Multipurpose Wire Bonding – Bumps, Wires, Combination Interconnects, and Operation Efficiency

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Abstract

Today's multipurpose wire bonding machines are required to deliver a combination of wires, bumps, and specialty interconnects for RF, automotive, and optical markets with odd-form factor parts. These market production requirements are generally lower volume with a higher mix of products compared to typical high-volume semiconductor packaging of memory and logic. These markets also require multipurpose wire bonders to accommodate large work area, deep access, and a complex mix of bond surfaces, wire shapes, and bumps. The number of components in a package can vary from one with a few wires up to hundreds of components with thousands of wires. Programming methods, process development, traceability, and rework are different for customers using this class of bonder.

A survey of customer application cases shows the range of capabilities available to packaging engineers.

The four primary cases presented highlight the range of applications that can be handled for odd-form factor packages and specific areas of focus to maximize productivity for these classes of products.

- Case 1: Ball Bump Size and Shape Examples: acheiving119µm down to 44µm bonded ball diameters and range of shapes.
- Case 2: Ambient Wire Bonding to a 6" Tall Package: demonstrating allowable bonding volume and tooling flexibility plus the ability to bond Au with substrates at ambient temperature.
- Case 3: Batch Load Tray (Mechanical and Vacuum Clamping): allowing quick change over for radically different sized packages.
- Case 4: Complex High Part Count Packages: supporting alternate parts and alternate bonding wires, stand-off stitch, and security bonds require special features for programming and navigation methods to allow easy creation and navigation of complex programs for maximum productivity. Breakdown of timing and efficiency is provided showing programming efficiencies of 2X or better.

These cases will help packaging engineers extrapolate to their own cases and show how a multipurpose automatic wire bonder can be an effective way of automating or semi automating these manually or automatically presented packages for higher throughput, higher quality and consistency, and less labor usage for lower cost.

Key words: Wire Bond, Large Area, Deep Access, Hybrid, SIP, MCM, RF, Optoelectronic, Optical, Automotive, Ball Bump, Stud Bump

Background

Motivation for the work is to show the latest advances in helping customers reduce cost of ownership to achieve automated ball bonding for non-standard, odd-form factor packaging applications.

Odd-Form factor applications have significantly different inputs and requirements than typical semiconductor packaging applications. Table 1 lists the primary characteristic differences between semiconductor and odd-form factor wire bonder requirements. The work area range in XY and the Z axes are significantly different between the two types of machines. Semiconductor machines typically use a hitch feed style handler to pull segments of the parts into position for a limited bonding area while the large workspace of the odd-form style machine can bond all of the parts in a 6" by 12" area in one pass.

The primary difference in input packages is easily seen when comparing Figure 1 and Figure 2. The semiconductor package formats are designed as strip-like formats for ease of handling in magazines and in-line conveyors. Odd-form packages for optoelectronic, RF, and other miscellaneous applications differ greatly in their shape and size. Additionally, odd-form packages can have a single die or hundreds of die in the same package. With a large number of parts and part types in the same package, the odd-form wire bonding machine software must allow the flexibility to have parameter sets for multiple bond surfaces and loop profiles plus provide a user interface that simplifies operator navigation through complex program production bonding or rework. Programmable focus allows the odd-form wire bonder machine to reference and bond across a wide range of bond surface heights as shown in Table 1.

Table 1 – Semi versus Odd-Form Wire Bonders

Characteristic	SEMI [1]	ODD/Hybrid [2]
Machine Price	Lower	Higher
Machine Throughput	Higher	Lower
Package Formats	Leadframe Strip	RF, Optoelectronic, Automotive, Defense, Other
Part Presentation	Leadframe Strip Boat	Tray Boat Custom Fixture
Machine Feed	Mag-Mag	Mag-Mag In-line Manual Batch
Work Area XY	2.2" x 3.1" 56mm x 80mm	6"x12" 152.4mm x 304.5mm
Bondable Depth Z	~0.100" Tilt Z 2.54mm	0.545" Linear Z 13.8mm
Features	Programmable optics with a full 2.5mm focus range	Programmable Focus with 15mm focus range

Odd-Form Case Examples

Three specific examples are provided below to highlight the primary challenges and solutions in odd-form package assembly, requiring capabilities significantly beyond conventional semiconductor wire bonders.

