Anisotropic Conductive Film for Flip Chip Applications: An Introduction

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Preface

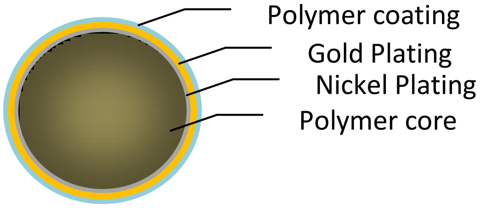
Anisotropic conductive film, commonly known as ACF, is a lead-free and environmentally-friendly adhesive system that has been used for more than 30 years in the flat panel display industry to make the electrical and mechanical connections from the drive electronics to the glass substrates of the displays. Chip-on-glass (COG) applications now commonly use ACF at pitches down to 25um and spaces of 10um while anisotropic chip-on-flex (aCOF) has stabilized in the 40um pitch range as a standard technology. A single one of these driver chips can have more than 1300 pads that are all simultaneously interconnected during the ACF assembly process.

Compared to COG and aCOF, aCOB (anisotropic chip-on-board) assemblies are still in their infancy. They have, however, made great strides in the past several years in applications requiring high density and low profile characteristics in a robust and cost-sensitive package. Mobile phones are by far the largest consumers of these kinds of chips, and although in comparison to COG and aCOF the penetration is not high, it is still in the millions of units per month.

History

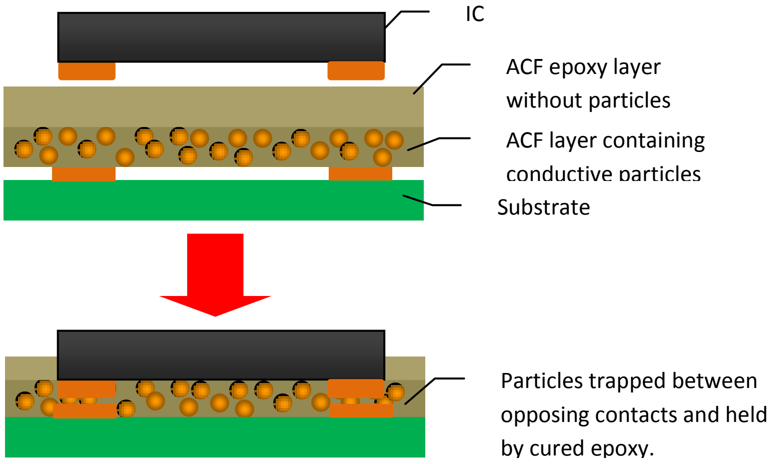
ACF started as a solution to provide low-cost reliable interconnection for the first wave of small, cheap calculators coming out of Japan. The initial adhesive materials were thermoplastic, supporting pitches of 1.0mm down to perhaps 0.7mm. By the mid-1980s, the pitches were down in the 0.2mm range and thermoplastic adhesives were dropped in favor of more reliable thermoset epoxies. In non-flip chip applications, ACFs have moved toward incorporating more acryl-based adhesives to capitalize on the lower temperatures and faster cure times achievable with these compounds, but flip chip assemblies using ACF, whether they are COG, COF, or COB assemblies, continue to rely solely on epoxy for its reliability and durability under high heat and humidity.

How ACF Works



ACF works by trapping conductive particles between the corresponding conductive pads on the IC and substrate. Flip chip ACFs typically consist of a matrix of epoxy containing 3-5µm polymer spheres, each nickel-gold plated and then coated with a final insulating layer that protects them against shorting through contact with a neighboring particle.

In the past 12-18 months there has been a growing trend toward using multilayer ACFs as well, with the conductive particles contained in the bottom layer lying against the substrate. An upper layer facing the device is made of similar and compatible adhesive as the lower layer, but it contains no particles and is designed to have a lower viscosity during the bonding process. As the device is pressed into the ACF, heat is transferred through the device and first heats the upper layer. The upper layer begins to flow and the device settles through it and begins pressing on the lower layer before that layer has a chance to reflow.



This has two positive effects on reliability within the assembly. First, it increases the number of particles trapped on the contact pad by reducing the amount of time between when the ACF surrounding the particles begins to flow and when the particles begin being contacted on both sides by the device and substrate. Second, it reduces the overall particle loading of the assembly by concentrating the particles only in the layer being bonded. This results in fewer particles flowing out from under the assembly and therefore the chance that these particles could somehow agglomerate or become compressed in an unwanted area and cause a short.

