We are IntechOpen,
the world's leading publisher of
Open Access books
Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Study of Structure and Failure Mechanisms in ACA Interconnections Using SEM

Laura Frisk
Tampere University of Technology, Department of Electronics,
Finland

1. Introduction

The trends in the electronics industry have for several decades been for smaller size combined with greater functionality. One enabler for this trend has been development of new packaging solutions which has required the development of new materials and also new interconnections technologies. In the development of these technologies it has been essential to have effective tools to study the structure of the packages and their failure mechanisms. Due to the versatility of electronics packages concerning materials, structures, and functions a plethora of different methods have been used. These include for example electrical characterization technologies, x-ray, scanning electron microscopy (SEM), scanning acoustic microscopy (SAM), optical microscopy, differential scanning calorimetry (DCS), and thermomechanical analysis (TMA) (Chan et al., 2000; Jang et al., 2008; Yim & Paik, 2001).

This chapter concentrates on flip chip technology, which is one of the technologies developed to miniaturise an electronics package. In this technology a bare chip is attached directly onto a substrate without wiring needed to connect the chip. As the attachment is done with the active side of the chip towards the substrate, the chip is flipped before bonding. Hence the name flip chip. Flip chip technology has several advantages as it enables the production of small, very high density packages. In addition, it has good electrical performance due to the short interconnection path (Lau, 2000). This method can be used to attach a chip directly onto a substrate, but also as an attachment method in single-chip packages, such as a ball grid array (BGA) and a chip scale package (CSP), and in multi-chip modules.

One problem with this technology is that the quality of the joints is relatively difficult to assess. Semiconductor chips used in this technology may have hundreds of contacts which form an area array below the chip. In order to study the joints a cross-sectioning is often needed. Although cross-sections give lots of valuable information, they are restricted to very small area of a package and thereby often several cross-sections are needed. Additionally, the information of the interconnections may need to be increased using other techniques. For example scanning acoustic microscopy may be used to study the amount of delamination in a package. The cross-sections may be studied by optical microscopy. However, for detailed information scanning electron microscopy is the preferred method of analysis.

Currently mainstream flip chip technology is based on solder bumps. These can be produced using both traditional tin-lead and new lead-free solders. However, mounting environmental concern has increased interest in electrically conductive adhesives, as they are environmentally friendly. In addition to being lead free, they can be used with substrate materials which do not withstand soldering temperatures. Thus they can be used to solve the problem caused by the high reflow temperature needed by most lead-free solders (Li & Wong, 2006).

Compared to solders adhesive materials are more complex as they are polymeric materials containing conductive particles. They have several advantages which makes their use profitable. However, due to their complex structure quality of the interconnections made by these materials needs to be determined carefully to attain good reliability. There are two types of electrically conductive adhesives. In isotropic conductive adhesives (ICA) the concentration of the conductive particles is high and they conduct in all directions. On the other hand, in anisotropic conductive adhesives (ACA) the concentration of conductive particles is low and the adhesive conducts in z-direction only after the bonding process. This chapter will concentrate on ACA materials used in flip chip applications. This chapter will discuss specifically how SEM may be utilised to study the quality and failure mechanisms of ACA interconnections.

2. Polymeric interconnections for electronics

Electrically conductive adhesives used in electronics consist of polymer binder and conductive particles. Polymer resins used in these adhesives are inherently insulators. To obtain an electrically conductive adhesive they must therefore be filled with electrically conductive fillers, such as metal particles. In the following properties and materials of two main types of electrically conductive adhesives are discussed. Isotropic conductive adhesives (ICA) have high concentration of the particles and they conduct in every direction. These materials may be used to replace solders. If the concentration of conducting particles is low, an anisotropic conductive adhesive (ACA) is formed. ACAs conduct electrically only in a vertical direction and thereby may be used in very high density applications.

2.1 Isotropic conductive adhesives

Isotropically conductive adhesives are formed by adding enough conductive filler to a polymer matrix to transform it from an insulator into a conductor. This transformation has been explained by a percolation theory. When the concentration of conductive filler is increased, the resistivity of the adhesive drops dramatically above a critical concentration, and this is called the percolation threshold. It is believed that at this concentration the conductive particles contact each other forming a three dimensional network, which enables the conductivity. After the percolation threshold the resistivity decreases only slightly with increased concentration of the conductive filler. (Lau et al., 2003) The mechanical interconnection of an ICA joint is provided by the polymer matrix. If too high a concentration of the conductive filler is used, it may impair this interconnection. Thus the amount of conductive filler needs to be large enough to ensure good conductivity without sacrificing the mechanical properties of the adhesive (Lu, 2006). A typical volume fraction of the conductive filler is approximately 25 to 30 percent (Licari, 2005).

Several materials can be used in ICAs. The most widely used ICAs in the electronics industry are silver-filled epoxies, which also provide a high level of thermal conductivity. The popularity of epoxies is due to their excellent properties as a conductive adhesive. They have good adhesive strength, thermal stability and dielectric properties. Furthermore, they have good retention of these properties under thermomechanical stresses and under demanding conditions such as high humidity. However, other thermoset resins, such as silicones, cyanate esters, and cyanoacrylates, can also be used. Another option is thermoplastic resins. (Licari, 2005) Silver is the most commonly used filler material (Lau, 2003). The popularity of silver is due to its excellent conductivity and chemical stability (Morris 2005). Moreover, its oxide is highly conductive.

ICAs have been used in the electronics industry mainly as die-attach adhesives. However, lately they have also been proposed as an alternative to solders in surface mount and flip chip applications. For use in flip chip applications ICAs need to be carefully applied only on those areas which need to be conductive. Additionally, spreading of the adhesive should be prevented during the bonding process. A separate underfilling step is needed to improve the reliability of the joints. (Lau, 2003; Li, 2006) A typical cross section of an ICA flip chip joint is presented in Figure 1.
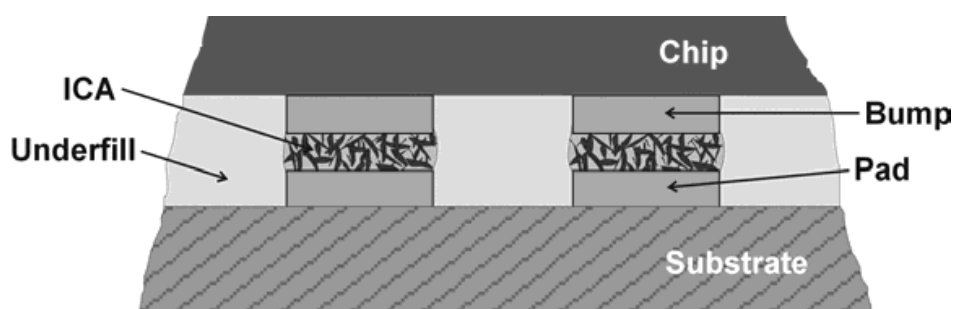

Fig. 1. Schematic illustration of an ICA flip chip joint with underfill.

2.2 Anisotropic conductive adhesives

In an anisotropic conductive adhesive (ACA) the concentration of conductive particles is below the percolation threshold (Lau, 1995; Licari, 2005) and the adhesive does not conduct before the interconnection is formed. Typically the number of particles is 0.5% - 5 % by volume (Licari, 2005) but depends largely on the size and shape of the conducting particles and on the application the ACA is used in (Watanabe, 2004). Normally the particles are randomly dispersed in the matrix, but adhesives having uniformly dispersed particles have also been developed (Ishibashi & Kimura, 1996; Jin et al., 1993; Sungwook & Chappell, 2010).

During the ACA attachment process the adhesive is placed between the mating contacts. The ACA interconnection is established by applying pressure and heat simultaneously to the interconnection. When the temperature is raised the adhesive matrix will transform into low viscosity fluid (Tan et al., 2004), which allows excess adhesive to flow from the joints and fill the spaces around the contacts forming a physical connection between the parts to be attached. The conductive particles are trapped between the contacts and deform forming an electrical connection. As a result, electrical conduction is restricted to the z-direction and the electrical insulation in x-y directions is maintained. During cooling residual stresses are formed as a result of contraction of the adhesive matrix. In addition, residual stresses form

when the adhesive shrinks during curing. However, it has been shown that the residual stresses formed during cooling dominate (Kwon & Paik, 2004). This contraction builds up a sufficient force to create a stable, low-resistance connection. A typical cross section of an ACA flip chip joint is shown in Figure 2.
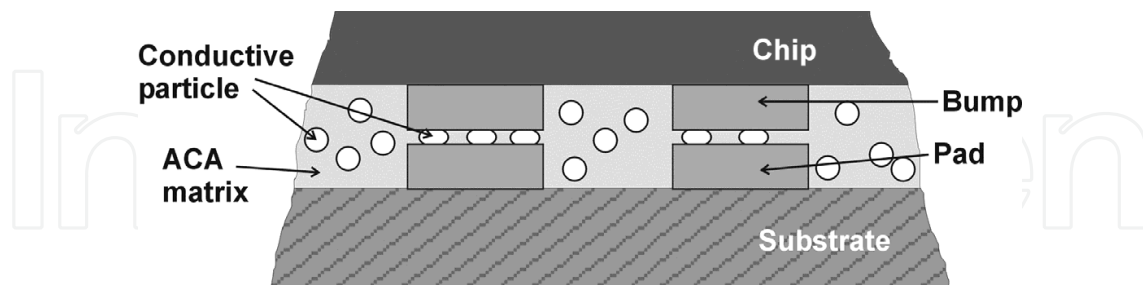

Fig. 2. Schematic illustration of an ACA joint between a chip and a substrate.

ACA joints have several advantages compared to underfilled solder interconnections. As the ACA process is solderless, there is no lead or alpha emission (Zhong, 2005). Moreover, the process is fluxless and no cleaning is required (Zhong, 2005). Furthermore, the process temperature is lower than that needed in soldering (Yim & Paik, 1998), which enables the use of heat sensitive or non-solderable substrate materials (Uddin et al., 2004). As the polymer matrix protects the contacts from mechanical damage and no underfilling is required (Lai & Liu, 1996), the ACA process costs less due to fewer processing steps (Yim & Paik, 2001). The ACA joining also enables very high interconnection density. On the other hand, the ACA joint has higher contact resistance and lower current capability than that made with solder (Jim & Paik, 1998; Zhong, 2005). Since the ACA has no self-alignment capability, a special bonding machine is needed for accurate alignment. During the bonding process heat and pressure also need to be applied simultaneously.

2.2.1 Materials used in ACAs

Both thermoplastic and thermoset materials and their mixtures have been used as an ACA matrix. Initially, the ACAs were made of thermoplastic materials, as they have better reworkability and pot life (Lau, 1995). However, their stability at high temperatures is not good and the thermoplastic material is not strong enough to hold the conducting particles in position, which increases the contact resistance of the joint (Asai et al., 1995; Kim et al., 2004). Thermoset adhesives were developed to overcome the problems with thermoplastic adhesives. Thermoset adhesives are stable at high temperatures and enable low joint resistance. Epoxies are commonly used as an ACA matrix due to their good properties. Epoxies have excellent adhesion to a variety of substrates, due to the highly polar hydroxyl and ether groups (Luo, 2002). In addition, they have high glass transition temperature (T_g) and favourable melt viscosity (Kim et al., 2004; Yim & Paik, 1999). Furthermore, epoxies give low contact resistance and by selecting suitable curing agent long self-life and fast-cure properties can be achieved. The epoxy resin forms a crosslinked structure during bonding with good mechanical properties. However, their reworkability is problematic, as they are not thermally reversible and do not dissolve in common organic solvents (Lau, 1995).

The electrical conduction in ACA is formed by the conductive particles. The size, concentration and material of the conductive particles depend on the application area and

on the manufacturer. Typically the conductive particles are approximately 3-10 um in size. Nowadays, the most common conductive particles are nickel, which may be gold plated, and metal plated polymer particles. However, other materials, such as carbon fibres and solder balls, have also been used (Asai et al., 1995). The polymer particles are made of polystyrene cross-linked with divinyl benzene (Asai et al., 1995) and the metal plating on them may be of nickel, silver, or gold (Liu, 1996). The polymer particles are pliant and during the bonding process they deform, thereby forming the connection to the contacts. The deformation of the rigid nickel particles during the bonding process is less than that of the soft particles and the contact area formed is smaller. However, if the bonded contacts are made of softer metal, such as gold or copper, these contacts deform during bonding increasing the contact area with the rigid particles (Divigalpitiya & Hogerton, 2004; Yim & Paik, 1998; Frisk & Ristolainen, 2005; Frisk & Kokko, 2006).