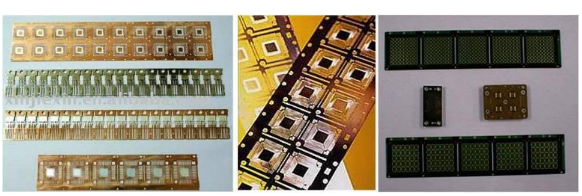


Figure 1 – Semi Format Input Materials

Figure 2 – Odd-Form Material Inputs (Boat or Trays Not Shown)

Case 1: Ball Bump Sizes and Shapes

The multipurpose wire bonder can generate a variety of bump shapes and sizes. Specific cases are shown in Figure 3. The largest bump with 119µm mashed ball diameter (MBD) is nearly as tall with an untraditional shape. Ball in corner is still in use today for joining two perpendicular conductive surfaces together. The 80µm MBD is a more traditional shape of ball bump. The 44µm MBD is one of the smaller bumps produced by Palomar Technologies. Although smaller bumps may be produced for wire bond, smaller ball bumps may have difficulty resisting the force of removing the wire from the bump.

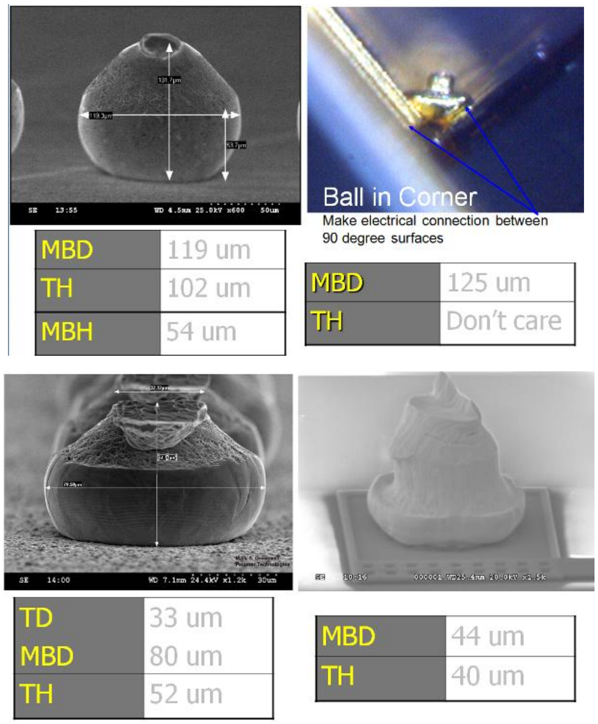


Figure 3 – Ball Sizes and Shapes

Case 2: Ambient Wire Bonding to a 6" Tall Package

This specific case in Figure 4 is an example of a 6" tall part that is bonded at ambient temperature. The part required ambient bonding because of heat sensitive components plus it was impractical to get heat from the part base up through the entire 6" of length. A tool heater wrapped around the capillary is used to create the extra activation energy for bonding as shown in Figure 4A. The tall part is shown mounted on the wire bonder in Figure 4B.

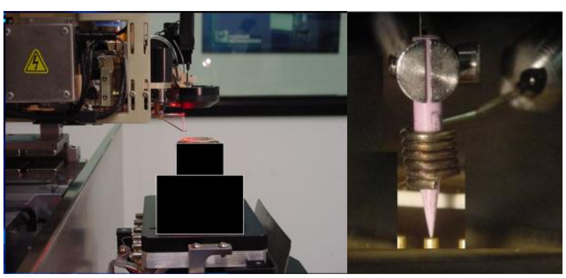


Figure 4 – Ambient Pin to Substrate bonding on 6" tall part: A) Tool Heater, B) Tall part on mounting stage

The wire bonder machine in Figure 5 has a flat plate of ¼-20 screw holes for mounting and adjusting tool stages to present a 6" tall part into the proper bond zone. Bonding a thin or thick part only requires moving the stage in the Z axis as shown in Figure 5. Dual pyrometers for conductive heater plate and convective radiant tool heater are available. In this case the tool heater was used since the part could tolerate heat.

