A Buyer's Guide to Flip Chip

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SUMMARY

Flip chip packaging is becoming a "must-have" for many smaller-faster-cheaper applications. But as flip chip has flourished, its technology has blossomed into a dozen different varieties, each with its strengths and weaknesses. This paper gives you some guidance, based on my 14 years experience in flip chip development, production, and consulting, to help you find the flip chip that's best for you.

A. FLIP CHIP ADVANTAGES

The forces driving flip chip's continuing growth are the flip chip advantages in size, performance, flexibility, reliability, and cost over conventional micropackaging.

Smallest Size. Flip chip is the smallest "package," only slightly larger than the chip itself. Eliminating conventional packaging and connections reduces the board area for a single chip up to 95%, reduces the height by up to 90%, and reduces weight to as little as 5% of packaged device weight.

Highest Performance. Flip chip gives the highest speed electrical performance of any interconnection method. Replacing bond wires with bumps reduces the delaying inductance of the off-chip connection by a factor of 10, and shortens the path by a factor of 25 to 100.

Greatest Flexibility. Wire bond connections are limited to peripheral pads, driving die sizes up rapidly as the number of connections increases. Flip chip can use the whole area of the die, allowing many more connections on a smaller die. Flip chips with more than one thousand bumps per die are now unremarkable.

Most Rugged. Flip chips, when completed with an adhesive "underfill," are solid little blocks of cured epoxy. They have survived laboratory simulations of rocket liftoff and of artillery firing, as well as millions of hours of actual use under automobile hoods.

Lowest Cost. Flip chip in some applications can be the lowest cost interconnection, with costs below $0.01 per connection. This explains flip chip’s longevity in the cost-conscious automotive world, pervasiveness in low cost consumer watches, and growing use in smart cards, RF-ID cards, cellular telephones, and other cost-dominated applications.

B. FLIP CHIP BASICS

Understanding what a flip chip is and how it is made is a good starting point for choosing the most suitable variety.

Flip chip assembly is broadly defined as the direct electrical connection of face-down (hence, "flipped") electronic components by means of conductive bumps on the bond pads. Flip chip is also called Direct Chip Attach (DCA), since the chip is directly attached to something by the conductive bumps.

Flip chip is most commonly connected to a laminate printed-circuit board (PCB) bond pads. However, it could connect to a substrate or carrier of other materials, a flexible circuit, a glass flat-panel display, or even to another chip or package.

The next sections describe the three generic steps in creating flip chip assemblies: bumping the die with conductive bumps, attaching the bumped die to the PCB, and filling the remaining space between the die and the PCB with an adhesive underfill. Subsequent sections compare the assemblies.

Bumping The bump serves several functions in the flip chip assembly. It provides the electrically conducting path for power and signals and a thermally conducting path to carry heat away. It mechanically attaches the die to the substrate, and acts as a short lead to relieve mechanical strain. The conductive bump material and method of formation, the attachment materials, and the attachment processes distinguish the varieties of flip chip assemblies.

Preparing the bond pad is the first step in bumping. This generally requires re-coating the pads with "underbump metal"(UBM) to make a better connection, protect the semiconductor from the bump materials, and define the bump size and location. UBMs vary with the pad material, the intended bump materials, the deposition method, and the intended application.

Solders were the original bumps, and are still the most common flip chip bumps. Solder bumps may be formed by various methods, described on pages 4 – 5 , and reflowed to form a bump.

Figure 1. Reflowed solder bump

Assembly Flip chip assembly attaches the bumped die to the PCB. The materials, equipment, and process required vary with the type of bump.

Solder bumped die may be placed on the substrate pads along with a tacky solder flux, to hold them in position until reflow. Heating the assembly in an oven melts the solder, connecting chip and board. Non-solder bumped die might be assembled by thermocompression or thermosonic bonding, or with adhesives.

Underfill The space between chip and board may be filled with a non-conductive underfill adhesive, joining the entire surface of the chip to the substrate. Underfill provides environmental protection, and mechanically locks together chip and substrate so that differences in thermal expansion of the two materials do not break or damage the electrical connection of the bumps. However, underfilling adds a process step, requiring special equipment and increasing both throughput time and production cost. Fast-cure underfills and pre-dispensed or co-dispensed underfills have been developed to minimize the delay and better fit underfill into the standard production process. Figure 2 is a cross-section showing underfill surrounding a bump.

