Anisotropic Conductive Adhesives

Peter J. Opdahl

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Abstract

Anisotropic conductive adhesives (ACAs) are a set of materials typically combining either epoxy or acryl adhesives and conductive particles to allow electrical connection across what would otherwise be a standard mechanical adhesive assembly. They differ from isotropic conductive adhesives such as silver epoxy in that the conductive particles are loaded and distributed in such a way that they do not conduct within the bulk of the adhesive but do conduct in the *Z*-axis when they are trapped between electrodes on the top and bottom substrates. This allows them to offer some unique advantages compared with isotropic adhesives or various solder technologies. In the case of touch panels, these advantages are primarily related to its low temperature and high interconnect density capabilities, although cost and speed of assembly may also be considerations.

ACAs are widely used in the display and electronics assembly industries. In flat panel displays, they are used to make the connection between the drive circuitry and the display itself. They are also used extensively in other

P.J. Opdahl (✉)
Ito Corporation, Chuo-ku, Tokyo, Japan
e-mail: peter@ito-group.com

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applications that require high-density and/or low-temperature assembly at high volume. This includes touch panels, camera modules for mobile phones, touchpads for notebook computers, and RFID assemblies for smartcards. ACAs have also had limited success in semiconductor packaging, but the reliability requirements for these applications are not always possible to achieve with ACA technology.

List of Abbreviations

ACA	Anisotropic conductive adhesives
ACF	Anisotropic conductive film
ACP	Anisotropic conductive paste
COB	Chip-on-board
COF	Chip-on-flex
COG	Chip-on-glass
DSC	Differential scanning calorimetry
FOB	Flex-on-board
FOF	Flex-on-flex
FOG	Flex-on-glass
FPC	Flexible printed circuit
FTIR	Fourier transform infrared spectroscopy
PCB	Printed circuit board
RFID	Radio frequency identification
SMT	Surface mount technology
UPH	Units per hour

Introduction

Anisotropic conductive adhesive (ACA) is the generic term used to refer to anisotropic conductive film (ACF) and anisotropic conductive paste (ACP). The technology is based on the premise that a balanced loading and distribution of conductive particles within an adhesive matrix will allow those particles to become trapped between the upper and lower sides of an assembly, thereby conducting electricity through the vertical axis while not creating shorts in the horizontal axes. ACA is widely used in assemblies that do not lend themselves to solder or connector interconnections, such as high-density connections to glass or to low-temperature substrates such as polyester or other polymers (Fig. 1) (Savolainen et al. 2004).

ACAs were first developed in the mid-1970s, beginning as very simple hot-melt adhesive systems for driving LCD calculator displays using cheap connectors made with conductive inks screen printed on polyester films. These systems were improved; ACF as we now know it was first released to the market in 1984.

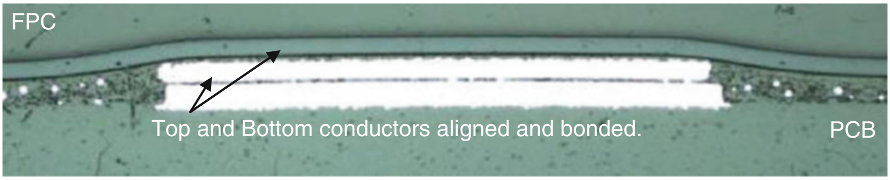

Fig. 1 Cross-sectional view of an ACA assembly. *White dots* are conductive particles

Materials

ACF is currently much more common than ACP, although this is changing as materials and process technologies mature. The primary advantage of ACF is that the distribution of particles within an ACF can be fixed by the manufacturer during the curing stage after the material has been cast on the release film. Until the ACF undergoes the thermal compression required in the final assembly process, these particles are locked in the solid adhesive matrix, preventing their movement. Conversely, ACPs can settle after manufacturing and must be thoroughly mixed before use. ACPs may also create uneven distribution during the dispensing process as particles can agglomerate as they pass through the needle on their way to the substrate. ACP is not often printed due to the cost of wasted material.

ACF is supplied on reels, typically in 50, 100, and 200 m lengths and in widths as narrow as 1.0 mm. ACP is supplied in a variety of industry-standard syringe sizes. Both must be refrigerated during storage, typically at 0 °C, ±5 °C. The pot life for ACPs varies significantly but is usually less than 24 h. ACFs can be used for up to 2 weeks after being removed from their original packaging.

ACAs are generally defined by their adhesive type, particle type, and particle loading. An example base specification would be an epoxy binder with 9 μm diameter nickel-gold-plated polymer spheres at a loading of 750,000 particles/ mm^3. The adhesive system and particle type are determined by the type of assembly being made, while the loading required is a function of the interconnect density. Table 1 shows some of the key characteristics and applications for which different ACAs are used.

