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CCGA - SOLDER COLUMN ATTACHMENT FOR ABSORBING LARGE CTE MISMATCH

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ABSTRACT

Replacing solder balls with solder columns makes a device known as a Column Grid Array (CCGA). CCGA packages provide a trusted solution for overcoming 10ppm/^{o}C mismatch of coefficient of thermal expansion (CTE) between large ceramic IC packages and glass-epoxy printed circuit boards (PCB). Solder columns are compliant and absorb strain in applications typically found in the fields of military, aerospace and defense where significantly varying temperatures, high vibration and shock are present.

Plastic ball grid array (PBGA) packages using solder ball interconnections perform reasonably well in commercial applications. This is not the case with large size ceramic ball grid arrays (CBGA). Solder balls on large CBGA ceramic packages encounter dangerously high stress due to the inherent mismatch between the ceramic's CTE and the PCB. The array of solder balls are stretched and squeezed, especially at the corners of the ceramic substrate and directly under the corners of the silicon die or flip chip.

As the temperature swings hot to cold in repeated cycles, the strain induces physical movement in solder balls measured from the neutral point, typically the center of the IC package. While the amount of movement may seem small - about the thickness of a sheet of paper - such stretching may be equivalent to 10% of the overall diameter of the solder ball. Under conditions of repeated thermal cycles, solder balls will delaminate from the IC package and/or the PCB, resulting in catastrophic electrical failure.

Replacing solder balls with solder columns provides stress relief on large ceramic area array IC packages. There is also interest to study improvements in reliability by attaching solder columns to large plastic BGA packages as a way to reduce stress for certain applications.

This paper reviews the types of commercially off-the-shelf (COTS) solder columns commonly available, including plain Pb90/Sn10 columns, copper wrapped Pb80/Sn20 columns and the NASA invented Micro-coil Spring. This paper also reviews practical ways to attach solder columns and Micro-Coil Springs to IC packages in a high-mix, low volume benchtop environment.

Key words: CCGA, column grid array, solder columns, Micro-Coil Spring, Pin-Pack

INTRODUCTION

Even though billions of plastic ball grid array (PBGA) devices are in use, it is still worthwhile to acquaint ourselves with its legacy cousin, the Column Grid Array, known as CGA or CCGA. Column Grid Arrays have practical use as compliant interconnects on large area array ceramic packages used in the fields of military, space and defense. Column Grid Arrays are also of benefit in applications involving high-end computing, down-hole electronics, automotive and other rugged environments.

Development of CCGA packages actually predates the BGA. International Business Machines (IBM) is credited with developing the Column Grid Array in the early 1970s. Bell Laboratories is credited with introducing the first ball grid arrays, mounted on ceramic substrates (CBGA) in 1979. A decade later, plastic ball grid arrays - originally called Over Molded Plastic Carrier (OMPAC) - were introduced by Motorola along with Citizen Watch in 1989 [1]. Remarkably, IBM noted in 1969 that an hour-glass shaped solder terminal for withstanding stress was superior to a cylindrical or barrel-shaped terminal [2].

CCGA packages use high melting temperature cylindrical solder columns instead of spherically shaped solder balls to connect to the printed circuit board (PCB). Solder columns do not collapse during attachment to the semiconductor package. Nor do columns collapse during secondary board level assembly. Only a fillet of low melting temperature solder, such as Sn63/Pb37, reflows to hold the solder column in place.

In 2012, NASA invented the Micro-coil Spring as an alternative to solder columns. Micro-Coil Springs are attached to ceramic or plastic semiconductor packages with tin-lead (Sn63/Pb37) or lead-free SAC305 (Sn96.5/Ag3.0/Cu0.5) solder paste.

Solder columns and Micro-coil Springs are more compliant than solder balls to absorb strain during repeated thermal cycles of hot and cold temperatures. The solder balls on large ceramic CBGA packages deform during wide temperature excursions and are prone to delamination when attached to glass-epoxy PCB boards. Repeated strain on the solder ball causes cracking of the solder joint, ultimately resulting in catastrophic electrical failures.

