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ScienceDirect

Procedia Engineering 168 (2016) 1763 – 1766

Procedia Engineering

www.elsevier.com/locate/procedia

30th Eurosensors Conference, EUROSENSORS 2016

Reliability of anisotropic conductive adhesive flip chip attached humidity sensors in prolonged hygrothermal exposure

Laura Frisk, Sanna Lahokallio, Milad Mostofizadeh, Anniina Parviainen and Janne Kiilunen

Department of Electrical Engineering, Tampere University of Technology
P.O.Box 692, 33101 Tampere, Finland

Abstract

Sensor components may markedly differ from typical silicon chips. Consequently, versatile attachment methods are required for their interconnections. Anisotropic conductive adhesives (ACA) are interesting materials for attachments of sensors due to their versatility. In this study reliability of ACA attached humidity sensors was studied in hygrothermal conditions. The reliability of the interconnections was found to be excellent even under prolonged exposure showing that high reliability can be achieved with ACA materials in sensor applications.

Keywords: Humidity sensor; Flip chip, Anisotropic conductive adhesive; FR4, Polyimide, Reliability; Humidity testing

1. Introduction

Interest to use sensor components both in commercial and in industrial applications has increased considerably. In humidity sensors the sensing is often based on changes in the properties of a specific material. This makes their structure and packaging different from typical silicon chips. To function, these sensors need also to be open to their use environment. This may make their packaging difficult, as the package needs to be open to the environment too and therefore cannot fully protect the component and its interconnections from the environmental stresses.

If a sensor has structures and materials which differ from those traditionally used to package silicon chips, the use interconnection materials and processes may be restricted. If soldering is not a viable technique for the electrical attachment of a sensor, electrically conductive adhesives (ECA) may provide a suitable alternative. ECAs are polymer materials filled with conductive particles. In anisotropic conductive adhesives (ACA) particle concentration is low and they conduct only after the attachment process.

doi:10.1016/j.proeng.2016.11.509

ACA materials are especially well suited for flip chip technology, in which an unpacked chip is attached an active side down onto a substrate [1]. This technology has increased its popularity, since it provides a possibility for very small and light weight sensor packages. ACAs are typically epoxy-based materials to which conductive fillers, such as nickel or gold-plated polymer particles, have been added. During the ACA bonding process, the adhesive is pressed between the mating contacts on the chip and the substrate. The ACA interconnection is established by applying pressure and heat simultaneously to the interconnection. Part of the conductive particles is trapped between the contacts and deforms, forming an electrical connection.

The use of ACAs in sensor applications has increased due to their many advantages. These include for example capability for very high density, simple and low cost attachment process, low attachment temperature, and a wide variety of materials available for different applications. As the structure of the sensor components may be very different from the silicon chips used in the majority of the ACA studies and, additionally, the conditions they are used in are often very demanding, there is a clear need for further studies with sensor components. Since the ACA matrix is polymer based, it is often vulnerable to environmental stresses such as humidity and high temperature. Therefore, it is important that the behaviour and stability of the ACA interconnections is studied using prolonged tests before the ACA technique is adapted to commercial products.

The aim of this study was to investigate the reliability of ACA attached sensor components under long-term exposure to humid environments. Humidity sensor components were attached using an ACA flip chip technology on a thin FR-4 and a flexible polyimide (PI) substrates. The attached sensors were exposed to hygrothermal testing. During testing the attachments of the components were studied in-situ which gave accurate information of the interconnections and their failures. After testing the logging data was analysed for failures.

2. Experimental

A humidity sensor was used in the study. The functionality of the sensor was based on specific polymer material which changed its properties in humid environments. The sensor chip consisted of a glass substrate, onto which the polymer material had been attached as a film. The size of the sensor chip was 4mm × 5mm. For the measurements two contacts were manufactured on the sensor chip. One contact was processed on top of the polymer film and the other was processed directly on the glass substrate. Consequently, there was a variation of approximately 2µm between the heights of the contact areas. Due to the structure no bumping of the chip was possible. Both contact areas had gold coating. The structure of the sensor component is shown in Fig 1a.