In the flip chip process the interconnection is formed between pads on the substrate and bumps on the chip. However, as the cost of bumping may be unattractive in certain applications, bumpless chips are also used. The most commonly used bump materials are gold plated nickel, and gold. The gold bumps can be manufactured using an electroplating process. Copper bumps formed by similar electroplating techniques have also been considered as an alternative to gold because of their lower cost (Lau, 2000, Lau, 2003). However, copper oxidizes and corrodes easily, which may cause problems if it is used without plating. The nickel bumps can be made using an electroless plating process. This process has high potential for cost reduction, as it enables metal deposition directly on the aluminium pads on the chips. Thus the costly equipment needed in the electroplating process for sputtering, photoresist imaging, and electroplating is eliminated. The gold bumps may also be processed using a modified wire bonder to form stud bumps. The advantage of this process is that bumps can be formed on single chips in addition to whole wafers. (Lau, 1995)

2.2.2 The ACA bonding process

ACAs can be used either as films (ACF) or as pastes (ACA or ACP). The type of the ACA affects the bonding process and the equipment needed. ACFs are typically supplied in a reel and a dedicated in-line bonding machine is needed for cutting, aligning, and tacking to achieve high assembly speed. On the other hand, ACPs can be applied either by printing or by dispensing using a syringe. Even though the ACF process requires special equipment, ACFs are often used as they offer advantages compared to ACPs. The ACF process consumes less material than the ACP process. Moreover, the ACP process may destroy the randomness of the particle distribution leading to problems in process quality.

In the ACF bonding process the adhesive film is first cut to the correct size to cover the bonding area. After this the adhesive is aligned to the substrate and pretacked using light pressure and low temperature to attach the ACF to the substrate. After pretacking the carrier film on the ACF is removed. Next a chip is picked by a flip chip bonder. Typically a special flip chip bonder capable of simultaneously applying pressure and heat is used. The bumps on the chip and the pads on the substrate are aligned. The chip is pressed onto the substrate and heat is applied to the chip and the polymer matrix is cured. A schematic illustration of the bonding process used is presented in Figure 3. In case ACP material is

used the steps a and b are replaced by deposition of the ACP. After this steps c and d are performed similarly to the ACF process.
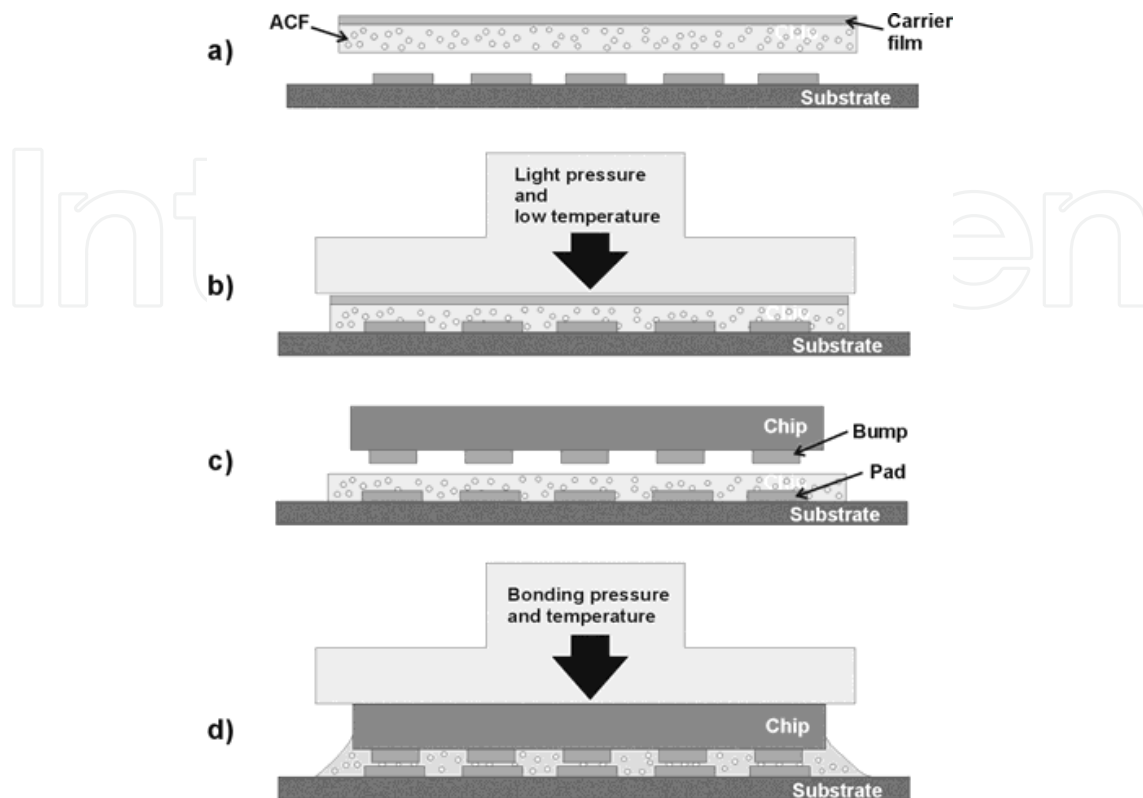

Fig. 3. Schematic illustration of the ACF flip chip bonding process: a) placement of ACF on the substrate, b) prebonding, c) alignment of the chip and the substrate and d) final bonding.

3. Evaluation of the quality of ACA interconnections

The quality of the ACA interconnections may be studied using several techniques. In general, a good quality ACA interconnection is characterized by low contact resistance and good mechanical properties. Therefore, electrical measurements may be done to assess the quality. However, often this is not possible due to the design of the semiconductor chip. Electrical measurements may show alignment and planarity problems as higher resistance values. However, this is not always the case, as it is possible that the electrical connection seems good even though there are problems in the joints causing reliability problems during use. The alignment of an interconnection may be studied through the substrate in the case of transparent substrates such as glass or thin polyimide film. However, often the most effective way to examine both alignment and the structure of the interconnection is to make a cross-section of the structure and study them using either optical or scanning electron microscope. SEM especially is often very a effective tool yielding a plethora of information of the joint, which is important for optimisation of the bonding process.

The mechanical properties of the ACA interconnections may be studied using adhesion testing, which will indicate how well the ACA material is attached to the substrate and the chip. In this technique both adhesion strength and failure mechanism during testing will give valuable information. In the following several different parameters affecting the quality

of ACA interconnections are discussed. Special attention is paid to the information obtained from the interconnections using SEM analysis.

3.1 SEM analysis of ACA interconnections

As mentioned above, both optical and scanning electron microscopy may be used to study the cross-sections of ACA interconnections. Although, studying the cross-sections is typically very effective it has some drawbacks. The number of particles in ACA interconnections is typically quite low. Thus, when a cross-section of an interconnection is studied, the probability of seeing particles in interconnections is small even if there are sufficient particles in the interconnections to ensure proper joining. From a cross-section only one side of a chip is seen. Therefore, to determine planarity and alignment issues several cross-sections are needed. Furthermore, making a cross-section of a sample destroys it thereby gravely restricting further analysis. Optical microscopy may give valuable information especially when planarity and alignment are concerned. However, typically it does not give very good detailed information. Especially, if interfaces of different materials are studied an optical microscope does not give reliable information. On the other hand, SEM is often a very powerful tool to determine the quality and structure of an ACA interconnection. However, SEM analysis benefits from information of other analysis methods if they are available such as, for example, electrical characterisation and scanning acoustic microscopy.

For SEM analysis the quality of the cross-sections needs to be good and they need to be clean. Typically epoxy moulding is used followed by grinding and polishing. However, other materials are possible such as acrylics. Use of high temperature mould materials may cause problems depending on the structure studied and its materials. As the ACA structure has many different materials the analysis is often challenging and the parameters used for SEM need to be determined according to the samples studied. Additionally, the area of interest in the interconnection affects the parameters. Both thin gold and carbon layers may be used to make samples electrically conductive. However, gold gives better quality of analysis and is recommended if elemental analysis is not needed.

3.2 Bonding parameters

Bonding parameters are the key factors when the quality and the reliability of the ACA interconnections are considered. The ACA process makes the bonding parameters especially important as the complex mechanical, rheological, and chemical properties of the ACA materials need to be considered (Dou, 2006). The most important parameters in the ACA bonding process are time, temperature and pressure. However, other bonding parameters, such as application rates of pressure and temperature, also affect the quality and reliability of the joints (Ogunjimi et al., 1996; Whalley et al., 1997). Moreover, the parameters may interact with each other.

Finding optimum process parameters necessitates careful study. Quite often the quality of the bonding parameters cannot be determined on the basis of electrical or adhesion measurements only and cross-sections are needed for verification of the interconnection quality. For thermoset adhesives the bonding temperature together with the bonding time determine the degree of cure of the adhesive matrix. The higher the bonding temperature

used the higher the degree of cure of the adhesive matrix is within the same amount of time (Chan & Luk, 2002a; Rizvi et al., 2005; Tan et al., 2004; Wu et al., 1997) as the higher temperature accelerates the crosslinking reaction (Uddin et al., 2004). Similarly, longer bonding time increases the degree of cure. Both bonding time and temperature needs to be high enough to achieve adequate curing of the adhesive matrix as the mechanical and chemical properties of the ACA have been found to depend heavily on the degree of cure (Wu et al., 1997). Too low degree of cure is often seen as high contact resistance values and also as inadequate adhesive strength.

The bonding pressure determines the deformation of the conductive particles. If the bonding pressure is too low the conductive particles cannot make good contact with the bonded surfaces and the contact resistance will be high (Chan & Luk, 2002b; Lau, 1995). In addition, the reliability of this kind of joint is poor (Frisk & Ristolainen, 2005; Lai & Liu, 1997). Examples of only slightly deformed particles are shown in Figure 4. In this case the variation is assumed to be caused by too fast curing of the adhesive during the bonding process. This adhesive has been designed to cure very quickly. Consequently it may have started to cure before the adhesive had flowed properly, leaving the particles insufficiently deformed.
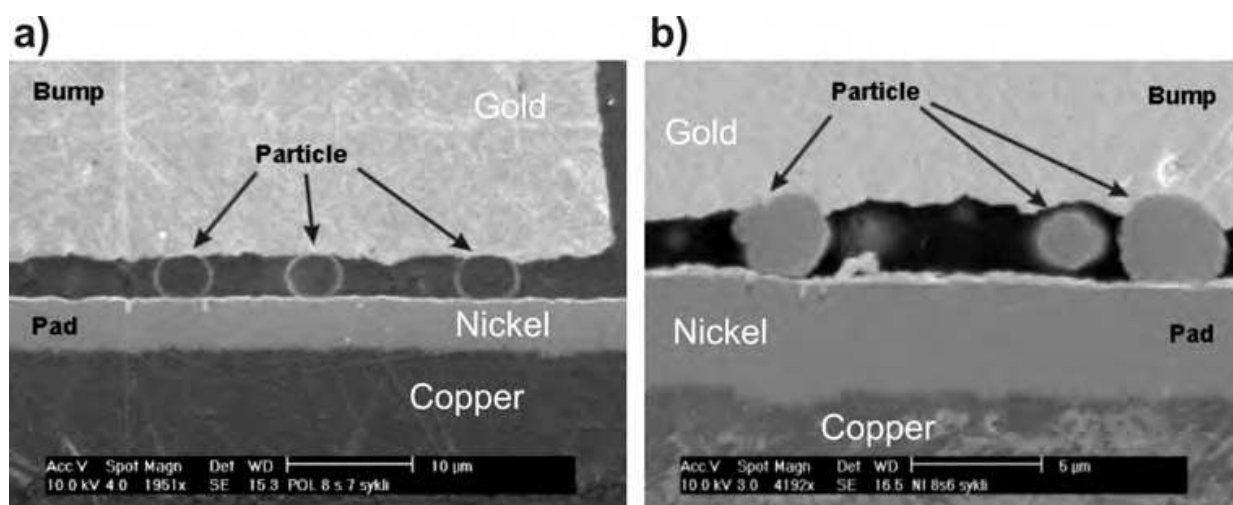

Fig. 4. An example of slightly deformed particles: a) gold coated polymer particles and b) nickel particles.

