

Micron Level Placement Accuracy for Wafer Scale Packaging of P-Side Down Lasers in Optoelectronic Products

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Abstract

Applications requiring ultra high placement accuracies of $\pm 1\mu\text{m}$ to $\pm 3\mu\text{m}$ are resurfacing in several optoelectronic applications such as Arrayed Laser Print Head and Multi-Channel Optical Communication products. Some of the higher performance optical communication products rely on P-side down laser attachment. This paper reviews measurement, materials, and processes required to successfully achieve $\pm 3\mu\text{m}$ accuracies for P-Side down laser attachment at wafer level for Chip to Wafer (C2W) or Die to Wafer (D2W) eutectic solder attachment.

Key words: LED, Laser, P-Side Down Laser, Eutectic Attach, AuSn, Wafer Scale, D2W, C2W

Background

P-side down laser attachment using gold-tin (AuSn) eutectic solder is a mature process used extensively for long haul and metro distance laser transmission modules [3]. The P-side down laser has traditionally been assembled using singulated heat spreaders with a pulsed heat *in situ* reflow stage where each eutectic assembly is built in the same XY location on the machine tool. This allows for optimization of placement accuracy and attachment quality at a given XY location.

Continued work in P-side down laser attachment has expanded the technology to Wafer Scale. This technology shifts away from singulated submounts to bonding lasers directly on a wafer matrix of submounts. Laser assembly design considerations for light output, component heat flow, power limits, and reliability are significantly affected by specific geometry, materials, and interconnect processes. This paper focuses on the pick-and-place alignment and attachment process and results of Wafer Scale P-side down eutectic laser attach. Substrate time at temperature and aging effects on solder reflow are summarized from prior work. Measurement methods for P-side down laser attachment provide some challenges during process development. A review of guidelines and results will also be shared.

High Accuracy Die Attach Requirements and Challenges

The application breakout given in Table 1 is useful to explore general application, attachment, and accuracy requirements for ultra high accuracy die attach. The main breakout is by application product or technology. This paper will focus on P-Side down laser eutectic attachment.

Table 1 – High Accuracy Application Overview

Case	Attach	Accuracy
P-Side Down Laser	Eutectic	$\pm 3\text{-}5\mu\text{m}$
VCSEL Array	Epoxy	$\pm 3\text{-}5\mu\text{m}$
LED Laser Print Head	Epoxy	$\pm 2\text{-}5\mu\text{m}$
Lithography/Screen Interconnect	Epoxy	$\pm 3\text{-}5\mu\text{m}$
Thru Via Die Stacking	Misc.	$\pm 3\text{-}5\mu\text{m}$
3D MEMS Stacking	Epoxy	$\pm 5\text{-}10\mu\text{m}$

Terms and Definitions

Pick and place is composed of geometric accuracy and interconnect method. To completely define placement accuracy would require specifying all six (6) degrees of freedom, as shown in Figure 1.

Most pick and place accuracy applications specify Z as a bond line and placement accuracy as X error, Y error, and Theta-Z error.

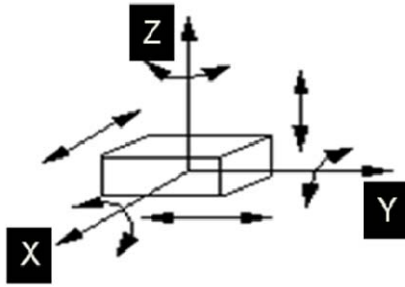


Figure 1 – Geometric Six Degrees of Freedom

This paper will focus on AuSn eutectic metallurgical attachment as opposed to epoxy based attachment. Eutectic solder attachment is an in-situ (serial) process and is completed during the placement operation for each laser. The laser is held in alignment position using a programmed Z force during the ramp-up, reflow and cool-down process. This requires a machine tool that can go through the temperature extremes required for eutectic solder attach while still holding tight placement accuracies in X, Y, and Theta-Z.

Material and Process Considerations

When approaching micron level placement accuracies, there are several important factors that need careful management and control:

- Substrate flatness, cleanliness, and fiducial clarity (particularly in case of edge alignment)
- Die flatness, cleanliness, and fiducial clarity
- Attach material uniformity, symmetrical and flat, e.g., pre-deposited solder

Measurement Considerations

Measuring the actual placement accuracy down to 1-3 μ m requires both well characterized measurement equipment and measurement methods [1]. Even if the equipment can support the resolution, the bonded samples usually have imperfections beyond the targeted accuracy requirements. Measurement methods must include ways to handle these imperfections and still yield acceptable gage capability. P-Side down laser attachment has the added complexity of critical alignment features that are no longer visible after attachment.

