAS), in a swallowable diagnostic sensing capsule. This paper describes the work carried out to mechanically characterise the ACA joints when they are inserted in the capsule to determine the smallest capsule diameter that could be used without imparting excessive stress on the interconnect in the DAS integration process for a specific substrate and chip design. Three point inward bending was used to study the effect of the mechanical loading on the joints during the insertion process. The results showed that the insertion force linearly increased and leveled off at a, low friction, constant value. The spring constant of the linear region in a 23 mm was 0.2729 N/mm and increased to 1.5 N/mm for the 15 mm diameter hole. It showed that the spring constant decreased linearly as the diameter increased, signifying that for the same distance, less force will be required in a larger diameter hole than in the small diameter holes. During insertion the stress in the assembly, was higher towards the centre of the chip and the window than at the edge of the chip and the ACA fillet. This was characterised by it exhibiting lower voltage values measured in the partial daisy chains that were close to the window rather than the ones that were situated away from the window. The insertion test suggested that the 23 mm diameter hole would be the smallest suitable hole for insertion of this assembly. Failure analysis revealed that the depression and the wide crack close to the window imply that the stress was high in this region. The cross sectional analysis showed that failure occurred within silicon/silicon chip pad and that the ACA contacts form a strong joint and was able to withstand the insertion force required to secure the ACA sensor in place before encapsulation.

1. Introduction

With recent advances in microelectronics, wireless communication and sensor development, the limitations of endoscopy is overcome in the format of a biomedical swallowable capsule [1]. The swallowable capsule is an autonomous system which contains a sensor, the associated electronics for signal conditioning and amplifying and a radio transmitter, all encapsulated in a biocompatible material. The swallowable capsule is based on a non-invasive technique which can provide information about the whole gastrointestinal (GI) tract. The concept of the first radio telemetry ingestible capsule was put forward by Mackay and Jacobson in 1957 [1,2]. Swallowable capsules can be classified into families of imaging capsules (PillCam, Olympus Optical) [2–4], drug delivery systems [2,4,5] and sensing capsules [1,2,4–12]. Unlike imaging and drug delivery capsules where none of the parts are exposed, chemical sensing capsules have one or more sensors that can measure biochemical variables related to the gut ecosystem through exposed sensors. But in none of the diagnostic sensing capsules is the sensor attachment (the first level packaging of the sensor in a swallowable capsule) is achieved through Flip Chip (FC), and in particular by the Flip Chip Over Hole (FCOH) method using Anisotropic Conductive Adhesive (ACA).

ACAs relatively simple process steps [13] make it suitable for bonding a Direct Access Sensor (DAS). In a DAS, ACA not only provides the electrical interconnection to the sensing die but simultaneously seals the interconnect area around the die and the flexible substrate. This sealing should provide protection to the underlying electronics in a capsule application, as shown in Fig. 1.

During DAS integration into a swallowable capsule, a mechanical force is required to push the sensor assembly through the length of the capsule before securing the chip and the substrate in the capsule for the encapsulation process [14]. The compressive force during the securing of the chip used in this study has been shown to be 7 N [14]. This study also showed that the DAS packaging was reliable (as the electronic functionality and chemical

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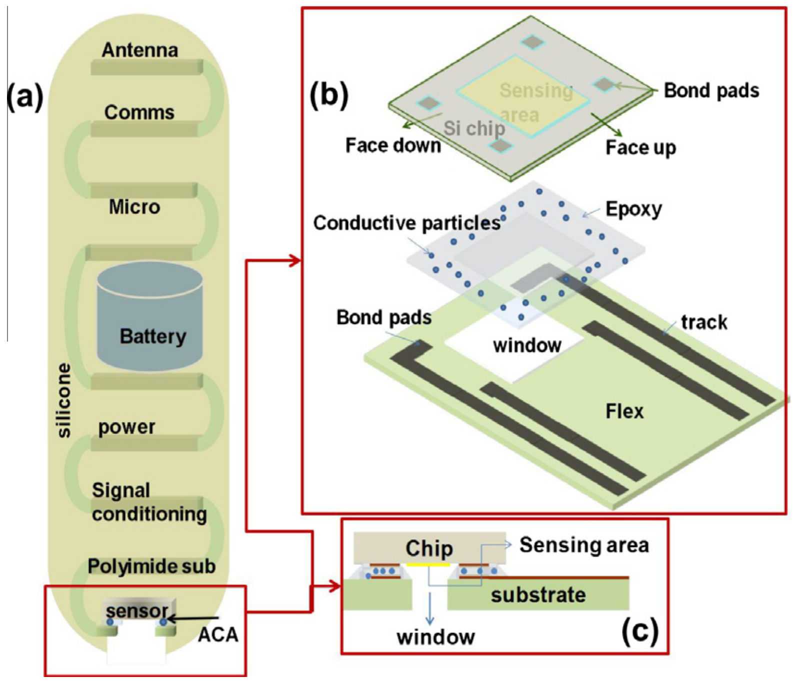