When the bonding pressure is increased, the contact resistance typically decreases sharply at first before evening out (Yim & Paik, 1998; Yin et al., 2003). This is caused by greater deformation of the conductive particles leading to a larger contact area between the particle and contacts (Kwon et al., 2006; Yin et al., 2003). Figure 5 shows examples of properly deformed particles. However, if the pressure is increased too much, the contact resistance may start to increase again (Chan & Luk, 2002b; Yim & Paik, 1998). If metal plated polymer particles are used, too high pressure may crush the particles (Wang et al., 1998) and lead to direct contact between the bump and the pad. The cracking of the metal plating may separate it from the polymer core and reduce the amount of conductive path between the pad and the bump (Yim & Paik, 1998). Another problem with too high bonding pressure is elastic stress formed in the chip or in the substrate (Frisk et al., 2010; Lai & Liu, 1996). In some cases, the high temperature used during the bonding process may soften the substrate material used and it will deform markedly during the bonding process.
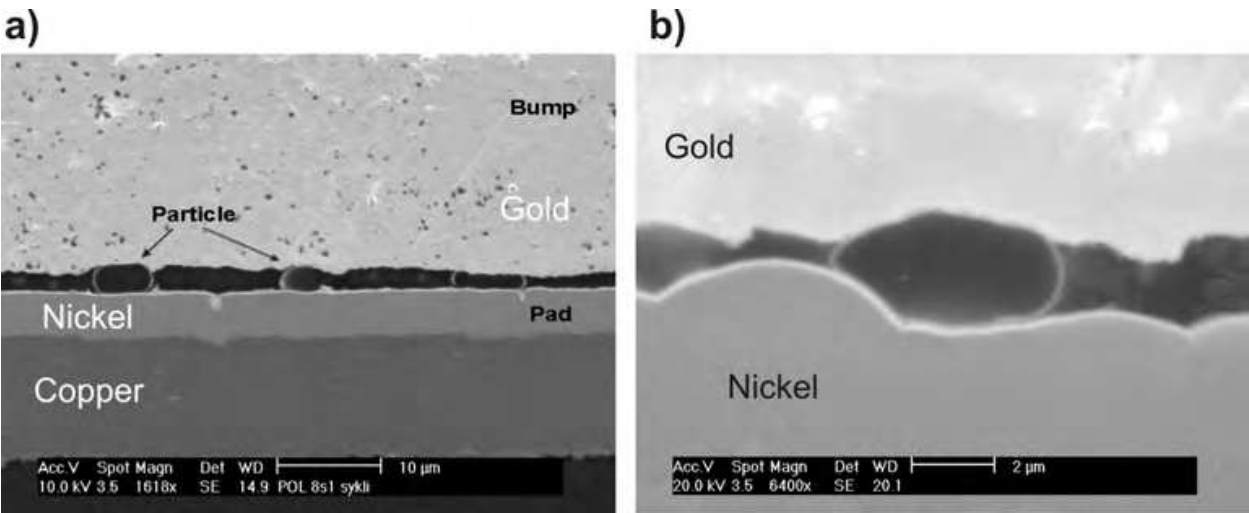
Fig. 5. a) and b) examples of marked deformation of gold plated polymer particles.

If rigid particles are used, the bump and the pad material also have a strong effect on the bonding pressure. With soft bump materials, such as gold or copper, the particles will sink into the bump forming a strong bond. If high bonding pressure is used, the particles will sink completely into the bumps and direct contact between the pad and the bump will be formed. An example of direct contact is presented in Figure 6. The hard nickel-plating on the pads prevented the penetration of the particles into the pads.
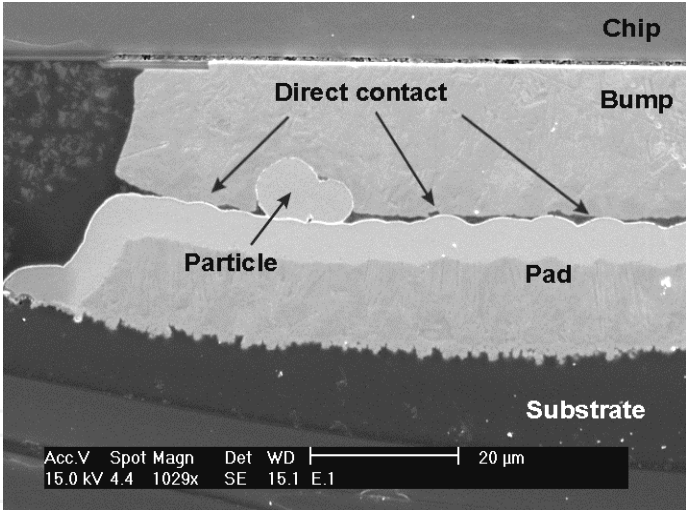
Fig. 6. Penetration of the nickel particles into the copper bump and direct contact between the bump and the pad.

3.3 Effect of the substrate material

Poor substrate and chip quality may cause coplanarity problems. This may increase the contact resistance, as not all joints have adequate deformation of the particles. For the flip chip process to be usable with the organic substrates, the planarity of the substrate is very important. Planarity issues often need to be determined using cross-sections. In the following examples of SEM analysis used for quality studies of ACA interconnections with different substrate materials are given.

3.3.1 Glass fibre reinforced substrates

Glass fibre reinforced materials are commonly used as substrates in electronics. The most widely used material is FR-4, which is a grade designated by the National Electrical Manufacturers Association (NEMA), which determines that the material is flame resistant, is primarily epoxy based, and has woven glass fibre reinforcement (Coombs, 2000). As the resin material between different FR-4s may vary, the properties of FR-4 materials are not identical. For example typical T_g of FR-4 is between 130 and 140 °C or between 170 and 180 °C. The popularity of the FR-4 is based on its good properties, availability, and low cost. When rigid glass fibre reinforced substrates are used in ACA applications, coplanarity problems may arise due to the woven structure of the substrate (Frisk & Cumini, 2009). During the bonding process the high temperature may soften the resin, which leads to its deformation under the pads. This deformation has been found to depend on the orientation of the glass fibres in the substrate and affect the electrical conductivity and reliability of the joints (Liu et al., 1999).

Deformation of substrate in ACA interconnections was studied using cross-sections and SEM (Frisk & Kokko, 2006; Frisk & Cumini, 2009; Frisk et al., 2010). SEM has proven to be a very effective method for such studies as the different materials and their interfaces may be clearly seen. Figure 7 shows micrographs of a FR-4 substrates after an ACA bonding process. Deformation of the substrates may be seen between contacts. Deformation is especially considerable in the areas where the glass fibres were far from the surface. This varying deformation of the substrate causes pressure variation in the joints (Pinardi, 1998). The varying pressure is important as it may result in different deformation of the particles leading to variation in the contact resistance and also impairing the reliability of the joints.

Quite often in flip chip applications with ACA materials very high wiring densities are needed. These are difficult to achieve with the traditional FR-4 substrates shown in Figure 7 One possibility to meet these demands is to use sequential build-up (SBU) processes. However, in this process conductor and dielectric layers are formed one after another on a rigid core board, which may be an FR-4 glass reinforced laminate (Tagagi et al., 2003). The electrical connection between the core board and the build-up layers is formed using microvia technologies. An example of a substrate made with the SBU process is presented in Figure 8. The typical dielectric materials used in SBU build-up layers are resin-coated copper foil (RCC or RCF), thermally cured resin, and photo-imageable resin (Tagagi et al., 2003). The most widely used dielectric material in the SBU process is RCC. The RCC is formed by adding a layer of resin to a thin copper foil, which is laminated to the core board. A typical resin material is epoxy. The RCC has several advantages and is suitable for processing in standard printed circuit board processes.

As the RCC layer does not have glass fibres, it is more pliable than an FR-4 substrate. Its effect on the interconnection structures was studied using cross-sections and SEM (Frisk & Kokko, 2006). During the bonding process the depression of the copper pads into the RCC was found to be much stronger than the depression into the FR-4 substrate. In Figure 9 an example of the depression is presented for test samples with the RCC test substrate. As can be seen, the RCC has deformed markedly more during the bonding process than the pure FR-4 substrates shown in Figure 7. Furthermore, some deformation of the FR-4 substrate beneath the RCC has occurred. Although the deformation of the RCC is greater, it is almost identical under every pad leading to more uniform distribution of pressure. This causes the

deformation of the particles to be identical in the joints and increases reliability compared to the substrate without the RCC.
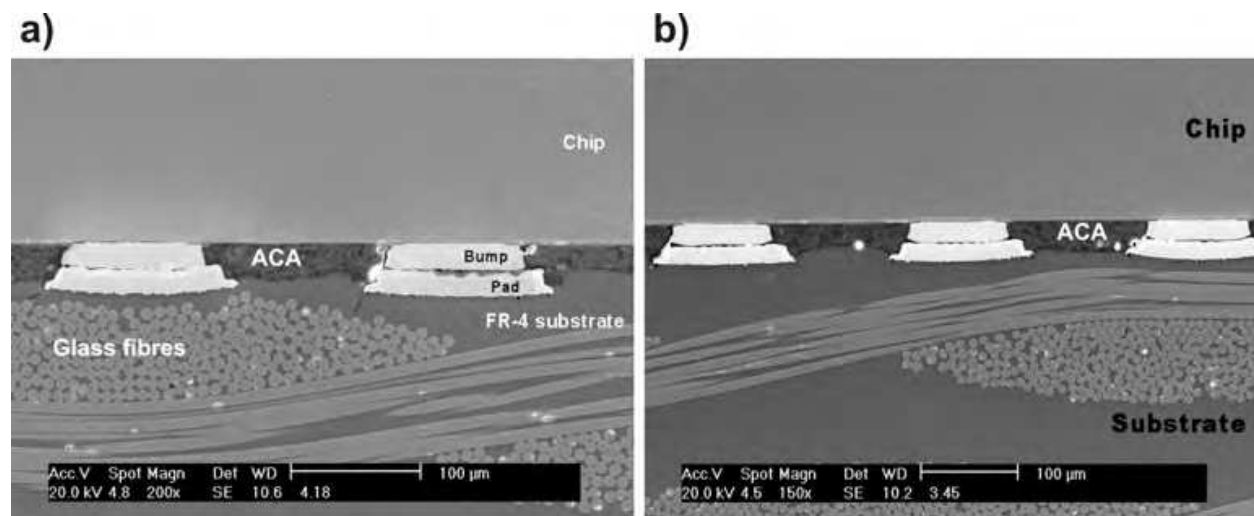

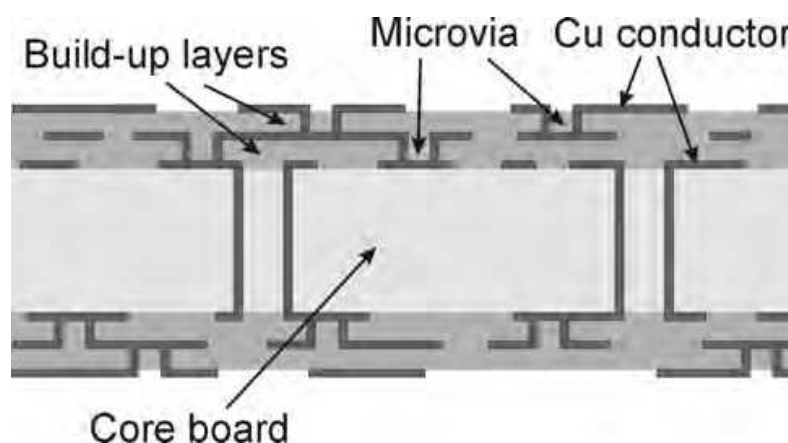Fig. 7. a) and b) micrographs showing deformation of a FR-4 substrate

Fig. 8. Schematic cross-section of a printed circuit board made with SBU process.

