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Micro Bump Array Constructions on the Organic Substrates for the Non-Permanent Terminations

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Summary

A series of electrical plating processes to build various kinds of micro bump arrays on the organic substrates has been developed for non-permanent connections.

Copper bump arrays with nickel/hard gold plating on the organic substrate with small pitches have been required for the non-permanent terminations. Electrical test probes of the semiconductors and micro size components have been demanding reliable micro bumps on the organic substrates for the repeated contacts of more than one million times.

Several combinations of the micro hole generation processes and the electrical plating processes have been developed to satisfy the requirements. The new electrical plating processes are capable of building the micro bump arrays with copper, nickel and hard gold for pitches smaller than 50 microns on the substrates of FR-4 boards and polyimide films with epoxy or polyimide insulation layers. The plating processes provide broad choices for the shapes and heights of the micro bumps with copper, nickel and gold. Several drilling processes have been introduced to generate small holes with high dimensional accuracy for the exact alignment of the micro bumps on the narrow traces. A series of studies were conducted to review the capability of the drilling process. The whole process has a broad capability for the all kind of organic substrates. A set of design guidelines has been introduced to optimize the productivity.

Introduction

Micro bump arrays built on the organic substrates including the thin flexible film substrates have been recognized as valuable constructions for the high-density packaging terminations. The solder ball grid array has become a popular technology as the common construction for electronic packaging. However, more varieties of the micro bump arrays are required for reliable terminations. Copper, nickel, gold and lead-free solder have been employed as the raw materials for the micro bump arrays of the high density organic substrates.

Several processes have been developed to build micro bump arrays on organic substrates for non-permanent connections. In this study a series of evaluations were conducted on the electrical plating processes to build the micro bump arrays on the organic substrates combining various drilling technologies and photo-lithography technologies. This series of studies provides a broad variation of layer constructions, substrate materials, bump shapes and metals. The optimized process provides pitches finer than 100 microns with higher accuracy of +/- 5 microns.

Basic Constructions

Various bump constructions are required for the different substrates because of the new termination technologies. More varieties of the bump constructions are required for flexible circuits because of the different layer constructions. Figure 1 illustrates the basic constructions of the micro bump arrays on the organic substrates. The constructions (a) and (b) have the micro bumps on the conductor traces without and with solder mask (overlay for the flexible circuits). Construction (c) provides a valuable function on the flexible circuits. The micro bumps are built through the base film. This construction makes the mechanical reliability of the micro bumps higher. The construction provides more functions for the backside of the flexible circuits to reduce the size of the semiconductor packaging.

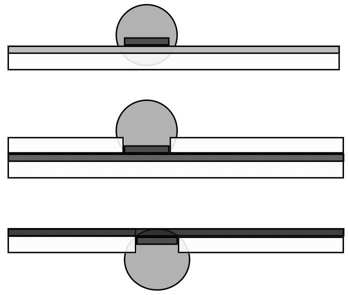


Figure 1 - Basic Constructions of the Micro Bump Arrays on the Organic Substrates

Micro Hole Generation on the Mask

Photolithography processes have been conducted with the plating resist to build the micro bump arrays on the fine bare traces with an exact alignment. An appropriate process condition provides a +/- 5 micron accuracy.

Conventional solder mask and overlay materials are available to generate the access holes for the micro bump arrays. But conventional screen-printing and pre-punching of the films are not suitable to generate holes finer than 500 micron diameter. The photo imaging processes are capable of producing holes smaller than 100 micron diameter. One issue is the limited availability of the materials that have photosensitivity. Generally, photosensitive chemicals perform as dielectric materials for the cover of the fine traces.

Dimensional stability, especially in the case of thin flexible substrates, is a major issue if one is to have exact alignments of the micro bumps on the fine pads or traces.

Several new supplemental drilling processes have been introduced to generate access holes to build the micro bumps on the different substrate materials. The new micro hole generation processes make the capability of the electro-forming process much broader. Laser drilling with Excimer, UV-YAG and carbon dioxide are very capable of generating small holes on all kinds of organic substrates. The new alignment system with CCD cameras gives accuracy greater than +/- 2 micron.