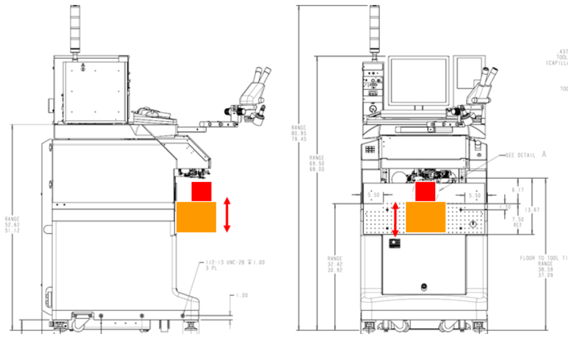


Figure 5 – Mounting Stage on Adjustable Plate

Case 3: Batch Load Tray (Mechanical and Vacuum Clamping)

In this case, a customer has a wide range of odd-form packages that they manually load/unload onto a wire bonder. The batch load system in Figure 6 is used to improve throughput and efficiency. There are two classes of parts that require either mechanical or vacuum clamping as shown in Figure 6A or 6B respectively. Vacuum clamping is used to minimize tooling complexity where possible. However, there are cases where mechanical clamping is required to hold the parts. In both cases, trays full of parts are manually manipulated with a detachable handle. The handle locks into position and isolates the operator from heat. Each tray type has a mating heated base that is mounted to the bonder heater stage. Switching from one part type to another is accomplished by changing the base plate and loading another program on the bonder. Tooling is designed to minimize change-over time by ensuring that no adjustments to the EFO wand are required.

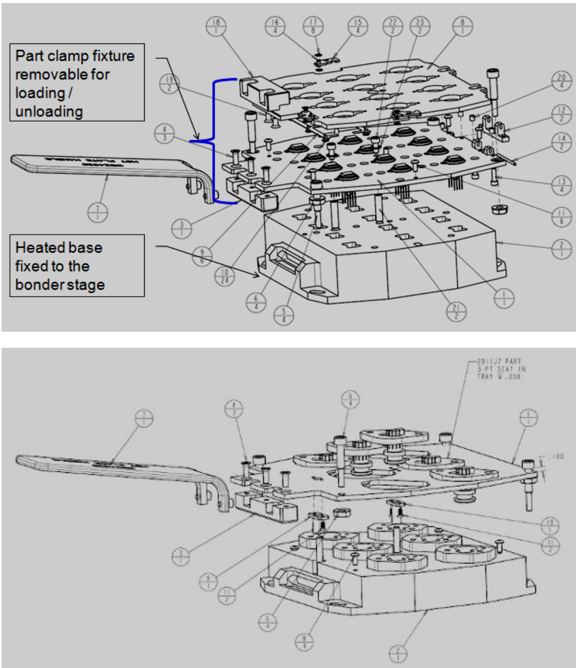


Figure 6 – Batch Load Trays with matching Heater Bases: A) Mechanical Clamp Tray, B) Vacuum Tray

The large XY area in odd-form wire bonders can support two stages, as shown in Figure 7. This allows batch loading of many parts for bonding.

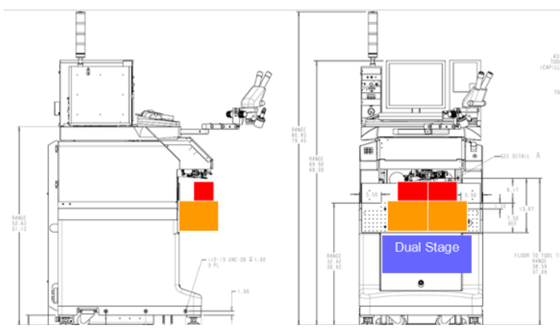


Figure 7 – Dual Stage for Batch Load

Case 4: Complex Program Navigation and Control

Odd-form factor packages come in a variety of complexities, from simple one die packages to hundreds of die in a single package. Some of these complex packages also allow alternate parts with alternate wires to be included within a single program. The operator interface should support the following five distinct phases of a package:

1. Program creation and process development
2. Documentation and transfer to production
3. Production runs
4. Product rework
5. Long term program maintenance

Program creation and process development is typically performed by a process engineer. The process engineer must have the capability to program and navigate efficiently and to set/verify process parameters quickly. Package programs can be thought of in two ways: parent-child relationships ("who carries who" in a part tree view) and a XY geometric relationship for large parts in a 2D view (part graphical display). Both views are important to fully understand the package as shown in Figure 8. Multi-purpose large area bonders also must handle matrix array linking or copying of a base part. The process engineer can check for typical errors such as crossed wires before bonding parts.