TYPES OF SOLDER COLUMNS

The first solder columns, introduced by IBM, were constructed of high melting temperature Pb90/Sn10 wire. The liquidus temperature of Pb90/Sn10 is around 302°C, whereas its solidus is 275°C. The wire columns are attached using surface mount techniques with Sn63/Pb37 solder paste shown in Figure 1. Sn63/Pb37 is considered low temperature (compared to the column), with an eutectic liquidus/solidus temperature rating of 183°C. In practice, Sn63/Pb37 paste is reflowed above its eutectic melting point, but well below the melting point of the high temperature solder column. Current industry standards require the Sn63/Pb37 paste to form a fillet covering least 270-degrees around the circumference of the column. In practice it is desirable for the fillet to completely surround the base of the column a full 360-degrees. IBM eventually standardized columns measuring 0.51mm (20 mil) diameter by 2.21mm (87 mil) length. However, IBM also built columns with diameters up to 0.89mm (35 mils) and lengths as short as 1.27mm (50 mil).

Figure 1. Pb90/Sn10 solder column shown with eutectic Sn63/Pb37 fillet.

In 1999, IBM introduced the Column Last Attach Process (CLASP) utilizing palladium (Pd) doped Sn63/Pb37 solder paste. The CLASP columns are constructed with normal Pb90/Sn10 solder wire. IBM determined that Pd doped solder paste reflowed similarly as non-doped Sn63/Pb37 during first attachment to the ceramic package. However, Pd doped fillets have the added benefit of slightly elevating the liquidus temperature after secondary attachment to the PCB. The benefits of using the CLASP process come into play only in case rework is necessary to remove the CCGA from the PCB. During PCB rework, columns that have been attached to the CCGA package with Pd doped fillets will remain attached to the ceramic during removal of the CCGA package from the PCB. As a result, most, if not all columns remain on the CCGA package during lifting from the PCB. This is a welcome improvement during rework, where there is a 50-50 chance that some columns will remain on the CCGA package while some columns will remain on the PCB. Anyone experienced in rework can appreciate the benefit of completely removing the CCGA package with all columns attached, rather than having to deal with the tedious task of removing remnant columns from the PCB [3]. As of the date of this paper, no commercial COTS source for Pd doped Sn63/Pb37 solder paste was found to be available.

In 1993 IBM introduced CAST columns which were formed directly on pads on the ceramic package simultaneously with a molten Pb90/Sn10 solder fillet. Sn63/Pb37 is not used to attach CAST columns to the ceramic package. Sn63/Pb37 solder paste is still required during secondary board level assembly to attach the free end of CAST columns to the PCB. IBM stopped manufacturing and divested Column Grid Array packages at the end of 2014.

Raychem Corporation invented an improved solder column in 1983 by spiral wrapping copper ribbon around a mandrel of high melting temperature Pb80/Sn20 solder wire. A coating of Sn63/Pb37 is applied over the entire solder column to secure the copper to the column as shown in Figure 2 and Figure 3. CCGA packages made with copper wrapped Pb80/Sn20 columns survive more temperature cycles than ceramic packages made with plain Pb90/Sn10 columns. The liquidus temperature of Pb80/Sn20 is around 280°C, whereas its solidus is 183°C, making the reflow process window more challenging than with Pb90/Sn10.

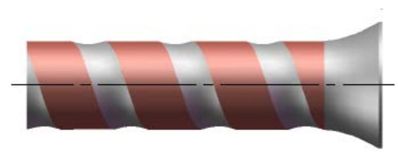

Figure 2. Pb80/Sn20 solder column with helix wound copper ribbon shown with eutectic Sn63/Pb37 fillet.

Typically 0.51mm (20 mil) diameter copper wrapped columns are used for 1.0mm pitch ceramic packages. Slightly larger 0.56mm (22 mil) diameter columns may be used on 1.27mm (50 mil) pitch ceramic packages. Standard column length is 2.21mm (87 mil) however, column lengths up to 3.8mm (150 mils) are available for IC packages that require high off-sets from the PC board. Plastic IC packages require smaller diameter columns since pads on plastic packages tend to be smaller diameter.

Figure 3. Pb80/Sn20 copper wrapped solder column without fillet (shown after coating with Sn63/Pb37)

In 2012, National Aeronautical and Space Administration (NASA) invented a novel interconnect known as the Micro-coil Spring constructed of beryllium-copper (Be-Cu) alloy C17200 with double closed-end windings [4]. Micro-coil Springs are an alternate to solder columns as shown in Figure 4.