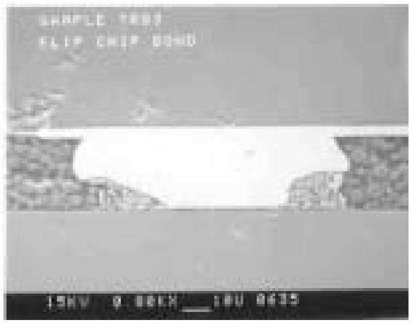

Figure 2. Underfill cross-section.

C. FLIP CHIP COMPARISONS

With those flip chip basics, we can now compare bumping materials and methods for their suitablity to different applications. For this discussion, the word "solder" refers to the common lead-tin solders. In this section, we'll first compare solder with some other bump materials having special advantages. We'll then compare several methods of creating solder bumps, each with its benefits and limitations.

Solder versus alternatives Two major advantages of solder for flip chip are familiarity and history. Solder has been used in electronics for many decades, and in other applications for many centuries. While lead solder is not perfect for flip chip, its technical flaws are well known and tolerable.

Because circuit boards generally are populated with solder-attached surface mount components, solder bump flip chip may be least disruptive to production flow. Sometimes it can share surface-mount equipment. For example, the surface tension of molten solder self-aligns the chip to the substrate bond pads during reflow. This may eliminate requiring high precision placement equipment solely for the flip chip components. Reflow ovens for surface-mount components can also reflow solder bumps.

Negatives of solder bump flip chip include cracking and creep. Fatigue cracking under thermal cycling is controlled by proper underfill; creep makes solder unsuitable for maintaining the precise mechanical alignments required in some optronic assemblies. Also, solder bumps tend to merge when molten, limiting bump pitch.

Beginning in the early 1990's, non-solder bump materials were developed for applications where they have advantages in cost or performance over solder. Alternatives to lead solder presently include lead-free alloys, gold-tin solder, gold, and indium.

Lead-free solders are scheduled to replace lead in mid-2006. As the costs and consequences of eliminating lead become more obvious, a number of temporary exceptions have been made. These short-term concessions are at best delaying the inevitable. Any management decision towards flip chip should include selecting lead-free solder alloys or alternative materials.

High melting-point gold-tin solder provides superior high temperature performance, and robust mechanical properties. Gold-tin is not subject to mechanical creep as lead is, thus better suiting it for optronics devices, where maintaining the device alignment is critical.

Pure gold bumps may be electroplated, vacuum deposited, or formed by a modified wire bonding technique. Electroplated gold bumps have finer pitch than solder bumps, and are used with conductive adhesive assembly for driver connections to flat-panel displays

Gold stud bumps (also called ball bumps), are formed with a modified wire bonder that severs the wire after attaching it to the chip bond pad, leaving a gold bump. Stud bumps on standard aluminum bond pads require no UBM. Stud bumps may be placed on singulated die as well as wafers. The die or wafer may have raised surface features, incompatible with most wafer bumping methods. Figure 3 shows a gold stud bump.

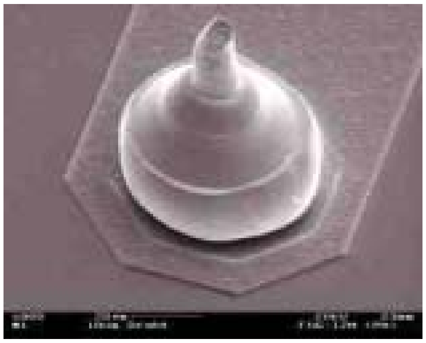

Figure 3. Gold stud bump on bond pad.

Indium bumps may be electroplated or vacuum deposited to form fine-pitch arrays. Indium maintains good electrical conductivity at extreme low temperature, important for cooled detector arrays. Indium bumps can cold-weld to each other for room temperature assembly, an advantage for large detector arrays.

Solder versus solder. The several methods of creating solder bumps, described below, determine the size, cost, and performance of the bumps.

Physical vapor deposition includes **evaporation** or **sputtering** in a vacuum chamber. Evaporation produces high quality, fine pitch bumps, but evaporation is not adaptable to today's larger wafers. Also, differing evaporation rates of the metals composing multi-component lead-free alloys makes them unsuitable for evaporation.

Electroplating produces high quality bumps on fine pitch with good yields. But electroplating is limited by its wet chemistry processes. Electroplating baths for high quality bumps must be closely controlled in composition, temperature, and uniformity of current flow during bump deposition.

Plating is relatively inflexible. Changing bump composition requires a new formulation of plating chemicals. Plating materials are often environmentally hazardous, with consequent high handling and disposal costs. Plating has high equipment and maintenance costs, as well as high materials acquisition and materials disposal costs.

