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# The Journey to Full Scale Semiconductor Packaging Manufacturing

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## A comprehensive walk through of the various stages of package development in the semiconductor industry

## Abstract

The journey from concept to full-scale semiconductor packaging is often hindered by a number of different obstacles along the way including everything from diverse teams scattered across the world to simply not understanding how the manufacturing process of die bonding, wire bonding or vacuum reflow impacts the package design and visa versa. In this article the challenges faced from package design and prototyping, through process development and process optimization are presented to ensure the device can indeed be manufactured with the desired throughput and quality.

## Contents

## Introduction

First, the challenges of manufacturing semiconductor packaging that many small, start-up companies may face will be presented. Often, start-up companies or divisions of larger companies may not have a complete team available and might not be aware of how to take their package from design to full-scale production.

Next, the process optimization challenges that are often faced throughout the manufacturing cycle moving from prototype to production will be discussed. The various approaches to optimizing throughput and creating consistency to improve yield will be the focus. These methods will primarily deal with Palomar semiconductor packaging equipment specific details and revolve around material presentation choice, equipment work envelope layout, process step sequencing, and parameter choices. After walking through some of the best practices for each process element, some actual cases of process optimization will be presented.

Last, as a product enters high volume production, continuous improvements are made regardless of how robust or mature the process is. These improvements are driven by process data or from mitigating potential risks that can stem from a variety of factors. Within a stable production, it is often difficult to introduce changes into the process or develop new products or iterations. There is a constant risk of production faults occurring from peripheral influences, such as process personnel. In order to ensure optimal full-scale production of your product, it is imperative to understand the challenges present at this point in the production life cycle.

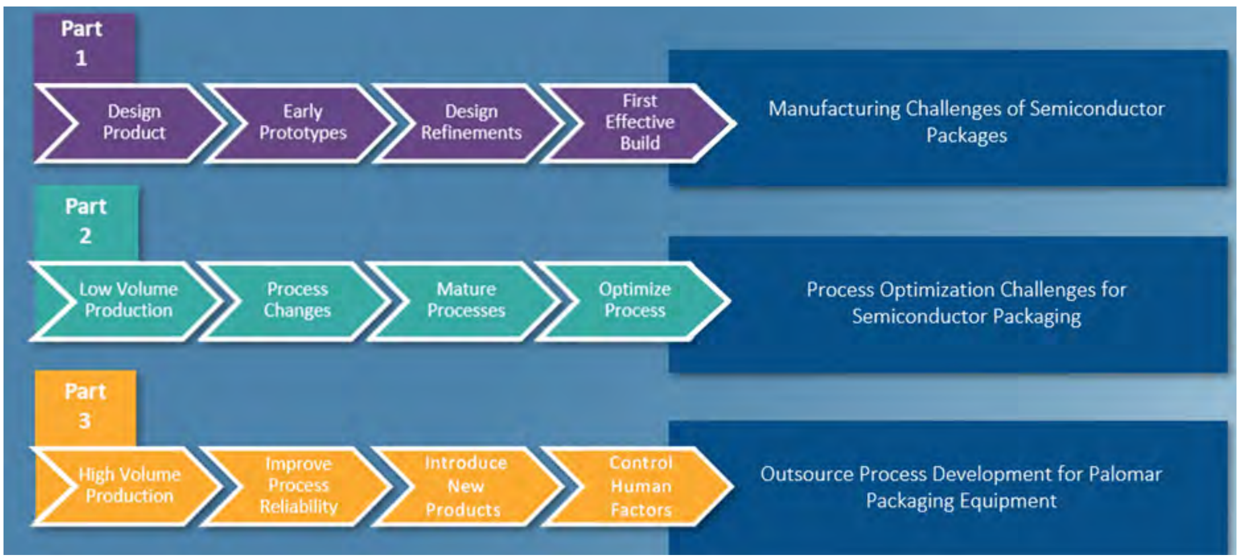



*Figure 1: Overview of the Journey to Full Scale Manufacturing.*

## Part 1 - Manufacturing Challenges of Semiconductor Packaging

It's a sobering reality and not-so-fun-fact: 95% of new products will end up failing at some point or another. The 95% refers to the idea of a product and its first design; so, while it's not stating that all products fail, it is true that there are going to at least be some significant bumps in the road; designs will have to be changed, manufacturing issues will need to be worked through. Something will happen, and nothing will be perfect from the outset.

Another industry fact is that delays will occur and can certainly impact a product launch. In fact, according to Gartner, 45% of the new product launches are delayed in some form. As such, accelerating time to market with the least amount of risk is critical to keeping product launches on-time and ensuring a successful product. Going from the idea, to planning, to selection, to release, as quickly and efficiently as possible is key. Doing this comes down to understanding all of the components of a product release.


*Figure 2: Common process steps during product development.*

Figure 2 is a diagram of the common process for a new semiconductor package. Starting with the definition of requirements, drawings are created, material is procured, and inspected through the proof-of-concept testing and all the way to pilot production and then low volume production. While the diagram may present the idea that this is a simple process with straightforward successive steps, in many cases, the reality couldn't be much further from the truth. The development and release of a new product is often full of repeat steps and parallel efforts; however, that is why Palomar is always committed to providing aid in navigating these complex challenges.

## Early Development Challenges

The biggest misconception is the belief that going from an initial design to a first article build is an easy one step process. Producing that first build; getting it functional; getting it to be exactly what is desired is not straightforward. There are several steps to go through; perhaps there is a need to go through multiple builds. There will be learnings about design issues, which may be material or process based; and the designs may need to be changed or refined to be able to get that first effective build.

It's very important to understand that creating a successful package requires more than one or two build quantities. Several build quantities will be necessary because there is going to be a great deal of learning and discovery about the manufacturability of the package, the materials selection and the process to manufacture. Keeping all this in mind will ensure less wasted time or extra cost. Ordering sufficient build quantities at the outset is advised to prevent waiting through multiple long procurement cycles. To mitigate those risks requires focusing on achieving a minimum viable product.

### Minimum Viable Product

Some key points to keep in mind when discussing a minimum viable product are the following:

Firstly, it is important to ensure that the product is able to be manufactured with the equipment available on the market. Whether that's the equipment that's available everywhere or the equipment that's available for the contract manufacturer or whoever may be building these products; it is important to keep in mind the equipment capabilities. The next thing to consider is the need to create test vehicles for any difficult aspects of the design or any high-risk elements. Doing so will translate into much more efficient use of time. It will also provide more clarity of the results if high-risk elements are separated into separate test vehicles.

Lastly, it is necessary to focus on the practicality of the design. While, at this point in the product lifecycle, it is common to pay attention to certain elements of the design such as the device's purpose, how well does the product perform, or how well does it function in specific use cases; it is also just as important, in this prototyping phase, to focus on the practicality of the design – or simply how easy it is to manufacture and test the design.

### Tolerances

One of the most important and also yet one of the most common issues is the lack of concern paid to design tolerances. Tolerances are something every semiconductor design engineer is familiar with and are definitely at the forefront of many designs, but at this early stage of development, may not be the highest priority. Instead of paying special attention to ensure that the initial builds are set up with proper tolerances and are coming in to a certain degree of quality, it is more common to think that it's just a prototype, so the design just needs to be functional for testing – thereby neglecting important elements that should have tolerancing.

There are actually many hidden nuances to smaller or seemingly less significant tolerances that can heavily impact the ability to test and gain information from a build. For instance, let's take a very simple build with a die on a substrate, attached via eutectic bonding and connected through Au wire bonds. If a certain level of flatness on the ceramic substrate or other material isn't specified then the package can come in with significant bowing or cratering. This can greatly skew testing results that were meant to provide feedback on the design of the chip or selection of solder material, with issues that won't be present in a final design with proper tolerancing.

### Material Selection

Proper material selection means not only making sure the materials coming in are of high-quality but it's also ensuring that the right materials have been chosen. Often, materials such as adhesive or bond pad metallization are the main culprits of the downfalls of early designs.

For adhesives specifically, this is because there a large selection on the market in terms of specialty materials that have a wide variety of characteristics without clear information on how those characteristics may affect the end product. It is very important to understand which characteristics are needed in a material and what specific elements are needed for the design. For example, is an adhesive suited for encapsulation or is it intended for non-conductive attach for structural properties? Questions such as “What are you looking for in your material?”, “What are the industry standards for that material<” and “Why are they the industry-standard?” are great to help guide choices.

There’s a great deal of science behind how the material can affect the final performance of the device or even the ability to bond with those materials; so, paying careful attention to the material types chosen is another very important facet during initial builds. Poor material selection is something that impacts a packaging manufacturing tremendously and delays product launches as a result of not paying attention to all the variables required.

### Fiducials

Fiducials are essentially the instruction book or the guide for complex assembly equipment to follow. Much of the equipment nowadays has very high accuracy and powerful capabilities to operate with extreme precision and repeatability; however, if you don’t give the equipment the proper instructions that it requires to be able to perform to its maximum capability, then it’s not going to be able to reach those really high accuracies or build with the quality that is desired. This is because it doesn’t know where to place components or bonds, or the instructions aren’t nearly legible enough for the bonder to follow.

Ensuring deliberate creation of fiducials in the design is essentially setting clear markers for where the bonder should be bonding, which is extremely important when operating at the micron level. If there’s no clear indication of what that feature on the die is, nor repeatable and robust design of the feature that can guide the bonder reliably, then the accuracy of the bonder will be compromised and will be unable to deliver the highest quality or throughput.

### Tooling and Process Changes

One of the specific elements of the assembly sequence that is often overlooked is the tooling. While it seems simple, as Figure 3 illustrates, changes to design can impact tooling. Package and component placements designs necessitate good control of the part while  bonding, especially when it comes to a wire/wedge bonding. Making sure the substrate is held tightly is paramount to the bonding quality. As a result, not paying attention to what some of these smaller changes affect, may require having to procure new tooling with each package design change. This requires designing the new tooling, paying for it, and waiting for it. All of this impacts the development cycle and efficiency.