Micro-coil Springs are available in a variety of diameters and lengths. Typically, Micro-coil Springs measuring 0.50mm (20 mil) by 1.27mm (50 mil) long are attached to ceramic packages with 1.0mm or 1.27mm pitch. Smaller size springs, such as 0.40mm (16 mil) diameter by 1.0mm (40 mil) long are attached to plastic packages with 1.0mm pitch.

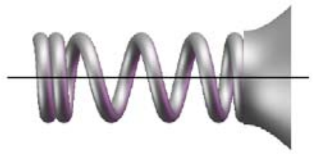

Figure 4. Micro-Coil Spring shown with Sn63/Pb37 Fillet.

Micro-coil Springs are available with choice of electroplated tin-lead Sn60/Pb40 surfaces or electroplated nickel-gold (Ni-Au) as shown Figure 5 a,b.

a) Tin-Lead b) Gold

Figure 5. a) Micro-Coil Spring with Sn60/Pb40 Tin-Lead electroplating; **b)** Nickel-Gold plating for lead-free applications.

Tin-lead Sn63/Pb37 or lead-free SAC305 (Sn96.5/Ag3.0/Cu0.5) solder paste form the fillet at the ends of the Micro-coil Springs as shown in Figure 6.

Figure 6. Micro-Coil Springs attached to CCGA.

In 2000, IBM described a copper plated column as shown in Figure 7. This column is constructed of high melting temperature solder wire, such as Pb90/Sn10 which is electroplated with a layer of copper. The exterior of the column is electroplated with a thin coating of tin (Sn). IBM intended the tin plating to serve as a barrier layer to meet RoHS requirements. This electroplated copper column may be re-introduced with a tin-lead (Sn60/Pb40) or nickel-gold (Ni-Au) coating as a drop-in replacement for copper wrapped columns. Electroplated copper walls thermally enhance the column to conduct more heat away from the chip to a massive ground plane layer on the PCB. The plated copper layer provides a shorter thermal path as compared to helix wrapped copper ribbon columns [5].

Figure 7. Sectional drawing of electroplated copper column over high melting temperature Pb90/Sn10 solder wire.

ATTACHMENT OF SOLDER COLUMNS TO SEMICONDUCTOR PACKAGES IN HIGH MIX, LOW VOLUME ASSEMBLY ENVIRONMENT

Only a few companies make of Column Grid Array packages in high volume. However, there is a need to build CCGA packages in small lots in a high-mix, low volume environment. This paper discusses techniques of attaching columns to CCGA packages in small lots where package sizes and pin counts frequently change. This paper suggests ways to process lots as small as one piece and larger volumes up to 1000 units per month.

This paper provides practical conditions for attaching copper wrapped columns, plain solder columns and Micro-Coil Springs to semiconductor packages. It is beyond the scope of this paper to cover attachment of the IC package onto the PCB.

Well-known processes for attaching solder balls to BGA do not apply to attachment of columns to CCGA packages. Column attachment (sometimes called columnization or columnizing) requires specialized equipment and mastering of skills that are different than used for solder ball attachment.

CCGA solder columns are difficult to work with. Solder columns behave much differently than solder balls. Solder columns are cylindrically shaped. Solder columns do not roll into place. Solder columns are soft and can be easily bent.

By comparison, BGA solder balls are easy to work with. Solder balls are spherically shaped. Solder balls roll into position. Solder balls typically self-center on the pads during reflow.

COLUMN AND PAD DIAMETER REQUIREMENTS

Column diameters must be 30% to 35% smaller than the pad so that a proper solder fillet is formed around the perimeter of the column as described in Table 1. Said another way, the metal pad on the IC package typically needs to be 30% to 35% larger than the diameter of the solder column. Typically, CCGA pads are non-solder mask defined.

In contrast, the pad geometries on plastic BGA packages follow different design rules. BGA solder balls typically are 20% to 25% larger than solder mask defined pad openings. Said another way, solder mask defined pads tend to be roughly 75% to 80% smaller than the diameter of the solder ball.

Table 1. Typical Column Diameter

PACKAGE PAD DIAMETER	COLUMN DIAMETER[1]	
	MINIMUM	MAXIMUM
0.35mm	0.20mm	0.25mm
0.40mm	0.25mm	0.30mm
0.45mm	0.30mm	0.33mm
0.50mm	0.33mm	0.38mm
0.60mm	0.38mm	0.43mm
0.70mm	0.43mm	0.52mm
0.80mm	0.52mm	0.56mm
1. Copper Wrap Column or Plain Solder Column		

Micro-coil Springs may be mounted on pads that are 25% larger in diameter because a fillet is formed inside as well as outside the perimeter of the spring. See Table 2 for pad diameter guidelines for Micro-Coil Springs.