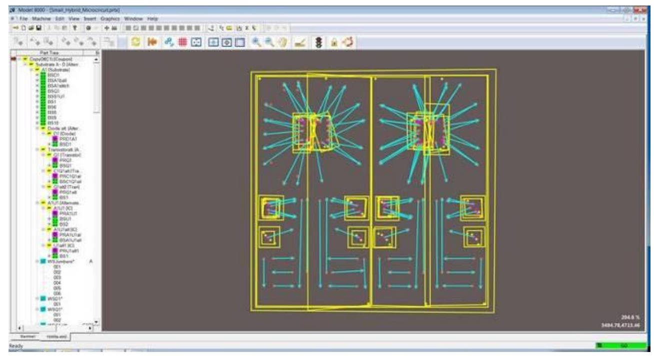


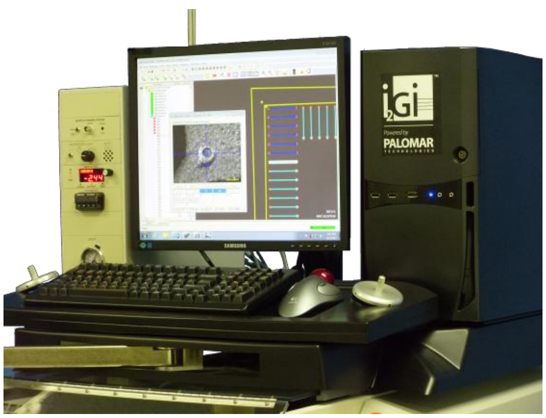
Figure 8 – Machine Program Interface Showing Part Tree Display on the Left and Part Graphical Display on the Right.

Documentation and transfer to production is aided by self-documenting features in the machine software such as visual indicators for targeting points and expected reference image scenes shown in Figure 9. The software should allow the process engineer to use real part numbers and reference designators to draw a clearer connection between assembly drawing documentation and program navigation. Operating systems which allow screen captures and then pasting into traditional word processors significantly reduce the process engineer's documentation efforts. All of these features simplify the training and transfer of a new product / process to production. Time savings for documentation and training are realized using pictures rather than words in both the program and the manufacturing documentation.

Production run efficiencies are enhanced if the interface presents a natural view of the run status, such as in a part tree display and the program graphical display. The operator can be further guided if there is a video graphical overlay of geometry features—such as bond pads, wires, ball bumps, and references—during navigation of the machine in the video graphical display, as show in the bottom of Figure 9. Interaction and association between the three program views amplify the navigation power and ease of control. Finding a particular wire set and adjusting parameters in a 100-die program can be completed in 1/5 the time.

Rework efficiencies are enhanced if the interface simplifies finding a specific wire in a program requiring rework. The operator can be further guided if there is a video graphical overlay of geometry features—such as bond pads, wires, ball bumps, and references—during navigation of the machine. This allows the operator to quickly tell if a wire is missing. Efficiency improvements for wire specific rework are based on finding the correct wire promptly and utilizing the rework wizard available on the bonder.

Long-term program maintenance efficiencies are enhanced for all of the reasons stated in the previous phases but is particularly important due to the long gaps in time between production builds or personnel turnover during the course of a product's life. Some products can last several years and may be run infrequently. The factors discussed earlier are even more important during the maintenance phase of a product.



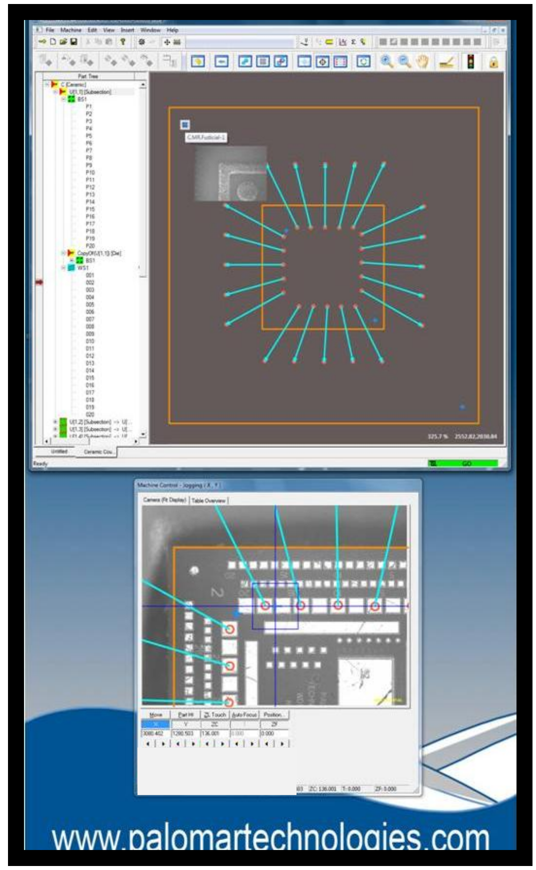


Figure 9 – Machine Program Interface Showing Part Tree Display on the Top and Part Graphical Display on the Bottom.

