The Great Debate: Ball Bonding versus Wedge Bonding

PALOMAR TECHNOLOGIES

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Introduction

Over the years, microelectronic wire bond process and packaging engineers have debated whether to use ball or wedge bond technologies. This has been the question of most process engineers because, generally speaking, the electrical characteristics of the package are affected by the method of wire bonding. This is especially true with RF designs and fine-pitch packaging. There is little debate that ball bonding is faster and more robust; however, due to a need for low profile interconnects or fine pitch, wedge has continued to dominate in some key market segments.

Additionally, there are cases where certain packages have physical constraints such as temperature limitation (low heat or no heat applications), such as the use of aluminum wire instead of gold, use of ribbon instead of wire and fine pitch applications. Knowing which bonding method to choose is important to a successful package.

This article will focus on the advantages of wedge bonding over ball bonding and vice versa. These relative advantages for each method will aid in illustrating potential situations where one approach might be more appropriate than the other.

The Wire Bond Market and Applications

There are many methods that have been developed over the years for interconnections between dies and packages; ball bonding, wedge bonding, flip chip, clip attach, as well as hybrid bonding. And while many of these methods have nuances and can could be broken out even further; the fact remains that over 85% of packages and devices produced use some form of wire or wedge bond. And due to the fact that these methods share many similarities, it is important to investigate what the differences are and how those differences contribute to the decision of which method is right for any given device.

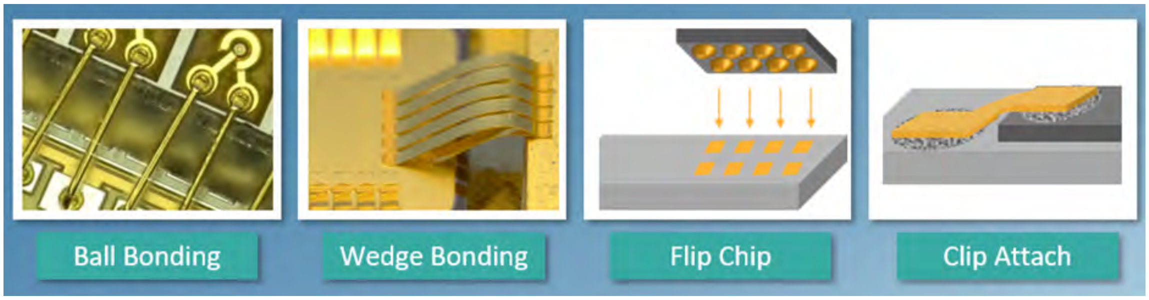


Figure 1: There are many different types of wire bonding.

The primary distinction between wedge and ball bonding is the bond head. Specifically, the tools used for bonding are capillaries for ball bonding and wedge tools for wedge bonding. While both pull wire through to weld to the package, they do so in slightly different fashions. The wedge tool will flatten the wire underneath the tip of the tool to create bonds, while the ball bonder relies on another tool to melt the wire into a ball shape before using its tool to bond the ball to the surface.

Figure 2 & 3: A ball bonder relies on another tool to melt the wire into a ball shape. A wedge tool will flatten the wire underneath the tip of the tool to create bonds.

Ball bonding is used several times more frequently than wedge bonding. However, there is a reason why, despite ball bonding's prevalence in the market, the argument on which interconnect method to use isn't always so simply answered.

Wedge Bonding and It's Advantages

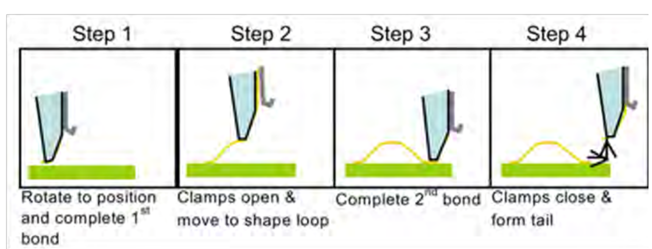


Figure 4: The steps to creating a wedge bond.

To begin, let's start with a brief overview of wedge bonding. Unlike ball bonding, wedge bonding does not have a flame-off action, as there is no ball. And the wire is typically clamped behind the wedge tool instead of above the tool such as for ball bond. Figure 4 describes a process for creating a wedge bond. With the wire below the tool, the system rotates to position and welds the wire to the surface forming the first bond, the clamp then opens up allowing for the system to draw out the wire path towards the second bond location. It then bonds the second bond and moves to terminate the wire with the clamp closed, leaving behind a small tail of wire below the tool for the bond one of the next wire.

Wedge bonders enable bonding with a large variety of wire and ribbon materials, such as Au, Al, and silver to name a few. With some only needing small changes, depending on wire size and type differences. This makes wedge bonding the bonding of choice in high mix environments.