The chemical etching process provides a low cost solution for polyimide film substrates. But the severe conditioning of the wet process and waste treatment are issues for this technology.

Building of the Micro Bumps

Several technologies have been developed for the building of micro bump arrays on the circuit boards and semiconductor wafers. (Table 1) Many ideas for the solder ball bumping processing have been proposed for the building of BGA constructions. Screen-printing of the solder paste could be the low cost solution. A mechanical mounting process of solder balls is the secondary standard for building the BGA construction. These processes have technical limitations for the high-density bump arrays with smaller pitches than 300 microns. They have no capability to build other bump constructions such as copper and nickel/gold.

A differential chemical etching process of copper foils has been developed to build specific micro bump arrays on the polyimide film substrates. The process provides an accurate bump height with low cost using appropriate thickness metal foils. However, it has a limitation for termination density higher than 200 micron pitches.

Table 1 – Comparison of the Building Processes of Bump Arrays

	Screen Printing	**Solder Ball**	**Chemical Etching**	**Plating**
Material	**Eutectec Solder Led Free Solder**	**Eutectec Solder Lead Free Solder**	**Copper**	**Eutectec Solder Lead Free Solder Copper Nick/Gold and More**
Bump Shape	Ball	Ball	Rectangular	Various
Substrate	Limited	Limited	Limited	Broad Choice
Min. Pitch	< 300 micron	< 400 micron	< 250 micron	< 50 micron
Cost	By panel	By bump	By panel	By panel
Productivity	Very high	Low	Very high	High
Uniformity	Good	Excellent	Good	Good
Combination	Low	Low	Low	Very High
Bus line	No need	No need	No need	Necessary

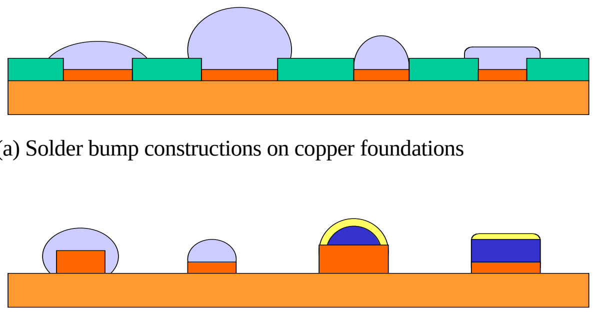
Electro Forming for the Micro Bumps
The basic idea of electrical plating is not new, but it has a broad capability and it has been seeing further technical progress. It can plate various kinds of metals including copper, nickel, gold, tin and many alloys. Different conditions provide both soft gold and hard gold. It is capable of lead-free solder plating by a tin/copper composition.

The electrical plating process has no physical limit for small pitch pads. It depends on fine masking processes such as laser drilling or photolithography, but the latest technologies have been plating smaller than 50 micron pitch pad arrays.

The bumping cost by the electro forming does not depend on the number of the bumps, but on the plating thickness that is equivalent to the height of the micro-bumps. Therefore, the process could have cost advantages when there are more micro bumps in the same size space.

Varieties of the Shapes and Metals
Several new technologies have been introduced to the plating process for building micro bump arrays on the organic substrates.

Figure 2 shows examples of the shapes of the micro bumps made by the combination of the electro-forming process with the copper plating foundations.



(a) Solder bump constructions on copper foundations

(b) Hybrid micro bumps with copper foundations

Figure 2 Varieties of the Micro Bumps by Electro Forming

Choices of the Metals
A big advantage of electrical plating is providing a broad choice for metals and alloys. Two or more metals can be combined to build various functional micro bumps with complicated shapes.

The soft gold bumps on nickel foundations were designed for gold wire bonding and flip chip packaging. The hard gold bumps are designed for non-permanent terminations as the test fixture of the IC testers.

A copper foundation process prior to the bump building was introduced to increase the reliability of the micro bumps. The copper foundation makes for good bond strength between the micro bumps and the copper pads.

Design Parameters
Another big advantage of the electro-forming process for the building of micro bump arrays is a broad capability in shape and material selection. An appropriate combination of hole generation and plating conditions provides for accurate shape and size of the micro bumps.