Being aware of what design changes may impact is important, so that changes can be intelligently combined to limit the frequency of changes that affect tooling. Optimizing the development process is key, and maintaining efficiency going towards the final product design should always be a primary concern.

The manufacturing process could change as well when changes are made to the package layout, components used, or bonding techniques. The changes to the process could be in the form of having to reprogram equipment or procuring new materials, new adhesives, etc. It is critical to be keenly aware of what these changes may do and what their effects will be.

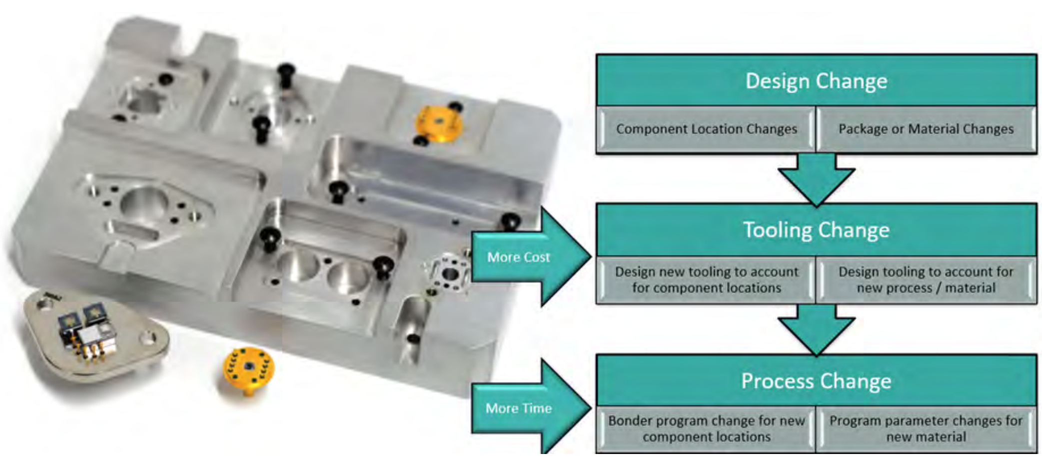



*Figure 3: Tooling and overview of design changes that lead to tooling or process changes.*

### Testing Features

The key takeaway for testing features is making sure that how the package will be tested is considered during the design phase. While it seems trivial, the amount of consideration placed towards how to test the assembly will greatly impact the ability to quickly churn out design turns. If the testing is quick and efficient with very telling and clear results then it is easier to move to the next phase in your development cycle. Thus, the move to the next iteration comes sooner and with more confidence. Optimizing the initial designs for testing is necessary, even if those features may not need to be present in the final design.

### Traceability

Often times in manufacturing, there are some issues that are not controllable, and are simply an inevitability. These will likely be supplier or material issues that occur when procuring the builds. The root cause of these problems are often times difficult to properly identify.

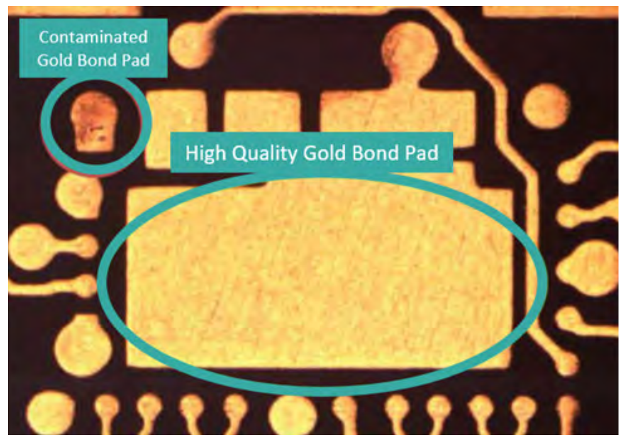



*Figure 4: Contaminated gold bond pad.*

Especially in lower quantities, it's going to be very difficult to differentiate what is a design issue, what is a process issue, and what is a problem caused by the material. That essentially stems from a lack of confidence in the design because of the low build numbers and the lack of clarity on what the performance of the device will be. Questions can arise whether the process technique is at fault or if the design is incorrect, and so on. Often, material issues are overlooked which results in spinning wheels chasing something that is not actually an issue, not making any progress, and focusing on the wrong design element.

One way to really combat this is to create very detailed incoming inspections for the material – put it under a magnifying glass; go through it with a fine-tooth comb; whatever is needed, be very aware of the quality of the incoming material. This can be achieved well by implementing traceability across all of materials: keeping track of which product was built with which lots or batches and connecting that with good record-keeping of the quality of those materials that were delivered. Figure 4 shows an example of a high-quality gold bond pad and a contaminated gold bond pad. Keeping track of the material, lot and supplier can help to create traceability and aide resolving potential future issues with builds that use that material.

When an issue is found during testing downstream, the problem build can be traced to create an understanding of where the issues were first found. This goal of implementing traceability is to reduce wasted time and inefficient use of resources chasing something that isn't an issue.

## Part 1 Case Studies

### Case Studies Introduction

The following case studies highlight where an issue was found in the prototyping phase or initial proof of concept phase and how the issue was solved. The first two case studies review a customer introduced issue or vendor introduced issue and the third case study is an example of how a customer solved a fairly complex application.

### Case Study 1 – Unintended Consequences of a Design Change

- Customer made a design change focusing on altering final assembly functionality but did not pay attention to manufacturability.
- The design change resulted in un-bondable pads.
- All of the prototype materials could not be used to generate builds for testing and validation.

Case Study one offers an overview of an unintended consequence of a design change. The device was a custom MEMs die in an emerging technology field and was at the beginning phase of conceptualization and proof of concept.

The first revision of the device included wire bonding. While the metallization of the part allowed for successful wire bonding, the device itself did not meet the desired performance metrics. The MEMS die was then redesigned to improve performance. However, during the redesign process, changes were made to the die's wire bond pads making them no longer wire bondable.

Figure 5 is an example where the appropriate care was not spent on the wire bond metal stack up, therefore resulting in cratering or bond pad lifting which is seen in the lower part of this image. This cratering/delamination of the bond pad can be caused by combination of poor metallization on the device coupled with the ultrasonic action from the wire bonder.

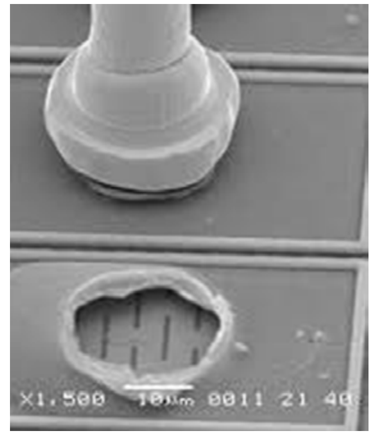


Figure 5: Cratering of a bond pad.

An immediate solution to this problem was to use moly tabs, also called wire bond tabs, as intermediary surfaces to bond on and to overcome some of these issues. Moly tabs are typically used at the board level of a PC board if the surrounding SMT components are over reflowed and the solder migrates to where the wire bonding is to happen. This makes it impossible to bond to industry specifications because it is not possible to wire bond on top of solder.

The Moly tabs were bonded directly on top of the wire bond pad with electrically conductive epoxy. This allowed for the circuit to be maintained, while also providing an ideal surface for the wire bonds to be bonded onto. This provided a short-term solution for the customer to keep testing the functionality of the parts, as well as provided feedback for improvements for the long-term device improvements.


Figure 6: The primary benefits resulting in greater return on investment for this case study.

The benefit to the customer in this case study was that waste was reduced in this phase of the prototyping build, as well as reduced development time because the devices were useable for this prototyping phase.

### Case Study 2 – Identifying the Root Cause

- Severe performance issues were found in several devices of the first batch.
- The initial reaction was to assume fault with the design or build process.

Case Study two pertains to a vendor-introduced issue on sensitive parts. A custom die was attached, cured, and then wire bonded. Because it is a high-power device in which thermal transfer is critical for this device to function, X-ray analysis of the bond line for voids was performed with favorable results. There were some nuances to the die attach and a number of samples were created. However, the devices had a high failure rate during the customer's functional testing.

The first assumption was that the workmanship of the device packaging was low quality.  To determine the root cause of failure, incoming inspection and final inspection reports were reviewed. Additionally, high-resolution images were taken using dimensional equipment and surface features were measured.


*Figure 7: The primary benefits resulting in greater return on investment for this case study.*

These investigations and "forensics" uncovered indications that the devices were received from the device vendor with defects that were difficult to view with standard visual inspection. Failure analysis showed subtle markings on some parts of the wafer used for the assemblies and that the traces were broken. These damaged traces were very thin and fragile and, therefore, any contact with these surfaces was intentionally avoided during device packaging. All of this evidence resulted in tracking the quality incident back to the wafer supplier.

One way to really combat this is to create very detailed incoming inspections for the material – put it under a magnifying glass; go through it with a fine-tooth comb; whatever is needed, be very aware of the quality of the incoming material. This can be achieved well by implementing traceability across all of materials: keeping track of which product was built with which lots or batches and connecting that with good record-keeping of the quality of those materials that were delivered. Figure 4 shows an example of a high-quality gold bond pad and a contaminated gold bond pad. Keeping track of the material, lot and supplier can help to create traceability and aide resolving potential future issues with builds that use that material.

As a result of finding the root cause of the problem, the device was able to be manufactured without defects making for an efficient-use of resources. A longer-term solution included new quality reporting with that vendor and phase two of the product life cycle was able to proceed.

**Case Study 3 – Working with Advanced Test Vehicles**

- Separate high-risk packaging techniques into multiple test vehicle builds.
- Test each of the advanced process elements in separate batches.