Deformation of the particles between these test boards was also studied with SEM. With the test substrate, which did not have the RCC, the particles sank into the copper bump. However, the fairly thick nickel plating on the pads prevented the particles from sinking into it and caused deformation of the particles, as can be seen in Figure 10 a). In addition, due to relatively high magnification of the SEM micrograph the gold layers on both conducting particles and pad can be easily seen. The thinner nickel plating on the RCC test board enabled the particles to sink into the pad, as can be seen in Figure 10 b). Moreover, as the RCC gives in more under the pads during bonding than the FR-4 substrate, the deformation of the particles was less on the substrates with the RCC. Deformation of the particles is important for the reliability of the joints. Sufficiently deformed particles form a strong atomic interaction between the pad and the bump creating increased stability of the joint (Lai & Liu, 1996). Using SEM the interface between the particles and the pad or the bump may be studied and problems such as thin layers of polymer matrix may be detected. In both Figures 10 a) and 10 b) a good contact of particles is seen to both the pad and the bump .
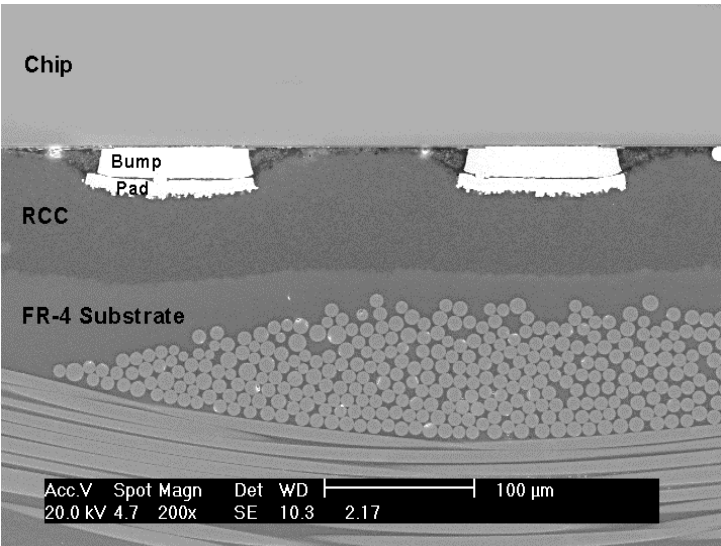
Fig. 9. Micrograph presenting the immersion of the pads in the RCC, when high bonding pressure is used.
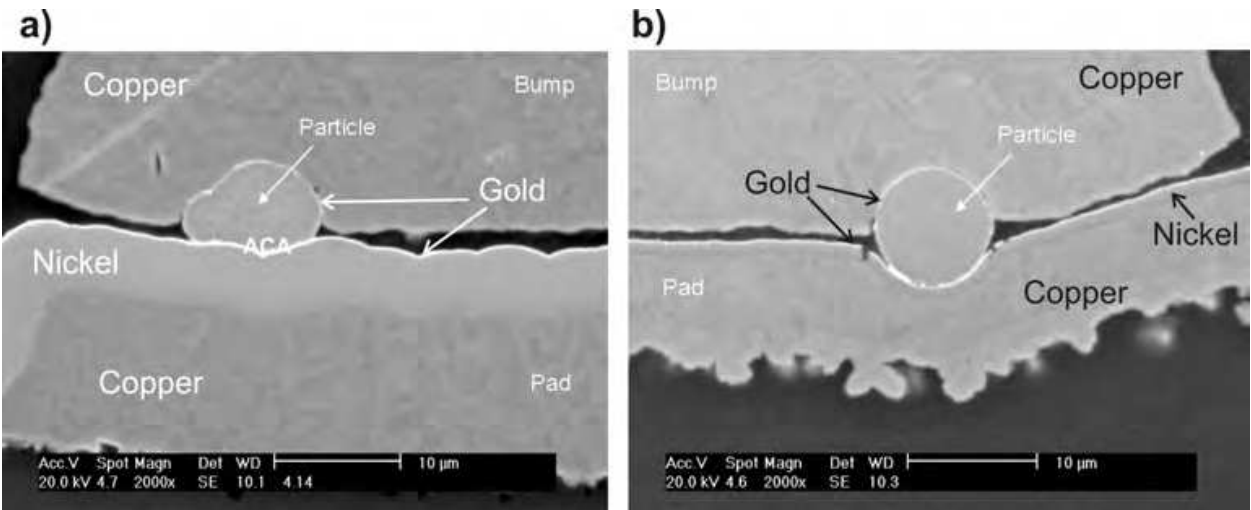

Fig. 10. a) Micrograph presenting the deformation of the rigid nickel particle, when a FR-4 substrate is used. b) Micrograph presenting the immersion of the rigid nickel particle in the pad and the bump, when the substrate with the RCC is used.

3.3.2 Flexible substrates

ACA materials are often used with flexible substrates, which are fabricated using pliable unreinforced polymeric materials. Flexible substrates have several advantages compared to fibre-reinforced substrates and lighter and thinner products can be produced using them. Flexible substrate may absorb stress, which may be important for the reliability of the interconnections, especially in flip chip applications. In addition, the thermal transfer through a thin substrate is more effective. Furthermore, very high density substrates are available with flexible substrates and this is often critical for ACA applications. On the other hand, the thinness of the substrate may cause problems in the stability of the construction. Moreover, the cost of the flexible substrates is higher than that of the rigid substrates. (Coombs, 2001)

The pliability of the flexible substrates may cause some problems during the bonding process. Figure 11 shows SEM micrographs of ACA interconnections with flexible liquid crystal polymer (LCP) substrates with two different pressures. A marked deformation of the liquid crystal polymer film with high pressure may be seen. Such deformation may cause problems. On the other hand, it may also even out some planarity problems as deformation can absorb the height variations (Connell, 1997; Savolainen, 2004) and thereby increase the quality of the interconnection. However, in some cases deformation may cause cracking of the wiring and thereby lead in to reliability problems. With the lower pressure the pressure exerted to the particles may not be high enough and therefore cause reliability problems.
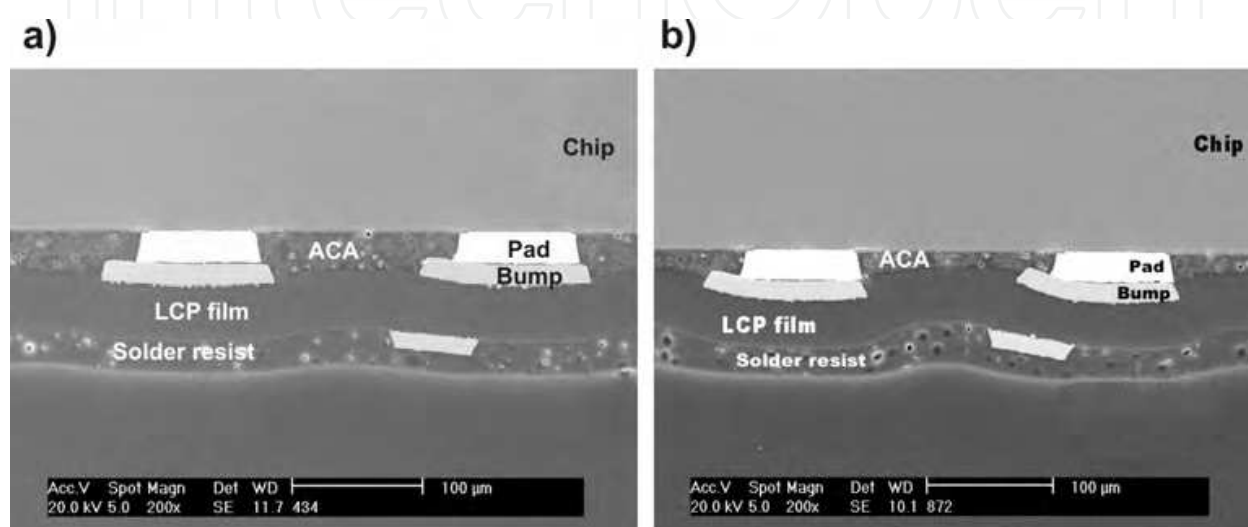

Fig. 11. An example of deformation of the LCP substrate when a) low bonding pressure and b) high bonding pressure was used.

With thin flexible substrates routing may also be critical to the distribution of the pressure, if the substrate has several conductive layers (Lai & Liu, 1996). If double sided flexible substrates are used they may have wiring on both sides of the bonding area. This may cause uneven distribution of the pressure and deformation of contact areas. Figure 12 shows an interconnection with a polyimide substrate having double sided wiring. As can be seen, the gold bump has markedly deformed during the bonding process because of the wiring on the other side of the substrate. A similar effect may be seen in the LCP substrates in Figure 11. However, as the solder resist on the LCP substrate evened out the effect of the wiring, there is clearly less deformation. Consequently, the design of flexible circuitry is very important for good quality interconnections. Furthermore, such quality problems are difficult to detect without cross-sectioning.

Another problem in a substrate may be overetching of the pads. As flexible substrates are often used in application where very high density substrates are needed such as attachment of driver chips is display application, overetching may cause marked problems. It reduces the contact area and may cause alignment and planarity problems. Figure 13 shows a SEM micrograph of a interconnection with an overetched polyimide (PI) substrate. In the original substrate layout the pad width was designed to be slightly greater than the bump. However, due to overetching the size of the pad is clearly less than that of the bump. Such overetching may be seen when substrates are quality checked before use. However, cross-section is a good way to evaluate the effect of overetching on an interconnect.
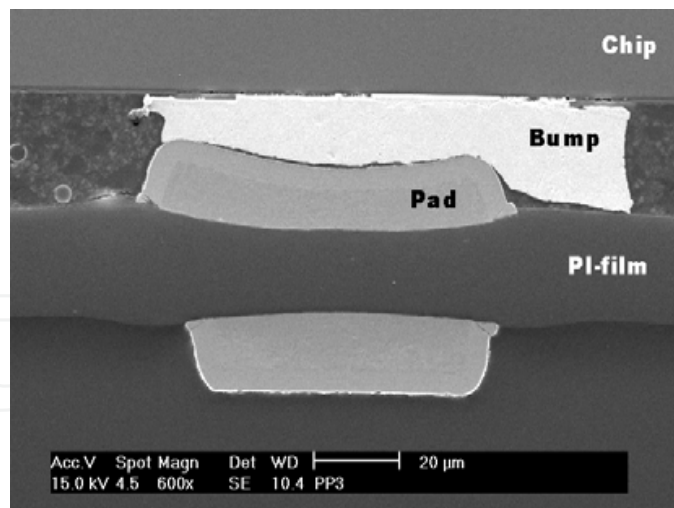
Fig. 12. Effect of the tracks on joint deformation on the PI substrate when the tracks are on both sides of the substrate.
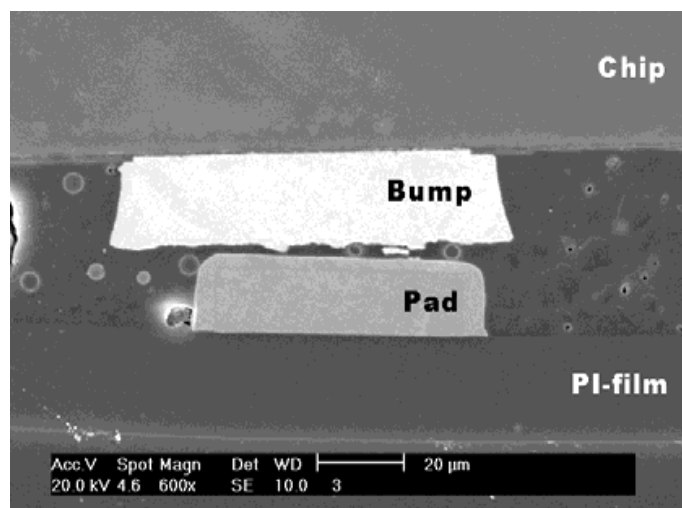

Fig. 13. An overetched pad on the PI substrate.