Figure 3 shows examples of the basic parameters of the electro-forming process. The opening diameter “d-1” identified by drilling process. The bump height “h” is controlled by the plating time. The bump diameter “d-2” depends on the “side growing” factor of the plating process.

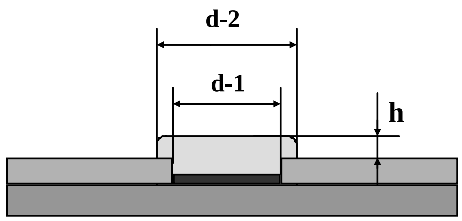


Figure 3 - Design Parameters for the Electro-Forming Process of the Micro Bump Array

Modified Plating Process

Several new technologies have been introduced to the plating process for the building of micro bump arrays on flexible circuits. Table 2 indicates the capabilities of the modified plating process for the building of micro bump arrays on organic substrates.

Figures 4 and 5 show the examples of the dome shape 6/4 solder micro bumps made by electrical plating with the copper foundations. These solder micro bumps are designed for low cost, non-permanent terminations. They demonstrated uniform and stable physical performance.

Table 2 – Capabilities of the Plating Process for Micro Bumps

Material	6/4 Solder, 9/1 Solder, Tin Lead Free Solder, Sn/Cu Solder Copper, Nickel, Silver, Soft and Hard Gold
Bump shape	Ball, Ball on Foundation, dome, Column Flat Disc, Mushroom, Umbrella
Process	Electric and Electroless
Substrates	Polyimide, PET, FR-4, BT, Etc.
Insulation	Epoxy, Acrylic, Polyimide, Etc. Screen Print, Photo Lithography
Additional process	Laser, Chemical and Plasma Etching
For isolated pads	Add Seed Layer

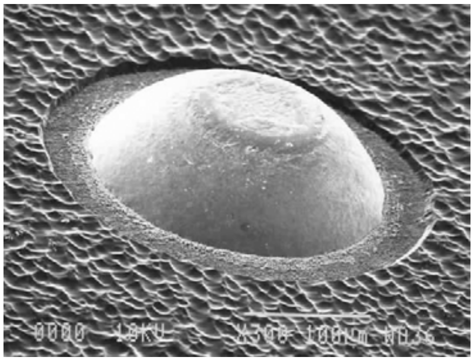


Figure 4 - SEM Photo of the Dome Shape Solder Bump

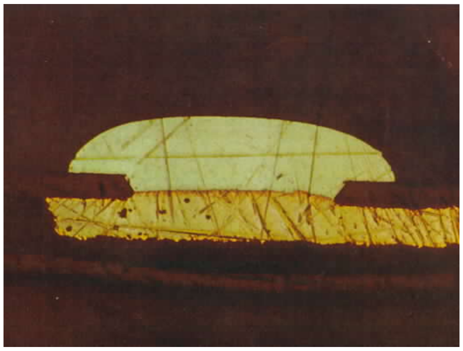


Figure 5 - Cross Section Photo of the Dome Shape Bump with the Copper Foundation

Nickel/Gold Bump
A hard gold plating on the nickel bump is the most common construction for the non-permanent termination with long life such as for IC test probes. Previously to gold plating, the underlying nickel is plated on the copper traces. The copper foundation plated under the nickel plating makes the bump reliability remarkably higher.

Figures 6 and 7 show an example of the flat disc type micro bump array built through a polyimide base film layer. Nickel bumps covered with hard gold were built on the copper foundations. The bump array was designed for a fixture probe of the IC tester, and the bumps demonstrated a long contact life.

Figure 8 also shows column shape copper bumps with nickel/gold plating on 200micron pitch traces through polyimide film base layer. The straight column shape was made by an appropriate plating method with a photo resist. It was designed for the connection of a special module.