Case Study three was a challenging application including high accuracy stacked die placement of eutectic bonds. These stacked layers needed to be placed at fixed heights with good x, y, theta, and z accuracy. It was decided to use a test vehicle to reduce the risk of the challenging aspects of the design concepts without consuming expensive and valuable live devices. There were numerous different high accuracy placement criteria throughout the full assembly. This case study is focusing on only one of those.

The device consisted of vertical stacking of chips that needed to be very accurate from layer to layer in XY rotation and also the real Z height as shown in Figure 8. These devices were also very expensive and in limited supply. Using tests vehicles made it possible to refine the discreet challenges within the full package and process capability without consuming large sums of money.

*Figure 8: Vertical stacking of chips with wire bonds.*

This was achieved by using blank silicon chips that had the same dimensions as the actual chips and had identical fiducials on those silicon chips in the same locations that they would be on the real chips. All the other circuitry was not necessarily important for these test vehicles.


*Figure 9: The primary benefits resulting in greater return on investment for case study three.*

This enabled hundreds of samples to be tested which provided good statistical data which identified additional process capabilities that were needed for the assembly.

Because the Palomar Innovation Center is ideally situated with Palomar Technologies engineering, the missing process capability was on the Palomar technical roadmap and was able to be prioritized and accelerated in development. This led to the implementation of new features enabling the missing process to be deployed on this project with good success. By using this test vehicle approached to test the discrete challenges for their application, it proved very cost-effective.

## Part 2 - Process Optimization Challenges of Semiconductor Packaging

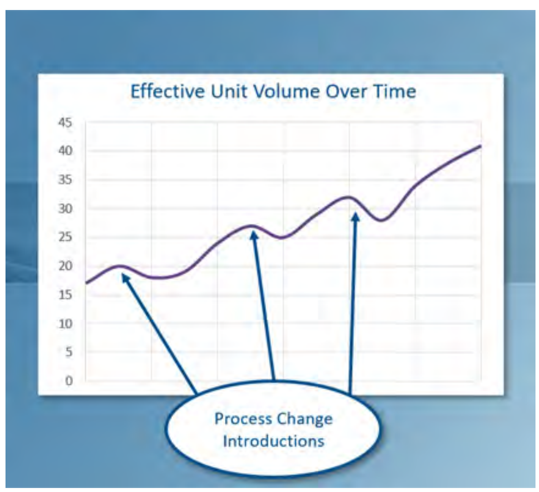



*Figure 10. Simplified effects of process changes.*

### Introduction

In this section, low volume production will be reviewed while focusing on the process changes that are necessary to make to advance towards higher volume. These process changes have a multitude of options and resulting paths, each with their own set of benefits and potential detriments.

Once a semiconductor package has been successfully built and tested at low volume, there will likely be some potential areas of improvement within the manufacturing processes. Making processes changes in light of feedback from early product batches will move the manufacturing towards a mature process but can often result in some negative impact in the short term rather than positive impacts. Anytime a process change is made, there will always be new elements of the process to optimize or re-optimize. This typical pattern is represented in Figure 10. As there are many possible process changes and options for improving throughput or yield, ensuring the best path may be difficult, especially for new and evolving products.

There will always be a cycle of process development where a mature version of the process will help to identify potential areas for improvement – which in turn will necessitate process changes that require optimizations before effective increase in production volume is seen. After the process matures again, new potential improvements will likely be found. This cyclical nature of process optimization is simplified in Figure 11.

This section will present some of the critical elements in a die bonding or wire bonding process that could be changed, along with the pros and cons for each option, to help dictate the best route for each process but also shorten the time to see the positive effects of each process change.

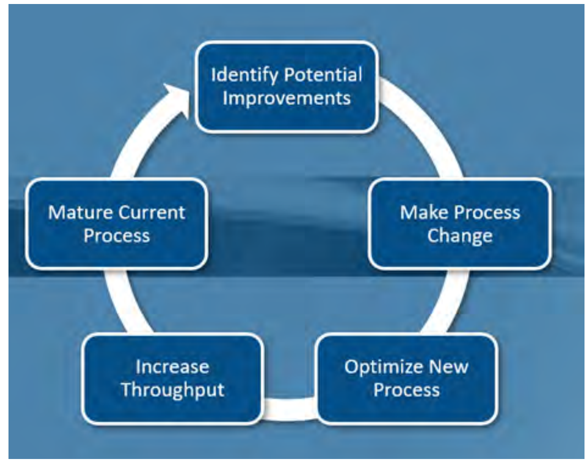



*Figure 11: Simplified process optimization cycle.*

## Process Optimization Challenges

Some of the common process optimization challenges include:

- What is the best form factor for ordering and presenting materials during the bonding process?
- What should the optimal process order be for increasing both throughput and yield?
- What are the best configurations and parameters for wire and die bonders?

None of these major challenges have a single right answer and depend highly on the situation, but there are definitely cases where one approach or answer is more appropriate than another.

### Material Presentation Overview

When trying to improve a process, often looking at the way components are presented can provide ample chances to increase yield or throughput. Although seemingly unimportant whether a component is presented to a die bonder via gel pack or tape and reel, the material packaging can actually greatly affect the overall process performance. Whether its accuracy, quality, cycle time, consistency, or traceability, material presentation has a strong influence on many of the metrics for an assembly sequence. While die bonding has the most options available, wire bonding and vacuum reflow also have some decisions to make regarding how to best present materials for bonding. Figure 12 shows some of the presentation methods covered in this section; including tape and reel, die ejection, custom tooling, and gel pack.

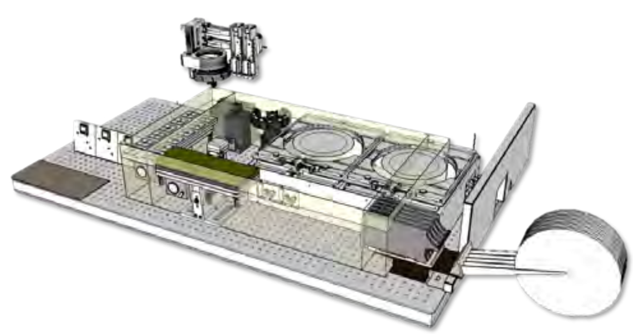


*Figure 12: 3880-II work envelope with multiple presentation options.*

### Material Presentation – Gel and Waffle Packs

In general, waffle and gel packs (Figure 13) are great for low to medium volume production using pre-sorted and organized components. This gives the advantage of being able to build product with binned sets of die based on specific characteristics. Both are also great for shipment and storage of components when necessary.

When accuracy is a prominent concern in the die bonding process, gel packs will outperform waffle packs when both are specified correctly. In fact, gel packs are actually the best presentation method for high accuracy applications that will be highlighted in the following case studies. Using a waffle pack for high accuracy applications is possible but may necessitate an extra step to correct for loss of control during the pick – which either comes from the poor surface planarity and stability of the molded plastic or the close proximity of walls that may contact the component as it is raised out of the pocket.

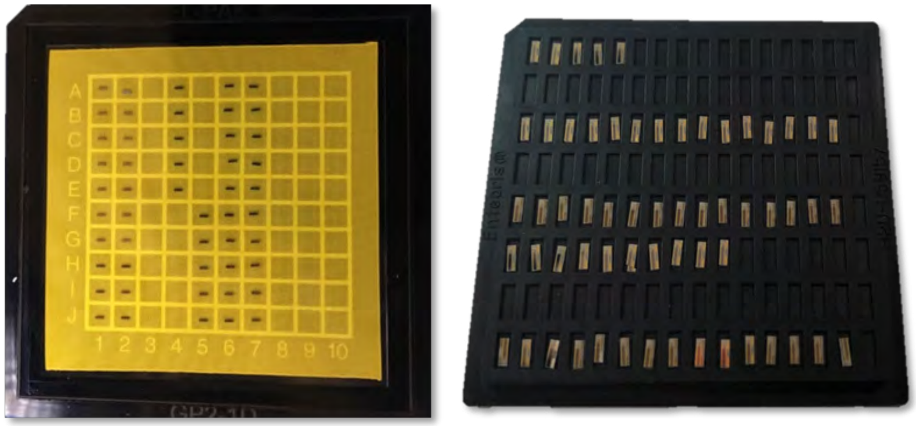



*Figure 13: Gel pack and waffle pack of components.*

Care must be taken when sourcing both gel and waffle packs though, as poor quality or incorrect types of packs can bring further issues. The tack level of the gel pack can greatly affect control of the die when picking from the surface as too much tackiness can twist the component as it releases from the gel. Too little tackiness on the other hand can result in shifting or damaging of the die when the gel pack is handled or moved. Waffle packs with walls that are too high or too low can interfere with access and control during the pick process; and poor-quality waffle packs can be warped which can result in significant issues.

Overall, the ability to present binned, pre-sorted die reliably is a vital asset for maturing processes and can be essential for high accuracy, high volume processes. However, adequate considerations must be given to ensure the final device quality and yield is not affected by poor material presentation method choices.

**Material Presentation - Wafer**

The next method to consider is picking directly from a wafer for the bonding process. In general, this presentation option provides the highest amount of cost savings as the packaging costs for gel packs and waffle packs are not insignificant in large quantities. This can help save on the costs of the material supply or remove the time needed to expand, eject and sort die off the bonder. The bonder can also use the die in the order specified by a wafer map or can be set to ignore die based on inkdots. Both methods allow for full tracking and traceability as each die position in a wafer can be correlated with the other components and package it was bonded into, through the ID tracking system incorporated into the bonder.

There are a large variety of wafer options available, but the focus of this article is the primary three types of tape – standard, UV release, and heat release. Standard tape requires the most "tenting" – which comes from stretching of the tape and needle excursion. UV and heat release have other mechanisms which can result in easier picking but have their own considerations. UV release tape in particular can leave residue on the backside of the die if the correct UV recipe is not used or if the components are left on the wafer to age for too long. This residue can pose issues to bond quality for eutectic applications, result in obstruction or optical disruption in optical devices, and may be volatile enough to be problematic in hermetic packages.