Fig. 1. Schematic of (a) capsule with (b) expanded image of FCOH/DAS and (c) cross sectional view of FCOH/DAS interconnections based on ACA.

sensing performance was not compromised) and that the mechanical securing did not degrade the ACA joints. But it did not provide any information about the joint behaviour during the capsule insertion process.

Fig. 2a and b shows the three point bending and four point bending tests [15–19] that are often used to assess the mechanical reliability of ACA joints. Depending on the position of the die on the substrate and the *z* axis, the bending could be classified into two categories [20,21]: (i) the outward bend characterised by the die positioned on the negative part of the *z* axis as shown in Fig. 2a and b and (ii) the inward bend distinguished by the die positioned on the positive side of the *z* axis, Fig. 3.

Most of the literature deals with outward bending using three or four point bending. A study conducted by Rizvi et al. [15] on the outward three point bending on the ACF joint behaviour showed that the stresses were high on the corners where the chip and ACF were connected together. The high stress at the corners led to increased ACF thickness at the corners and eventually caused a greater gap between the chip and the substrate at the corner positions and the failure of the corner joints.

Cai et al. [20,21] reported on the reliability evaluation of a flexible RFID tag using ACA. The flexibility reliability test showed that the outward bend was more destructive on the contact conductivity than the inward bend. It was concluded that the outward bend caused a tearing effect and that the bend cycle caused the particles between the bump and the pad to undergo an open–close action. Furthermore the inward bending created a constant compressive stress on the ACA joints providing a stable contact resistance during the test.

The DAS capsule integration of the FCOH sensor assembly in this work could be only achieved by an inward bending of the sensor assembly. This paper describes the work carried out to mechanically characterise the ACA joints during the capsule insertion process and to determine the smallest capsule diameter that could be used without imparting excessive stress on the interconnect in the DAS integration process for a specific substrate and chip design. It will investigate the forces required for the insertion of the flex assembly (fixed size) into different sized capsules. The following section describes the materials and the method used for the research. This is followed by the ACA assembly insertion test into different diameter holes to determine the smallest diameter that could be safely used for a specific assembly.

2. Materials and method

2.1. Test chip

The test chip was a 5 mm × 5 mm silicon die with a thickness of 0.5 mm. The test chip was designed specifically for this FC reliability investigation and had an array of 144 (100 μm × 100 μm) pads, with a pad pitch of 400 μm, as shown in Fig. 4. An interleaved sequence of connective pads was laid out on the chip so that it could be used as a daisy chain in the final assembly and thus monitor the

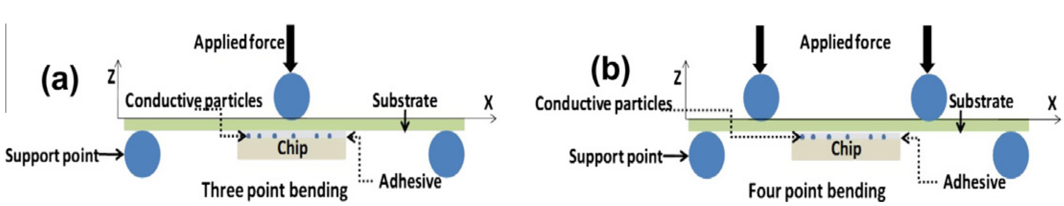

Fig. 2. Schematic of (a) three point; and (b) four point outward bending, force applied to substrate.