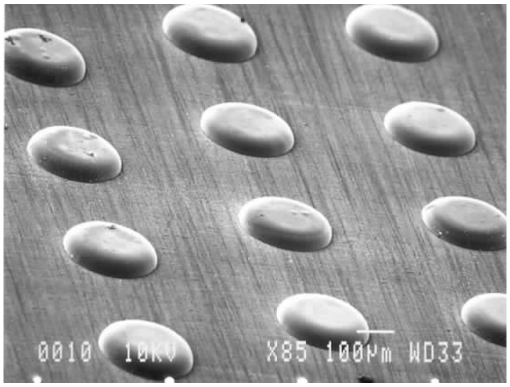


Figure 6 - SEM Photo of the Flat Disc Shape Micro Bump Array Built Through Polyimide Film

Figure 7 - Cross Section of the Ni/Au Flat Disc Bump with the Copper Foundation

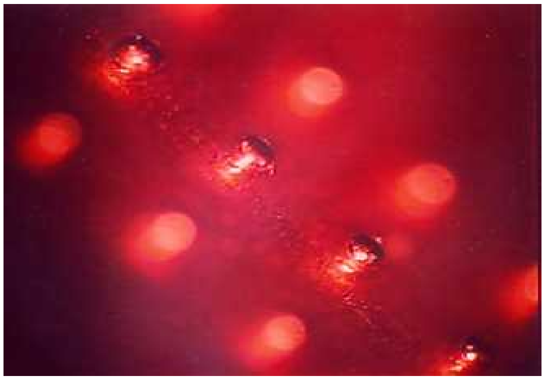


Figure 8 - Straight Column Bump Array of Copper, Nickel and Gold on the 200 Micron Pitch Traces

Accurate Bump Alignment
A higher alignment accuracy than +/- 5 micron is required to build micro bump arrays on fine traces with a density higher than 100 micron pitch. Several alignment ideas have been introduced to achieve these requirements.

Figure 9 shows a 3D image of the Ni/Au straight micro bump array built on the 100 micron pitch fine traces. A high accuracy alignment system was introduced for the plating resist mask to generate the exact access holes on the copper traces.

A less than 5 micron shift was achieved for the 100 pitch bump array on the 25 micron thick polyimide film substrate.

Figure 10 shows another example of the high accuracy alignment with the non-circular micro bumps built through an epoxy base solder mask on a fine trace. A smaller dimensional tolerance than +/- 2 micron was required because of the small width traces. A direct image process was introduced to provide the exact rectangular opening with accurate alignment. A small size beam of the Excimer laser was employed with the CCD guide system. 30 x 90 micron Ni/Au bump arrays with uniform height (+/- 2 micron) were built on the 30 micron wide pads. The direct laser drilling with a step-by-step guide system did not make a shift larger than 2 microns.

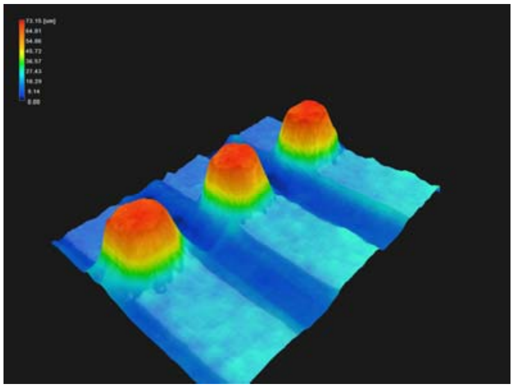


Figure 9 - Three Dimensional Image of the Flat Head Ni/Au Micro Bumps

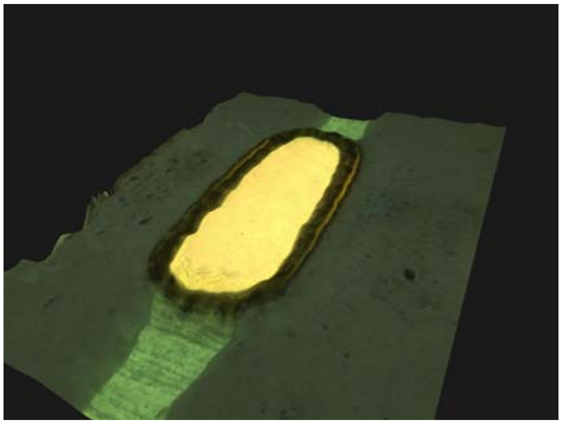


Figure 10 - 3D Photo of the Rectangular Ni/Au Micro Bump Build on the FR-4 Substrate

Special Constructions
Many kinds of bump shapes have been tried according to the requirements of the application. Figure 11 shows one of the examples of the trials. Appropriate combinations with the photo plating resist or plasma etching provide complicated bump structures such as umbrella shapes. This special structure was required for the air insulation of the test probes.