4. Failure mechanisms of the ACA flip chip joints

In general, a good ACA joint is characterized by low contact resistance. A key issue for the ACA to function properly is the retention of this contact resistance during the operational life of the product. Failure of a product can be defined as its inability to perform its intended function [For an ACA flip chip joint this typically means too great an increase in contact resistance. There is no single specific definition of failure of ACA joint resistance, as this depends largely on the application.

To improve the reliability of interconnections the reasons for their failure and the failure mechanisms must be understood. During the design phase reliability is typically assessed using accelerated environmental testing. The aim of such testing is to predict the future performance of a product in a shorter period of time than the service life of the product. Accelerated life tests can also be used to detect failure mechanisms occurring in products under different conditions of use. The acceleration is accomplished by using elevated stress

levels or higher stress cycle frequency during testing compared to those under normal operational conditions of the product (Suhir, 2002). Depending on the condition failures may occur through several mechanisms. It is important that the testing conditions are determined so that the failure mechanisms during testing are similar to those occurring under normal conditions of use. The test conditions depend decisively on the application of the product. For example, the test conditions for products used in military and space applications are much more rigorous than those for consumer electronics.

Several different accelerated life tests have been used to study the reliability of ACA joints; see for example (Frisk & Ristolainen, 2005; Frisk & Cumini, 2006; Jang et al., 2008; Kim et al., 2004; Lai & Liu, 1996; Saarinen et al., 2011). These include high temperature aging tests, temperature cycling tests, high temperature and high humidity tests, and humidity and temperature cycling tests. The reliability and failure mechanisms of ACA interconnections depend on several factors, including the materials and bonding parameters. The materials used in the pads, bumps, and conductive particles need to be compatible with each other. The substrate material may also have a marked influence on the reliability of the joints. As the properties of the joints are much influenced by the bonding process, it is important that optimum bonding parameters are determined and used in the bonding process. In the following failure mechanisms and analysis of ACA interconnections are discussed.

4.1 Failures of ACA interconnections with rigid FR-4 substrates under thermal cycling

One of the major problems in ACA assembly using organic substrates is the great difference between the coefficient of thermal expansions (CTE) of chip and substrate. The bonding process is done at elevated temperatures. When the package is cooled down the contraction of the silicon chip is very small due to its low coefficient of thermal expansion and high Young's modulus (Kwon et al., 2005). On the other hand, the contraction of the substrate is much greater. At low temperatures this causes stresses to form between the chip and the substrate and the ACA flip chip package to warp downwards. At temperatures below its T_g the adhesive matrix holds the chip and the substrate together enabling this warpage (Kwon & Paik, 2006). However, when the T_g of the adhesive is exceeded, its mechanical strength decreases and it cannot provide mechanical support between the substrate and the chip. The warpage is evened out and both chip and substrate may expand with their inherent CTEs (Kwon & Paik, 2006). The warpage of the ACA package is presented in Figure 14. If the ambient temperature fluctuates, as in a temperature cycling test, the flip chip package warps repeatedly. The warping reduces the shear stress in the joints and a greater degree of warp has been reported to decrease the shear strain in the joints (Kwon et al., 2005).

The amount of warpage depends on the difference between the coefficient of thermal expansions of chip and substrate, but also on their stiffness. When a rigid fibre reinforced substrate is used, the shear stress caused by CTE mismatches is localised between the pad and the bump as the of deformation the substrate is less than that of the adhesive matrix (Lai et al., 1998). On the other hand, deformation of an unreinforced flexible substrate occurs much more easily due to its low modulus, and some of the shear stress may be absorbed by the substrate (Connell et al., 1997). This decreases the shear stress in the interconnection reducing the delamination and increasing the reliability.

Above T$_g$ of ACA

The elastic modulus of the ACA is low at temperatures
above its T$_g$ allowing the chip and the organic substrate
to expand freely. No warpage occurs.

Below T$_g$ of ACA

At low temperatures the organic substrate contracts
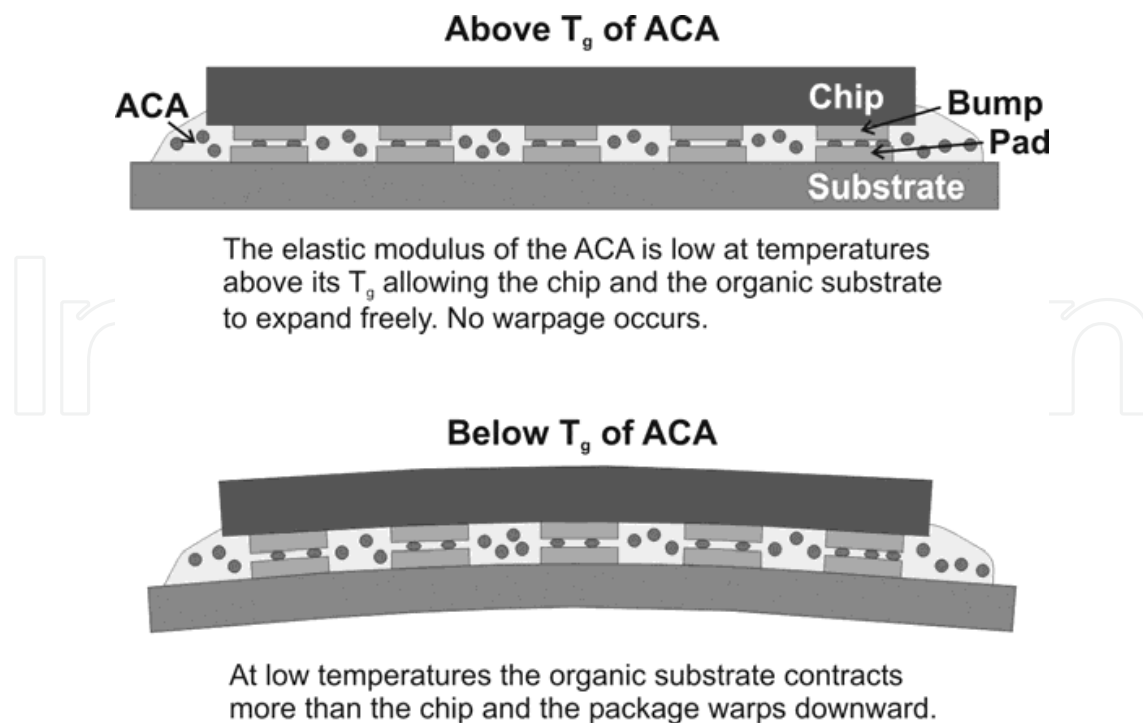more than the chip and the package warps downward.

Fig. 14. Warpage of the ACA flip chip package during temperature cycling test.

ACA interconnections with rigid FR-4 substrate were exposed to thermal cycling between -40 °C and +125 °C (Frisk & Kokko, 2006). When the failed test samples were studied using SEM, delamination was found in several test samples after testing. This delamination is probably caused by shear stress between the pad and the bump formed due to differences in the coefficient of thermal expansion of the substrate and the chip. As shown in Figures 16 a), 16 b), and 16 c) with SEM the delamination is seen clearly and its place can be determined. In some cases delamination may be less pronounced and therefore harder to detect. In Figure 16 c) another example of delamination which is more difficult to detect is shown.

Another phenomenon seen in these samples was cracking of the substrate material. This is assumed to be caused by repeated warping of the substrate as the duration of testing was several thousand cycles. This type of cracking was typically found in areas where the glass fibres were far from the surface of the substrate. They started from the corners of the pads and often continued into the substrate until they reached the glass fibres. Examples of such cracking are presented in Figure 16. The formation of such cracks has probably facilitated delamination between pad and the bumb by providing sites for crack initiation, as the cracks often connected to the delamination between the pad and the bump. An example of this is presented in Figures 16 b) and 16 c).

It has been suggested that during thermal testing above the T$_g$ of the ACA matrix sliding between the pad and the bump occurs (Kwon et al, 2006; Uddin et al., 2004). This may break the conductive particles and lead to failure. Furthermore, this phenomenon may cause fretting and thereby the formation of oxides on the conductive surfaces, which increases the resistance of the joints above an acceptable value. When ACA interconnections having nickel particles or gold coated polymer particles, were studied after thermal cycling clear indication of this phenomenon was seen. Figure 17 a) shows a SEM micrograph of polymer particles form a failed ACA interconnection. In the picture cracking of the gold layer in the

particle can be clearly seen. Additionally, agglomeration of material under the particles can be seen indicating failure caused by this sliding. Figure 17 b) shows a similar situation for nickel particle and similar agglomeration of material.
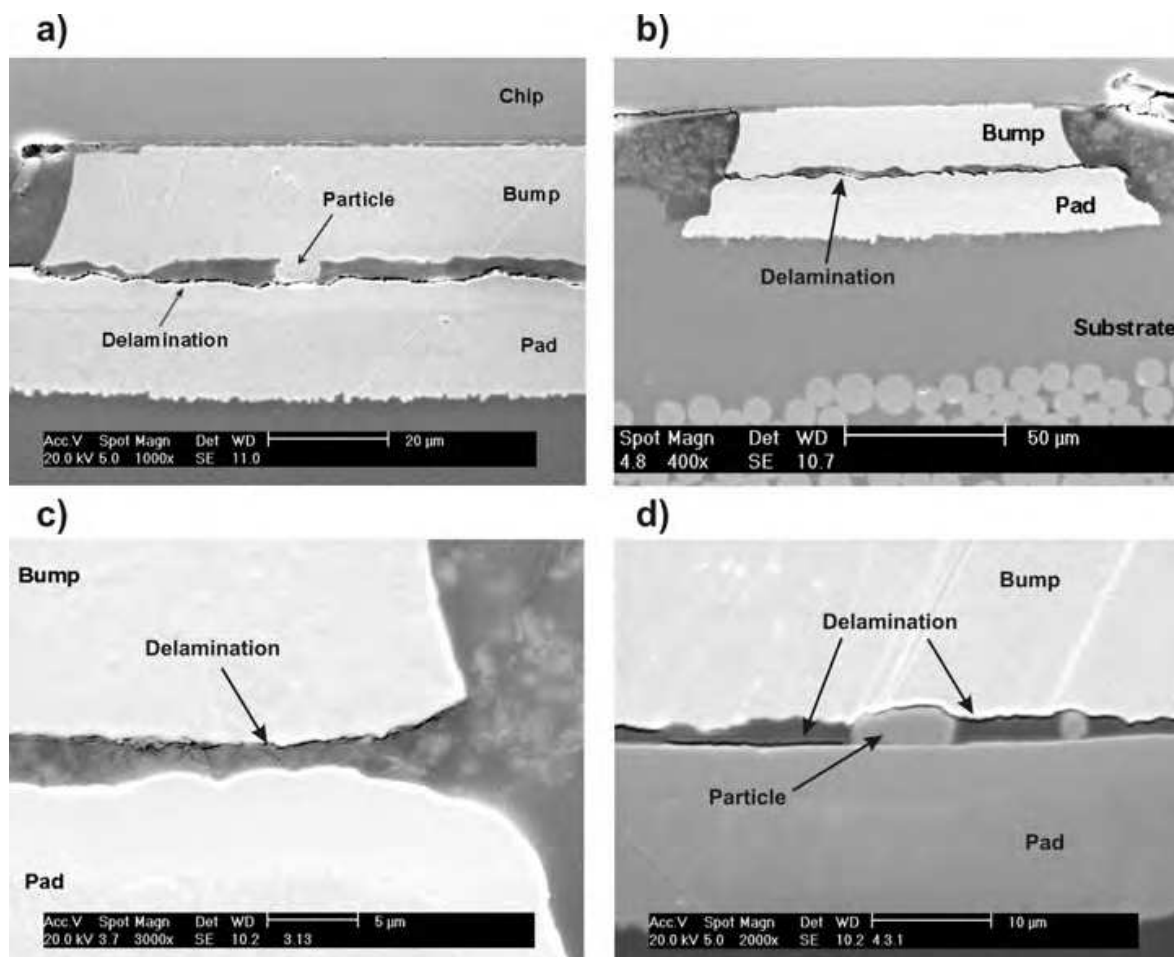

Fig. 15. Examples of delamination in test samples with FR-4 substrates after thermal cycling
a) clear delamination between ACA and pad, b) delamination between bump and pad
which continues to ACA-chip interface, c) less pronounced delamination, and
d) delamination varying between the ACA-pad interface and the ACA-bump interface.