Miscellaneous Cases: Automated Handling

Moving beyond batch loading of odd-form parts requires adding automated material handlers to the bonder by removing the manual stage and then attaching the appropriate handler. Handlers are available for standard 3.1", 4.3", and 5.4" by 12" boats. Handlers to support custom pallets and lead frames are available. Corresponding boat magazines and magazine handlers are also available to support these boats, as shown in Figure 10. Since the system is SMEMA [3] compatible, the magazine handlers can be moved up or down stream and the bonder inserted between other SMEMA compatible equipment in a production line.

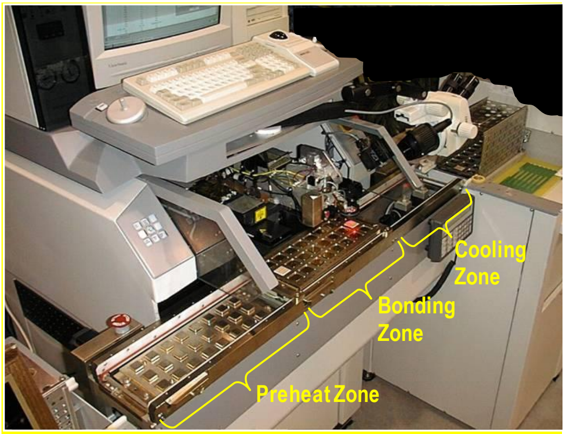


Figure 10 – Automated SMEMA Compatible Boat Handler with Preheat, Bonding, and Cooling Zone Plus Magazine Input and Output

Highly customized material handlers are also possible, as shown in Figure 11. These systems are built to specification based on the odd-form part. The system in Figure 9 is a system for automotive parts that required heat soaking the parts before presentation to the bonder.

Figure 11 – Through Conveyor System with Odd-Form Part

Odd-Form Wire Tools

There are a series of wire bonding tools that allow handling the range of challenges seen when bonding odd-form parts.

Stand-off stitch (SOS) and Security Bond (SB), shown in Figure 12, provide examples of using bumps or wires in combination with other wires or bumps. Using a bump under a stitch is not only useful for die-to-die bonding—as in SOS.B—but can also be an effective means to bond a stitch to a poorly bondable substrate as in SOS.A. Bumps can also be used to bond to pins (horizontal or vertical), as shown in SOS.C. Some high-reliability packages can also require SBs, as shown in Figure 12.

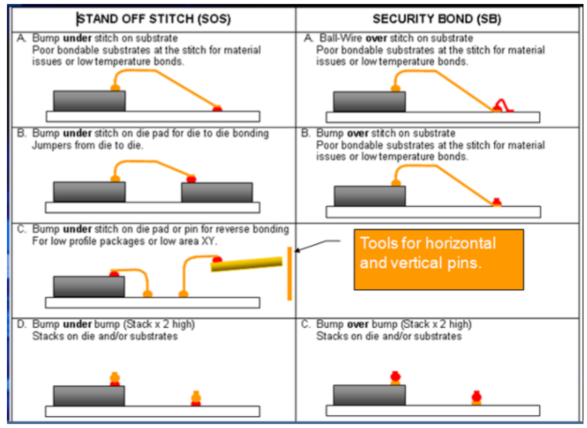


Figure 12 – Odd-Form Wire Bond Tools A) Stand-Off Stitch, B) Security Bond

Additional wire bonding tools, such as chain bonding technology, can also be combined with SOS and/or SB technology, as shown in Figure 13. A chain bond begins with a standard ball bond and loop but with a modified stitch which does not cut through the wire. That stitch is then followed by another loop and stitch, etc. Ultimately, the final stitch in the chain is terminated to form a tail and free air ball for the start of the next chain.