Figure 11 - Umbrella Shape Micro Bumps made by Plasma Etching

Processes for Isolated Pads

Electrical plating needs bus lines to supply the electricity. This is a limitation in applying the process to electrically isolated conductor pads. Sometimes the pads need extra lines that must be cut off by the end of the manufacturing process. However a new thin electroless plating process provides a solution for these limitations. It still needs a final etching process to remove the extra seed layer. But the electroless copper plating make the design freedom much more flexible.

Conclusion

A broad capability of electrical forming processes to build micro bump arrays on high-density organic substrates has been demonstrated through many trials. The combinations of electro-plating processes and high accuracy alignment systems are able to build many kinds of micro bump arrays of copper, nickel, soft gold, hard gold, tin and alloys with pitches smaller than 50 microns. The appropriate combinations with overlay and solder mask create more functions for micro bump arrays on the organic substrate.

Acknowledgement

Authors would like to thank Mr. Sakata of Taiyo Industrial and Mr. Ueki of Keyence for providing valuable examples and new micro photo technologies. Also we would like to thank Ms. Margaret Sims of DKN Research for the great contribution for this art

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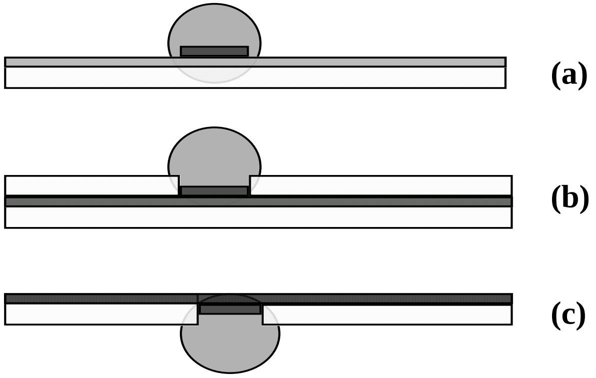
Micro Bumps

- What are they?
- Why do we need them?
- How are they formed?
- What are the advantages?

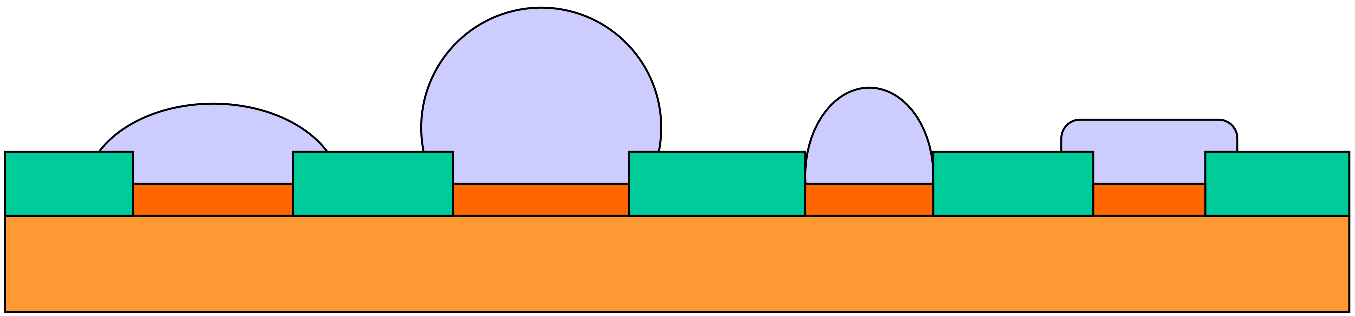
What Are Micro Bumps?

