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Effects of different anisotropically conductive adhesives on the reliability of UHF RFID tags

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ABSTRACT

Radio frequency identification (RFID) system consists of a reader and tags which can be attached to the object to be identified. Such systems are used to identify multiple objects individually and reliably using radio waves without visual connection to the reader. An RFID tag has a simple structure with an antenna to which a chip is attached. Typically anisotropic conductive adhesives (ACAs) are used as attachment materials between the antenna and the chip. ACAs may have a significant impact on the reliability of a tag. In this paper the behaviour of RFID tag interconnections made with four different commercial ACAs was studied. For purposes of comparison the ACAs were characterized using several techniques. The reliability of the interconnections was studied using temperature cycling and constant humidity tests. Clear differences in the failure times between the ACAs were observed. Furthermore, different environments were found to have different effects on the reliability of the ACA interconnections. The results showed that the properties of the ACA should be carefully considered and reliability aspects taken into consideration when ACA for RFID applications is chosen.

1. Introduction

Currently the trend in electronics is towards smaller and lighter devices offering superior performance [1]. At the same time better reliability, environmental friendliness and lower costs are also required [1]. Anisotropic conductive adhesives (ACAs) may be used to achieve these goals. ACAs are electrically conductive adhesives consisting of polymer matrix and conductive particles. In ACAs the number of particles is below the percolation threshold and thus the ACA serves as an insulator before the attachment process [1]. In the attachment process some of the conductive particles are trapped between the contact areas of a chip and a substrate, thereby forming an electrical path in the z direction, but serving as an insulator in the other directions. The cured polymer matrix serves as a mechanical backup and keeps the bumps on the chip and the pads on the substrate in contact [2].

ACAs are a viable alternative to solders, which are more commonly used in electrical attachments. Compared to solders, ACAs can be used in finer pitch applications, and they are more environmentally friendly as their bonding process involves fewer processing steps [3–5]. Fig. 1 shows a typical bonding process for an ACA flip chip interconnection using anisotropic conductive paste (ACP). Relatively high pressure is needed during the process to ensure adequate deformation of the conductive particles. The ACA is cured by heating through the chip and often also through the substrate. Depending on the ACA matrix, relatively low bonding temperatures may be used. Consequently, ACAs can be used in sensitive applications and with various low-cost substrates and components [3,4,6]. ACAs are therefore widely used in the flip chip interconnections of different applications, for example in low-cost radio frequency identification tags (RFID tags) [7,8].

RFID is an emerging technology in the field of identification and security. An RFID system consists of a reader and an RFID tag attached to the identified object. With RFID technology multiple objects can be identified using radio waves simultaneously without human assistance and without visual connection to the reader [9]. The RFID tag consists of an antenna, which receives and backscatters the radio frequency signal, and a microchip which controls the operation [10]. The microchips are typically attached to the RFID tags with ACAs using flip chip technique [11]. The components and the operating principle of an RFID system are described in more detail in [12]. RFID tags are typically inexpensive and compact, and suitable for numerous applications [10]. Passive ultra-high frequency (UHF) RFID tags operating at frequency bands from 840 MHz to 960 MHz, are extensively used to track and identify products during manufacture, distribution and shipment [13–16].

Due to the numerous application options, RFID tags may be exposed to various environmental conditions likely to impair their reliability, making reliability studies crucial. Accelerated life tests

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(ALTs) are widely used in reliability studies. With these tests locus of failure and failure mechanisms can be studied relatively fast. According to earlier studies, polymeric interconnections, such as ACA joints, are susceptible to stresses caused by high temperature and humidity, and variation in these factors. Temperature cycling tests and constant humidity tests with elevated temperature and humidity are therefore widely used in reliability studies on ACA joints [1,3,5].

In our earlier studies we have studied the ALT methods for RFID tags [12,17–19]. The results of these studies showed that the failure mechanisms of the tags depend greatly on the test conditions. In addition to the test conditions, other factors such as attachment conditions and the structure of the tag affect the reliability [20–22]. Although, the selection of the ACA material in RFID tags may also have a significant impact on their reliability and, furthermore, different use environments may require different kinds of ACA materials, very little research has been conducted to compare different ACA materials in RFID structures. Rasul has compared the different commercial ACA materials to show that their reliability fulfils the typical industrial ALT requirements [23]. However, as no failures occurred, reliability comparison between the materials was not possible. Cai et all compared two ACAs in humid conditions [24]. Although some changes were seen in this study, the test duration was long enough to properly compare the behaviour of the ACAs. Furthermore, no data of the ACAs was given.