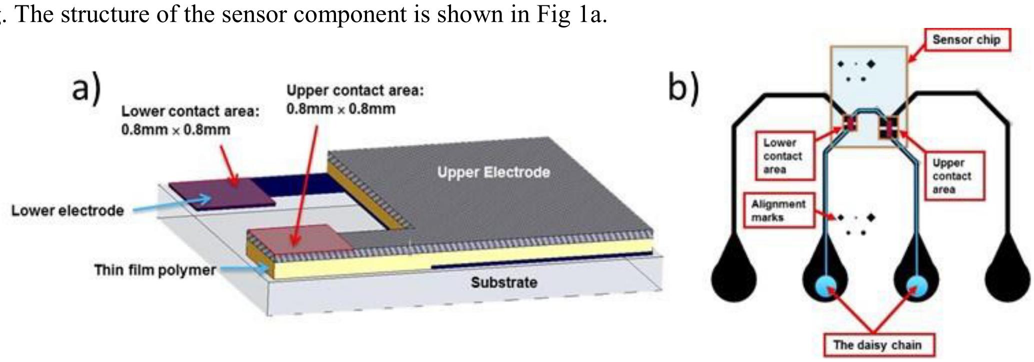

Figure 1 a) The structure of the sensor component. b) A schematic picture showing the attachment site for a single sensor.

The sensors were attached using a commercial epoxy based ACA film (ACF). The film had compliant polymer particles of 5 µm with gold coating. Pliable particles were used due to their considerable deformation and therefore capability to even out the height differences between the contact areas.

Two different substrates were used in this study. Both substrates had the same layout and size and connection sites for eight chips. The first substrate studied was an FR4 test board made of glass fibre reinforced epoxy. This test board was relatively thin (120µm), which made it fairly flexible. The other substrate was a 50µm thick flexible polyimide (PI) substrate. Both substrates had copper tracks with nickel gold coating.

Sensor chips were attached onto the substrates using a Toray FC-1000 flip chip bonder. Bonding time and temperature were chosen on the basis of earlier studies with the same ACF and recommendations of the manufacturer. The bonding temperature used was 220°C and the time was 25s.

The bonding pressure may have a major effect on the reliability of the ACF interconnections [2]. In this study the contact areas were very large compared to the typical contact areas of flip chip components. Because of this three different bonding pressures were studied. The chosen pressures were 25MPa, 50MPa and 100MPa. The pressure range recommended by the manufacturer of the ACF was 50-150MPa. Therefore, the lowest pressure used in this study was markedly below the recommended value. However, as the recommended values had been calculated according to the typical contact areas of a flip chip component, the aim was to see if a lower value would be sufficient for the large contact areas. In addition to the bonding pressure, the amount of the ACF was also varied. A part of the test samples was attached using a ACF film large enough to cover the whole area of the sensor component and a part of the test samples were attached using a ACF film which covered only the contact area of the sensor component. The test series manufactured are presented in Table 1.

Table 1 Test series assembled with the FR-4 and PI substrates.

Substrate	Pressure	Number of samples / series	Test
FR4	25MPa, 50MPa, 50MPa small amount of ACF, 100MPa	8	85°C / 85%RH, 13,000h
PI	50MPa small amount of ACF, 100MPa small amount of ACF	20	85°C / 85%RH, 10,000h

The main aim of this study was to investigate the reliability of the ACF interconnections. Consequently, a simple daisy chain (DC) structure was formed between the substrates and the components. To do this the contact pads on the substrates matching the contact areas on the chips were divided into two. A pitch of 200µm was used between the pads on the substrates. The sizes of the pads for the upper contacts were 1.2mm × 0.5mm and for the lower contacts 0.8mm × 0.3mm. A schematic picture showing the attachment site for a site of a single sensor component is shown in Fig. 1b. The daisy chain has been marked with a blue line and blue dots show the measurement pads for the daisy DC structure.

The effects of harsh humidity conditions on the sensor interconnections were studied using a constant humidity test. The test temperature was 85°C and relative humidity (RH) 85%. The overall test duration varied from 10,000h to 13,000h (approximately 60-77 weeks). The DC resistances of the test samples were measured before testing to ensure their functionality. Additionally, to study the behaviour of the contact resistances during testing the resistance values were measured in-situ.