- Conductive Materials on Organic Substrates
- Top Side and/or Bottom Side
- Pitches of 400 to <50 Micron

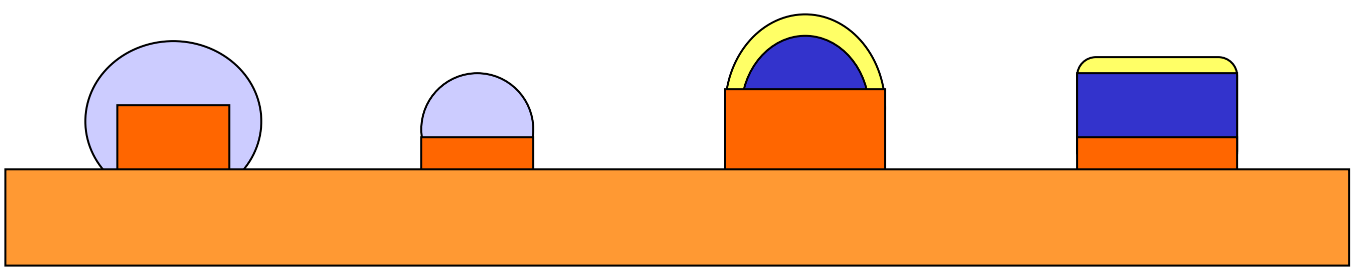
What are Micro Bumps?



What are Micro Bumps?



(a) Solder bump constructions on copper foundations



(b) Hybrid micro bumps with copper foundations

Why Do We Need Them?

- Non-permanent Applications
- Higher Densities Require Them
- Cost Considerations

How Are They Formed?

- Forming Methods
- Materials Used
- Bump Shape
- Openings in Covercoat / Substrate