Of course, the UV release and heat release tapes do have the benefit of providing better control during pick as the component does not need to be forcefully peeled from the tape and balanced on a needle point. This is what makes picking directly from a standard wafer less ideal in applications with tight accuracy requirements.
Overall though, when looking at high volume production, picking directly from wafer can be an attractive option due to the cost saving measures and less resource intensive tracking of components.

**Material Presentation - Tape and Reel**

Tape and reel feeders are extremely efficient in terms of machine workspace usage per unique component and total components presented. They offer rapid changeover to other processes and can keep the bonder running longer before components need to be presented again. This positions tape and reel as an ideal option for high volume applications that use common components. The number one downside is that the pockets that these components can be picked from are not optimal for high accuracy picking.

This can be remedied with other steps or different referencing methods, but is definitely a point of consideration as this is the method that poses the greatest risk to the final placement of the component.

Other points to consider are the mounting locations which have to be on one of the three sides of the machine or restricted in other ways due to the presence of specific options. This can pose limitations on cycle time, which we will discuss later in this article.

All in all, this is a fairly simple and straightforward presentation method that can be used for non-critical, common components in a device.

### Material Presentation – Custom Tooling

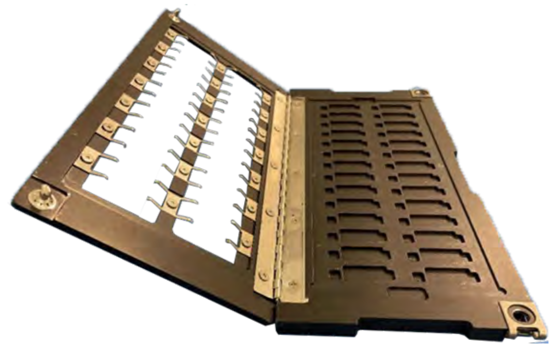


*Figure 14:Custom tooling tray designed to hold components in place for wire bonding.*

Custom tooling as shown in Figure 14 is going to be a necessity for most applications – whether this is tooling that holds packages for die bonding or wire bonding and whether it is made to be stationary on a stage in the work envelope or is designed for use with a conveyor. In each case, the tooling properties and form factor must comply with the package and process requirements. However, what is variable, is the complexity of the tooling. Tooling with features that ease operator interaction and support higher volume production can be extremely beneficial to mature processes. This type of tooling can be referred to as production tooling and is the go to for processes that don't expect significant changes in the short-term. The only downside is that this tooling will be costly, and an alternative tooling with less features may be preferred when the process is still experiencing frequent changes. This prototype tooling can be more agile and quicker to fabricate at lower costs. It is important to note, that while the tooling may not have a direct impact on yield and production volume; it will still affect the ability to adapt to new process changes quickly and effectively.

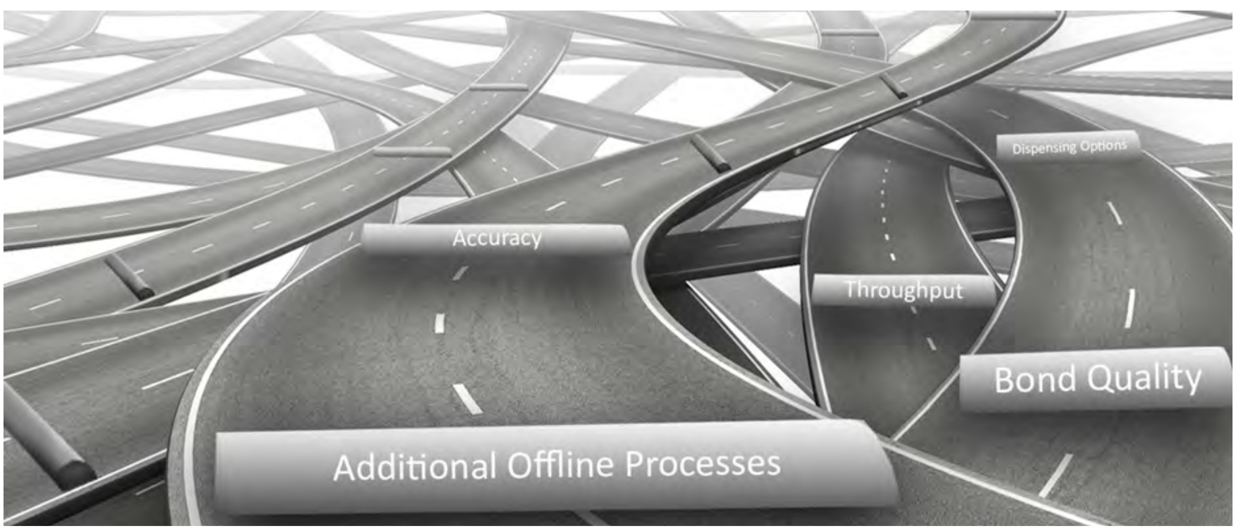



*Figure 15: Various speed bumps that are encountered when looking to optimize processes.*

### Process Order Overview

Now that some of the available options for material presentation, which may see changes as processes mature, have been covered, the actual process and the effects from the order of how the assembly sequence is actually carried out will be reviewed. With complex devices, there can be many process steps and a similarly large number of paths that can be taken to carry out each step. Along each path, setbacks that can affect the process due to the order in which the build is carried out can be encountered.

The process elements that are related to process order are: placement accuracy, throughput, bond quality, potential additional offline processes, and changes to material choices. Any decision on the process order can also affect which pieces of equipment are needed for the process as well.

**Process Order – Epoxy Die Attach**

Looking at epoxy die attach applications as a whole, process order considerations can be arranged into three major categories based on the frequency of depositing epoxy to the surface. Adhesive is either dispensed or daubed onto the package in between each pick and place, in larger groups such as a full package or large section of a device, or deposited on an array of substrates - potentially even the maximum number of packages presented in the work envelope. Figure 16 is a visual representation of these process order approaches.

The third option is obviously the best choice for throughput when it comes to dispensing adhesive. Reducing machine movement and removing the need to engage/disengage the dispenser between pick and places saves time. However, there are some concerns when it comes to longer processes. In the case of very large and complex devices, certain types of adhesive may present quality issues such as excessive bleed out if left on the package for too long. The first option is sometimes better for high accuracy as there are some cases where the fiducial may be covered with adhesive and it may be important to place directly after referencing for optimal placement. This does negatively impact the throughput for dispensing but generally does not affect daubing.


*Figure 16: Three possible approaches to applying adhesive for epoxy die bond applications.*

Daubing in general can be sped up through a process called gang-daubing – which is transferring adhesive with a multi pinned tool. Specialized nozzles for dispense can improve consistency and throughput as well.

Lastly, in UV adhesive applications, there is the option to cure components in situ or flood cure later in the process. Much like the examples for depositing epoxy discussed earlier, there is a balance between accuracy and throughput. Flood curing presents the shortest cycle time, while curing in situ ensures the highest accuracy. The middle of the line approach for UV is to execute a short UV sequence, in situ to tack the component and finish with a mass UV cure later.

**Process Order – Eutectic Die Attach**

For eutectic applications the process order has a much closer relationship to the material and device choice for the process. Some materials naturally lend themselves to multi-component reflow over single component bonding and vice versa. As such, each bonding method will be reviewed and compared with the potential benefits.

When looking for process changes to make that improve throughput, switching to a solder paste may be a good option. Using solder paste allows for depositing the solder material in one continuous step, saving machine movement and reflow time for each component. This does come at the cost to accuracy and having to use flux which can be a detriment to bond quality or just simply not be an option for the end device. It is also possible to screen print the solder paste upstream for even further cycle time reduction.

Preforms are definitely more suited to single component reflow – where the bond quality, consistency and reflow time are all really strong when compared to other single component reflow techniques. Although they can be used in a process which executes a single batch reflow, bond quality becomes a large concern as scrubbing is generally required for void reduction and proper solder distribution when using preforms. However, If the components are small enough, and they are the same thickness and planarity, they can be reflowed together on the bonder while being held down by a gang pick tool. This situation is rare, and it is often better to place the components on top of preforms with an additional substance to tack them before transferring the assembly to a vacuum reflow oven for mass component reflow while maintaining accuracy and bond quality with specifically designed tooling. This approach is more of a middle ground – best of both worlds method that can be fairly quick in terms of throughput and produce decent eutectic bonds; though is still eclipsed in terms of throughput by batch reflow screen printed solder paste attach.

Pre-deposited solder on the back side of a die or on the substrate surface provides extremely high consistency from part to part and removes the need to pick and place a preform or dispense solder. As long as the solder amount is correctly spec'd, the results will be quite favorable in terms of quality.

In the end, component placement requirements and bond thermal conductivity targets will likely dictate the process order and bonding equipment, but should there be flexibility in the design, there are a multitude of paths to take when attaching a component via solder that can greatly affect the end device quality and production volume.

## Process Order – Wire Bonding

In the process order for wire bonding, one of the major concerns is with wedge bonding where the bonding is directional. Executing bonds that are close together and in the same direction will greatly benefit throughput. In addition, referencing the required pads and fiducials all at once before beginning bonding will also benefit throughput.

Other than that, there are just some nuances to combining each of these process orders in more complex packages that have solder attach, epoxy, UV cure, and wire bonds. An example of this is explored in the case study section later.

### Bonder Optimization Overview

In addition to process optimizations related to materials and the processes themselves, the different packaging and assembly equipment configurations can be set up for maximum throughput through nuanced parameters that set the fine balance between speed and control.

### Bonder Optimization – Die Bonders

When optimizing a die bonder, it is important to make sure the source and destination locations for the majority of the pick and places are as close together as possible.

This will greatly limit machine movement and speed up the process considerably. Several seconds per package can be saved on larger modules with many components. As mentioned earlier on, some presentation methods may have limitations in their work envelope mounting locations, such as the die ejector or tape and reel feeder. In general, though, the Palomar 3880-II is extremely flexible in how it can be set up in the workspace.