P-Side Down Laser Placement Requirements

The placement requirements are based on positioning the laser for optimal optical coupling of the laser optical output to transmission optics as shown in Figure 2. The substrate (grey) contains

alignment features to which the laser (yellow) is placed. The laser's (yellow) critical P-Side features for alignment include the laser stripe and the laser front edge facet where the laser light (red) exits the laser.

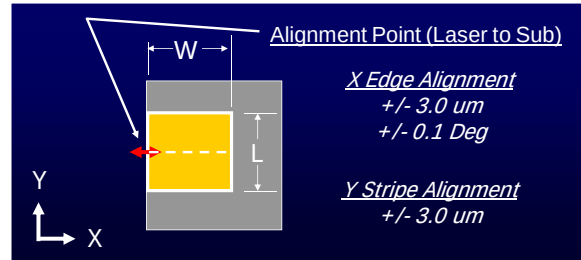


Figure 2 – P-Side Down Laser Alignment to Substrate Requirements

The laser also has N-Side features which can be used for production level measurement of alignment and attachment accuracy since they are visible after laser attachment. However, known shifts between P-Side and N-Side lithography will make N-Side measures only an indirect measurement for Y alignment. Facet edge cut or cleave angle may affect the N-Side measure for X edge alignment as shown in Table 2.

Table 2 – Tolerances for P-Side (Align) and N-Side (Measure)

Measure	P-side	N-side
X Edge Alignment	$\pm 3\mu\text{m}$	$\pm 3\mu\text{m}$
X Edge Angle	$\pm 0.1\text{deg}$	$\pm 0.1\text{deg}$
Y Stripe Alignment	$\pm 3\mu\text{m}$	$\pm 4.5\mu\text{m}$

Wafer Scale – Eutectic Die to Wafer P-Side Down Laser Attach (Single to Wafer Level Transition)

The physical samples in this paper include a 6" wafer with a matrix of substrate devices upon which the laser will be solder attached. The wafer substrate has fiducials for each laser place site with alignment targets and gold pads pre metalized with AuSn eutectic solder. The laser is 300 μ m long by 250 μ m wide by 125 μ m thick with backside (P-Side) plated gold pads for solder attach. The N-Side also has lithographic features for post placement measurements. However, there is some degree of XY misalignment between the P-side and N-side lithographic images which have been characterized as shown in Table 2. The P-Side of the laser provides alignment features that are a combination of fiducials and the stripe alignment point intersection with the facet edge as shown in Figure 2. The P-Side laser features are referenced during the alignment phase using an upward looking camera.

Once the references are found, a laser alignment algorithm is applied to determine the final placement location on the specific wafer substrate site.

Figure 3 shows a close-up view of the Palomar Technologies Model 6500-WSP with a 6" wafer steady state heated stage, pulsed heat pick tool, and lookup camera with alignment algorithm that was used for execution of this work.



Figure 3 – Steady State Heat Wafer Stage and Pulsed Heat Pick Tool Optimized for Laser Diode Eutectic Solder Attach

The pulsed heat tool is controlled through a temperature profile as shown in Figure 4. This is not the profile used for the study but it shows a representative shape. While holding the laser in place on the heated wafer, the tool's temperature ramps from a background temperature to the reflow temperature, holds the reflow temperature during the reflow time, and then cools down to the background temperature by means of forced cooling.

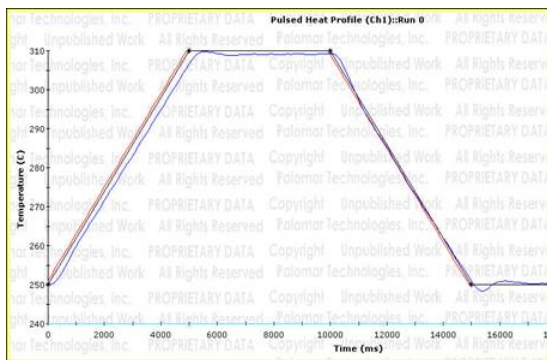


Figure 4 – Generic Example Pulsed Heat Tool Profile

The pulsed heat tool used to pick the laser die includes the following capabilities and benefits:

- Pulsed heat controller with real-time feedback and closed loop control

- Temperature up to 600C
- Temperature accuracy $\pm 3C$
- Fast ramp (up to 65C/s) - minimal overshoot
- Parts at high reflow temperature for a limited time
- Programmable 'point and click' profiling
- Real-time data logging of each profile execution

The wafer assembly process steps include:

- Load wafer onto steady state heated stage and enter the wafer ID
- Load laser die Gelpak™ (pre-flipped with P-Side down) into machine and enter the Gelpak™ ID
- Automatically download the Wafer INPUT map describing substrate sites available for population
- Repeat the following process for all bond sites:
 - Vision find wafer at next available laser site
 - Vision find N-Side of next available laser die and pick it
 - Vision find P-Side of laser die on pick tool using lookup camera with laser alignment algorithm
 - Align and place laser die to laser site
 - Apply bond force and initiate pulsed heat profile
 - Release laser die upon completion of pulsed heat profile including forced cooling cycle to below reflow temperature
 - Optional in the machine program: use the machine vision system to make N-Side measurements of placement accuracy and store to a data file (allows real-time monitor of the accuracy on the machine during build).