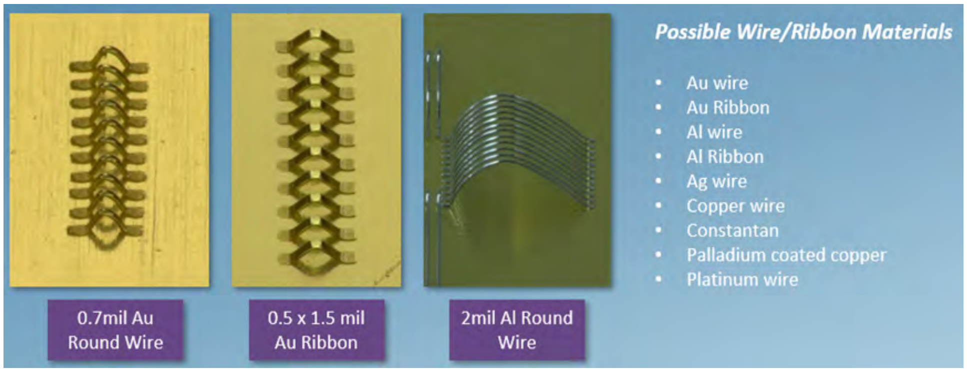


Figure 5: There are a wide range of materials that can be wedge bonded.

Wedge bonders are directional, due to the wedge-to-wedge nature. This means two things: Firstly, wedge bonders need a theta axis to rotate to the orientation of the loop. This allows for bonds to be placed at orientations other than in line with the wire direction. This is called orthogonal bonding. Secondly, wedge bonds are typically longer than they are wide, allowing for tighter pitch while maintaining a good amount of bond area, unless it is ribbon that is being bonded.

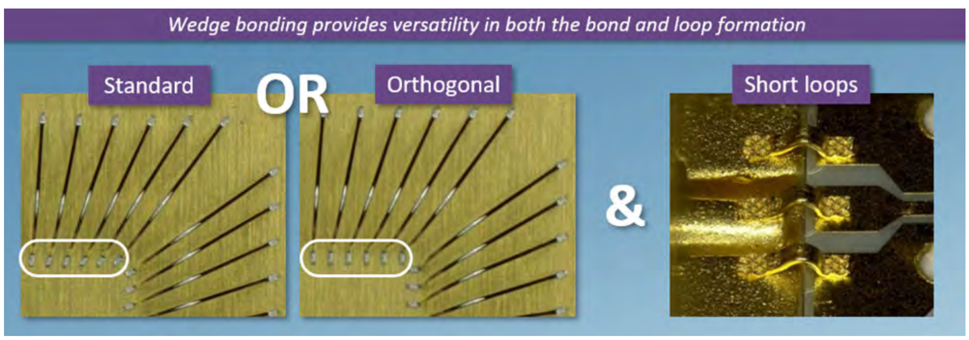


Figure 6: Wedge bonding can create standard or orthogonal bonds and short loops.

Another difference between wedge bonders and ball bonder is that no ball is needed for bonding which allows for lower, shorter loops, depending on tool design. Wedge bonders are capable of deeper access than ball bonders due to not needing to flame off. Ball bonders need a little extra vertical clearance to be able for the EFO wand to clear the part and to have the capillary clear the EFO wand.

With the wedge tool design, wedge bonders are capable of bonding wire closer together with vertically relieved sides. They are also capable of deeper access as they are not limited in vertical range by having to move up to a flame off height with every wire.

Ribbon is unique to wedge bonding due to its shape and cannot be bonded omni-directionally like wire on a ball bonder. It needs to be oriented the right way that can only be provided by specifically designed wedge tools. Ribbon bonding as shown in Figure 7 is preferred in high frequency applications due to the skin effect, due to ribbon's high surface area to cross sectional area ratio, which means the ribbon will suffer less resistance at higher frequencies. Ribbon bonding is stiffer than round wire and is more resilient to wire sway. And also provides a larger bond area allowing for stronger connections.

Figure 7: Typical ribbon bonding.

Typical Wedge Bonding Applications

A fairly typical application for wedge bonding is aluminum wire. In this example, 2 mil Al wire will be used. Al wire is unique to wedge bonding due to the oxidation issues at high temperatures. This application uses a 90-degree clamp and is bonded at room temperature. To run Al wire, it's advised to use a concave wedge tool designed for 2mil Al.

When performing standard bonding, the bond head moves to the location of bond one, rotates it to the orientation of that loop profile. The first bond is welded, then the bond head performs the loop motion, moves to bond two and will make the second weld. The wire is then terminated with a small section of wire under the tool and then the process repeats all over again. All bonds are at the orientation of the wire. As the wires fan out, so do the bonds. This is the most common type of bonding due to the speed penalty seen with orthogonal bonding.

Wedge Bond Looping

There are three primary looping techniques as seen in Figures 8 – 10; these describe the path the bonder makes with the tool to create loops of various shapes and specifications. Although there are some other influences on the final shape of the loop such as air settings and tool design; looping provides the bulk of the loop structure.

The first loop mode is a basic set path with a kick back and is a common choice for its simplicity and robustness. This allows for larger variance in span at the cost of loop height consistency. This is especially useful for development and can handle a large range in bond to bond span.