4.2 Failures of ACA interconnections with rigid FR-4 substrates under humidity testing

In addition to temperature changes, humidity has been found to have a major influence on the reliability of ACA interconnections. Under humid conditions the adhesive matrix may deform as it absorbs water. The adhesive matrix may also relax due to the increased temperature. The effect of water absorption depends on the structure of the adhesive and also on the duration of the exposure. The most common adhesive material is epoxy. It has been suggested that the water absorbed in the epoxy polymer has two states to which the water molecules can diffuse. The water may either fill the free volume in the polymer matrix or form hydrogen bonds with the epoxy polymer. If the water is hydrogen-bonded, it causes swelling of the adhesive matrix (Chiang & Fernandez-Garcia, 2002; Luo et al., 2002). This swelling due to humidity typically increases with temperature, but decreases sharply across

the T_g of the polymer (Wong et al., 2000). Swelling due to moisture differs significantly between the materials used in flip chip packages causing the formation of hygroscopic stresses in the structure (Mercado et al., 2003; Wong et al., 2000).
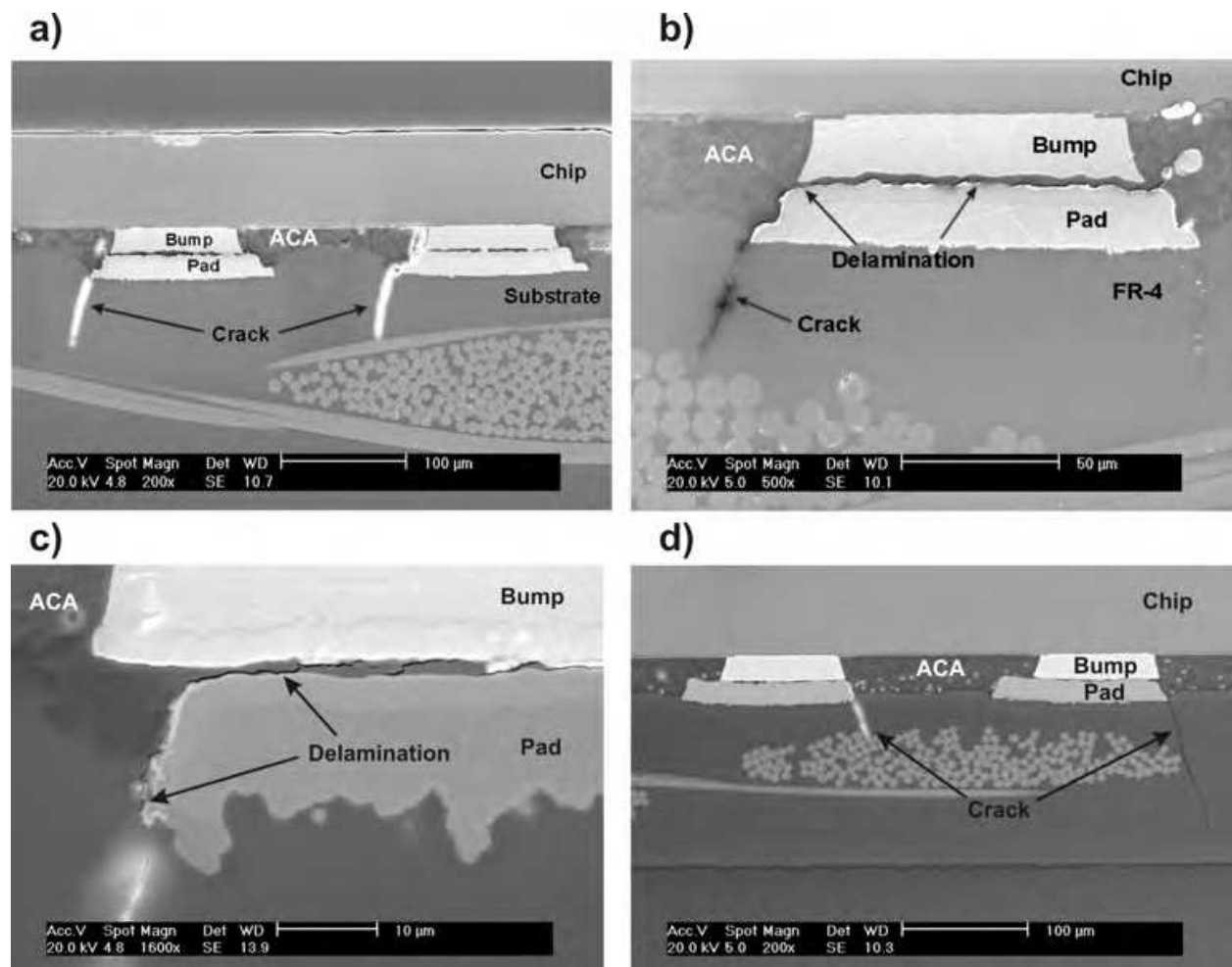

Fig. 16. Examples of cracks in FR-4 substrates: a) marked deformation and clear cracking of the epoxy matrix, b) cracking which continues between the pad and the bump, c) less pronounced cracking which continues between the pad and the bump, and d) cracking of thin FR-4 substrate

The swelling of the adhesive matrix may be marked (Mercado et al., 2003) and concurrent with thermal expansion may cause the conductive particles to lose contact. However, it has been reported that the absorbed water may also weaken the mechanical properties of the adhesive. Unlike the hydrogen-bonded water, the water filling the free volume in the epoxy polymer does not cause swelling, as it occupies a volume that already exists (Chiang & Fernandez-Garcia, 2002). However, it acts as a plasticizer affecting the mobility of the chains and increasing chain flexibility, which decreases the T_g of the polymer. As the water acts like a plasticizer it may also impair the mechanical strength of the adhesive.

The substrate material may also have a great influence on the reliability of the joints under humid conditions (Frisk & Cumini, 2006). If the substrate material absorbs water, it penetrates the interfaces more easily and may cause delamination. A large amount of

moisture in the substrate also facilitates the moisture absorption of the adhesive matrix, and may accelerate the formation of moisture related failures. The effect of humidity at elevated temperatures on the ACA joints was studied using an 85°C/85RH test. Flexible polyimide was used as a substrate material. When studied after testing using SEM, every test sample with the PI substrate which showed an open interconnection after testing also showed delamination. An example of the delamination is presented in Figure 18. The moisture absorption of polyimide is marked and it is assumed to be the reason for the formation of delamination during testing.
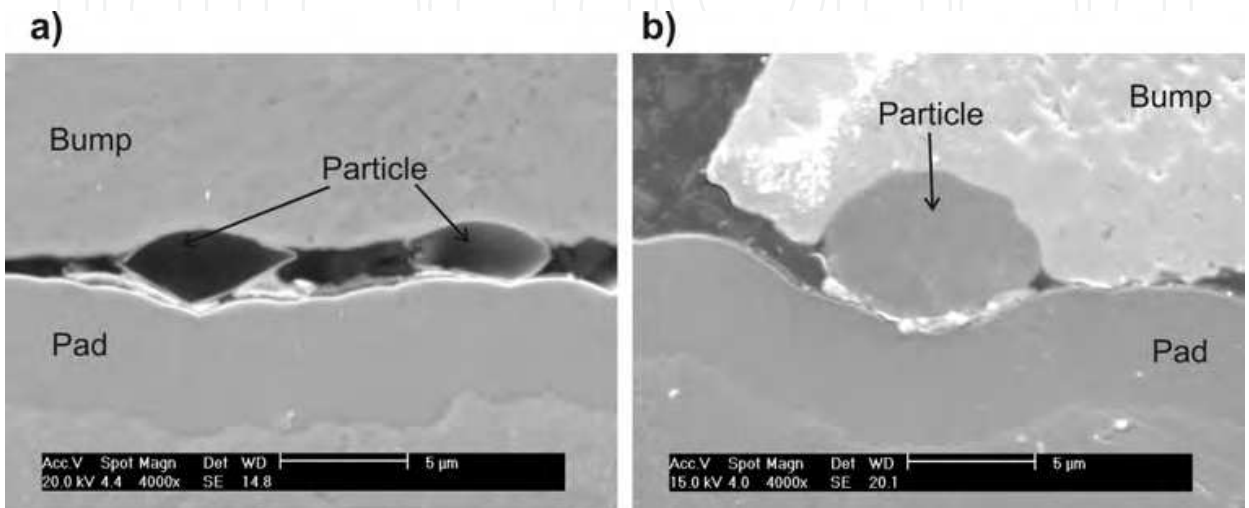
Fig. 17. Micrograph of a failed ACA interconnection after thermal cycling a) with polymer particles and b) with nickel particles.
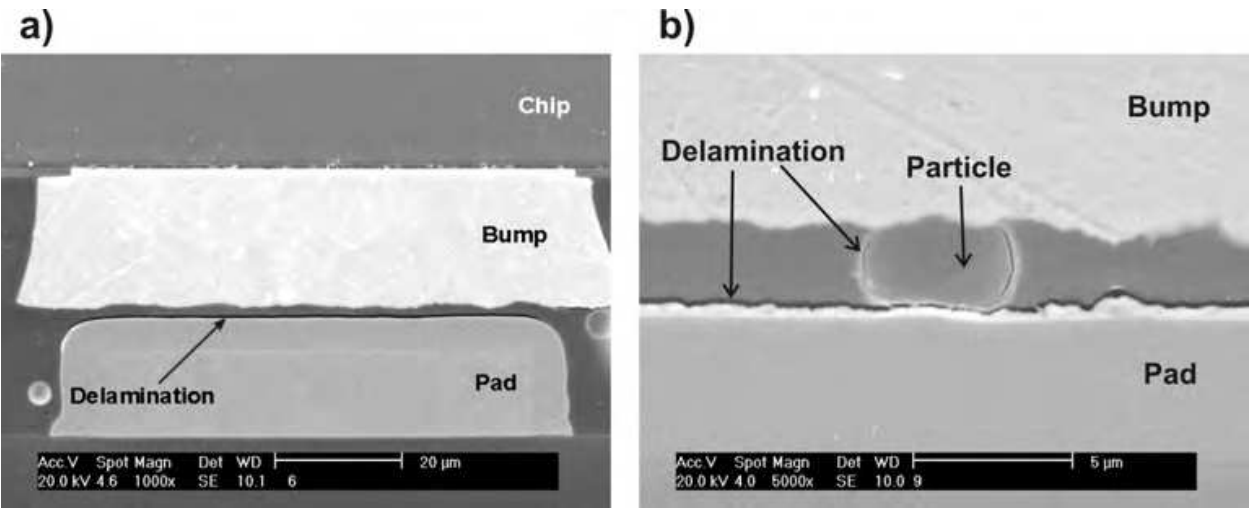

Fig. 18. a) An example of delamination after constant humidity testing on the PI substrate.b) close view of delamination after constant humidity testing on the PI substrate and on particle.

ACA technique was also studied with thinned silicon chips. When silicon chips are thinned below 100 um, they become pliant and can be used in solutions where they are bent. Consequently, they can be used in flexible electronics. Thinning also allows the chips to dissipate more heat, which is important when the densities of the packages increase.