Printing solder paste by screening or stenciling is a low cost approach to bumping. Solder paste may be purchased in a wide variety of solder compositions, readily accommodating multi-metal lead-free alloys. Solder printing equipment is common in surface mount lines, and has a relatively low cost compared with evaporation or plating equipment.

Printing's benefits are also its limitations. Printing cannot provide the finest bump pitch. The deposited diameter must be considerably larger than the bond pad, because paste shrinks up to 50% in forming the final bump. Paste shrinkage variations also make achieving uniform bump heights challenging. The paste spreading method and solvent shrinkage may also cause voids in the bump, which can affect reliability. Paste printing primarily serves high volume, low cost consumer products.

Bump Transfer includes two methods of placing pre-formed solder bumps directly onto the device bond pads. **Solder sphere** transfer places room-temperature spheres onto the pads mechanically. The spheres are typically held in position by a sticky solder flux until reflowed to form bumps. Spheres share the paste advantage of being readily available in a range of compositions, including lead-free alloys; spheres do not share the paste disadvantage of shrinkage. However, since they are mechanically handled and placed, spheres are limited to relatively large bumps and to wide pitch.

Injection-molded solder transfer prepares the bumps separately from the wafers, in a mold with cavities matching the wafer bond pads. The molded bumps are transferred to the wafer in a reflow-like step. Injection-molded solders produce bumps with the pitch and quality of plating, in any composition of alloys, at relatively high speed. The process is just beginning commercialization.

Solder Jetting deposits molten solder directly onto bond pad UBM. Jetting can be used in bumping devices such as MEMS which have non-planar wafer surfaces. Jetting, like gold stud bumping, is a serial, one bump at a time process.

Table 1. Comparison of Four Solder Bumping Processes

Process	Evaporation	Plating	Printing	Molding
Cost	Medium/High	High	Medium/Low	Low
Quality	High	High	Low	High
Pitch	Fine	Fine	Coarse	Fine
Flexibility	Low	Low	High	High

Table 1 compares the common bumping methods of evaporation, plating, and printing, along with the newly-introduced injection molding. Evaporation provides high quality bumps at medium to high cost but is poorly suited to today's trends towards larger wafers and lead-free solders. Electroplating produces high quality, fine pitch, solder bumps. It has low flexibility to handle lead-free alloys, and a relatively high cost. Stencil or screen printing is a low-cost method providing acceptable consumer quality bumps at coarse pitch. It easily handles lead-free alloys. Injection molding is expected to offer fine pitch, high quality bumps at relatively low cost. It easily accommodates lead-free alloys.

D. FLIP CHIP DECISIONS

In helping many companies make the right choices in starting up flip chip programs, I've found it important to address the following five questions early in the planning stage.

1. Why are you considering flip chip?

Flip chip offers many advantages, but generally not all at the same time, in a single flip chip. Smallest size and highest performance rarely come with lowest cost. Determining where you are in the size-cost-performance space helps to identify which flip chip approaches— if any — might best meet your needs

2. What volume do you need?

High volume, low cost end-products are best suited to one subset of technologies, high performance products to another. Most bumping and assembly service providers are set up for high rather than low volumes.

3. Have you unusual packaging requirements?

Is pioneering a key element of your success, or are you planning to apply well-proven packaging technologies? If packaging innovation is critical, packaging concerns must be included from the earliest stages of the project.

4. Will you source internally, outsource, or both?

Depending on packaging complexity, volume, and your capabilities, product development and production could be entirely in-house. Alternatively, some early steps, such as bumping, might be contracted out, with volume production in house, outsourced or shared.

5. What technical assistance do you need?

Consultants can help you with specific issues and problems, or provide continuing guidance through the development and initial production stages. Like bumping houses, no single consultant is an expert in all technologies, but may call in or consult with specialty experts as needed.

E. CONCLUSION

The key decisions for a successful flip chip program are the earliest ones. Determining the driving need for flip chip and selecting the most suitable flip chip technology leads you to the required materials, equipment, services, and suppliers. Including flip chip packaging decisions in the early stages avoids problems later. Whether flip chip becomes your solution — or your problem — depends on picking the proper path.

ABOUT THE AUTHOR

My 14 years in flip chip includes development, manufacture, and consulting for more than 50 companies. I can help you to determine if flip chip is right for you, and to select the processes which best meet your needs. I can work with your key employees in starting a successful flip chip program, or fixing a struggling one. My wide network of industry contacts helps in evaluating suppliers and equipment as the program proceeds.

My consulting site, **www.DrFlipchip.com**, details my credentials and publications. My educational site, **www.FlipChips.com**, offers over 350 pages of free micropackaging information, including more than 60 tutorials.

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