P-Side / N-Side Measurement Characterization

Since it is not straightforward to directly measure the P-Side interface of the completed assembly, glass substrates were used for initial process development by measuring placement accuracy through the backside of the glass. The P-Side measurement results in Figure 5 show that all samples were below $\pm 3\mu m$ in the X and Y directions.

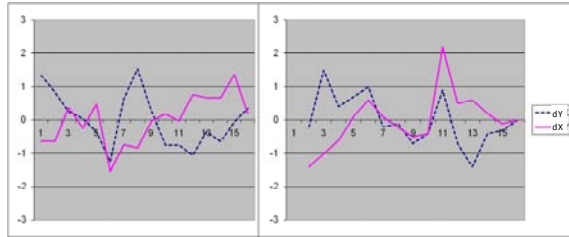


Figure 5 – P-Side Measurement Results for 2 Glass Substrate Runs

P-Side measurements are time consuming due to sample preparation and are nearly impossible to perform on actual wafer level substrates. To mitigate this problem, a correlation between P-Side and N-Side measurements was established which resulted in a more efficiently measurable N-Side measurement specification of $\pm 3\mu\text{m}$ in X and $\pm 4.5\mu\text{m}$ in Y. The correlation was based on previously characterized misalignment tolerances between the lithography masks for P-Side and N-Side on the laser for the Y direction. Under this assumption, all further measurements were performed on a Nikon VMR3200 Automated Optical Inspection Microscope (additional lots of materials showed that some lasers required $\pm 6\mu\text{m}$ in Y for N-Side measurements to compensate for P-Side to N-Side lithography shift).

A small rectangular matrix substrate sample was then built and measured using N-Side measurement techniques as shown in the chart of Figure 6. Most samples were within specification for both X and Y dimensions.

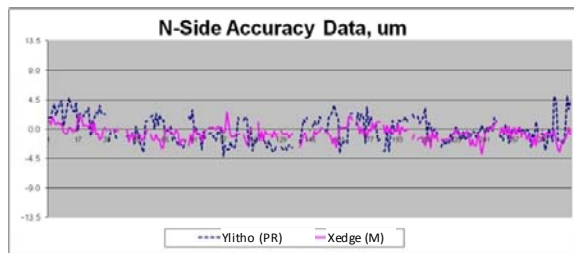


Figure 6 – N-Side Measurement on Wafer with Correlated Tolerance of X $\pm 3\mu\text{m}$ and Y $\pm 4.5\mu\text{m}$

Wafer Scale – Considerations

Single P-side down laser attach is accomplished with single substrate laser sites which are pulse heat reflowed at a fixed XY machine position and then removed from heat. Wafer scale laser attach must consider the affects of both solder aging and accuracy consistency as lasers are attached across the entire wafer XY area on the machine.

Solder Aging: Solder aging at temperature is typically not considered for singulated substrates since the solder is exposed to temperature for a short duration of time only. When moving to wafer level

substrates, however, solder can be exposed to background temperatures over 200C for tens of hours depending on the number of bond sites and the process throughput.

Tables 3 and 4 provide a summary of the results from a study on the effects of exposure to time at temperature. A combination of time intervals at a background temperature of 230C was used to evaluate both non-reflowed solder and reflowed solder in completed assemblies. The study involved waiting the pre-bond time intervals and then attaching a set of 4 laser die each. These laser die sets were then sheared after waiting the post-bond time intervals. This particular test sequence allowed testing of solder exposure to temperature before laser die attach (0 to 72 hours), solder exposure to temperature after laser die attach, and a combination of both (0 to 96 hours = Pre-bond Attach Time + Post-bond Shear Time).

Table 3 – Solder Attach: Average Shear Strength vs. Time

Shear Average [grams]		Post-bond Shear Time [Hrs]				Shear Time [Hrs]
		0	24	48	72	
Pre-bond Attach Time [Hrs]	0	270	275	310	253	24
	24	217	210	241	193	48
	48	239	206	202		72
	72	192	189			96
	Grid	1		2		

Table 4 – Solder Attach: Shear Strength Range vs. Time

Shear Range [grams]		Post-bond Shear Time [Hrs]				Shear Time [Hrs]
		0	24	48	72	
Pre-bond Attach Time [Hrs]	0	36	128	128	87	24
	24	53	21	90	38	48
	48	6	7	119		72
	72	24	31			96
	Grid	1		2		

Table 3 shows a reduction in average shear strength from 270 grams to a minimum of 189 grams over all aging conditions compared to zero pre-bond attach time and zero post-bond shear time. Visual inspection of the sheared samples showed no observable differences in solder joint quality at 60X magnification.