There are several universal die bonder parameters to look at when attempting to optimize a process, which primarily deal with bond head speeds. The first is the search speed and search height. These parameters dictate how long the bonder spends "looking" for the component in order to pick it up. The search height, also called down tolerance, is how high above the part the die bonder tool stops before slowly moving down to sense touch. Making sure this is as low as possible, but still above the natural variation in heights of the components and presentation method will ensure fast and accurate picks without damaging the die. Search speed simply dictates how quickly the bonder moves down while trying to sense a surface. Both of these parameters should be maximized on the pick but may need to be slowed down on the place when placing into adhesive or in extremely high accuracy applications.

Lift height and lift speed are important parameters to set correctly when picking from either a wafer or gel pack. These parameters cannot be set to their fastest values most of the time, as it is much better to slowly peel off the components then to rip them off at full speed in order to have the best control of the component. This requires finding the optimal value where total control of the die is preserved but speed is maximized.

Transfer speeds can almost always be set to maximum as there should not be any factors affecting the control of the component during movement, unless it is an extremely large and/or heavy part. In this case, speeds may need to be reduced.

Overall, these changes can be performed rapidly on the equipment but may require a large sample size to see their effects on quality and yield. Then it is just a matter of balancing the throughput and yield for the specific packaging assembly situation. There are also plenty more application specific parameters to adjust such as pattern recognition algorithms, reflow profiles, dispense settings, and so on, but those are a little too much in this article.

## Part 2 Case Studies

### Case Studies Introduction
Two case studies from the Palomar Innovation Center will be presented. The first case study focuses on the process order which includes mapping out the processes and reviewing how to reduce process steps, while keeping all of the other process optimization tools in mind. The second of these case studies focuses on optimization through improved attachment methods and parameters that focus on throughput, yield and consistency.

### Case Study 1 – Unintended Consequences of a Design Change


*Figure 17: General layout of the package used in this case study.*

This case study will be focusing on the die attach aspect of this package, but do note that there are a high number of wire bonds on this package as well. Figure 17 shows that this assembly contains a number of different components and multiple levels that are placed into a ceramic package. These are color coded by grouping to help clearly articulate the process order while guiding through the various process maps.

Some of the challenges within in this package are: thermal hierarchy, multiple levels, and different methods of epoxy application. Please also note that these assemblies are processed in tooling plates that presented 100 units at a time

Figure 18 shows a process map where the right side focuses on “bottom up” assembly. This is not possible for this particular application because of the thermal hierarchy. The green eutectic solder subassembly will require temperatures of around 320° C whereas the rest of the components are attached with epoxies that are cured at 150° C, so there is quite a delta in temperatures between these processes. If all of the epoxy components were to be attached and then the eutectic solder attach was performed last by applying the appropriate temperatures through the epoxy joints, reliability issues may be introduced in the epoxy joints, as these are not intended to experience these temperatures. As such, the eutectic solder subassembly will need to be processed in a separate, isolated process and then epoxy attached into the package with all of the upper level components.

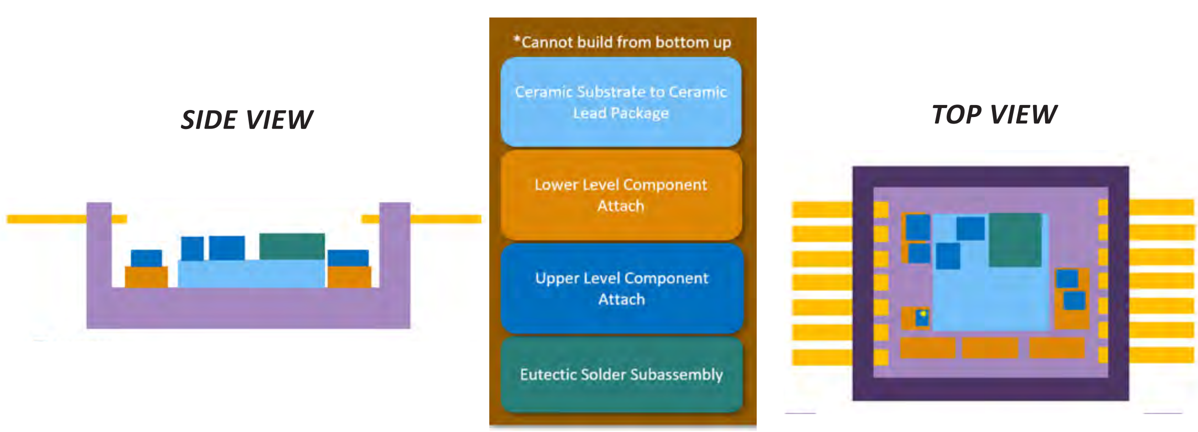



*Figure 18: General layout of the package and initial build process.*

This process map in Figure 19 shows the first process pass developed.

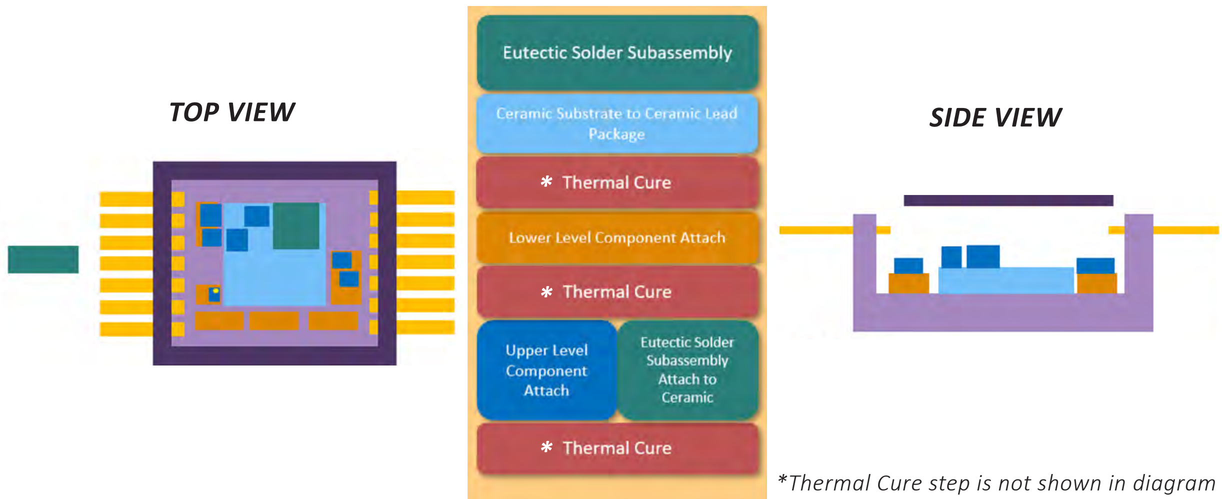



*Figure 19: General layout of the package and both the bonder and offline process structure.*

The eutectic solder subassembly is processed offline in an isolated process and set aside for placement into the package at a later process step. The ceramic substrate is then attached to the ceramic package with a particular epoxy that was specified. This epoxy requires curing with a specific thermal profile in an offline oven. Then the assembly was brought back to the bonder and ran through a dispense and pick and place of the lower level components which used a more traditional epoxy that is cured at 150° C. Then the parts were brought back to the bonder for a final pass where epoxy was dispensed and pick and place was performed for the upper level components and eutectic solder subassembly. Lastly, the assemblies were cured in the convection oven for a final cure.

After establishing the first process map and running production with this approach, the next step to pursue for process order was reducing the number of offline thermal cures and system process setups/total passes. To achieve this, a common epoxy for the ceramic substrate and the lower level components was defined and spec'd out so that the custom thermal profile cure step for the ceramic substrate was reduced to create a single cure for all of the lowest level attachments, which worked well as a solution.

Figure 20 shows the starting process map which included four machines setups and three thermal cures, which was able to be optimized to two machine setups and two thermal cures. This results in less machine setups, less programs to manage, and less offline processing- all while maintaining the same or improved yields.

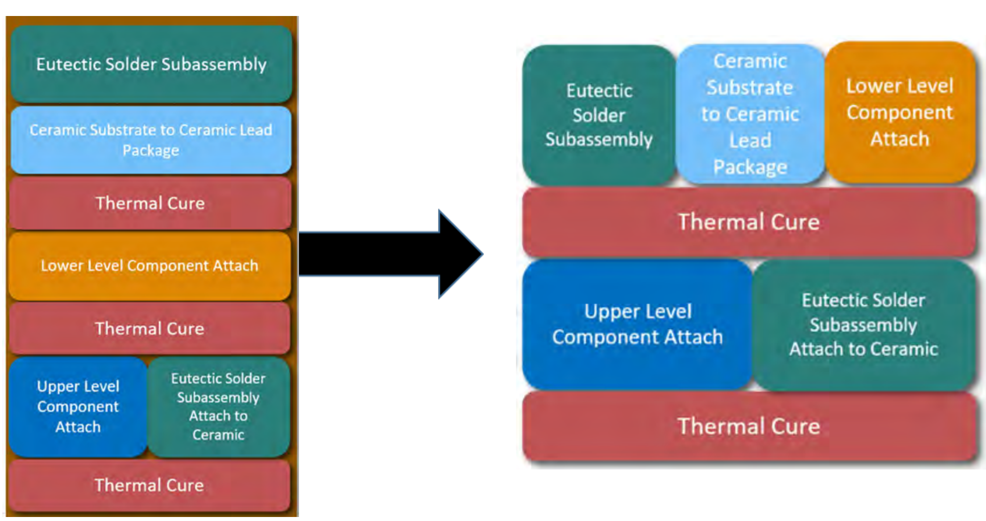



*Figure 20: Evolution from the initial build process to the optimized process.*

These benefits resulting from these process improvements include:

- Increased production volume
- Reduced process steps and operator interactions
- Reduced operation costs
- Robust production processes

**Case Study 2**

For the second case study, a die attach and wire bond process was targeted to make throughput and quality improvements through process methods and parameters for both epoxy die attach and fine wire bond.