Table 2. Typical Micro-coil Spring Diameter

PACKAGE PAD DIAMETER	MICRO-COIL SPRING DIAMETER	
	MINIMUM	MAXIMUM
0.35mm	0.25mm	0.28mm
0.40mm	0.28mm	0.32mm
0.45mm	0.32mm	0.35mm
0.50mm	0.35mm	0.40mm
0.60mm	0.40mm	0.50mm
0.70mm	0.50mm	0.56mm
0.80mm	0.50mm	0.64mm

Solder balls roll and tend to self-center on the package pad during reflowed. However solder columns are held upright and are constrained within the silo of a graphite tool, which inhibits the column from seeking the center of the pad.

NASA GSFC-STD-6001 standard requires that at least 75% of the fillet cover the circumference of the column. Said another way, a fillet must be formed around at least 270-degrees around the circumference of the column. It is more desirable to produce CCGA packages with fillet formed around the entire 360-degree base of the column. The column is not allowed to escape outside the pad.

Co-firing during manufacturing of HTCC or LTCC ceramic substrates result in packages with wide tolerances. The accumulative tolerance of the pad pitch of a 27x27 pad array (CCGA717) might be +/- 0.33mm; whereas, the pad pitch of a 42x42 pad array (CCGA1752) might be +/- 0.41mm tolerance. This wide variation in the ceramic package tolerance might result in a column landing (escaping) off the package pad, which is not allowed according to the standards.

TILTING OF COLUMNS

Slanting columns is another condition (problem) to contend with. Tilted columns are caused by a number of factors. The diameter of the holes machined in the graphite fixture that hold the columns upright during column attachment might contribute to titling columns. If the diameter of the hole in the graphite fixture is too small, then it becomes exceedingly more difficult to extract the package after column attachment. If the diameter of the hole in the graphite fixture is too large, then columns will tend to tilt during reflow. Poor handling contributes to tilting of columns. Post attachment processes including cleaning, trimming, polishing and planarizing of columns also contribute to tilting of columns. Standards specify that an individual column shall not be bent more than 5° relative to other columns. Multiple column tilt is acceptable if all columns are tilted uniformly up to maximum 10°.

COLUMNS CONSTRUCTION

Copper wrapped columns are typically constructed by winding 25~50um (1.0~2.0 mil) thick copper ribbon around a high melting temperature Pb80/Sn20 solder wire mandrel. It should be noted that other high melting point temperature wires (such as Pb90/Sn10 or Pb85/Sn15) can be wound with copper ribbon. It is best that all sides of the copper ribbon be pre-tinned with 2.5~5.0um (100~200 micro-inch) coating of tin-lead electroplated solder. The wound assembly is run through a eutectic solder wave of molten Sn63/Pb37. Excessive Sn63/Pb37 tends to reposition along the skin of the copper ribbon due to capillary action. This phenomena causes the diameter of the column to grow in excess of 25um (1.0 mil) in some places which might result in columns getting temporarily stuck in the graphite fixture. Be aware that flux build up in the holes of the graphite fixture gradually reduces the diameter of the holes, which compounds instances of the columns becoming stuck after reflow of the CCGA substrate in the graphite fixture. It is important to frequently ultrasonically clean the empty graphite fixtures between use to remove flux build.

LOADING COLUMNS INTO GRAPHITE FIXTURE

Columns do not roll, as solder balls do. Columns may be loaded into the graphite fixture by hand, using tweezers with lots of patience. It takes about 75 minutes (assuming loading rates of one column every 4 seconds) to load a CCGA1152 graphite fixture by hand. A CCGA1752 will take about two hours to load by hand. Faster ways using automated pick and place machines to load columns into graphite fixtures have also been tried. A novel way to speed up the column loading process by using a pre-loaded apparatus called a Pin-Pack. Up to 1752 columns can be loaded into the graphite fixture in less than one-minute using a Pin-Pack. The Pin-Pack consists of a disposable plastic frame with silos (holes) matching the same pattern as the CCGA pad matrix. A single layer of adhesive tacky tape holds the tips of the columns in place at the top side of the Pin-Pack. The

Pin-Pack is placed by hand into the seating area of the top graphite plate. When the tacky tape is peeled back from the top surface of the Pin-Pack, the columns will be released and gently drop into the lower graphite base by means of gravity, without the need for vibration or vacuum as shown in Figure 8.