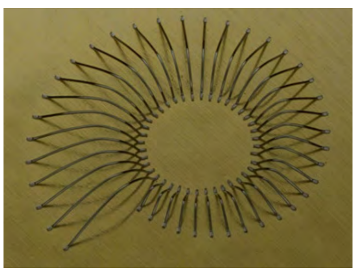


Figure 8

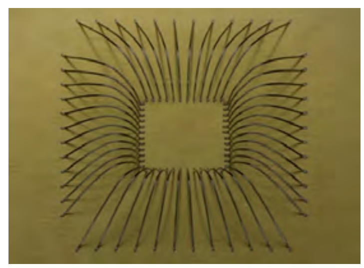


Figure 9

The second loop technique is similar to the first but introduces clamp actuation during the path. This controls the amount of wire in the loop more finely at certain points. And helps maintain loop consistency and height over a narrower range of spans. This technique is widely used for established processes with limited variation for better loop consistency.

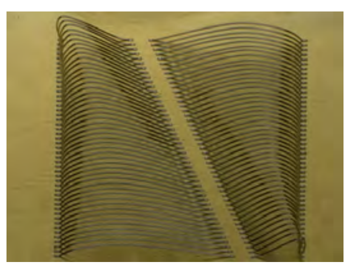


Figure 10

These loop techniques are able to satisfy the majority loop requirements and specifications for a wide array of applications. They provide easy avenues for development of processes based on the requirements.

Wire Bonding and It's Advantages

As previously mentioned, the primary difference between a ball bonder and a wedge bonder is the free air ball. Ball bonders bond round gold wire to a metallized surface via a capillary using thermosonics. Prior to bonding, a ball is formed by melting the Au round wire with an electronic flame off, creating a ball under the capillary. The size of the free-air ball (FAB) is tightly controlled with fully programmable parameters through the software. The optimal size range of the FAB is also determined by the gauge wire being used.

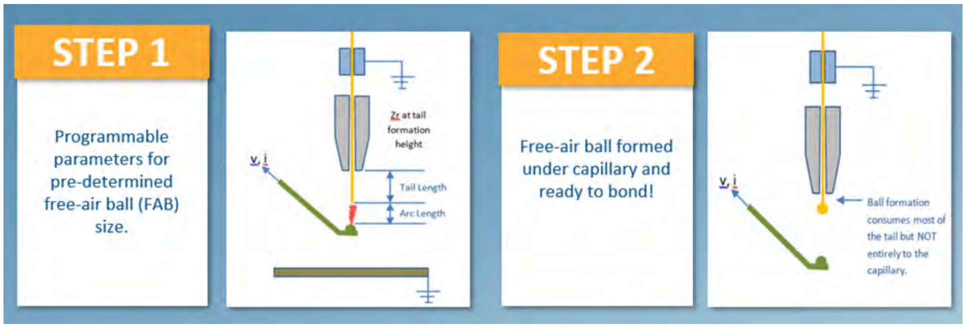


Figure 11: How a ball is formed in ball bonding.

Once a FAB is formed, the ball is then placed at the first bond location usually on a die bond pad. As seen in Figure 15. Ultrasonics is then transmitted through the capillary and scrubs the ball into the bond surface creating a metallurgical bond. Bond one creates a situation that prevents the capillary from coming into contact with the bond surface. The second bond is then terminated to a substrate pad. In this case, the capillary comes into direct contact with the bond surface, scrubs and cuts the wire forming the stitch bond.

Ball bonders typically bond two to three times faster than wedge bonders, which is one of the advantages of using a ball bonder.

Thermosonic ball bonding requires heat, pressure and ultrasonics. Ultrasonics are transmitted via a bonding capillary where the frequency of the ultrasonics and the geometry of the capillary can have a significant effect on the strength and shape of the bond. Bond pad pitch, bond pad opening, loop height, mashed ball and stitch deformation are all considered when determining the geometry of the capillary.

There are capillaries for stud ball bumping, long looping, deep access bonding, and standard wire bonding. The ultrasonics, transmitted to the tip of the capillary, normally use lower frequencies to bond at temperatures around 150•C. However, for lower temperatures, higher frequency ultrasonics are used to compensate for the absence of the thermal component of thermosonic bonding.

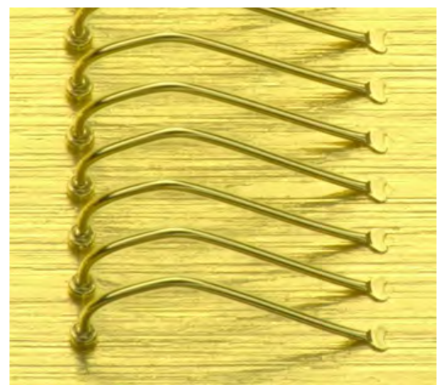


Figure 12: Example of a final ball bond.

Ball bonders use pure gold wire, oftentimes doped with controlled amounts of other elements, depending on the package requirements. In the current market, low-alloyed gold wire usually contains as much as 1% of alloying elements and as high as 5% in some cases with the most common alloying elements being Ag, Al, Be, Cu, Pd, and Pt. The main advantage of using alloyed gold wire is a significant increase in strength, high temperature strength, thermal stability and are good for higher speed, higher frequency and lower temperature bonding.

