Mechanical Ruggedization of Ceramic Column Grid Array with Polyimide Reinforced Solder Columns

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Abstract

Recent advancements in Area Array Packaging (AAP) utilize Ceramic Column Grid Arrays (CCGAs) to provide high-density interconnects for printed circuit boards that can improve reliability in harsh environments compared to traditional Ball Grid Array (BGA) architectures. However, CCGA assemblies can still experience premature failure, often manifesting as crack propagation induced by shear loading to the column when packages are exposed to severe thermal cycling and prolonged vibration. This work demonstrates the feasibility of a novel method using polyimide tubing to mechanically reinforce individual solder columns to improve shock and vibration robustness and reduce the risk of Foreign Object Damage (FOD). Alternative approaches, including corner staking and 3-D printed reinforcement, are limited by increased board space consumption and manufacturing difficulty. A process for manufacturing polyimide-reinforced solder columns has been defined, as well as methodology for attaching them to a ceramic package.

Key words

CCGA reliability, Reinforcement, Reliability, Solder columns

I. Introduction

Ceramic Column Grid Array (CCGA) is a high-reliability interconnect solution in applications where the package features high CTE mismatch or is utilized in environments with harsh mechanical vibration requirements [1]. Despite CCGA offering reliability advantages in these environments compared to other technologies, vibration and thermal cycle testing of these packages has demonstrated service life limitations [2], [3]. A common failure mode is cracking at the solder joint, affecting columns mounted at the package corner, which sit at the greatest distance from neutral point (DNP) and experience the greatest shear stress [1], [4]. This paper demonstrates the process characterization of two methods of mechanically reinforcing solder columns: a cover array design and polyimide tubing reinforcement, with a primary focus on the latter.

II. Overview of Approaches

A vertical column stiffener can be used to increase the solder columns resistance to compression and shear stress generated by CTE mismatch within a package. Two approaches were developed and tested in prototyping: a cover array, and polyimide tubing reinforcement. Both methods approach reinforcement by providing an external stiffener to solder columns. Manufacturability and process feasibility is the main driver in determining which approach will be used.

A. Cover Array

The cover array is a one-piece frame that surrounds, isolates, and reinforces all solder columns within an array. Solder paste can be deposited into each tube within the cover, forming the solder columns during the reflow process. A model of the cover array is shown in Figure 1, and the cover with array with solder is demonstrated in Figure 2.

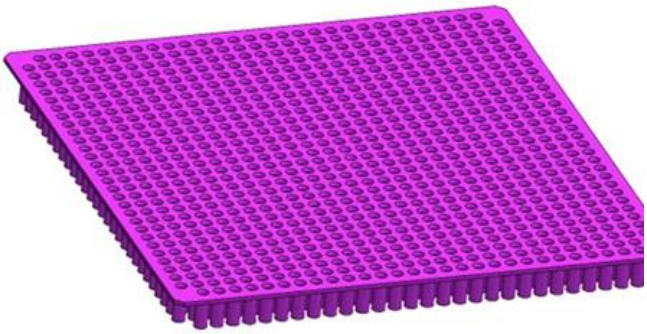


Figure 1 Cover array rendering.

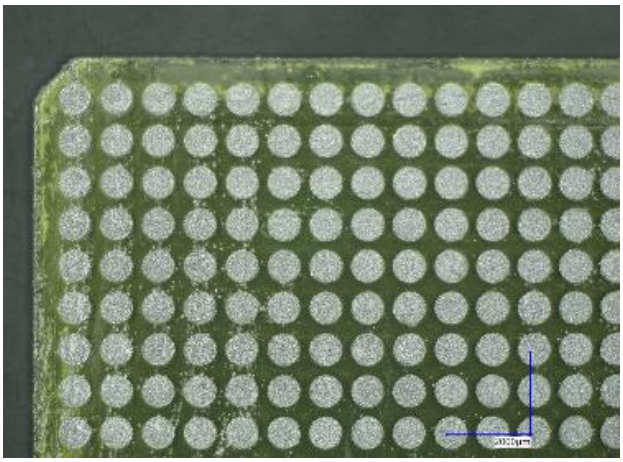


Figure 2 Cover array with solder applied.