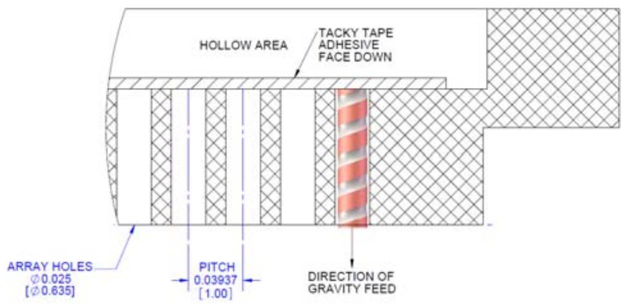

Figure 8. Sectional drawing of Pin-Pack with solder columns axially held on the top side with layer of tacky-tape. Columns fall and exit the bottom side of the Pin-Pack by means of gravity and drop into the graphite fixture.

GRAPHITE FIXTURE

The graphite fixture is a two-piece tool. Three stainless steel positioning pegs align the top graphite plate to the base plate. Typically, the holes (silos) and features are precision machined into the graphite plates using a CNC machine with tolerances of 12.7um (0.5 mil). It is recommended to use semiconductor grade, high purity graphite material to minimize sloughing during use. The thickness of the graphite plates depends on the overall thickness of the CCGA package including the heat-spreader. In most cases, 6.35mm (0.25-inch) thick graphite is sufficient. It might be necessary to use 12.7mm (0.5-inch) thick plates for the graphite base for tall CCGA packages with thick heat spreaders. Raw graphite sheets 15cm (6-inch) square produce finished graphite fixtures with 95.5mm (3.878-inch) square (after machining) to accommodate all sizes of CCGA (21~52.5mm).

Figure 9 shows an exploded view of the graphite system consisting of the Pin-Pack, top graphite plate, array of columns, ceramic substrate and base graphite plate. After releasing the columns from the Pin-Pack, the columns will land onto the solder paste which has previously been applied to the ceramic substrate (LGA) through a solder paste stencil (not shown). Deposition of solder paste onto the LGA pads using a Nordson EFD Asymtek or GPD dispensing system has also been used. The solder paste will form the fillet to hold the columns to the CCGA after reflow. The volume of solder paste depends on the diameter of the pads, diameter of the solder columns (or Micro-coil Springs) and the desired finished height of the fillet after reflow.

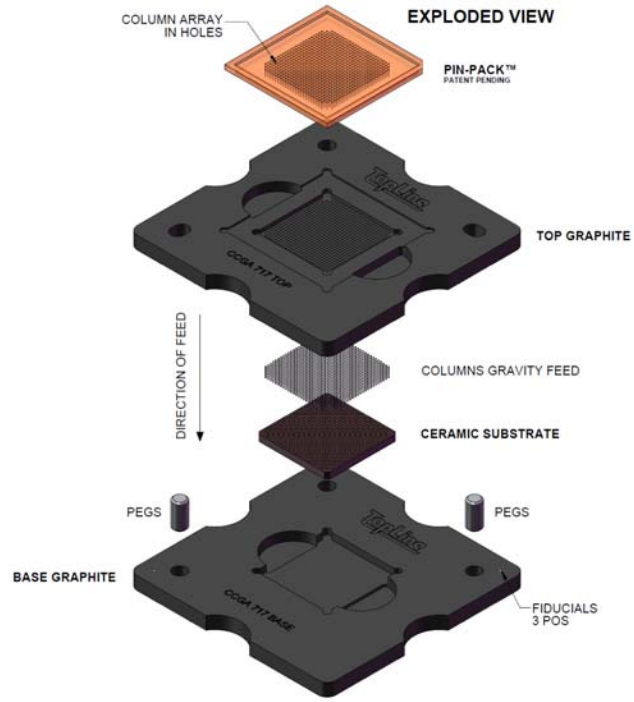

Figure 9. Exploded view of graphite system with Pin-Pack pre-loaded with solder columns. Columns fall and exit the bottom side of the Pin-Pack by means of gravity and drop into the graphite fixture.