Figure 17 shows basic ball bonding applications. Forward bonding typically has the first bond on the die and the second bond on the substrate. This can be further secured with a security bump placed atop of the stitch bond. Another common situation is reverse bonding with the first bond placed upon the substrate and the second bond placed on the die, typically with the use of a stand-off stitch. Ball bonders can also produce an array of ball bumps for flip chip applications. These ball bumps are the key advantage of ball bonders and their ability to bond to almost any package component.

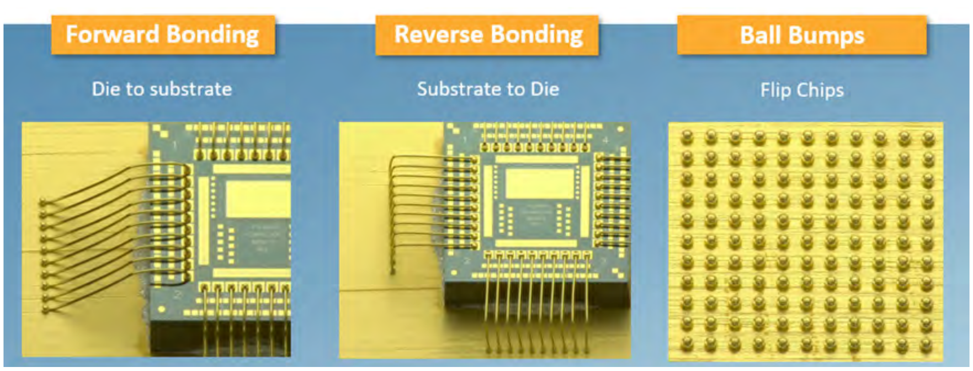


Figure 13: Basic ball bonding applications.

Ball bonders are known for their speed, as well as, their versatility. For instance, a single capillary can be designed to bond standard wires, chain wires, v-bonded wires, and ball bumps, which are necessary for stand-off stitch wires (SOS) and security bumps (SB). All of these wire types can be bonded at 150•C in a single process, and this is what makes a ball bonder so versatile.

In traditional ball-stitch wire bonding, the first bond (ball) is bonded to a die bond pad and the second bond (stitch) is terminated to the substrate. It is not recommended to bond from chip to chip with this configuration as the second bond is terminated directly to the die bond pad where the capillary comes into direct contact with the bond pad. This transmits mechanical force to the chip bond pad increasing the risk of damage to the pad's metallization. Usually this would mean that two interconnects would be needed to bond from one die to another. However, a stand-off stitch can be used to bond chip to chip, shortening the interconnect length while also maintaining the integrity of the die bond pad with the second ball bond.

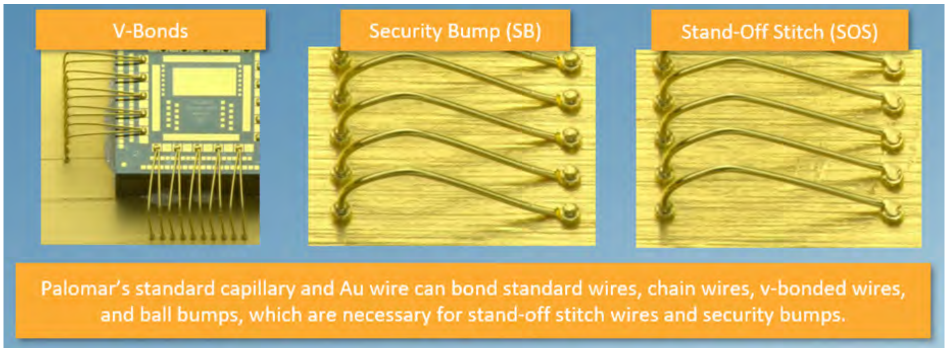


Figure 14: Ball bonders offer immense versatility in the types of bonds.

Typical Ball Bonding Applications

The primary hardware difference between a wedge bonder and a ball bonder is the electronic flame-off system (EFO) on a wire bonder. The servo actuated EFO wand, when under the wire and capillary, produces a plasma burning the wire, creating a free-air ball. With pre-programmed parameters, the flame off event can produce tightly controlled free air balls. The free air ball is then suspended below the capillary where it is ready to be bonded to a package.

The use of the ball bump is the key advantage a wire bonder has over a wedge bonder. The ball bump can be used in many different ways and allows ball bonding in many different configurations and many different environments. It provides a cushion so that when the capillary bonds the first bond of the wire for a ball bump, it doesn't come in contact with the die bond pad so there is very little chance of fracturing or cratering or damaging the bond pad. For this article, an assortment of wire bonds in different configurations will be presented using a package setup that allows to conveniently place wire bonds in the forward and reverse directions using Palomar's auxiliary wires. 1 mil Au wire, along with a standard Palomar capillary bonding at 140 degrees C is the setup. Several Palomar die placed on a gold coupon will be the substrate.