The aim of this study was to investigate how differing ACA materials affect the reliability of RFID tags. Four different, commercial ACAs were studied. Two materials were ACAs used in RFID application. The third was a new ACA developed especially for applications in which the bonding temperature is critical. This ACA could be cured at very low temperatures if necessary. The fourth ACA was designed for high reliability flip chip applications and was not designed for RFID use. The reliability of RFID tags with the four ACAs was studied using a temperature cycling test and a constant humidity test. The performance parameters of test tags were measured periodically during testing to monitor the effect of aging on the RFID tags. Material characterization for the ACAs studied was done with differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), thermomechanical analyser (TMA) and dynamic mechanical analyser (DMA). Failure analysis was performed with a scanning electron microscope (SEM).

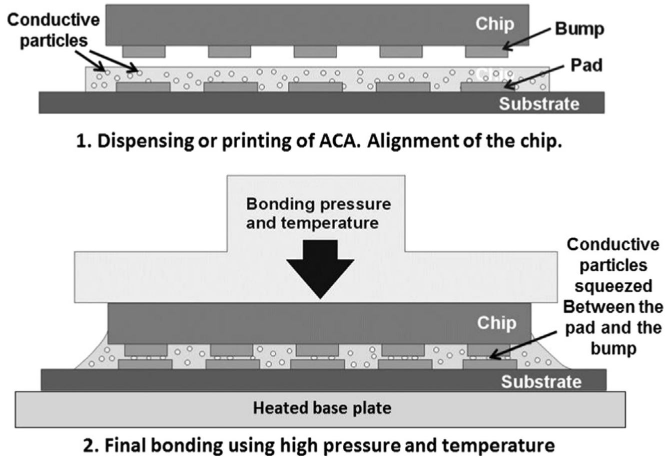

Fig. 1. The bonding process of an ACP interconnection. 1. The ACP material is dispensed or printed on the substrate. After this the substrate and the chip are aligned. 2. The ACP matrix is cured by heating through the chip and often also through the base plate. During curing high pressure is applied to the chip to ensure deformation for the conductive particles which are trapped between the pad and the bump.

2. Experiments

2.1. Test samples

The test sample was a passive UHF RFID tag manufactured on a thin and flexible polyethylene terephthalate (PET) substrate with a thickness of 50 μm. A dipole antenna was manufactured on the substrates with a length of 7 cm. The antenna and other metallization on the substrate were made of aluminium with a thickness of 9 μm and they were attached to the substrate with a thin adhesive layer. The test chip, a small radio frequency integrated circuit (RFIC) with four gold bumps, was attached in the middle of the antenna (Fig. 2). The dimensions of the chip are described in [12,17,18].

The chips were attached on the antennae with four commercially available anisotropic conductive adhesive pastes (ACPs). According to their datasheets three of the ACPs were epoxy based (ACPs A, C, and D) and one was modified polycarbaminacid derivative (ACP B). Some other characteristics of the ACPs according to their data sheets are listed in Table 1. In the attachment process, ACP was manually dispensed onto the substrate, the RFIC was aligned over the adhesive and the ACP was cured under pressure at elevated temperature with a Toray FC-1000 flip chip bonder. Bonding parameters (Table 2) were chosen according to the manufacturer′s recommendations. One set of bonding parameters was used for all the samples in the temperature cycling test. However, in the constant humidity test two different bonding tool temperatures were compared with each ACP. The second temperature was 20 °C higher for each ACP and is shown in brackets in Table 2.

2.2. Material characterization methods

Material characterization was done for the cured ACP B, C and D samples to compare their properties. Differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), a thermomechanical analyser (TMA) and a dynamic mechanical analyser (DMA) were used. The parameters studied included chemical structure, glass transition temperature (T_g), coefficient of thermal expansion (CTE) and storage modulus (E').

Mettler Toledo DSC 1 STARe system was used for the DSC measurements. Two measurements were taken between 35 °C and 260 °C with temperature change rates of 20 K/min and 10 K/min. The samples were measured twice for each change rate to study their properties after curing and without their thermal history. Nitrogen atmosphere was used during the measurements.

The FTIR measurements were conducted using Thermo Scientific Nicolet iS10 FTIR with diamond Attenuated Total Reflectance (ATR) system. Two measurements were taken for each material in different positions using 12 scans. After the measurements the average of the scans was calculated and used for the analysis.

The TMA measurements were taken with TA Instrument TMA Q400EM system. The measurements were taken between ambient and 200 °C with a temperature change rate of 2.5 K/min. Two runs

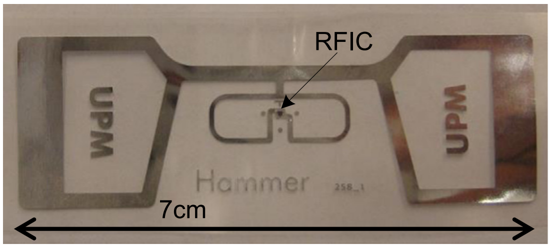

Fig. 2. Test tag used in this study.