B. Polyimide Tubing Reinforcement

The polyimide tubing reinforcement method uses individual solder columns that are formed by filling a polyimide tube with solder, with the polyimide acting as a structural reinforcement and method of shielding columns from debris, shown in Figure 3.

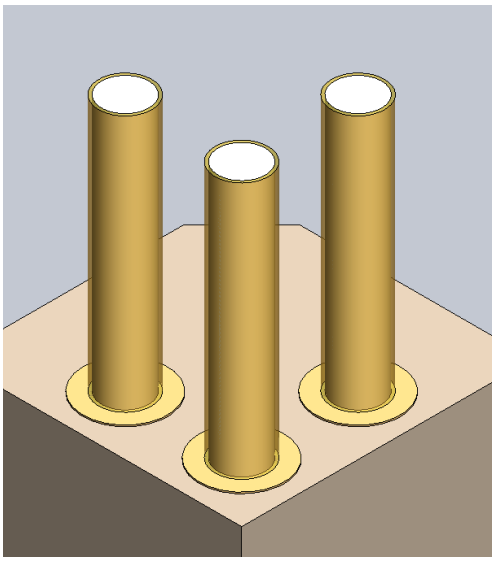


Figure 3 Rendering of polyimide reinforced columns attached to package corner.

III. Methods

A. Cover Array Fabrication Process

Prototypes were made using a Micro Stereolithography (µSLA) 3D-printer. Material resin options were limited since the application demands high print resolution for alignment and high temperature resistance to survive the reflow process. Solder paste was deposited into each tube in the frame to form solder columns. Custom aluminum fixtures were fabricated to provide alignment during assembly and contain the package during reflow, shown in Figure 4.

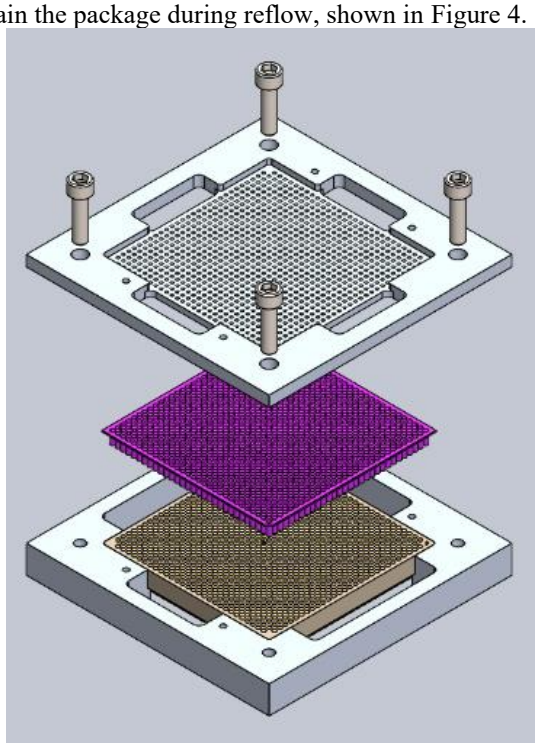


Figure 4 Cover array reflow fixture.

B. Polyimide Tubing Reinforcement Fabrication

Polyimide tubes were found to be commercially available in a geometry suitable for prototyping. The first step in the process is to fill a section of tubing with solder. The two approaches considered were sliding polyimide tubes over existing solder columns or filling the tubes with molten solder and forming rigid columns inside. Due to labor-intensive considerations of the slide-over method, a procedure called the "fill-method" was chosen. A section of polyimide tube is attached with silicone sealant to an eyedropper as a means of producing suction. The tube is placed into molten solder, the eyedropper bulb is compressed and released, and solder is pulled into the tube. Initially, this step resulted in the presence of significant voids in the solder. Further submerging the tube in the molten solder while filling decreases the number of voids present resultant to premature solidification of solder. A diagram and a photo of the "fill-method" are shown in Figure 5 and Figure 6, respectively.