The first example of bonding is standard forward bonded wire with a security bump placed upon the stitch. For the security bumps, Palomar's tailless smooth bump loop mode was used which allows for finely tuning the shape and size of the ball bump. A security bump is not necessary but when bonding to a subpar or low quality-controlled substrate metallization, the security bump can significantly increase the strength of the bond at the stitch for a minimal decrease in throughput. The security bump can further secure the wire especially in high vibration or high thermal variation in environments.

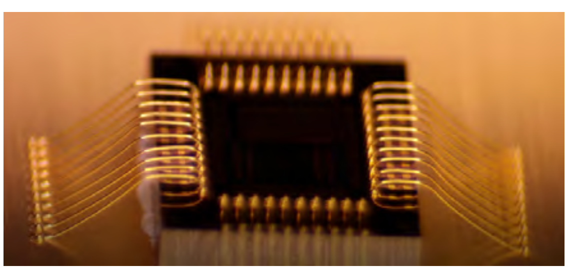


Figure 15: Example of forward bonded 1 mil Au wire with a security bump.

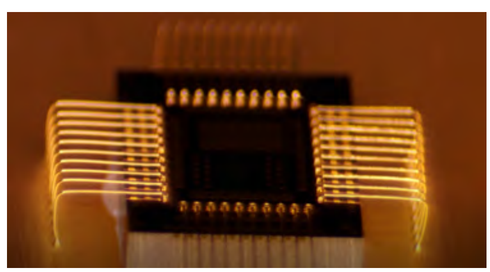


Figure 16: Example of a reverse stand-off stitch.

For reverse stand-off stitch wires, the ball bump is placed on the die pad first, then bond one of the wire is bonded on the substrate and then bond two stitched off on top of the ball bump. Finely controlled ball bumps with consistent shape and size provide better process control. Stand-off stitch wires are very useful in situations of extremely low and flat loop height especially for tight constraints on a package for loop height control. This reduces the risk of shorting or even for coming into contact with the lid of the package. Another advantage of the reverse stand-off stitch is the ability to bond die-to-die. This will reduce the total interconnect wire length and reduce the overall amount of wires needed to make that die-to-die connection. A stand-off stitch is quite versatile and can be bonded in the forward direction, similar to a security bump wire, which allows for better adhesion to the substrate with a ball instead of a stitch bond.

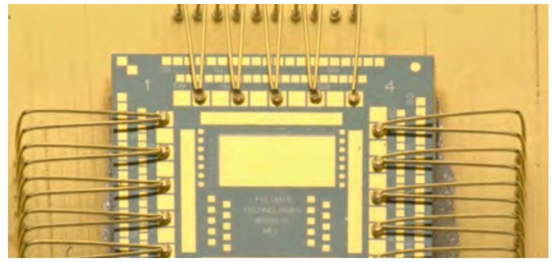


Figure 17: Example of a V-bond.

V-bonded wires are when two or more wires can share the same second bond location. This can be done simply by manually bonding the same bond over the location of a previously bonded wire but Palomar's software has stream-lined this function and made it easier to program and generate.

The V-bond process can be used with the stand-off stitch and with a security bump, if needed. It is extremely useful in situations where two wires need to be bonded onto the same bond pad with limited space such as in cases where a small die pad is just large enough to accommodate the first bond of two ball bonded wires.

However, to avoid damaging the first bonded wire, a small tipped fine pitch capillary is needed. In this case the second bond is either bonded to a substrate or capacitor with plenty of real-estate. Using a v-bond auxiliary wire type with Palomar's ball bonder, a slightly larger ball can be placed onto the die bond pad and reverse bond two wires from the substrate onto the ball bump in a stand-off stitch configuration. This doesn't require a custom fine pitched capillary and there is minimal to no risk in damaging an adjacent wire bond. In this case, it would be a re-verse bonded stand-off stitch v-bond and can accommodate up to three wires on a single ball bump.

Wedge and Ball Bonding Case Studies

Wedge Bonding Case Study One: Extremely low height and short loop span wires

This challenge included extremely low height, short loop span, die to die wires, such as is the challenge when bonding from VCSEL and photodiodes to drivers and TIAs, not to mention that there is a lens that is placed above these components limiting wire height.

Wedge bonders are capable of bonding these wires without leaving capillary impression on the die or the use of a stand-off stitch, which increases the height of the wire slightly.

Figure 18: Case study one.

Wedge & Ball Bonding Case Study Two: Low temp bonding with exotic wire metal

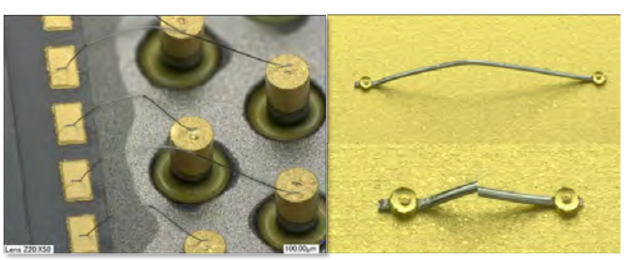


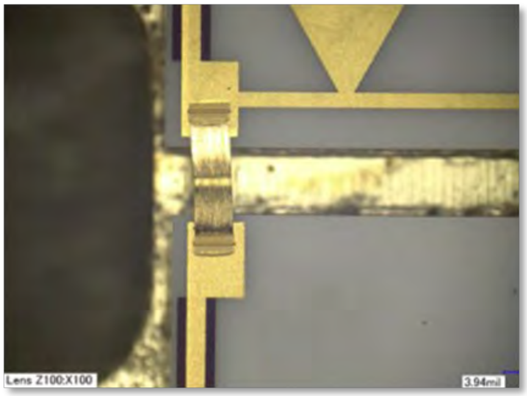
Figure 19: Example of wedge bond with a ball bond placed on top.