Forming Methods

- Screen Printing
- Solder Ball
- Chemical Etching
- Plating

Materials Used

- Eutectec Solder
- Lead-Free Solder
- Copper
- Nickel/Gold
- Tin
- Silver

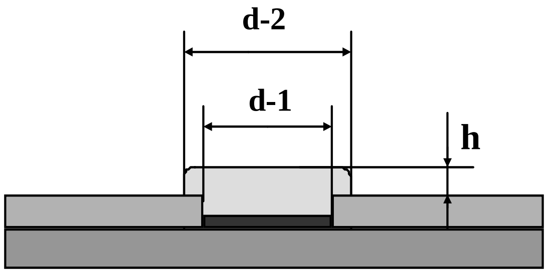
Bump Shape

- Design Parameters

D-1 Determined by via opening method

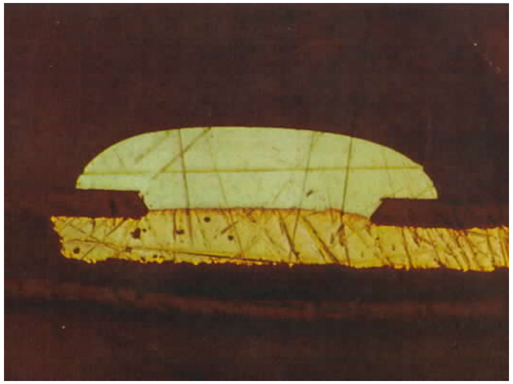
D-2 Controlled by side growth factor

H Controlled by plating process time

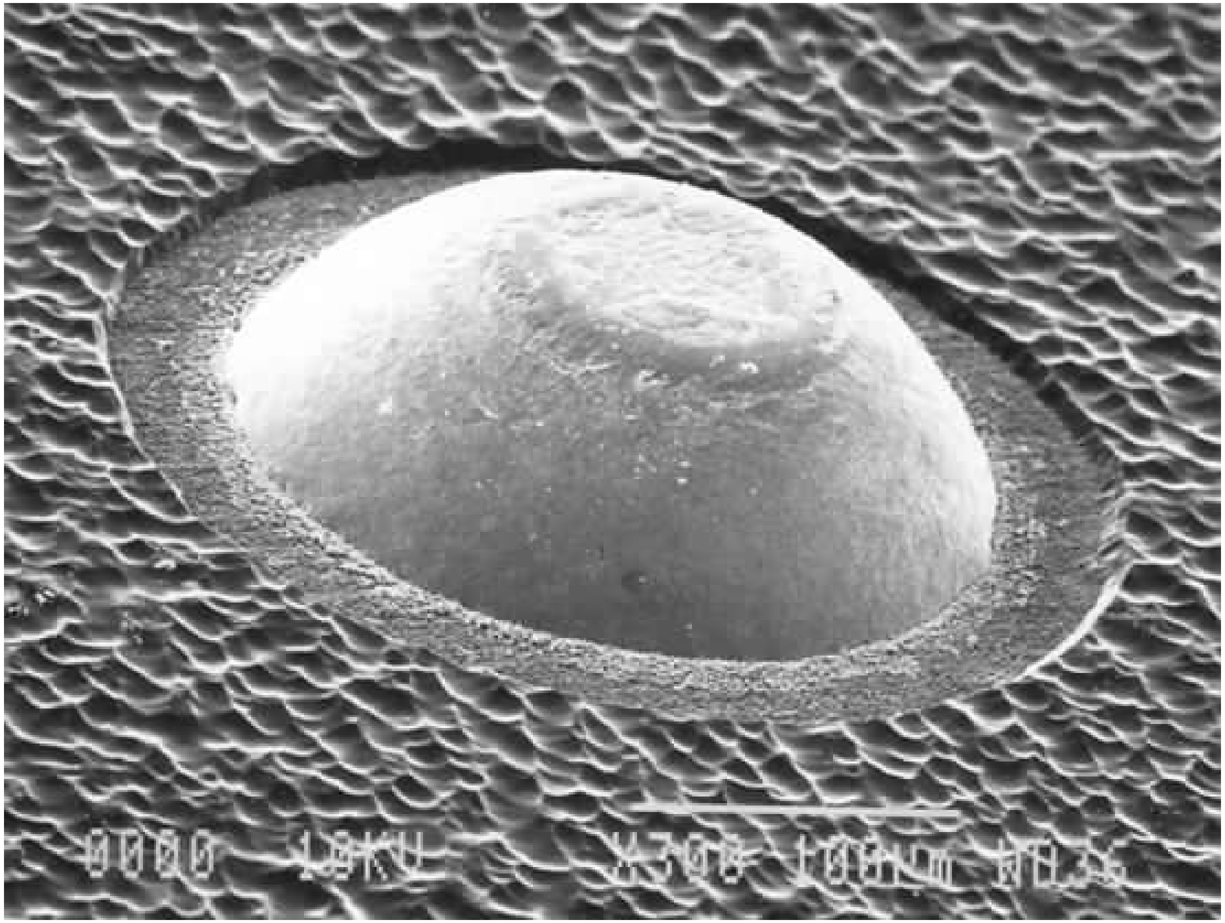


Bump Shape

- Solder Micro Bump with Copper Foundation

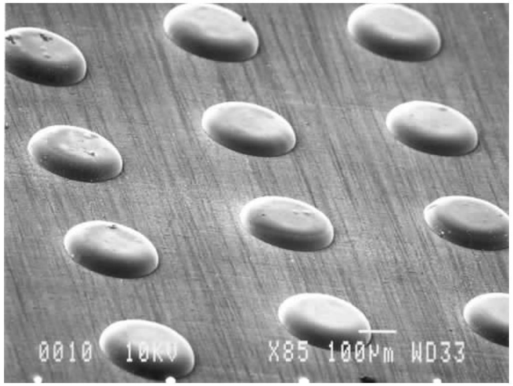


Bump Shape



Bump Shape

- Nickel/Gold Disk Micro Bump

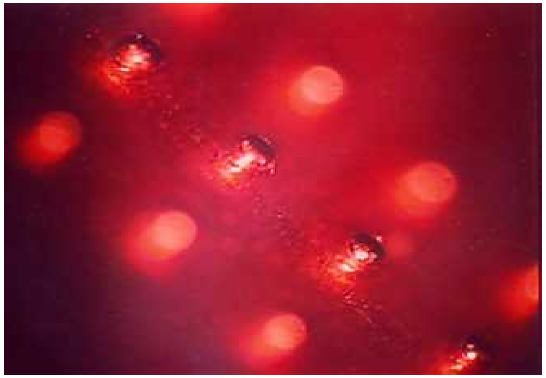


Bump Shape

- Nickel/Gold Disk Micro Bump

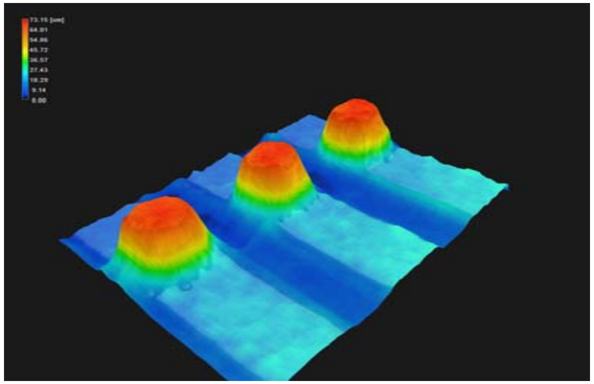
Bump Shape

- Column Micro Bump



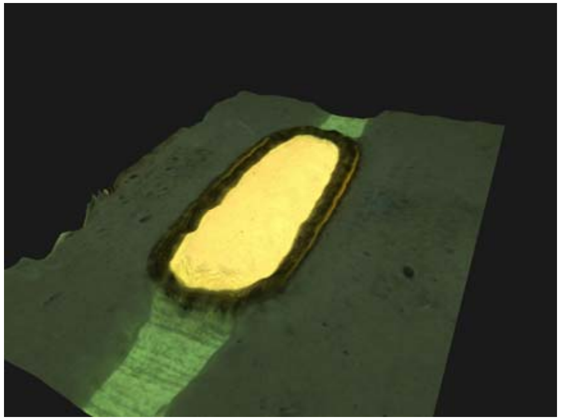
Bump Shape

- Flat Head Micro Bump



Bump Shape

- Rectangular Micro Bump



Bump Shape

- Umbrella Micro Bump

Openings

- Screen Printing
- NC Drilling
- Laser Drilling
- Photo Sensitive Films
- Chemical Etching

Advantages of Micro Bumps

1. There are few limitations for the construction and shape of the bump array.
2. Pitches of less than 50 micron are possible.
3. A copper foundation provides for higher mechanical reliability.
4. Electrically isolated pad can be covered by electro less copper plating.

Synopsis

Table 1 Comparison of the Building Processes of Micro Bump Arrays