In Figure 21, the left image shows a wire bond, which include a large step from the substrate to the die's wire bond pads, and the substrate bond site is close to both the die and the epoxy boundary. Additionally, there is a wall very near the die wire bond pads that reduced the options for wire bond approach and optimization.

In this case study, the throughput for epoxy die attach and wire bond throughput/quality is examined. The items that will not be covered, but were additionally applied are machine setup (proximity of die/substrates on the bonder), life heights/transfer speeds, presentation method (waffle pack), etc. These assemblies were provided as panelized boards with ~50 units per panel.

The first targeted optimization was the epoxy dispense pattern. A serpentine dispense pattern with a single time pressure dispense tip was initially designed. The initial requirements for this epoxy bond line were minimal fillet and low voiding. This pattern helped to achieve these requirements with good yields.

After running hundreds of thousands of parts, the performance and downstream requirements didn't require the tight specifications for the epoxy. The dispense method for both throughput and the new coverage requirements were reviewed and determined that a more traditional "x" pattern was the appropriate dispense pattern for this production.

The benefits of this change meant that the total dispense time for each assembly was decreased by reducing the total machine movement path and increasing the needle diameter and dispense speed to achieve the appropriate volume and coverage of epoxy.

There are additional follow-on optimization approaches for higher volume application, including gang dispensing options.

*Figure 21: General layout of the assembly and wire bonds in this case study.*

The benefit of gang dispensing is the elimination of any horizontal machine motions in x/y directions during dispensing and a reduction in parameters that need to be adjusted. It is a simplified vertical motion only with time and pressure as the inputs.

Two main options for this are seen in Figure 22 below.

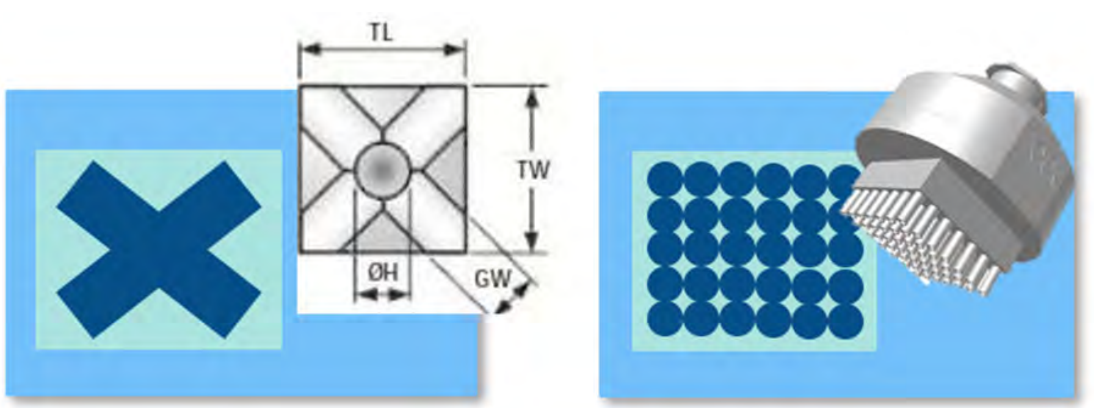



*Figure 22: X Groove dispensing tool (left) and array of circular dispense tips (right).*

The drawbacks to gang dispensing are cost/lead-time, cleaning requirements, design, and lack of flexibility. Lastly, the package needed wire bonding, which included some nuances. There was a fairly large step for wire bonding from the substrate to the die wire bond pad surface. Additionally, there is a wall that is very near the die wire bond pad.


*Figure 23: The improvements made to the wire bonding process.*

While the original production programs were passing quality and reliability standards, the process was slow and resulted in “swaying wires”. The Palomar Technologies software team developed a new loop formation mode for the Palomar 8100 wire bonder which eliminated the wire swaying and increased wire bond speeds significantly (by about 2x).

By optimizing both the die attach and wire bond process a total of 7.5 seconds per part was saved in the production cycle greatly increasing throughput. Over tens of thousands of parts per week, the resulted in a huge throughput improvement.

The benefits of this process improvement included:

- ROI though increased throughput
- Reduced quality incidents
- Simplified process complexity

## Part 3 – Continual Improvement for High Volume Production

### Introduction

As a product enters high volume production, there will always be improvements that can be made regardless of how robust or mature the process is. These improvements can be driven by process data or come from the need to mitigate potential risks to production that can stem from a variety of factors. When trying to maintain stable production it is often difficult to introduce changes into the process or work on developing new products or iterations.

There is also the constant risk of production faults occurring from peripheral influences such as process personnel. In order to ensure optimal full-scale production of your product it is imperative to understand the challenges present at this point in the production life cycle. In this conclusion to the journey to full scale semiconductor packaging, these common challenges and what the potential solutions are for each will be covered.

- How to mitigate risk when implementing changes into mature process
- How to efficiently bring the next revision or new product into production while effectively maintaining the current process volume
- How to reduce the potential for process disruption from personnel involved in production

Some of the major challenges that can result in disrupting mature processes can be split into the following three categories:

- Minor, or incremental changes to an active production process
- Introduction of next generation or new products into production alongside the current or legacy assemblies
- The human element or training and familiarity of process personnel

The techniques or best practices for mitigating the risks from each of these potential sources of disruption in the following section will be presented.

## Navigating Small or Incremental Changes

While it may seem insignificant at first, many small or incremental changes implemented into a production process can have ripple effects that can cause problems and disruptions to production if left unchecked. The question then is how to mitigate the risks of making changes.

### Clearly Identify Where and When a Change is Needed

When making incremental improvements to a long-standing production process, the first step is to gather enough data and information to clearly identify where an improvement is needed and calculate a quantifiable goal for the change in a mature process. Within depth process monitoring and data collection tools on your machines, along with clear statistics of product failure sources throughout the entire process, an accurate picture of the state of your production can be detailed.

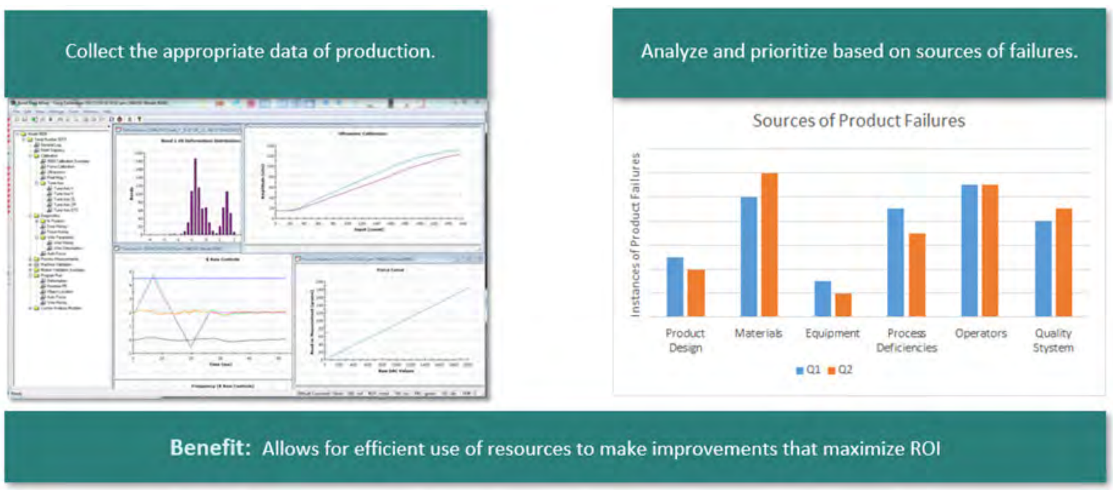



*Figure 24: Core requirements to ensure efficient use of resources when looking to make improvements that maximize ROI.*

Figure 24 shows some of the charts available on any Palomar bonder that can aid in this analysis. The next step entails isolating potential areas of improvement and drawing up a precise plan of action with an outline of potential side effects and an understanding of what to achieve with the plan. While following this may be straightforward and an obvious path to take, it is also important to note that the method of implementation is just as important as the planning.

### Isolated and Controlled Environment

An isolated and controlled environment is paramount to success when considering a process change to an active production process. The first element of such an environment is the separation of production and process development. While this doesn't need to take the form of a completely different system – e.g. a separate bonder for R&D than for production – it does simplify things.

Regardless, it is important to ensure the material used for production, and development or validation of the potential process change are tracked or kept separate. In addition, clear differentiation of the process procedures or programs is ideal. Since the development and validation of a process change will likely involve both iteration and a significant amount of production to completely verify its effects, keeping processes, materials, and equipment as isolated as possible will reduce confusion amongst process personnel and reduce the risk of affecting the actual production.

The isolated environment to develop and test the process change should be as flexible as possible. If this machine also runs production when not sampling new process changes, then it is especially important that time is not wasted with changeover when iterating on the approach to the process improvement. Even if it is a dedicated resource for R&D, it still needs to be as efficient as possible.

This means having all the capabilities on hand and ready to utilize greatly expedites any kind of separate process development; leading to faster implementation of the enhancement to production and the next process change validation.

The risk for error can be greatly reduced by keeping the environment as constant as possible; switching materials, devices, or other equipment in and out doesn't just take time but can introduce outside factors that can skew process testing results. The environment and machine must be easy to program and be reliable in terms of performance repeatability.

Lastly, it is important to both vet the change and implement it in a carefully controlled and comprehensively monitored setting. Ensuring the data received during development is complete and reliable is key to having the confidence in deploying a new process that will be beneficial to production.

Being able to correlate this data with performance metrics and process tracking when it is introduced into production is another plus. This data can take the form of process images, component tracking, assembly quality metrics, and precise measurements of end devices with offline metrology.

As mentioned, the isolated and controlled environment can be a separate piece of assembly equipment or a production machine that is reserved for development outside of production – which does introduce some added difficulties. However, by far the easiest path to take is to move development to a completely separate and much more tightly regulated and controlled environment such as a separate facility to do the process development and validation.