This case study included the challenges associated with low temp bonding with exotic wire materials. Either due to thermally sensitive components or due to the part being so large and tall that it may be unreasonable to heat the entire part. This makes ambient bonding the best choice.

Wires such as aluminum and constantan are both good options for ambient bonding, with constantan offering better thermal resistive properties at the cost of bond ability due to materials hardness.

Due to the material properties of constantan wire, the wedge bonds are not very strong when compared to bonding gold wire. To combat this issue, a ball bonder can be used to place a large gold ball bump atop of the wedge bond to further secure the bond.

Wedge Bonding Case Study Three: High frequency applications



For high frequency applications, ribbon bonding is preferred due its lower impedance and inductance at high frequency due to the skin effect. The ribbon can conduct more current thanks to its large size, and is stiffer and more resilient to wire sway than round wire.

Figure 20: Ribbon bonding is recommended for high frequency applications.

Wedge Bonding Case Study Four: Super tight pitch with fanning wires

Normally, bonding with a super tight pitch would cause the previous bond or loop to be disturbed during the formation of the current bond and loop. Orthogonal bonding may be necessary to maintain tight pitch as wires fan out to other pads. With orthogonal bonding this can prevent this orienting the bond such that it is in line with the surrounding wires leaving them undisturbed.

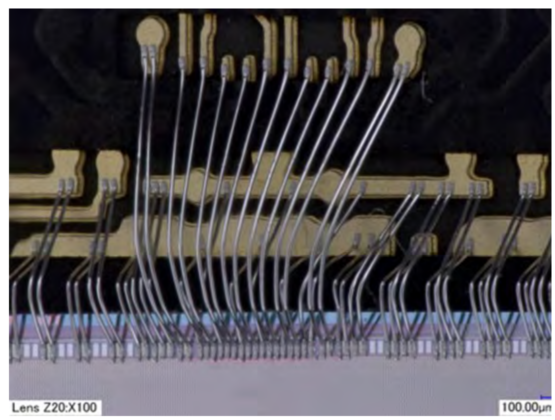


Figure 21: Orthogonal bonding with a tight pitch.

Wedge vs Ball Bonding Case Study Five: Thermally sensitive components

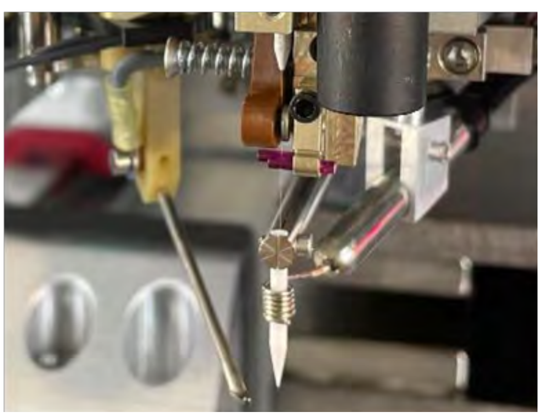


Figure 22: Thermally sensitive components can be wedge or ball bonded.

This case offers two different solutions that can be equally as good. A Wedge bonder can bond at ambient temperatures with more ease and efficiency than a ball bonder and depending on the package requirements can bond alternative metal wires and ribbons also at ambient temperatures.

However, if a ball bonder is preferred or required, it can bond gold round wire at ambient temperature with the use of a 120 kHz transducer and a tool heater which heats the wire prior to bonding onto the package. The advantage of using a ball bonder to bond at ambient temperatures is faster bonding at roughly two-three times the speed of a wedge bonder. And with the use of a stand-off stitch wire, the quality of the bond is improved due to the larger surface area of a ball bond.

An example of this is an application on a ball bonder that bonded a gold alloyed wire consisting of 75% gold and 25% Ag at ambient temperature with a 120 kHz transducer and without the use of a tool heater.

Ball Bonding Case Study Six: Close proximity of bond locations to package walls/tall objects

A ball bonder can utilize custom capillary designs with bottle neck or relieved capillaries to allow tight space bonding with adjacent objects. If the first bond location is on a die bond pad and adjacent to a tall object, attempting to place the first bond will usually result in the capillary coming into contact with the tall object during loop formation, however, a reverse stand-off stitch wire can be used to terminate the second bond onto the die where the only limitation will be the diameter of the capillary at that location.