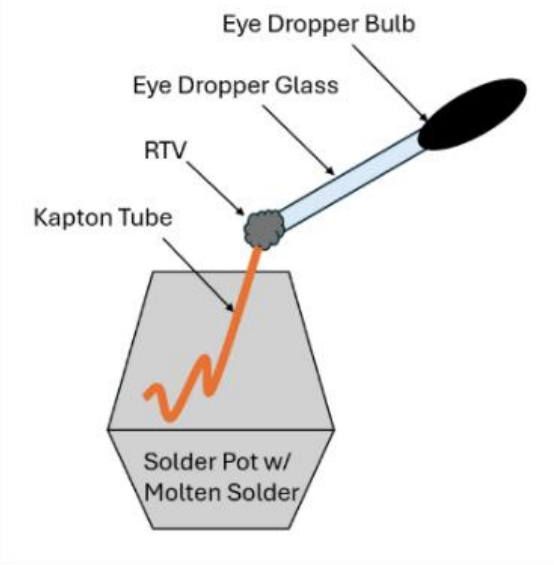


Figure 5 Diagram of tube fill-method.

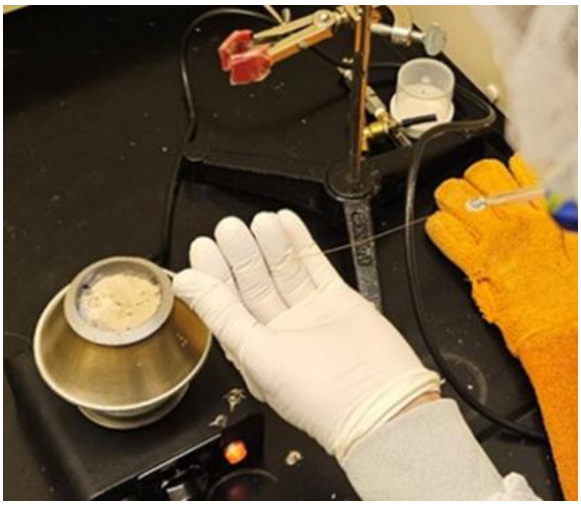


Figure 6 Photo of tube fill-method.

Once the filled tubes are formed, they must be cut to length. Mechanical cutting of the tubes poses risk of deforming the solder columns, so an LPKF U4 355nm UV laser was used for cutting 2.2mm length sections of tube from larger samples of solder filled tube. A fixture, shown in Figure 7, was made to secure and align each of the tubes for the cutting process. Each tube was placed inside a machined channel, and a stencil was placed on top to prevent shifting as many laser cuts are performed per operation. Laser power and repetition count were tuned until a clean cut was achieved, while laser frequency was kept at a constant 50 kHz. Laser power was tested between 1-3 Watts, with higher wattage cuts showing smoother cross-sectional area across the solder and polyimide. Repetition count was optimized to cut through the columns since insufficient repetition count led to incomplete cuts and excessive repetition count caused the solder to transfer to the cross-sectional surface of the polyimide and created a coarse finish. A slightly undersized column length was targeted to ensure adequate fitment within the reflow test fixture. The optimized laser parameters are given in Table 1. After laser cutting, the resulting reinforced structures are referred to as "solder columns", for simplicity.

Table 1 Optimized laser parameters

Frequency (kHz)	50
Power (W)	3
Repetitions	40

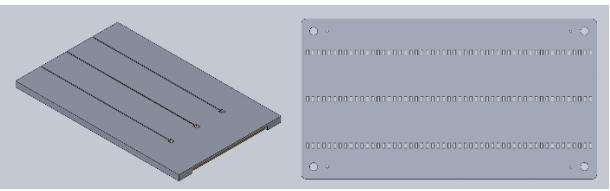


Figure 7 Laser processing fixture.

Once samples were cut, they were prepared in a fixture for attachment to a ceramic package, which is shown in Figure 8. Multiple iterations of custom fixtures were made from aluminum, to align and constrain solder columns during attachment. The fixture for reflow has three primary parts: a frame to support the ceramic package, a plate with individual holes to support each solder column, and a top plate that prevents the solder columns from lifting during reflow. SAC305 solder paste was manually deposited to each of the package pads before being secured in the frame. The alignment plate was then secured, after which solder columns were inserted, and then secured by attaching the top plate with screws. For reflow processing of polyimide tube samples, an IBL SV260 vapor phase soldering machine with Galden LS 230 fluid was used, providing a stable 230°C vapor zone. Cover array reflow attachments were performed using an infrared lamp SRO700 reflow oven with vacuum.