Nickel and polymer spheres used in ACAs may be Au or NiAu plated. Nickel dust and solder particles are never plated. The solder alloys used are lead free and may be of varying composition.

Nickel and solder particles may be used on OSP (organic solderability preservative)-treated substrates, but polymer particles require a conductive surface such as Au, Ag, or Sn.

The epoxy adhesive used is most typically a solventless single-part biphenol with imidazole accelerators. Curing temperatures are between 150 °C and 220 °C and the cure time ranges from 5 to 15 s.

Acryl-based ACAs cure at 130–180 °C in a time of 3–10 s.

Table 1 Common adhesive/particle configurations and their use

		Epoxy-based adhesives	Acryl-based adhesives
Processing	Assembly temp. (°C)	160–220	130–180
	Reworkability	Low	High
Reliability	Environmental stability	Very high	High
Particle type and application use	Nickel dust (1–30 μm dia.)	RFID	RFID
	Nickel spheres (6–10 μm dia.)	FOB, FOF, FOG	FOB, FOF, FOG
	Solder spheres (9–10 μm dia.)	FOB, FOF	FOB, FOF
	Polymer spheres (2–4 μm dia.)	COF, COG	N/A
	Polymer spheres (5–10 μm dia.)	FOB, FOF, FOG, COB	FOB, FOF, FOG
	Polymer spheres (10+ μm dia.)	FOB, FOF	FOB, FOF

COB Chip on board, *COF* Chip on flex, *COG* Chip on glass, *FOB* Flex on board, *FOF* Flex on flex, *FOG* Flex on glass

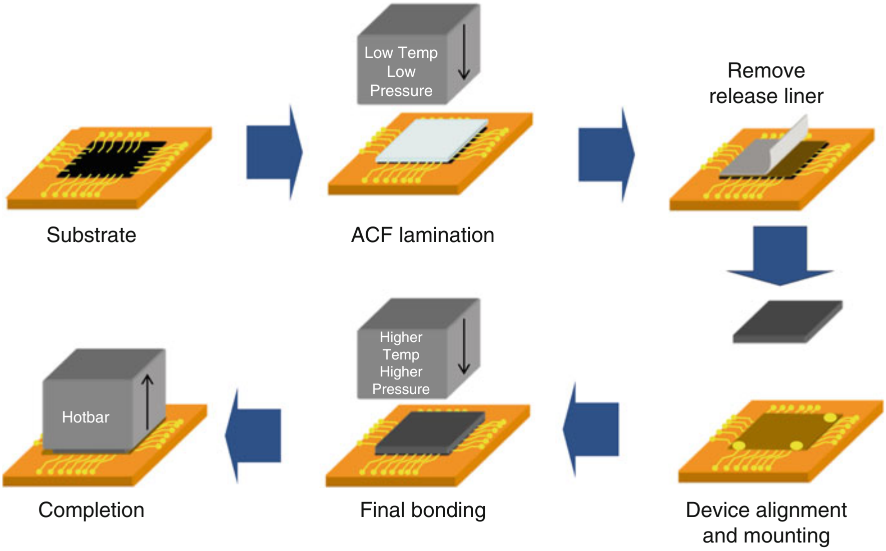

Fig. 2 ACA assembly process

Table 2 Typical cycle times per equipment head

	Lamination or dispensing	Mounting	Bonding
Head-down time	0.2–2.0	0.01–2.0	5.0–15.0
Total machine cycle time	4.0–10.0	1.0–10.0	8.0–25.0

Note: Times are in seconds. Total machine cycle time includes all equipment and operator operations except load and unload

Manufacturing Process

The ACA assembly process is generally the same for all types of assemblies, differing only in whether a paste is dispensed or a film is laminated (Fig. 2). In the case of ACF, the material is laminated to a substrate and its release liner removed to expose the top surface of the ACF. The top half of the assembly is then aligned to the substrate and mounted to it in a process analogous to SMT mounting. Lastly, the assembly is bonded together using heat to cure the adhesive. It is possible to combine the mounting and bonding steps into one step, but due to throughput restrictions they are normally separated for high-volume applications.

The highest-throughput general-use lines currently available utilize multiple ACF lamination, mounting, and bonding heads to achieve a total cycle time of under 2 s per bond assembly. Table 2 shows typical cycle times per head for semiautomatic or automatic machines. Specialty lines for RFID assembly using ACP offer up to 10,000 UPH of throughput.

Lamination or Dispense Process

Most ACFs are laminated at a pressure of 0.1–0.5 MPa, using 60–90 °C for 0.2–1.0 s. It is critical that no air be trapped under the ACF during this process as this can lead to higher levels of voiding and lower peel strength after assembly. Automated systems will often use image recognition systems to inspect the laminated ACF for position, wrinkles, or other defects. Typical ACF lamination accuracy is ±0.2 mm in both the *X* and *Y* axes.