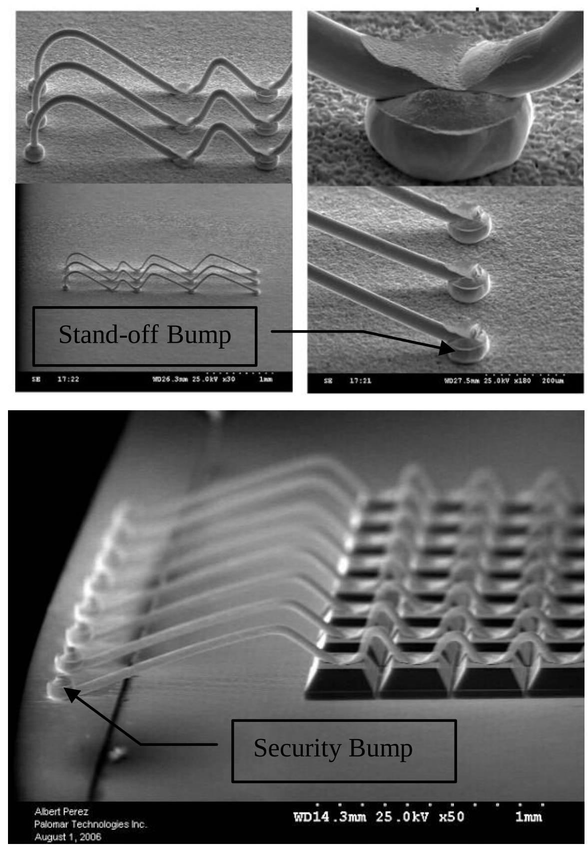


Figure 13 – Chain Bonds with Stitches on Stand-Off Bumps and Stitches Covered with Security Bumps

SOS can be used to change geometry of the loops or improve bonding on difficult surfaces. Chain bonding can also be combined with a security bond on the terminating stitch. The security bond can be a ball bump (shown) or ball-loop-stitch.

RFSOE power transistors are typically bonded with wedge bonder technology. Here, a ball bonder can effectively replicate a chain of wires, like in wedge bonding. The chain wire bonds in Figure 14 show different loop shapes in the same chain starting with a ball bond at the highest surface then bonding an intermediate stitch at the lowest surface, and then a terminating stitch at another surface height. Small jumpers are then bonded from die to die.

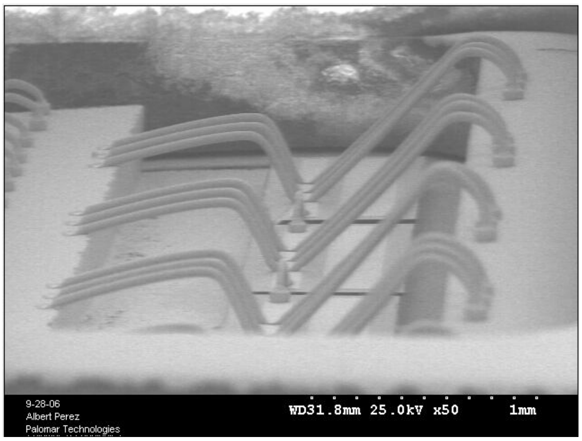


Figure 14 – RFSOE Chain Wire Bonds

Chain wire bonds in Figure 15 show a more densely populated set of chain wires compared to Figure 14. Some of the chain wires go left to right, while others go right to left. They all span different surface heights and materials. Some of the chains contain ultra-low loop heights as well. The wire bonder software must have flexible control of the order of bonding and allow different bonding and loop parameters for each of the surfaces and loop segments to create this interconnect pattern.

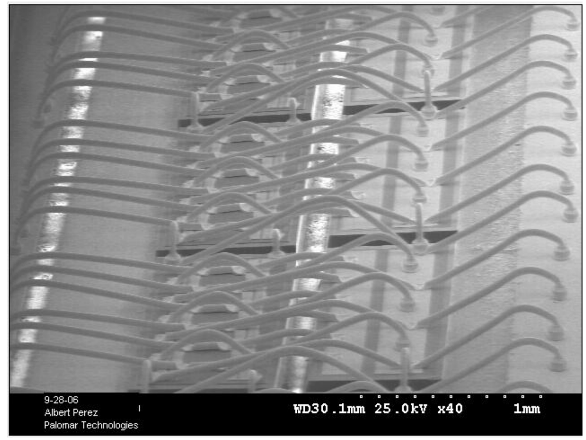


Figure 15 – RFSOE Chain Wires Show Loop Control and Sequence Order Control

Summary and Conclusion

The purpose of this paper is to show the differences in packages and capabilities between semiconductor and odd-form factor part (hybrid) wire bonding machines. The dramatic difference is the input part types shown in Figures 1 and 2. Odd-form factor wire bonders in this paper have larger work space and handle a wider range of part sizes. Multipurpose bonder machine programming and navigation interfaces require supporting packages with one to hundreds of die. Multipurpose bonders are typically more expensive and have lower throughput when compared to semiconductor package wire bonders. But many odd-form packages simply cannot be bonded on semiconductor bonders.

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