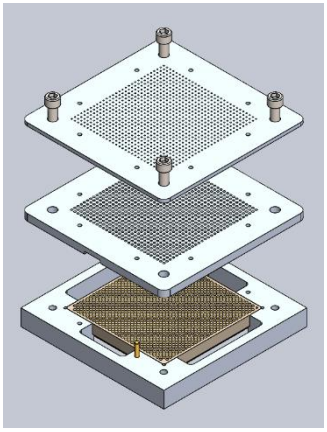


Figure 8 Polyimide tube reflow fixture.

IV. Results

A. Cover array

Testing µSLA array covers demonstrated several manufacturing and material challenges. The cover array parts received were highly brittle and warped. It is suspected this is due to thin features experiencing uneven shrinkage and stretching during the resin curing process. Although multiple iterations of fixtures were created, aligning the tubes with the corresponding package pads remained a difficulty, due to dimensional inaccuracy of the part. Figure 9 shows a side view of a cover array after a first, second, and third reflow cycle in the SRO700 oven. Inconsistent alignment, large voids, and material fracture were challenges that motivated the development of polyimide tubing reinforcements, as shown in Figure 10.

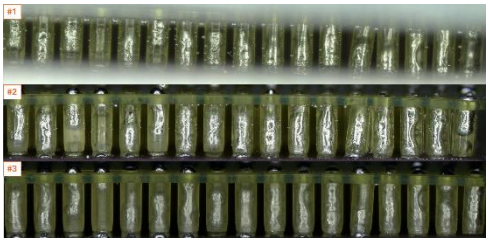


Figure 9 Side view of cover array after reflow.

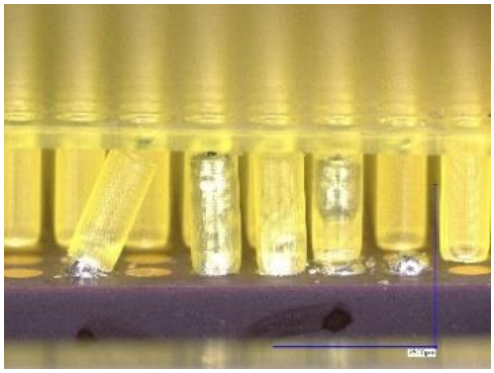


Figure 10 Cover array failure via cracking.

B. Polyimide tubing

1) Formation of solder filled polyimide tubing

Polyimide tubes were successfully filled with eutectic tin-lead solder using the fill-method, which is shown in Figure 11. Solder filled tubes were selected for use based on visual inspection. Externally visible voids were noted as present on some samples but were avoided in selection. A sample group of 18 pieces measured an average length of 57.9mm ± 23.2 (mean ± standard deviation, n = 18). The primary cause for length variation in this step was premature solidification of solder during the filling process, requiring the transition to a different tube piece.



Figure 11 Solder filled polyimide tubes.

2) Laser cutting process outcomes

Using the 355nm UV laser demonstrated feasibility for baseline attachment attempts. The process was iteratively improved with measurements for the final 3 sample groups in Table 2. Sample group #3 was the final and only sample group performed with a stencil placed over tubes, which demonstrated improvements to both length precision and processing time. A magnified image and a cross-section of the processed solder columns are shown in Figure 12 and Figure 13, respectively.

Table 2 Laser processed solder column measurements.

Sample Group	Sample Quantity	Mean Length (microns)	Standard Deviation (microns)	Note
1	**56**	**2223.45**	**27.17**	**Baseline**
2	**102**	**2203.84**	**26.58**	**Shift alignment 13.45 micron**
3	**30**	**2180.93**	**16.08**	**First iteration to use stencil on fixture**

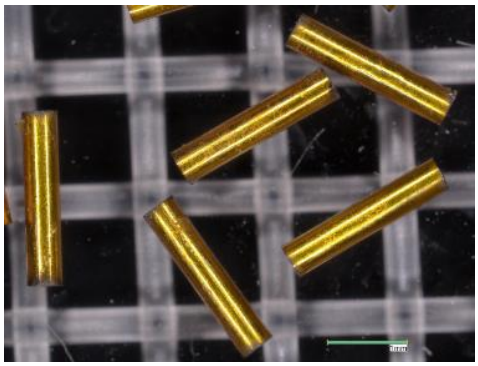


Figure 12 Processed polyimide reinforced columns



Figure 13 Cross-sectional view of polyimide reinforced solder column

3) Attachment Demonstration

Figure 14 depicts the result of a reflow operation featuring 38 solder columns successfully attached to a test package. Various locations on the package were populated to test the fixture alignment and verify adequate reflow temperatures are met across the package. All 38 solder columns were successfully attached. Several iterations of attachment attempts were made prior, demonstrating similar results. The attachment test from which these results reflect is the latest and most representative iteration.