	Screen Printing	Solder Ball	Chemical Etching	Plating
Material	Eutectec Solder Lead-Free Solder	Eutectec Solder Lead-Free Solder	Copper	Eutectec Solder Lead-Free Solder Copper Nickel/Gold And More
Bump Shape	Ball	Ball	Rectangular	Various
Substrate	Limited	Limited	Limited	Broad Chice
Min. Pitch	< 300 micron	< 400 micron	< 250 micron	< 50 micron
Cost	By panel	By bump	By panel	By panel
Productivity	Very high	Low	Very high	High
Uniformity	Good	Excellent	Good	Good
Combination	Low	Low	Low	Very High
Bus Line	No Need	No Need	No Need	Necessary

Synopsis

Table 2 Capabilities of the Plating Process for Micro Bumps

Material	**6/4 Solder, 9/1 Solder, Tin**
	Lead-Free Solder, Sn/Cu Solder
	Copper, Nickel, Silver, Soft & Hard Gold
Bump Shape	**Ball, Ball on Foundation, Dome, Column,**
	Flat Disc, Mushroom, Umbrella
Process	**Electric and Electroless**
Substrates	**Polyimide, PET, FR-4, BT, Etc.**
Insulation	**Epoxy, Acrylic, Polyimide, Etc.**
	Screen Pring, Photo Lithgraphy
Additional Process	**Laser, Chemical & Plasma Etching**
For isolated pads	**Add Seed Layer**

Conclusions

A series of trials of the electrical plating process demonstrated the board capabilities to build micro bump arrays on high density flexible flexible circuits.

The process is capable of satisfying the requirements of next generation termination technologies for high density flexible circuits.

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