However, thinned chips have certain drawbacks. They are more fragile than thicker chips, which needs to be taken into account when thinned chips are handled. Special tools may be needed since the fragile edges of the thinned chips are easily broken during handling. During the thinning and dicing processes a considerable amount of stress may be induced in the chips. It has been found that the thinning of the chips changes the shear stress distribution in a package (Frisk et al., 2011). In the analysis 50 µm thick chips were used instead of approximately 500 µm thick chips used in other studies. Very strong delamination was seen in these test samples which indicates failure mechanisms which is different from the one seen with the thicker chips. Examples of this delamination are shown in Figures 19 a) and 19 b). Furthermore cracking of the thinned chips was seen (Figure 19 c) and 19 d)). However, most of this occurred during the bonding process already before testing.
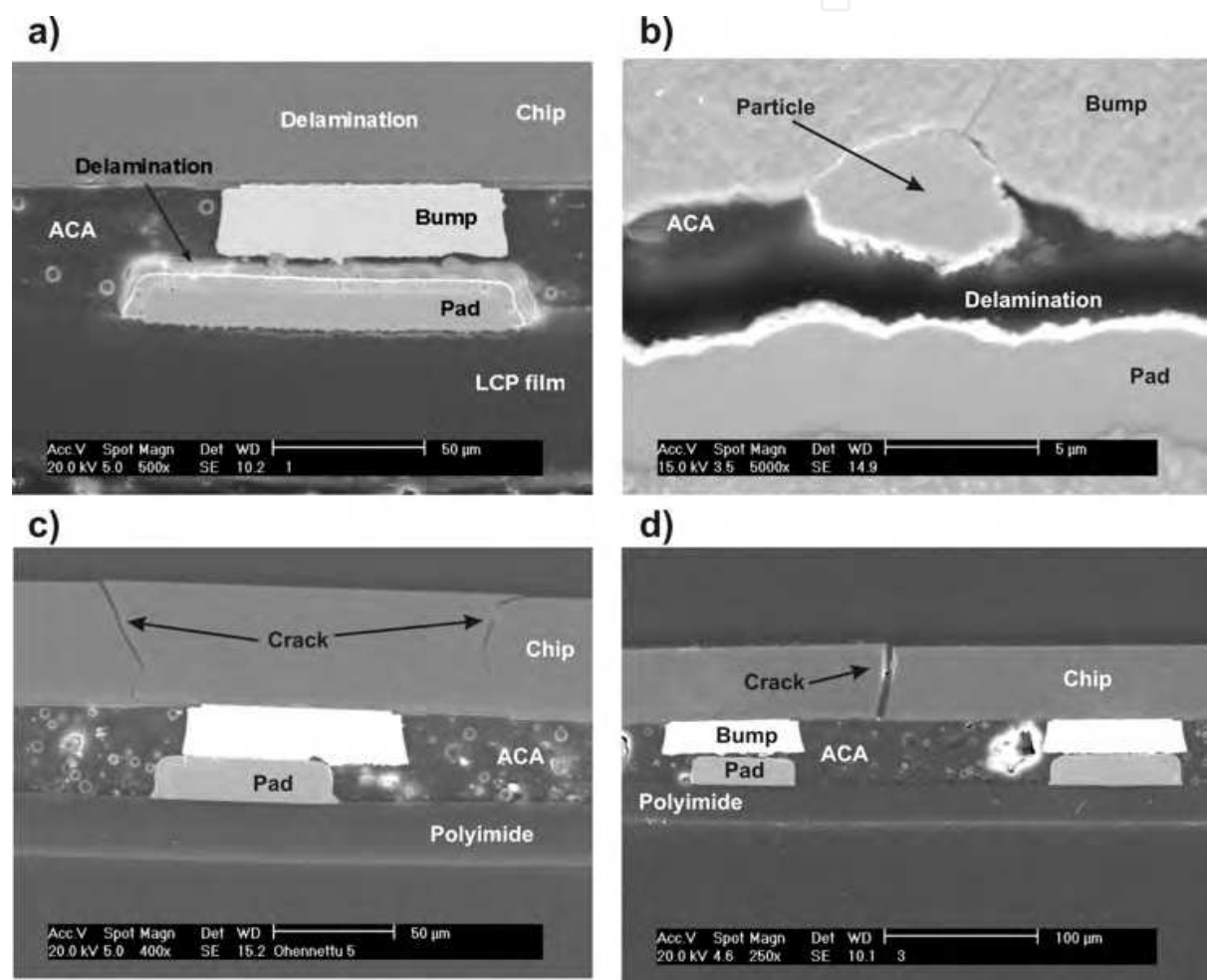

Fig. 19. Micrographs for ACA interconnections with thinned chips: a) marked delamination after humidity testing, b) close view of delamination under particle, c)and d) cracks in the thin chips.

5. Conclusion

Anisotropic conductive adhesives (ACA) are an interesting interconnection method for several applications. Due to the low cost of the ACA process and capability for high density they nowadays dominate many fields for instance attachment of chips in radiofrequency

identification (RFID) tags and attachment of driver chips in display applications. ACA interconnections often show the typical trend in electronics for very small size with high functionality. In general this means high density of contacts in a chip and often also a large number of contacts per chip. Such applications are often very challenging both for studies of the interconnection process and the quality and reliability of the interconnections. Making cross-sections of the interconnections has proven to be efficient way to obtain detailed information about the interconnections structures, their quality and failure mechanisms, and this has been used effectively with other characterisation methods such as scanning acoustic microscope, DSC, and x-ray. Due to the small features currently common in electronics applications SEM is often the preferred method for examinations compared to optical microscopy.

In this chapter several SEM analyses of ACA interconnections were described. Many of these have been critical to both understanding the bonding process of these materials and also for the development of the ACA interconnection techniques and their reliability. Studying cross sections with SEM has been shown to be an effective way to analyse several of the failure mechanisms found in ACA interconnections. However, in general a good understanding of SEM analysis technique is needed for analysis due to the complexity of the ACA structure. ACA interconnection has many interfaces and the failure may occur on any of these or in the bulk materials of the structure. For effective analysis the critical parts need to be already understood when the analysis is made, and therefore, a good understanding of the technique and materials is needed. Lately the use of ACA technology has increased and it has been adopted on new areas for example high temperature electronics and sensor applications. In the future, this will increase the need for detailed knowledge of this interconnection technique. Therefore, it is critical that studies such as presented in this chapter are continued as they give vital information for both development and applicability of this technique.

Making cross-sections of studied samples is favoured in ACA flip chip applications due to the difficulties of studying the interconnections below a component. This also applies to many other interconnections and packaging technologies and similar methods have been used successfully in other applications. For example in the research of lead free solders cross-sections are systematically used for failure analysis and studies related to the microstructure of the interconnections. Additionally, in other techniques, such as flex on board attachments for example, in which flexible substrate is attached to a rigid substrate, and small packaging solutions such as Chip Scale Package (CSP) cross-sectioning and SEM analysis is often needed to determine the structure. In the future, the size of interconnections in electronics will decrease and their number will increase. As a consequence, the need for techniques capable for the analysis of such structures will increase markedly. SEM has proven to be an extremely useful tool for analysing electronics structures as it is relatively fast, typically easily available, and capable for analysing small features.

6. Acknowledgment

7. References

Asai, S., Saruta, U., Tobita, M., Takano, M., and Miyashita, Y. (1995) Development of an Anisotropic Conductive Adhesive Film (ACAF) from Epoxy Resins. *Journal of Applied Polymer Science*, Vol. 56, No. 7, 1995, pp. 769-77. ISSN 1097-4628.

Chan, Y., Hung, K., Tang, C., and Wu, C. (2000) Degradation Mechanisms of Anisotropic Conductive Adhesive Joints for Flip Chip on Flex applications. *Proceedings of 4th IEEE Conference on Adhesive Joining and Coating Technology in Electronics Manufacturing*, ISBN 0780364600, Espoo, Finland, June, 2000.

Chan, Y. C. and Luk, D. Y. (2002a) Effects of Bonding Parameters on the Reliability Performance of Anisotropic Conductive Adhesive Interconnects for Flip-chip-on-flex Packages Assembly I. Different Bonding Temperature. *Microelectronics Reliability*, Vol. 42, No. 8, 2002, pp.1185-94. ISSN 0026-2714

Chan, Y. C. and Luk, D. Y. (2002b) Effects of Bonding Parameters on the Reliability Performance of Anisotropic Conductive Adhesive Interconnects for Flip-chip-on-flex Packages Assembly II. Different Bonding Pressure. *Microelectronics Reliability*, Vol. 42, No. 8, 2002, pp.1195-1204. ISSN 0026-2714

Chiang, M. and Fernandez-Garcia, M. (2002) Relation of swelling and T_g depression to the apparent free volume of a particle-filled, epoxy-based adhesive. *Journal of Applied Polymer Science*, Vol. 87, No. 9, 2002, pp. 1436 - 44. ISSN 1097-4628

Connell, G., Zenner, R., and Gerber, J. (1997). Conductive Adhesive Flip Chip Bonding for Bumped and Unbumped Die. *Proceedings of the 47th IEEE Electronic Components and Technology Conference*, ISBN: 0-7803-3857-X, San Jose, CA, USA, May, 1997.

Coombs, C. (2001). *Coombs' Printed Circuits Handbook*. McGraw-Hill Professional, 5th edition, ISBN 0071350160.

Divigalpitiya, R. and Hogerton, P. (2004). Contact Resistance of Anisotropic Conductive Adhesives. *Journal of Microelectronics and Electronic Packaging*, Vol. 1, No. 3, 2004, pp. 194-9. ISSN 1551-4897.

Frisk, L. and Ristolainen, E. (2005) .Flip Chip Attachment on Flexible LCP-Substrate using an ACF. *Microelectronics Reliability*, Vol. 45, No. 3-4, 2005, pp. 583-8. ISSN 0026-2714

Frisk, L. and Kokko, K. (2006). The Effects of Chip and Substrate Thickness on the Reliability of ACA Bonded Flip Chip Joints. *Soldering and Surface Mount Technology*, Vol. 18, No. 4, 2006, pp. 28-37. ISSN 0954-0911

Frisk L. and A. Seppälä A. (2006). Reliability of Flip Chip Joints on LCP and PI Substrate. *Soldering and Surface Mount Technology*, Vol. 18, No. 4, 2006, pp. 12-20. ISSN 0954-0911

Frisk L. and Kokko K. (2007). Effect of RCC on the reliability of adhesive flip chip joints. *Journal of Electronic Packaging*, Vol. 129 No. 3, 2007, pp. 260-5. ISSN 1043-7398

Frisk, L. and Cumini, A. "Effect of Substrate Material and Thickness on Reliability of ACA Bonded Flip Chip Joints", Soldering and Surface Mount Technology, Vol. 21, No. 3, 2009 pp. 15-23.

Frisk L. and Cumini A. (2010). Reliability of ACF interconnections on FR-4 substrates. *IEEE Transactions on Components and Packaging Technologies*, Vol. 33, No. 1, 2010, pp. 138-147. ISSN 1521-3331

Frisk, L., Saarinen K., and Kokko K. (2011). Reliability of ACA joined thinned chips on rigid substrates under humid conditions. *Proceedings of European Microelectronics and Packaging Conference, EMPC*, Brighton, UK, September 2011.