The insulation on each individual particle also works to prevent electrical contacts from developing where they are not wanted. As the particles are trapped, the insulation layer, which is an inelastic polymer, is pushed away, allowing the Ni-Au layer on the particle to conduct electricity between the IC and the substrate. Particles that are not compressed, but which may inadvertently contact each other or some other part of the assembly, remain individually isolated and will not cause an electrical connection.

The reliability of the assembly comes from two of ACF's key characteristics. While the polymer coating each particle is inelastic, the particle cores themselves are designed to be highly elastic. As they are deformed or crushed during the bond process, the epoxy around them cures and locks them in this state. The elasticity of the compressed trapped particles causes them to constantly press outward on both contact points, helping to maintain electrical connections through a wide range of environmental conditions. The second characteristic is the low moisture absorption and thermal expansion functions of the epoxy and filler materials selected. This works very similarly to the way that standard epoxy underfills function by limiting and distributing stress in the assembly.

ACF Assembly

The assembly process is simple, lending itself to a high level of automation and reliability.

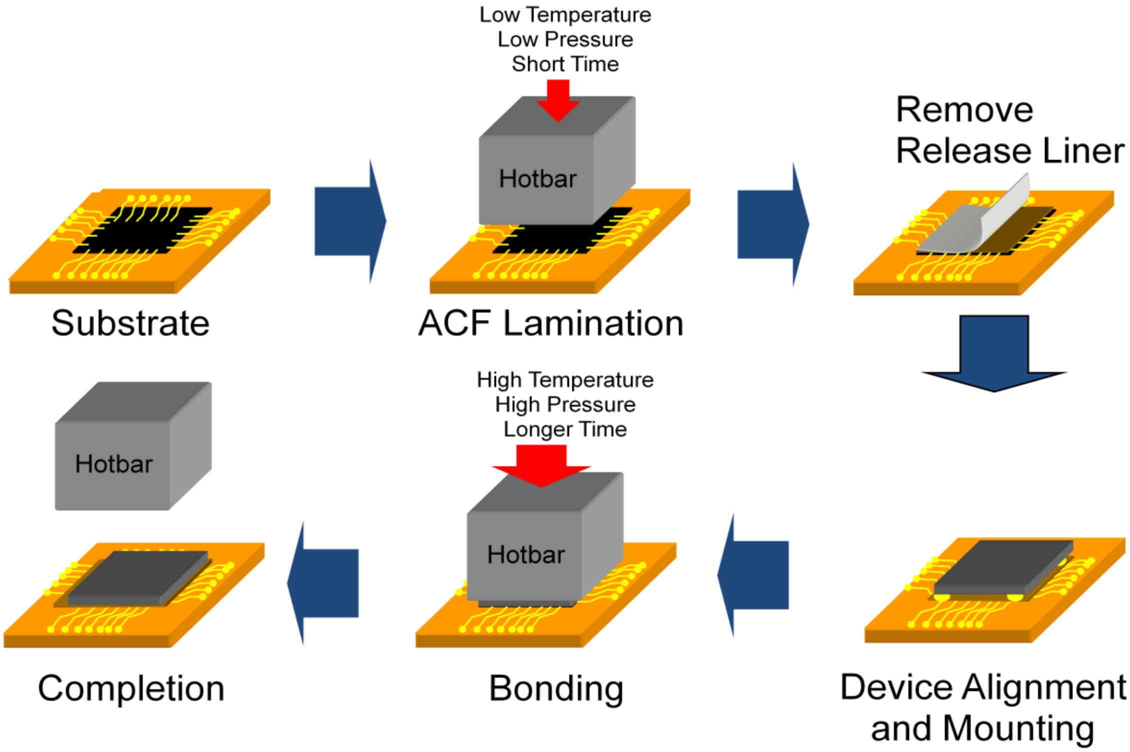
Step 1: Prepare the substrate. The material can be FR4, FR5, BT, ceramic, build-up, polyimide, or any other standard board material. ACF is currently used for flex-on-board (FOB) applications on OSPcoated boards, but for flip chip it is still highly recommended to use gold, or sometimes immersion tin, as the surface metallization.

Step 2: Laminate the ACF to the substrate. Typically this is done by cutting the required length of ACF from a reel of ACF pre-slit to the required width. The ACF is laid in place over the bonding area and 1-2MPa of force is applied for 1-3 seconds at 90-100°C.

Step 3: The ACF has a release liner on its rear surface to prevent the bondhead from adhering to the ACF during the lamination procedure. This must be removed without damaging the ACF layer or causing any delamination within the bonding area. Steps 1-3 are normally integrated into one piece of equipment called an *ACF Laminator*.