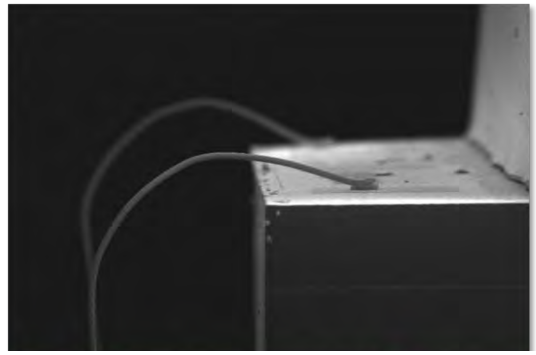
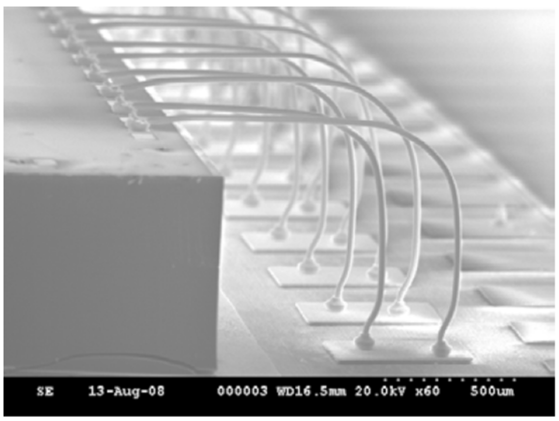


Figure 23: Reverse stand-off stitch for close proximity bonding.

Ball Bonding Case Study Seven: Low loop height requirements with the lid of the package requiring max loop height of 5 mils



Using a ball bonder to bond a reverse bonded wire will allow looping where the top of loop is parallel with top of the second bond surface. If the second bond surface is, for example a capacitor, the wire can lay flat on the capacitor and theoretically have a loop height of the diameter of the wire. If the second bond surface is a die, a stand-off stitch wire can be used to elevate the wire off of the second bond surface and keep the loop height to a theoretical height of the diameter of the wire plus the height of the ball bump or as low as just a few mils.

Figure 24: Example of reverse bonding for low loop heights.

Conclusion

As you can see in Table 1, there are times when Wedge Bonders hold the advantage and others where Ball Bonding does. There are also cases where both wire bonding methods have their own unique edge without a clear favorite. In fact, many of these cases are not going to be black and white and likely won't be the only application element or challenge. There are many factors to consider when looking to choose between ball or wedge bonding which is why it will always be the great debate.

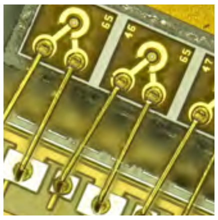
Package Element or Challenge	Wedge Bonder Advantage	Ball Bonder Advantage
Fine Pitch / Lack of Bonding Space	Wedge bonds are generally smaller and can be angled independent of wire direction	
Low Loop Heights and Angles	Ribbon has better structural stability; lower total heights due to lack of ball	
Long Loop Spans	Ribbon can achieve lower profile loops with less loop sag	Security bumps can be used to improve loop strength
Component Thermal Sensitivity	Different materials – such as aluminum – can bond at ambient temperature	A tool-heater can be used for localized heat instead of heating entire package
Deep Access / Close Proximity to Objects		Reverse bonding can be used for steep wire angles to circumvent difficult geometries
Bond Location Material Fragility		Stand off stiches can protect fragile bond pads
High Frequency Power Efficiency	Ribbon has greater power efficiency due to larger surface area	
Rugged Wire Strength Requirements		Security bumps and stand off stiches can improve both loop and bond strength
High Frequency Crosstalk Concerns	Ribbon geometry produces less crosstalk	
Chain / Stacking Wires	Ribbon stacks neatly; less chance of sliding	Ball bond is great cushion for multiple bonds

Table 1: Ball bonding versus wedge bonding summary.

8100 WIRE BONDER

BALL (STUD) BUMPER

The newest Palomar fully automated, thermosonic high-speed, ball-and-stitch fine wire bonder capable of ball bumping and customized looping profiles. Based on Palomar's proven wire bonder design and incorporating the latest productivity technology and operator ergonomics, making it the next generation of fine wire bonders.



VISIONPILOT® WITH RADAR REFERENCING®
Utilizes advanced geometric pattern matching technology to reliably and accurately locate parts that are randomly oriented or have greyscale variations by using a set of boundary curves that are not tied to a traditional pixel-grid.

INTELLIGENT INTERACTIVE GRAPHICAL INTERFACE® (i2Gi)
Supports advanced wire bond control through an intuitive interface that simplifies programming and provides real time graphical feedback to the user of bonding performance

BOND DATA MINER™
A comprehensive and centralized data management and analysis system that provides machine and process trend monitoring for increased yields and predictive maintenance.

- **VisionPilot®**
  VisionPilot with Radar Referencing pattern recognition software to maximize throughput.

- **Bond Data Miner**
  An all-inclusive and centralized data management and analysis system that is a powerful tool to improve yield and utilization.