Dispensing of ACPs is similar to dispensing of other adhesives. The rheological and thixotropic characteristics of the material used will largely determine the dispense technology and speed. It is notable that using heat in the dispenser to help control viscosity is not possible because it will cause the ACP to start curing.

Mounting Process

Mounting can be done at room temperature or with heat up to 100 °C. Heat is used to decrease the amount of time the head must remain down and pressing the top side of the assembly into the ACF, but the use of heat must be managed so that it does not begin to cure the adhesive and affect the quality of the assembly. The amount of pressure used in the mounting process varies widely from 0.05 to 0.5 MPa. In general, pressure limitations are a function of the assembly equipment, not the material set.

Mounting accuracy is dependent on assembly requirements, but for pitches down to 0.2 mm, which are typical for touch panel assembly, ±15–20 μm is common. Equipment capable of submicron mounting accuracy is also available, but most volume manufacturing equipment will be in the ±3–20 μm range.

Bonding Process

The final step is a thermal compression process where a heated press is brought into contact with the ACF assembly, causing the two sides to be pushed together, trapping the conductive particles between the opposing contacts and curing the adhesive. The heat may be supplied using several different methods.

The most common method is called "constant heat," where a heater is embedded into the press and heats a block of metal to a fixed temperature. This block then transfers heat through a tool made to the size of the ACF bond, curing the ACF assembly. The heater will engage and disengage only to keep the block at a predefined temperature and the block is sized to provide an appropriate thermal mass for the assembly.

"Pulsed heat" systems employ an active controller that monitors and alternately heats or cools the bonding tool to actively raise and lower the temperature. This allows a profile to be created with multiple temperature points on it, offering greater flexibility, but with the penalty of higher equipment cost and somewhat lower

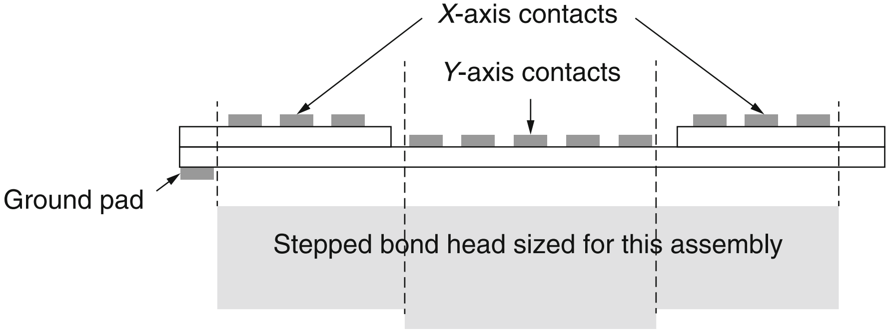

Fig. 3 Cross section of capacitive touch panel bonding area

equipment stability. With pulsed heat, the head is made of ceramic or metal and is designed to have a low thermal mass to assist with rapid heating and cooling.

Bond heads may be flat or stepped to accommodate different heights within the assembly. A capacitive touch panel that brings the X and Y contacts to the same side may have two or three different surfaces to be bonded. Using an appropriately designed head and nest, it is possible to do this in one pass, although two-pass assembly is also done.

In the example above, we see an assembly with two planes upon which bonds must be made (Fig. 3). There may also be a ground pad on the rear side of the assembly that will also use ACA. In this case, the reverse side must be bonded in a separate process and if possible should not be located such that it is under the bonding area on the top side of the assembly. This is to prevent the processes from adversely affecting each other.

The bonding process has the most impact on long-term reliability and will require testing to determine its robustness. The bonding profile contains heat, pressure, and time variables. Pressure will determine the gap remaining between the two sides of the assembly after bonding is complete. In general, this gap should be 30–50 % the original diameter of the particles in the selected ACA. The gap can only be precisely measured by using cross sections, but in-process monitoring can be done by observing the diameter of the crushed particles and deriving a presumed gap from those values.

Heat and time are adjusted together to inject the required amount of thermal energy into the bond. In general, a higher peak temperature will allow a shorter bonding time, but the adhesive must not cure so fast that it does not have time to adequately wet the surfaces being bonded or force out any trapped gases. The temperature must also not ramp too slowly, as this may also prevent adequate wetting. A typical process will achieve 70–80 % of the peak temperature within the first 2 s of the head contacting the assembly.

Reliability Testing

Reliability testing for ACA bonds can vary widely (Table 3). Many but not all materials can comfortably survive multiple solder reflow passes at 250–260 °C, and a well-implemented ACA interconnect is often more reliable than the SMT components surrounding it, particularly for drop tests.