Step 4: The IC is then aligned to the substrate and mounted on the uncured ACF. This works identically to standard flip chip mounting equipment with the caveat that in ACF there is no self-centering function as the ACF reflows so alignment is critical. Depending on the inherent tackiness of the ACF used, the mounting process can be done at temperatures ranging from ambient through 100°C. The amount of time spent holding the device to the ACF is 0.5-1 second. This process is contained in a machine called the *Mounter*.

Step 5: The final process subjects the ACF to high heat and temperature. This causes the ACF to reflow, the particles to be trapped, and the epoxy to finally cure and harden. A typical bonding profile will peak at 180-220°C and uses 40-300 grams/bump for 5-20 seconds. COG applications will be at the short end of the cycle time range and aCOB will be at the long end. This step takes place in the *Bonder*.



Reliability

People considering ACF typically assume that any solder processes must take place prior to the ACF bonding process. In fact, aCOF and aCOB packages quite commonly pass IPC/JEDEC J-STD-20 MSL (Moisture/Reflow Sensitivity Classification for Plastic Integrated Circuit (IC) SMDs) Level 1 requirements. The ability of ACF to withstand multiple solder reflows was a major milestone in its growing acceptance within the semiconductor packaging industry.

			Soak Requirements			
Lvl	**Floor Life**		**Standard Test**		**Accelerated Test**	
	Time Limit	Conditions °C/%RH	Time (hrs)	Conditions °C/%RH	Time (hrs)	Conditions °C/%RH
1	None	≤30/85%	168+5/-0	85/85	NA	NA
2	1 yr	≤30/60%	168+5/-0	85/60	NA	NA
2a	4 wks	≤30/60%	696+5/-0	30/60	120+1/-0	60/60
3	168 hrs	≤30/60%	192+5/-0	30/60	40+1/-0	60/60
4	72 hrs	≤30/60%	96+2/-0	30/60	20+0.5/-0	60/60
5	48 hrs	≤30/60%	72+2/-0	30/60	15+0.5/-0	60/60
5a	24 hrs	≤30/60%	48+2/-0	30/60	10+0.5/-0	60/60
6	<24 hrs	≤30/60%	<24hrs	30/60	NA	60/60

ACF also offers some thermal advantages by placing the surface of the die very close to the substrate, often within 20µm, while leaving the top side of the die bare and able to accept any variety of heatsink technologies. A well-thought-out design could easily place internal bumps on the die to contact a heat sink on the board and conduct heat out even more efficiently if required.

Cost

The semiconductor industry, while always investigating and using new technologies in high-end applications, relentlessly seeks lower costs for high-volume applications. ACF offers cost savings over older technologies. While cost models vary, a subset of cost drivers has emerged which show ACF as not only the most space-effective packaging method for certain applications, but also the most cost-effective method. These cost drivers are die size, redistribution layers, substrate costs, and underfill.

Die size is easily understood if one considers that pad sizes as small as 800µm^2 and pad-to-pad gaps of only 12µm have been commercial realities in aCOF applications for years. The IC with 1300+ pads mentioned in the introduction would likely come in a package around 20mm long by 1.3mm wide, or 26mm^2. The high aspect ratio is necessary to provide the required space for 1300+ connections – Consider that even at a pitch of 50µ it would take more than 65mm of edge space to accommodate that many interconnects. The only constraint preventing this kind of density in aCOB has been the technology available to make substrates with those geometries. The cost driver now is the balance between the savings achievable by going to a finer pitch versus these costs necessary to get there. At an average cost of well under \$0.005/mm^2, the cost of the ACF itself is a secondary concern.

Similarly, in current non-ACF flip chip applications, the designer may be forced to use an area array under the die to increase pad size and spacing while reducing die size and cost. However, this array requires additional redistribution layers within the die and on the substrate, negating the cost benefits of die size reduction. ACF lets the designer reduce die size while maintaining only peripheral pads that require no redistribution layer on the die, and often do not require one on the substrate, further reducing cost.

ACF also eliminates the need for solder resist under the die and between the contact pads. The solder mask required for C4 and other solder-based processes reduces yields, so limiting solder resist can significantly lower costs.

Finally, ACF has the further advantage of being its own underfill. Eliminating the need to dam, flow, and cure underfill bring significant total cost savings.

Conclusion

The reliability, packaging, and cost advantages of ACF cannot be ignored. Particularly in the hypercompetitive semiconductor arena, where cost, functionality, and reliability are continually driven to new levels, ACF represents a proven path to smaller, thinner, lighter packages with acceptable cost structures. ACF assembly equipment is now also extremely mature, with a wide variety of manual, semi-automatic, and fully-automatic platforms available around the world.