- **I2Gi® Software**
  Designed to enable technicians to work smarter, faster and with more control.

- **NEW Palomar Vision Standardization™**
  Standardizes the vision system across bonding platforms, allowing for seamless transfer of programs between systems.

- **NEW Ergonomic Design**
  Select from a wide range of motion for optimum operator comfort.

- **Based on a Proven Design**
  Compatible with legacy programs and processes

- **NEW NEFO Generator**
  Digitally controlled for precise parameter adjustments, real-time feedback and logging for readily available and simple process control and optimization.

- **NEW Bondhead Design**
  Restructured key user interaction points for optimal efficiency and ease of use

- **Patented Dual Z-Axis**
  Unique bond-head motion; Zr (rotary), Zl (linear). 20mm deep access allows the formation of precise gold ball bumps. Patent # 6,102,275

- **NEW Integrated Inline Conveyor**
  Palomar designed inline conveyor for volume production.

- **Magazine Feeder**
  Magazine feeder keeps your process flowing.

- **Service Contract**
  Achieve maximum ROI by adding a service contract complete with preventative maintenance visits.

- **NEW Easy Access**
  Redesigned electronics bay for easy service access.

- **Industry 4.0**
  Engineered to enable Industry 4.0 communications.

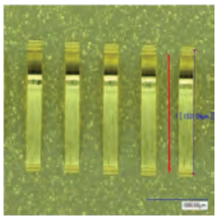
TYPICAL APPLICATIONS

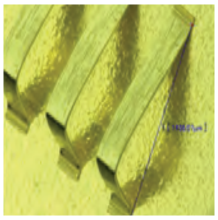
- Large complex hybrids
- Optoelectronic packaging
- System in packages (SiPs)
- Automotive assemblies
- Multi-chip modules (MCMs)
- LEDs with running stitch
- HB/HP LED arrays
- Chip-on-board (COB)
- Specialty lead frames
- Flex circuits
- Fine pitch devices

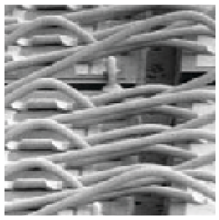
PALOMAR 9000

WEDGE BONDER

The 9000 Wedge Bonder is a high-speed fine wire wedge and ribbon bonder driven by voice coil technology in the bond head. This machine has interchangeable 45-60° and 90° deep access wedge clamps and operates across a single large 304 x 152 mm work area. As the entire bond head mechanism rides on theta, users realize excellent wire tension, a shorter wire feed path and inherent prevention of twisting of wire and ribbon, and better overall process control.







VISIONPILOT® WITH RADAR REFERENCING®
Utilizes advanced geometric pattern matching technology to reliably and accurately locate parts that are randomly oriented or have greyscale variations by using a set of boundary curves that are not tied to a traditional pixel-grid.

INTELLIGENT INTERACTIVE GRAPHICAL INTERFACE®
Supports advanced wire bond control through an intuitive interface that simplifies programming and provides real time graphical feedback to the user of bonding performance.

BOND DATA MINER™
A comprehensive and centralized data management and analysis system that provides machine and process trend monitoring for increased yields and predictive maintenance.

- **VisionPilot®**
  VisionPilot with Radar Referencing pattern recognition software to maximize throughput
- **Bond Data Miner**
  An all-inclusive and centralized data management and analysis system that is a powerful tool to improve yield and machine utilization
- **i2Gi® Software**
  Designed to enable technicians to work smarter, faster and with more control
- *NEW* **Palomar Vision Standardization™**
  Standardizes the vision system across bonding platforms, allowing for seamless transfer of programs between systems
- **Industry 4.0**
  Engineered to enable Industry 4.0 communications
- **No Touch Technology**
  Palomar's no-touch technology does not require the bonder to touch sensitive components with the bare wedge tool to sense the bond pad
- **Service Contract**
  Achieve maximum ROI by adding a service contract complete with preventative maintenance visits
- **Process Control**
  Assign control limits for deformation
- **Process Camera**
  Real-time view of the state of the wire/wedge tool
- **Speed**
  Up to 7 wires per second and up to 10 loops per second
- **Quality Control**
  Real-time bond monitoring and process control software with a robust, low maintenance voicecoil bondhead

TYPICAL APPLICATIONS

- RF-SOE
- Large complex hybrids
- RF and microwave devices
- Fine pitch devices
- Low profile wire bonds
- MCM power connections
- Running stitch interconnects (die-to-die)
- High frequency passive and active components
- Disk drives
- COB
- Compact hybrids
- Fine pitch devices
- Ribbon bonding

PALOMAR TECHNOLOGIES

Making the connected world possible™

Making the connected world possible by delivering a Total Process Solution™ for advanced photonic and microelectronic device assembly processes utilized in today's smart, connected devices. With a focus on flexibility, speed, and accuracy, Palomar's Total Process Solution includes die bonders, wire and wedge bonders, vacuum reflow systems, along with Innovation Centers for outsourced manufacturing and assembly, and Customer Support services, that together deliver improved production quality and yield, reduced assembly times, and rapid ROI.

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