*Figure 25: Innovation Center in Carlsbad, CA with ideal qualities for testing process improvements.*

Palomar's innovation Center in Carlsbad, California in the US is such a place; equipped with flexible R&D assembly machines and staffed with experts in both the operation of these systems and the know-how of semiconductor manufacturing industry standards – it is the perfect place to vet process changes for optimal results without risking the current production. This is especially true if the equipment used for production is the same as the equipment in the Innovation Center; however even if the process is manual or uses another equipment supplier, as long as the process is within the capabilities of the Innovation Center systems, then relevant data and feedback can be gained with low volume production for new processes or designs. The production revenue is preserved while receiving detailed process data and results for any potential process improvement ideas.

### Challenges with New Product or Next Generations

This next section shares quite a few similarities to what was discussed about mitigating risks when introducing process changes into mature processes, but the key difference is that new products or next generation products are much large in scope and risk.

Sometimes these introductions are driven out of necessity and others from a potential for a larger return on investment; regardless, these situations will be encountered and it is important to cover the nuances that come with trying to reduce the possible detriments when bringing new products into production

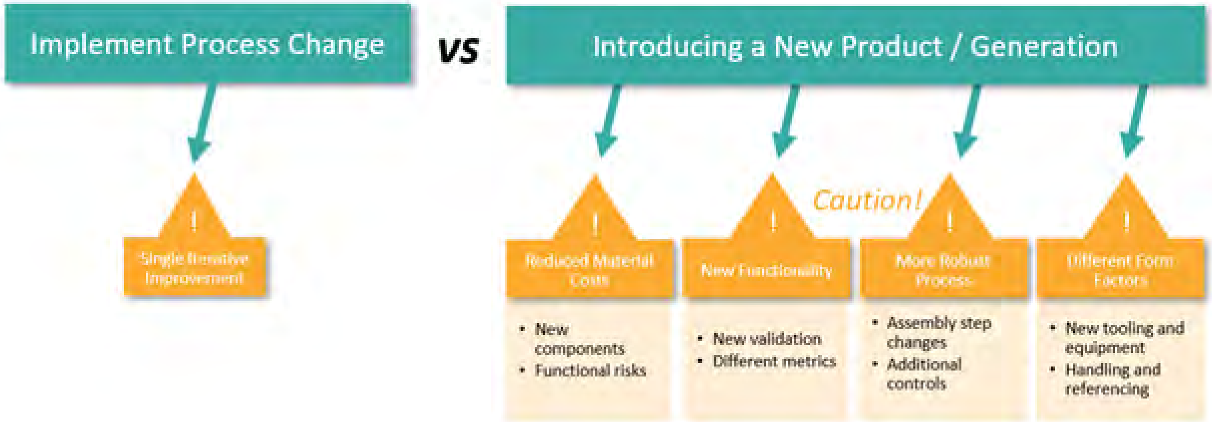



*Figure 26: Comparison of single process changes to new products or next generations.*

### Larger Scope and Bigger Goals

As mentioned, the most significant difference when looking at new products, is their larger scope and the greater amount of changes that come along with them. With more elements to be aware of instead of just a single iterative improvement more risk is introduced into bringing new products into production alongside current generation assemblies. Generally, these next generation devices target new functionality which can bring new validation methods or alternate metrics to focus on as shown in Figure 26.

There are likely new components in use either to support the new functionality, better performance, or as a means of cost reduction which adds more risks to device quality as well as to potentially introduce assembly program changes or different process equipment. The form factor of the package may also differ which can necessitate new handling equipment and tooling or different referencing techniques for automated assembly. Finally, it's likely that the introduction of a next generation product will be the best time to introduce any new assembly process changes that came from learning during the previous iteration which can extend the development time and grow the scope of validation process.

### More Risks and More Difficulty

Overall, new or next generation products are going to equate to more risks and more difficulty with implementation alongside maintaining current production. The key issue stems from trying to balance the usual challenges of full-scale production with trying to setup assembly equipment to run a brand-new process alongside the current production either temporarily or for the foreseeable future. With the end goal of running a new robust process on the same equipment used to generate revenue, it greatly raises the stakes. As such, making sure this is done right – with the lowest chance of interrupting production or introducing a process that can negatively affect assembly quality and volume, is quite important.

To accomplish this, it is critical to use a controlled and isolated environment to test drive this new product process; one that is strongly separated from production, that is flexible and has tools for effective process development, and one that can deliver comprehensive process data that comes from a controlled and monitored production environment. This is vital to reducing the larger risks seen with introducing new products alongside current production.

## Controlling the Human Element

One thing that can greatly affect process quality and volume is the human element. Especially when considering robust and mature processes, one of the few things that can hamper results is the unpredictability of personnel responsible for running the process. Assembly equipment can reach astounding levels of automation and process control, but at some point, direct human intervention will become necessary, which is why it is important to control it as much as possible.

### More Than Just Equipment

This method for control is actually quite simple; it generally just boils down to education or training. Informed and experienced personnel will be much more beneficial than detrimental to the production environment.

The difficulty lies in that the personnel need to be familiar with more than just knowing how to operate the process equipment.

Training extends to topics outside of machine operation such as common quality metrics like voiding, epoxy coverage for die attach, or shear and pull strength for wire bonding. Becoming familiar with common signs of failure such as bridging, shorting, non-sticks and so on can greatly enhance an operator's ability to respond to unexpected situations. Obviously understanding the process flow will also greatly benefit the overall efficiency of production outside of just pure system throughput.

*Figure 27: An operator in front of the 3880-II Die Bonder*

While gaining familiarity with industry standard epoxies, solders and material metallizations can lead to shorter development cycles, knowing best practices for specific equipment and processes can also benefit process maintenance. Finally, having an idea of the options available for process control and how to best gather quality data is indispensable as well.

### Putting it Into Practice

Usually, this experience and knowledge can just come with time, but there are certainly challenges that inhibit process personnel growing by themselves. High turnover rates and hiring of those new to the industry can certainly make the idea of letting them learn over time unfeasible. As such, having an environment where the workers can be surrounded by experienced individuals who can offer information and advice on their actual product is extremely beneficial to efficient learning.

At the Palomar Innovation Center customers validate and optimize their process changes and next generation products but also educate their staff members simultaneously. Ensuring the implementation of a robust process change while also providing experience that leads to increased production efficiency is invaluable. Having process personnel who not only are not a variable in production but who also aid in identifying the next potential improvement is not something to be underestimated when looking at fully optimized assembly processes and hoping for continual improvement.

## Part 3 Case Studies

The first of these two case studies focus on process order where the processes are mapped and viewed to reduce process steps, while keeping all of the other process optimization tools in mind. The second of these case studies focuses on optimization through improved attachment methods and parameters that focus on throughput, yield and consistency.

### Case Study 1

The challenges of this high-mix process were:

- Dealing with an array of different product form factors, processes, and component types
- Maximizing machine utilization
- Quickly training the workforce to be effective in production

One of the key challenges of a high mix production is being able to handle numerous form factors of parts and the ability to perform various process steps that apply to these types of packages.

Figure 28 shows an example a typical high mix range of products needed to run through a single production line.

- Panelized PCBs
- TO Cans
- Ceramic RF Packages
- Flip Chip Bonding
- Singulated Silicon Die
- Discrete Component attach onto 8" Wafer

This challenge was met by utilizing the large work area and customizability of the work envelope of the Palomar 3880 die bonder to incorporate various technologies to meet all of these needs in a single machine configuration.


*Figure 28: The various range of products in a high mix environment.*

Another challenge with high mix productions is handling common components and processes across multiple programs and assemblies. As you can see in this matrix in Figure 29, each component is used in at least two assemblies. Managing and standardizing references, pick and place, dispense, and wire bond parameters for each component is essential for quality and process control in a high mix setting.

| | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 | Component 7 | Component 8 | Component 9 | Component 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Assembly 1 | X | | X | X | | | X | X | | |
| Assembly 2 | | X | X | | X | | X | | X | X |
| Assembly 3 | | X | | X | | X | | | | |
| Assembly 4 | X | | | | | X | X | X | X | X |
| Assembly 5 | | X | X | | | | | | | X |
| Assembly 6 | X | X | | X | X | | X | X | | |

*Figure 29: The common components across multiple assemblies in this case study.*

Managing the challenge of common components was primarily accomplished with the die bonder software. The software has the capability to transfer parts, dispense patt¬¬erns, and parameters across programs to reduce unnecessary/redundant programming time and program to program variation – as well as minimize user-to-user variation in programming.

Identification schemes transfer from bonder to bonder as well – barcode, QR, Optical character recognition, manual, etc. This ensures that each component's traceability scheme is maintained and consistent across the entire suite of packages it is being used in. The Palomar die bonders also have the ability to store images of each reference to create a quality record for each component that was picked and placed. This is particularly helpful when tracking down lot-based quality issues.

A third challenge faced due to the large number of different components and attachment methods is the need for various epoxy application methods, custom pick tools, and "utility" stages. This included:

- 28 tools
- 6 different types of epoxy
- 4 different custom dispense tips
- 8 presentation stages

This can certainly present a challenge with process changeover – necessitating hardware changes for pick tools, stages, and epoxy dispense hardware – adding hours of machine downtime and potential setup variation between each run.

Another hardware solution that helps to meet this challenge is a triple dispense bracket capability which can be outfitted with various dispense technologies; such as time pressure, auger, or jetting.

Additionally, new and improved epoxy daub pots allow for quick changeover between epoxies, highly accurate epoxy depth setup, and ease of cleaning. The use of generic stages with customized tooling plates allows for numerous and highly varied form factors to be run without the need to add or remove any stages between processes.