3. Results

The yield of the attachment process with both substrates was 100 %. The average DC resistance values including the measurement system were 0.25 ohms at room temperature. The structures of the interconnections were studied using cross-sections and scanning electron microscopy (SEM). The quality of the interconnections was found to be good and good deformation of the polymer particles had been achieved with both contact areas and all bonding pressures. In Fig. 5a a cross-section of the interconnection with the upper contact area is shown. An example of the deformed conductive particles of the ACF is shown in Fig 5b.

Twenty times increase of the DC resistance was used as a failure criterion. A relatively high failure criterion was used as the sensor was based on a capacitance measurement and, therefore, was not very sensitive to the changes in the interconnection resistances. The resistance values were found to be very stable during testing. No failures were seen with FR4 test substrate with the 25MPa and 50MPa test samples. Only one failure was seen with the highest 100MPa bonding pressure. This sample showed increased resistance values during and after the tests. The amount of ACF did not affect the results. Similarly, with the PI substrate no failures were seen with the 50MPa bonding pressure. Two failures were seen with the highest bonding pressure of 100MPa. One of the failed samples showed an open interconnection during testing and the other sample had an increased resistance value of approximately 100Ohms.

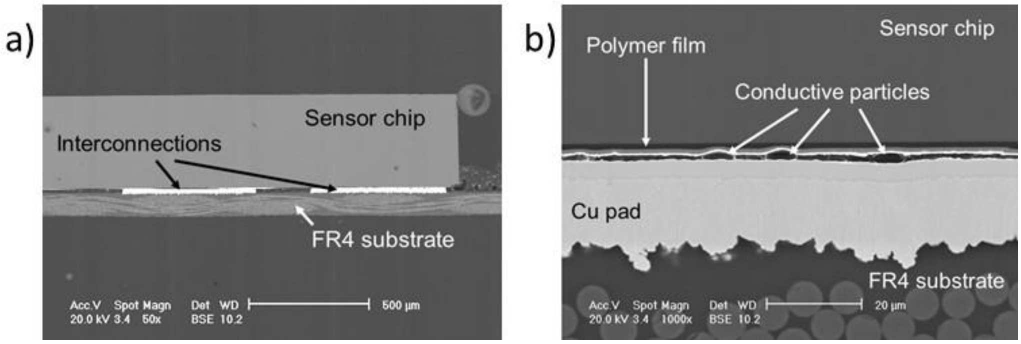

Figure 2 a) SEM image of an interconnection with the upper contact area. b) SEM image of deformed conductive particles.

Both substrates had an excellent reliability during the test even though a very long high humidity and high temperature test was used. This indicated that the ACF was well suited material for the studied sensor component. Both the substrate material and the ACF absorbed moisture during the hygrothermal test, but only a few failures were seen during the test. This showed that even though humidity is absorbed in the system it did not deform the structure enough to cause humidity related failures such as delamination, deformation and corrosion [3,4].

The only failures seen were with the highest bonding pressure, even though it was in the middle of the pressure range recommended by the ACF manufacturer. The studied humidity sensor had very large contact areas and the results indicate that relatively low ACA bonding pressure is beneficial when large contact areas are connected. Too high contact pressure may crush the conductive particles, cause microcracking in the components and form high stresses to the structure. These may all cause failures under demanding conditions and may be the reasons for the failures seen during testing.

4. Conclusions

The reliability of ACF interconnections with sensor components were studied. The sensor had a polymer film under one of the contact areas making its interconnections demanding. Two different substrates, FR4 and flexible PI, were used in the study. Additionally, three different bonding pressures and two amounts of ACF were used. To study the reliability of the interconnections a prolonged high humidity and high temperature test was used (10,000h-13,000h).

After the bonding process the quality of the ACF interconnections was found to be good. A DC structure was used to study the electrical behaviour of the interconnections. The yield after the bonding process was found to be 100%. Cross-sections of the interconnections showed the deformation of the particles to be good.

No failures were seen with either of the substrates with the two lower bonding pressures, even though the lowest pressure was considerably below the values recommended by the manufacturer of the ACF. Three failures were seen with the highest pressure. This indicated that the low pressure was beneficial for the studied structure most likely due to its large contact areas. No indication of humidity related failures such as corrosion or delamination was seen. The results show that very good reliability can be achieved with ACF interconnections in humid environments and this technique shows great promise for sensor applications with challenging contact structures or materials.

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