Ishibashi, K. and Kimura, J. (1996). A New Anisotropic Conductive Film with Arrayed Conductive Particles. *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, Vol. 19, No. 4, 1996, pp.752–7. ISSN 2156-3950

Jang K-W., C-K. Chung, W-S. Lee, K-W.Paik. (2008). Material properties of anisotropic conductive films (ACFs) and their flip chip assembly reliability in NAND flash memory applications. *Microelectronics Reliability*, Vol. 48, No. 7, 2008, pp. 1052-61. ISSN 0026-2714

Jin, S., Tiefel, T.H, Li-Ilan C., and Dahringer, D.W. (1993). Anisotropically Conductive Polymer Films with a Uniform Dispersion of Particles. *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, Vol. 16, No. 8, 1993, pp.972 - 977. ISSN 0148-6411

Kim, J., Kwon, S., and Ihm, D. (2004). Reliability and Thermodynamic Studied of an Anisotropic Conductive Adhesive Film (ACAF) Prepared from Epoxy/Rubber Resins. *Journal of Material Processing Technology*, Vol. 152, No. 3, 2004, pp.357-62. ISSN 0924-0136

Kwon, W. and Paik, K. (2004). Contraction stress build-up of anisotropic conductive films (ACFs) for flip-chip interconnection: Effect of thermal and mechanical properties of ACFs. *Journal of Applied Polymer Science*, Vol. 93, No. 6, 2004, pp. 2634-41. ISSN 1097-4628

Kwon, W., Yim, M., Paik, K., Ham, S., and Lee, S. (2005). Thermal Cycling Reliability and Delamination of Anisotropic Conductive Adhesives Flip Chip on Organic Substrates with Emphasis on the Thermal Deformation. *Journal of Electronic Packaging*, Vol. 127, No. 2., 2005, pp.86-90. ISSN 1043-7398

Kwon, W., Ham, S., and Paik, K. (2006). Deformation Mechanism and its Effect on Electrical Conductivity of ACF Flip Chip Package Under Thermal Cycling Condition: An experimental Study. *Microelectronics Reliability*, Vol. 46, No.2-4, 2006, pp.589-99. ISSN 0026-2714

Kwon, W. and Paik, K. (2006). Experimental Analysis of Mechanical and Electrical Characteristics of Metal-coated Conductive Spheres for Anisotropic Conductive Adhesives. *IEEE Transactions on Components and Packaging Technologies*, Volume 29, No. 3, 2006, pp. 528-34. ISSN 1521-3331

Lai, Z. & Liu J. (1996). Anisotropically conductive adhesive flip-chip bonding on rigid and flexible printed circuit substrate. *IEEE Transactions on Components, Packaging, and Manufacturing Technology, Part B: Advanced Packaging*, Vol. 19, No. 3, 1996, pp. 644-66. ISSN 2156-3950

Lai, Z., Lai, R., Persson, K., and Liu, J. (1998). Effect of Bump Height on the Reliability of ACA Flip Chip Joining with FR4 Rigid and Polyimide Flexible Substrate. *Journal of Electronics Manufacturing*, Vol. 8, No. 3-4, 1998, pp. 217-24. ISSN 0960-3131

Lau, J. (1995). *Flip Chip Technologies*, McGraw-Hill, ISBN 0070366098, New York, USA.

Lau, J. (2000). *Low Cost Flip Chip Technologies for DCA, WLCSP, and PBGA Assemblies*, McGraw-Hill, ISBN 0071351418, New York.

Lau, J., Wong, C.P., Lee, N., and Lee, R. (2003*). Electronics Manufacturing: with Lead-Free, Halogen-Free, and Conductive-Adhesive Materials*. McGraw-Hill Professional, ISBN 0071386246, New York.

Li, Y. and Wong, C.P. (2006). Recent Advances of Conductive Adhesives as a Lead-free Alternative in Electronic Packaging: Material, Processing, Reliability and Applications. *Materials Science and Engineering R 51*, 2006, ISSN 0927-796X.

Licari, J. J. and Swanson, D. W. (2005). *Adhesives Technology for Electronic Applications*, William Andrew Publishing, ISBN 0815515138, Norwich, New York.

Liu, J., Tolvgard, A., Malmodin, J., and Lai, Z. (1999). A Reliable and Environmentally Friendly Packaging Technology - Flip Chip Joining Using Anisotropically Conductive Adhesive", *IEEE Transactions on Components and Packaging Technology*, Vol. 22, No. 2, 1999, pp. 186-90, ISSN 1521-3331.

Liu, J. (2001). ACA Bonding Technology for Low Cost Electronics Packaging Applications – Current Status and Remaining Challenges. *Soldering & Surface Mount Technology*, Vol. 13, No. 3, 2001, pp. 39-57, ISSN 0954-0911.

Lu, D. (2006). Overview of Recent Advances on Isotropic Conductive Adhesives. *Proceeding of 6th Conference on High Density Microsystem Design and Packaging and Component Failure Analysis (HDP)*, ISBN 9781424404889, Shanghai, China, June 2006.

Luo, S., Leisen, J., and Wong, C. (2002). Study on Mobility of Water and Polymer Chain in Epoxy and Its Influence on Adhesion. *Journal of Applied Polymer Science*, Vol. 85, No. 1, 2002, pp.1-8. ISSN 1097-4628

Mercado, Lei., white, J., Sarihan, V., and Lee, T. (2003). Failure Mechanism Study of Anisotropic Conductive Film (ACF) Packages. *IEEE Transactions on Components and Packaging Technologies*, Vol. 26, No. 3, 2003, pp. 509-16. ISSN 1521-3331

Morris, J., Lee, J., and, Liu, J. (2005). Isotropic Conductive Adhesive Interconnect Technology in Electronics Packaging Applications. *Proceedings of the 5th International Conference on Polymers and Adhesives in Microelectronics and Photonics*, ISBN 0780395530, Wrocaw, Poland, January 2006.

Ogunjimi, A. O., Mannan, S. H., Whalley, D. C., & Williams, D. J. (1996). Assembly of Planar Array Components Using Anisotropic Conducting Adhesives-A Benchmark Study: Part I-Experiment. *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, Vol. 19, No 4, 1996, pp. 257-63. ISSN 2156-3950

Pinardi, K., Liu, J., Haug, R., Treutler, C., and Willander, M. (1998). Deformation study of the PCB during the flip chip assembly processing anisotropically conductive adhesive (ACA) as a bonding agent. Proceedings of 3rd IEEE Conference on Adhesive Joining and Coating Technology in Electronics Manufacturing, Binghamton, ISBN 0780349342, NY, USA, September, 1998.

Rizvi, M. J., Chan, Y. C., Bailey, C., Lu, H., and Sharif, A. (2005). The Effect of Curing on the Performance of ACF Bonded Chip-on-flex Assemblies After Thermal Ageing. *Soldering and Surface Mount Technology*, 2005, Vol. 17, No. 2, pp.40-8. ISSN 0954-0911

Saarinen, K., Frisk, L. and Ukkonen, L. (2011). Effects of different combinations of environmental test on the reliability of UHF RFID tags. *Procedings of 17th European Microelectronics and Packaging Conference, EMPC*, Brighton, UK September, 2011.

Savolainen, P. (2004). Display driver packaging: ACF reaching the limits?. *Proceedings of the 9th International Symposium on Advanced Packaging Materials: Processes, Properties and Interfaces*, ISBN 0780384369, Atlanta, Georgia, USA, January, 2004.

Suhir, E. (2002). Accelerated Life Testing (ALT) in Microelectronics and Photonics: Its role, Attributes, Challenges, Pitfalls, and Interaction with Qualification Tests. *Journal of Electronic Packaging*, Vol. 124, No. 3, 2002, pp. 281-91. ISSN 1043-7398

Sungwook, M. and Chappell, W. J. (2010). Novel Three-Dimensional Packaging Approaches Using Magnetically Aligned Anisotropic Conductive Adhesive for Microwave Applications. *IEEE Transactions on Microwave Theory and Techniques*, vol. 58, No. 12, pp. 3815-23. ISSN 0018-9480

Takagi, K., Honma, H., and Sasabe, T. (2003). Development of Sequential Build-up Multilayer Printed Wiring Boards in Japan. *IEEE Electrical Insulation Magazine*, Vol. 19, No. 5, 2003, pp. 27 – 56. ISSN 0883-7554

Tan, S. C., Chan, Y. C., Chiu, Y. W., and Tan, C. W. (2004). Thermal Stability Performance of Anisotropic Conductive Film at Different Bonding Temperatures. *Microelectronics Reliability*, Vol. 44, No. 3, 2004, pp. 495-503. ISSN 0026-2714

Uddin, M. A., Alam, M. O., Chan Y. C., and Chan, H. P. (2004). Adhesion Strength and Contact Resistance of Flip Chip on Flex Packages – Effect of Curing Degree of Anisotropic Conductive Film. *Microelectronics Reliability*, Vol. 44, No. 3, 2004, pp.505-14. ISSN 0026-2714

Wang, X. Wang, Y., Chen, G., Liu, J., and Lai, Z. (1998). Quantitative Estimate of the Characteristics of Conductive Particles in ACA by using Nano Indenter. *IEEE Transactions on Components and Packaging, and Manufacturing Technology* , Vol. 21, no. 2, 1998, pp.248 – 51. ISSN 1070-9886

Watanabe, I. Fujinawa, T. Arifuku, M. Fujii, M. Yasushi, G. (2004). Recent advances of interconnection technologies using anisotropic conductive films in flat panel display applications. *Proceedings of the 9th IEEE International symposium Advanced Packaging Materials: Processes, Properties and Interfaces*, ISBN 0780384369, Atlanta, Georgia, USA, August 2004.

Whalley, D., Mannan, S., and Williams, D. (1997). Anisotropic Conducting Adhesives for Electronic Assembly. *Assembly Automation*, Vol. 17, No. 1, 1997, pp.66-74. ISSN 0144-5154

Wong, E. H., Chan, K. C., Rajoo, R., and Lin, T. B. (2000). The Mechanics and Impact of Hygroscopic Swelling of Polymeric Materials in Electronic Packaging. *Proceedings of the 50th IEEE Electronics Components and Technology Conference*, ISBN 0780359089, Las Vegas, NV, USA, May, 2000.

Wu, S. X., Zhang, C. Yeh, C, Wille, S., and Wyatt, K. (1997). Cure Kinetics and Mechanical Properties of Conductive Adhesive. *Proceedings of the 47th IEEE Electronics Components and Technology Conference*, ISBN 0-7803-3857-X, San Jose, CA, USA, May, 1997.

Yim, M. J. and Paik, K. W. (1998). Design and understanding of anisotropic conductive films (ACF's) for LCD packaging. *IEEE Transactions on Components and Packaging Technologies*, Vol. 21, No. 2, 1998, pp.226-34. ISSN 1521-3331

Yim, M. J. and Paik, K. W. (1999). The Contact Resistance and Reliability of Anisotropically Conductive Film (ACF). *IEEE Transactions on Advanced Packaging*, Vol. 22, No. 2, 1999, pp.166-73, ISSN 1521-3323.

Yim, M. J. and Paik, K. W. (2001). Effect of Nonconducting Filler Additions on ACA Properties and the Reliability of ACA Flip Chip on Organic Substrates. *IEEE*

Transactions on Components and Packaging Technologies, Vol. 24, No. 1, 2001, pp.24-32. ISSN 1521-3331

Yin, C.Y., Alam, M.O., Chan, Y.C., Bailey, C. and Lu, H. (2003). The Effect of Reflow Process on the Contact Resistance and Reliability of Anisotropic Conductive Film Interconnection for Flip Chip on Flex Applications. *Journal of Microelectronics Reliability*, Vol. 43, No. 4, 2003, pp. 625-33. ISSN 0026-2714

Zhong, Z. W. (2005). Various Adhesives for Flip Chips. *Journal of Electronic Packaging*, Vol. 127, No. 1, 2005, pp. 29-32. ISSN 1043-7398
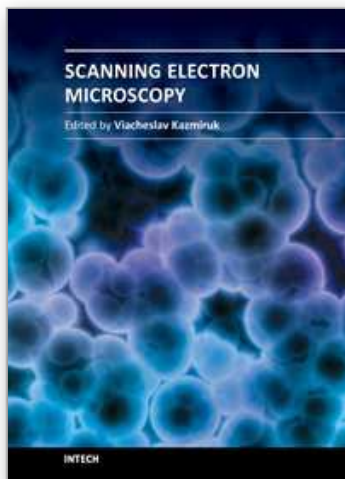
Scanning Electron Microscopy

Edited by Dr. Viacheslav Kazmiruk

Today, an individual would be hard-pressed to find any science field that does not employ methods and instruments based on the use of fine focused electron and ion beams. Well instrumented and supplemented with advanced methods and techniques, SEMs provide possibilities not only of surface imaging but quantitative measurement of object topologies, local electrophysical characteristics of semiconductor structures and performing elemental analysis. Moreover, a fine focused e-beam is widely used for the creation of micro and nanostructures. The book's approach covers both theoretical and practical issues related to scanning electron microscopy. The book has 41 chapters, divided into six sections: Instrumentation, Methodology, Biology, Medicine, Material Science, Nanostructured Materials for Electronic Industry, Thin Films, Membranes, Ceramic, Geoscience, and Mineralogy. Each chapter, written by different authors, is a complete work which presupposes that readers have some background knowledge on the subject.

INTECH
open science | open minds