Lastly, a new high force hardware improvement is available on the Palomar die attach systems. This gives the flexibility to run both traditional die attach processes that require lower forces, as well as those that require higher force such as flip-chip thermocompression, all on the same system. This new hardware option also allows for large/oversized pick tools for picking and placing much larger components that require tool sizes of 2-3 inches.

A fourth challenge for high mix production is that a particular part number that has the same performance characteristics may show up in various form factors and with different art/layout on the top surface. This becomes much more pronounced as global supply chains are strained. In Figure 30, an example of a part number that had three die layouts – each layout having the same performance characteristics, but with different lengths, widths, and bond pad locations is shown.

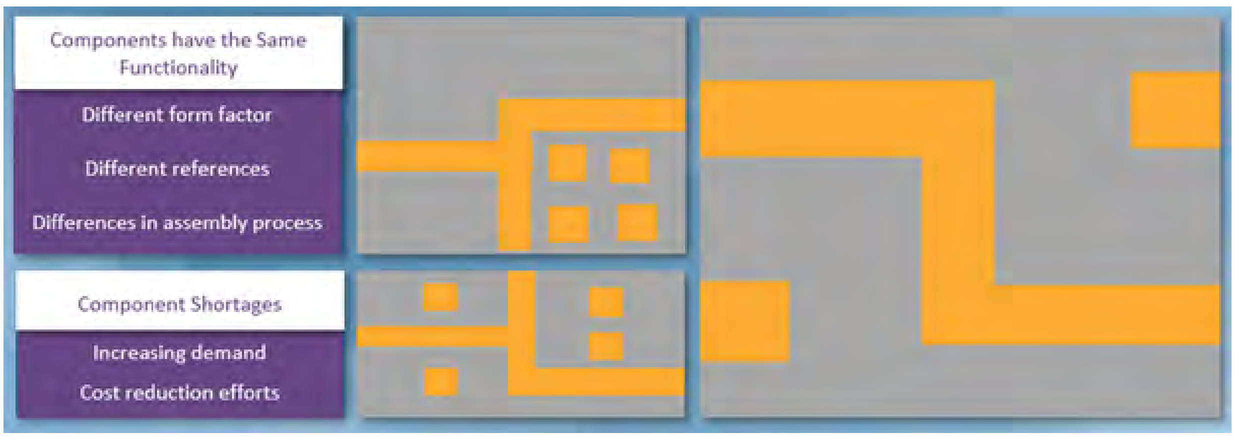



*Figure 30: Difference between alternate parts with the same performance characteristics*

The challenge of these alternate parts was managed and handled through software capabilities which allow for the programs to identify and recognize different part geometries and wire bond pad locations for alternate parts within the assembly.

Once programmed, the bonder will look for the first part iteration, then if it fails to find that first iteration, will move down a chain of part iterations until the correct part layout is identified. The program then knows where each wire should be connected for the layout that it identified. This reduces the need for managing various revisions of a program to accommodate all component iterations. Doing this type of management for a handful of assemblies is painful, yet manageable. However, in this case, there were over 100 unique assemblies running through the same line. This can certainly lead to "line down" situations to accommodate these variations unless the equipment has this capability built in.

Manufacturers face many challenges regarding the workforce when bringing new equipment and processes on line at their facilities, whether they are new employees with a bachelors or a master degree, to operators or technicians. One of the main challenges faced with these employees that were completely new to the industry, but certainly had the aptitude, was getting them up to speed not only on the new equipment, but also the processes on this equipment, including the ancillary process steps necessary for successful production.

Another challenge that manufacturers regularly face regarding employees is turnover and how to manage that on complex niche equipment and processes. This can be mitigated with training on the equipment including general equipment training - basic operator and programming training.

Once employees were familiar with the equipment and general operation, they shadowed staff within the Palomar Innovation Center who were doing the process development. This enabled new employees to see and learn best practices for programming and process development, as well as learn which checkpoints were needed for this process.

At the end of process development within the Innovation Center, a small volume run was completed to enable maturing of the process.

Then, the programs were transferred to the equipment on the final productions site and small volume qualification runs were performed to prove the process. This allowed for the employees to be involved and gain hands-on experience which ultimately led to a high degree of competency and self-reliance.

During the process, the Palomar Innovation Center provided “design for manufacturing” advice and helped to automate the manufacturing of the products to achieve high yield and avoid unnecessary challenges in production.

These collaborative efforts delivered the following benefits:

- Increased production volumes by minimizing downtime between processes
- Reduced quality incidents through thorough employee bring up
- Perform rapid process development and transition into production

**Case Study 2**

The second case study is at the opposite end of the production spectrum – high-volume, low-mix. In this scenario, one package type had very slight variations between iterations. These variations all followed the same process flow and attach method and material. In this case study, the processes were matured on 48+ Palomar die attach systems and recently experienced more demand surge. The challenge was to squeeze out more production volume while concurrently bringing up the next generation products.

The first challenge was how to balance next generation device prototyping vs production output. All of the die go through die ejection from wafer tape. However, these new devices were much thinner and therefore more brittle. This presents challenges when performing high speed wafer die ejection. Additionally, any time spent on these new devices or die ejection developments would interfere and negate production output.

Using sample parts, the Palomar Innovation Center performed development and testing for a variety of wafer die ejection hardware options and methods to produce a robust, controlled, and high-speed solution, which were analyzed. This allowed for full vetting of the hardware and process changes on both existing and next generation products prior to purchase and install on the equipment – all without production interruptions on current products.

The second challenge was to increase the output for mature production. The product has experienced an unexpected surge in demand and it was critical to find any possible throughput improvement. This means millisecond improvements of various aspects of the production process, which will translate into increased output over hundreds of thousands of assemblies.

Note that these are highly stable and optimized productions that have been running around the clock for years. Machine layouts, attach materials, and part design are optimized or fully qualified at this point of the intervention. Any process changes will need to be fully vetted and qualified before making their way into the production line. Prior to making any changes, data was gathered from the equipment that gave insight into each process step. Then this data was analyzed for where and how to reduce time in the process.

Recommendations, which ranged from minor parameter changes to software-level changes were made. All of these changes were vetted at Palomar and results were shared with the customer. A Palomar engineer implemented these process changes on the existing Palomar die bonders.

During this engagement with Palomar, production levels were maintained while working to both:

- Increasing capabilities to support an expanded product line
- Add production capacity without adding additional capital equipment

## Conclusion

In the journey from prototype to full-scale semiconductor packaging manufacturing, there are many challenges that will occur. These impediments range from not being aware of how to take their package from design to full-scale production, to how to optimize the manufacturing processes throughout the production cycle in order to efficiently ramp up from prototype to full-scale production.

Process improvements can vary and include everything from material presentation choice, equipment work envelope layout, process step sequencing, and machine parameters.  As a product enters high volume production, continuous improvements be continually made regardless of how robust or mature the process is. These improvements are driven by process data or from mitigating potential risks that can stem from a variety of manufacturing factors.

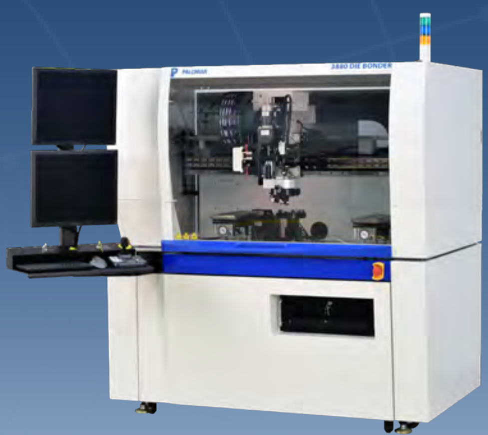
And once the production is ramped, up to a stable production, it is often difficult to introduce changes into the process or develop new products or iterations. There is a constant risk of production faults occurring from peripheral influences, such as process personnel. In order to ensure optimal full-scale production of your product, it is imperative to understand the challenges present at this point in the production life cycle.

While the journey to full scale manufacturing may be difficult and full of challenges, Palomar is committed to providing as much support as possible for each step along the way. Whether it is providing support and guidance during early development and design of a device, or as a specialty OSAT for low volume manufacturing to safely test new products separately from full scale production; the Palomar Innovation center is the ideal resource. While the challenges on the road of product development should not be underestimated, it should be noted that there is always a way forward; armed with sufficient knowledge and experience, traversing those challenges will be much easier.

# PALOMAR® TECHNOLOGIES

## Palomar Die Bonders

Flexible, high speed and accuracy, die attach with easily scalable levels of automation and process control.



## Palomar Wire and Wedge Bonders

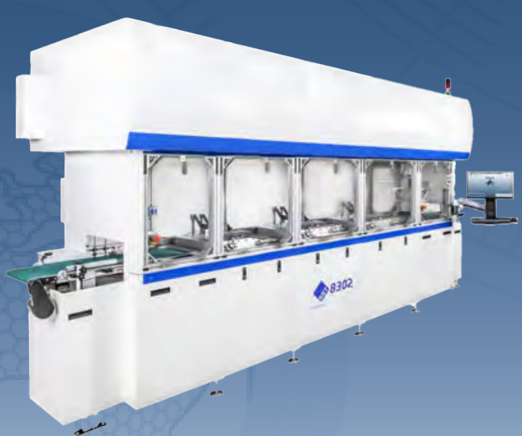
High speed, robust interconnections with capability for ball-and-stitch, ball bumping, wedge and ribbon bonding.


## Innovation Centers

Rapid new product prototyping and process development to deliver rapid ROI for new product introductions.

## SST Vacuum Reflow Systems

Unique combination of vacuum, pressure and heat to create highly reliable, void-free solder.

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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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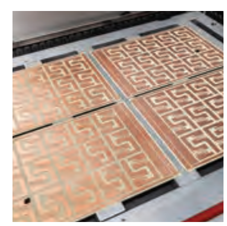

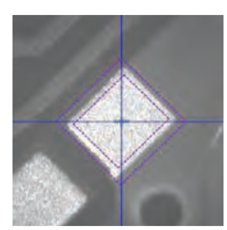

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