The base graphite plate, shown in Figure 10, holds the ceramic package with pads facing upward. Three fiducials 1.0mm (40 mil) diameter are machined and cured white epoxy to assist with vision systems. Three stainless steel positioning pegs align the base graphite plate to the top graphite plate. Perimeter thumb grips assist with handling the graphite plates. The ceramic package must snuggly fit into the base graphite to assure proper registration.

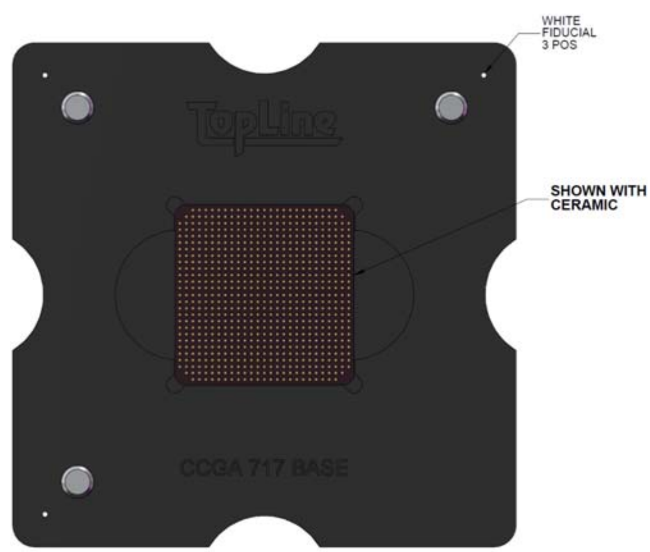

Figure 10. Graphite base holding ceramic LGA package. Positioning pegs align with the top graphite plate.

The top graphite plate, shown in Figure 11, is placed over the base graphite. The top plate has an array of holes (silos) that exactly match the matrix of the Pin-Pack and pad pattern of the ceramic or plastic LGA package.

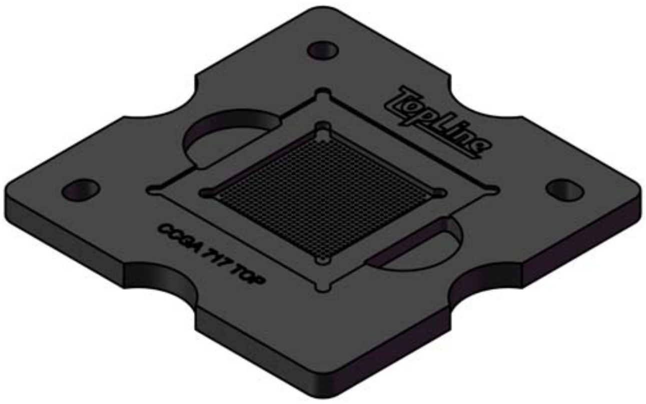

Figure 11. Top graphite has array of holes that match the matrix of the Pin-Pack and pad pattern of the ceramic LGA

The bottom side of the top graphite plate is recessed to prevent solder paste from touching the underside of the top plate. The same graphite system can be used for both copper wrapped and plain columns. However, a uniquely machined graphite system is required for Micro-Coil springs, to compensate for the shorter length of the springs.

Stainless steel positioning pegs align the top graphite plate over the graphite base. The Pin-Pack cassette, pre-loaded with columns, seats into the top graphite. The columns are released by means of gravity from the Pin-Pack by peeling back the tacky tape in the diagonal direction, at a very low angle. After releasing the columns, remove the Pin-Pack from the graphite, and set aside to for use later as a carrier to protect the columns on the assembled CCGA.

The columns should be visually inspected in the top side graphite under a microscope to assure that all columns are properly in place. Columns should be at the same elevation on the LGA. Micro-coil Springs are released from the Pin-Pack and loading into the graphite tool is done in the same manner as loading solder columns.

Since Micro-Coil Springs are light, a square graphite weight (shown in Figure 12) is placed over the top graphite to minimize springs from jettisoning out of the top graphite during reflow. Shooting springs (or light weight columns) is caused by flux volatiles in the solder paste during reflow.