Table 3 Reliability testing conditions

	Typical test conditions	
	Epoxy-based adhesives	Acryl-based adhesives
High heat/high humidity	85 °C/85 % RH	85 °C/85 % RH
	1000 h	1000 h
Thermal shock	−55 °C, 30 min ⇔ room temperature, 5 min ⇔ 125 °C, 30 min	−40 °C, 30 min ⇔ room temperature, 5 min ⇔ 100 °C, 30 min
	1000 cycles	1000 cycles

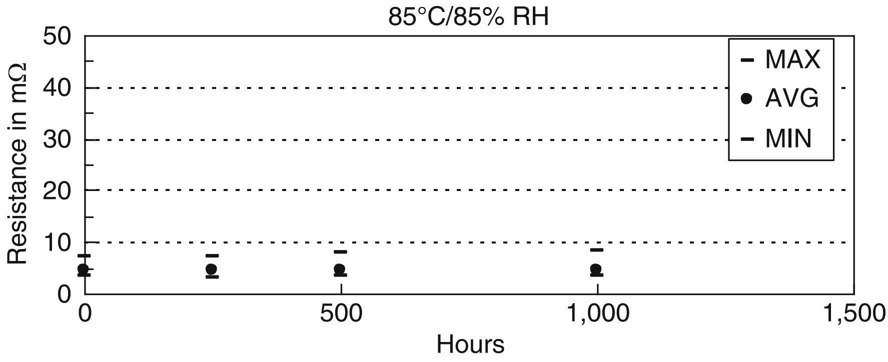

Fig. 4 Typical high-temperature/high-humidity resistance chart

Electrical reliability is tested by looking at how the contact resistance of the joint increases over time. ACA contact resistance will vary widely depending on ACA selected and the type of surface to which it is making the connection (Fig. 4). Gold-on-gold connections can have contact resistances of down to 5 mΩ. Typical contacts to ITO will yield a resistance of 10–15 mΩ. In a good ACA assembly, contact resistance will often decrease for the first 100 h or so of high-temperature testing as the adhesive continues to cure. It will then stabilize and very little change will be seen afterward (Islam and Chan 2004).

Peel strength is one area that is almost always tested. While a direct causal link between peel strength and reliability is often not possible to demonstrate, because it is easy to measure and easy to understand, users often spend a disproportionate amount of time trying to optimize it. The key metrics with peel strength should be the initial adhesion strength and long-term drop test reliability. Initial peel strength must be high enough to withstand any subsequent assembly processes prior to final assembly, and long-term adhesion must remain high enough to withstand normal use. Typical ACF assemblies using ACF for flex-on-flex (FOF) or flex-on-board (FOB) have peel strengths between 12 and 25 N/linear centimeter (Chen et al. 2005). At this level, the copper conductors on a PCB or FPC will typically delaminate prior to the ACF bond failing. Adhesion to other substrates such as flex-on-glass (FOG) is often slightly lower due to the flatter topography of the materials being joined (Kim et al. 2006).

FTIR (Fourier transform infrared spectroscopy) or DSC (differential scanning calorimetry) analysis is used to determine the final level of cure that was achieved within the adhesive. Levels over 85 % will pass most consumer-grade reliability requirements. This is typically a critical milestone in the development of an ACA process because it not only defines reliability to a great extent but also sets the head-down time of the bond cycle. Because the head-down time is almost always the longest part of the assembly process, this determines the throughput for that portion of the line.

Conclusion

ACAs provide an environmentally friendly and cost-competitive solution to high-density interconnects. They allow assembly at temperatures as low as 130 °C and offer reliability that meets or exceeds that typically required for consumer electronics. The technology is already widely used in both the flat panel display and electronics assembly industries, making it the leading choice for use in interconnecting touch panels and other assemblies requiring the density, reliability, economics, and industry-wide acceptance that ACAs offer.

Further Reading

A list of high-quality papers on ACF that are available online is maintained at http://autoacf.com/ACF_Online_Resources.aspx

Anisolm. http://www.hitachi-chem.co.jp/japanese/products/do/001.html

Anisotropic conductive film. http://www.sonycid.jp/en/products/dd1/index.html

Chen X, Zhang J, Jao C, Liu Y (2005) Bonding parameters of anisotropic conductive adhesive film and peeling strength. Key Eng Mater 297–300:918–923

Islam RA, Chan YC (2004) Effect of drop impact energy on contact resistance of anisotropic conductive film adhesive film joints. J Mater Res 19(6):1662–1668

Kim H-J, Chung C-K, Yim M-J, Hong S-M, Jang S-Y, Moon Y-J, Paik K-W (2006) Study on bubble formation in rigid-flexible substrates bonding using anisotropic conductive films (ACFs) and their effects on the ACF joint reliability. In: Proceedings of the 56th electronic components and technology conference, 2006, San Diego

Savolainen P, Saarinen I, Rusanen O (2004) High-density interconnections in mobile phones using ACF. In: Polytronics 2004 I.E. international conference on polymers & adhesives, Portland, September 2004, AP22