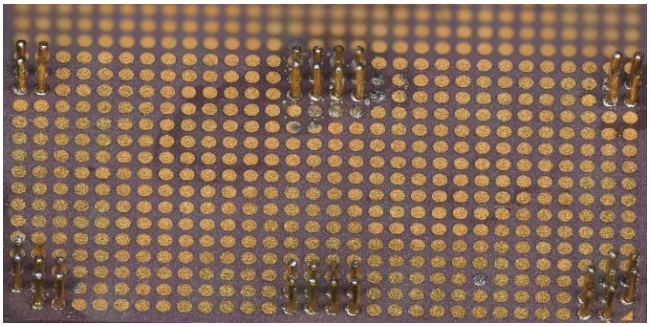


Figure 14 Ceramic package partially populated with test solder columns

Angle and length measurements were obtained from 4 representative columns located at the center of one side, selected due to consistent microscope viewing conditions. Measurements were made using a Keyence microscope. Lengths were measured from the face of the ceramic package to the top of the mounted solder columns, as shown in Figure 15. Measured lengths and angles showed low variation across sampled columns. Results are summarized in

Table 3.

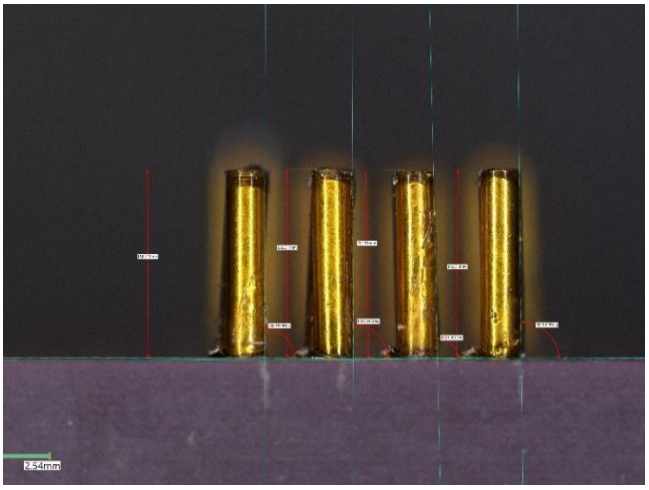


Figure 15 Side view of attached solder columns

Table 3 Attached column measurements

Column ID	Length (microns)	Angle (°)
1	2214	89.88
2	2211	90.25
3	2214	91.06
4	2214	90.50

4) Observed limitations

Among the results of several attachment tests, some tubes were noted to demonstrate varying measurements of solder height within the tube post-reflow. Figure 16 shows a group of columns attached to the package corner during an earlier attachment attempt. The rightmost column shows solder height substantially lower than others. This effect was not visible prior to reflow. While the exact cause of this phenomenon is unknown within the context of this application, internal void coalescence during reflow appears to be a likely cause for this observation.

One theory as to why this occurs is the hygroscopicity of polyimide tubing. In hygroscopic materials, such as polyimide, water is absorbed into the material from the environment. Without proper storage and bake-out procedures, the trapped moisture can volatilize in the presence of heat [5]. During the initial heating of the polyimide during the filling process, additional voids may be introduced due to this phenomenon. Upon second heating during reflow, the molten solder may slump inside of the tube due to capillary flow [6].



Figure 16 Column group with solder height variation.

V. Conclusion and Future Work

A process for fabrication and attachment of polyimide reinforced solder columns was developed and demonstrated. Custom fixturing and laser cutting enabled the fabrication and attachment of reinforced solder columns to a ceramic package. Attachment testing demonstrated successful assembly, although voiding and shifting solder will require further examination.

Future work will focus on identifying the root cause of geometric variations in the solder columns, such as height of the solder post-reflow, and minimizing the deviations in the solder columns. Destructive and nondestructive methods will be used to characterize the solder within the columns and to identify void formation. Additionally, manufacturing process optimizations during solder filling and storage will be implemented and documented to determine the impact on the uniformity of the columns.

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