Figure 12. Graphite weight to cover the top graphite plate

SOLDER PASTE

Eutectic Type 3 no-clean ROL0 Sn63/Pb37 solder paste such as Kester EP256 (or Kester EM907 Lead Free SAC305) or equivalent was applied during trials with a stainless steel stencil using standard stencil printing practices. Alternately, Type 5 solder paste may be deposited onto the LGA pads using a Nordson EFD, Asymtek or GPD dispensing system.

The thickness of the solder paste is typically 200um (8 mil) for solder columns and 150um (6 mil) for Micro-coil Springs. The volume of solder paste depends on the diameter of the pads and the desired height of the fillet after reflow. Experimentation is required for selecting the correct stencil aperture. Typically, there should be a 38um (1.5 mil) annular ring between the solder paste and the perimeter of the pad to assist with visual inspection and alignment. For example a stencil with 0.685mm (27 mil) aperture is placed on a 0.76mm (30 mil) pad. The height of the fillet after reflow should not exceed one-third of the length of the column. The fillet should not exceed two or two and a half turns at the ends of the Micro-coil Springs after reflow.

REFLOW OVEN

A benchtop IBL SV-260 vapor phase reflow oven was used during trials. Solvay Galden LS-215 (215^{o}C) solution was used during column attachment with eutectic Sn63/Pb37 tin-lead solder paste. Solvay Galden LS-230 (230^{o}C) solution was used with SAC305 solder paste. Future work is planned using an SST vacuum oven. A 10 or 12 zone convection oven with nitrogen can also be used.

EXTRACTING CCGA

Extracting the assembled CCGA from the graphite fixtures without damaging the columns is necessary after reflow. Future work is required to improve the technique of extracting the CCGA from the graphite fixtures.

TRIMMING, POLISHING AND PLANARIZATION

Copper wrapped columns are constructed by winding pre-tinned copper ribbon around a high melting temperature solder wire mandrel such as Pb80/Sn20. The wound wire assembly is coated with flux, then run through a eutectic solder wave of Sn63/Pb37. Capillary action causes excessive Sn63/Pb37 to flow from the side walls of the column to the free-end, forming a small bubble of solder at the top of the column as shown in Figure 13 a,b.

a) Side View b) Top View

Figure 13. a) Side view of excessive Sn63/Pb37 flowing to surface of column; **b)** Top view of solder bubble

It is necessary to planarize all columns within 150um (6 mil) as well as straighten the columns after attachment to the ceramic package. Figure 14 shows a bird's eye view after planarizing the columns using a rotating lapping and polishing wheel, commonly referred to as a jeweler's faceting machine. A 203um (8-inch) diameter coarse lapping paper coated with silicon carbide 240 grit and 53um particles is suitable for rough lapping of the columns. After coarse lapping, the columns were finely polished with 15um diamond lapping plastic film. Future work is planned using a pneumatic mechanical cutting blade for trimming.

Figure 14. Top view of solder columns after trimming, lapping and polishing.

SUMMARY

Replacing solder balls with solder columns results in a package called a Column Grid Array (CCGA). The CCGA is a trusted package of choice for large area array ceramic packages for surface mounting onto glass-epoxy FR4 (or polyimide) printed circuit boards (PCB). Solder columns are more compliant than solder balls. Solder columns are able to absorb 10ppm/^{o}C mismatch of coefficient of thermal expansion (CTE) when joining ceramic packages to the PCB.

The industry has invented creative solutions to improve the construction of CCGA packages over the past forty-years. IBM was the first in the development of CCGA packages in the 1970s using Pb90/Sn10 solder columns. In the 1980s, Raychem innovated the copper wrapped Pb80/Sn20 column. In 2012, NASA invented Micro-coil Springs, constructed with beryllium copper (Be-Cu). Today, most applications in the fields of military, space and defense require the use of tin-lead solders. In the future, nickel-gold plated Micro-coil Springs may provide a reliable pathway to achieving lead-free (Pb-Free) RoHS solutions with SAC305 solder paste.

We may see the commercialization of a new generation of thermally enhanced columns constructed by electroplating copper over Pb80/Sn20 (or Pb90/Sn10) rather than by mechanically wrapping copper ribbon. Electroplated copper columns provide an improvement by shortening the thermal resistance path to conduct heat away from the underside of IC packages to massive ground planes in the PCB, instead of depending on top mounted heat spreaders.

There is ongoing interest to further understanding ways to improve and innovate new solder columns and attachment processes and to reduce this understanding to practice.

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