Table 4 shows the effect on shear strength range for each data set. The data did not show continuing

degradation of shear strength range for pre-bond attach time or post-bond shear time exposure.

ACCURACY MAP: Accuracy measurement and process improvement for single substrate carriers and single lasers is well understood. The Model 6500-WSP machine tool changes this paradigm by fixing the wafer and assembling each laser at a unique XY position across the wafer. On the surface, this difference would not be considered; but at $\pm 3\mu\text{m}$ accuracy requirements, this subtle change could have a significant effect on accuracy of the lasers across the wafer.

In order to characterize the placement accuracy across the wafer, separate XY error versus XY position charts are shown below. The charts show Xerr (Figure 7) and Yerr (Figure 8) as a function of X and Y position on the wafer. The color coding is as follows: within tolerance (green), above but within twice the tolerance (pink), above twice the tolerance (blue). Additionally, each chart shows a placement error histogram to check statistical distribution.

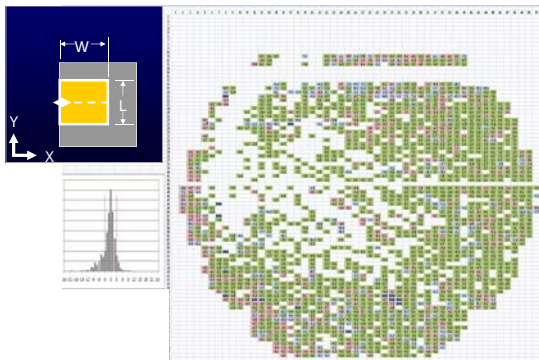


Figure 7 – X Accuracy Data #285 - 72.7% $\pm 3.0\mu\text{m}$ N-Side Meas. (Cnt 2033)

The Xerr map in Figure 7 was generated using the automatic inspection capability on the 6500-WSP machine. The data shows a normal distribution of all of the data and the color coding showing a relatively even distribution of the Xerr values across the entire XY area of the wafer. The Xerr yield of 72.7% for this wafer is a result of material and process issues and was improved to 86% as shown in Figure 9 using N-Side measures.

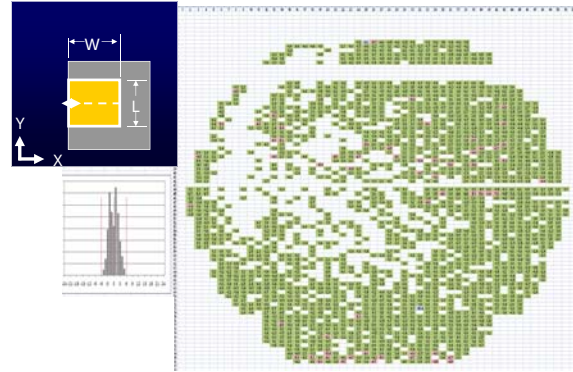


Figure 8 – Y Accuracy Data #285 - 97% $\pm 4.5\mu\text{m}$ N-Side Meas. (Cnt 2033)

The Yerr map in Figure 8 was also generated concurrently with the Xerr map using the automatic inspection capability on the 6500-WSP machine. The data shows a non-normal distribution with a dual peak at the center. This dual peak is related to the P-Side versus N-Side lithography shift between different laser lots. The color coding shows a relatively even distribution of the Yerr values across the XY wafer area. The Yerr yield of 97% for this wafer is a result of material and process issues and was improved to 100% as shown in Figure 10 using N-Side measures.

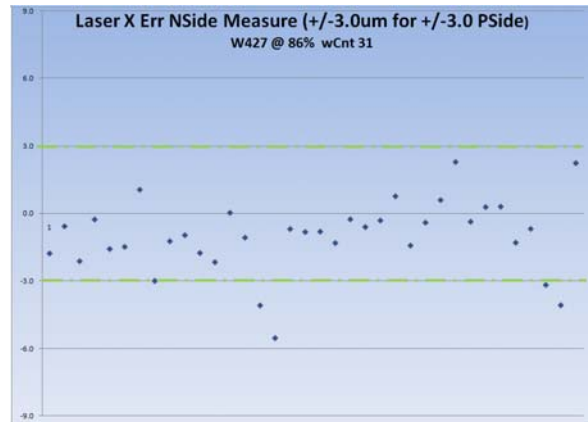


Figure 9 – X Accuracy Data #427 - 86% $\pm 3.0\mu\text{m}$ N-Side Meas. (Cnt 31)

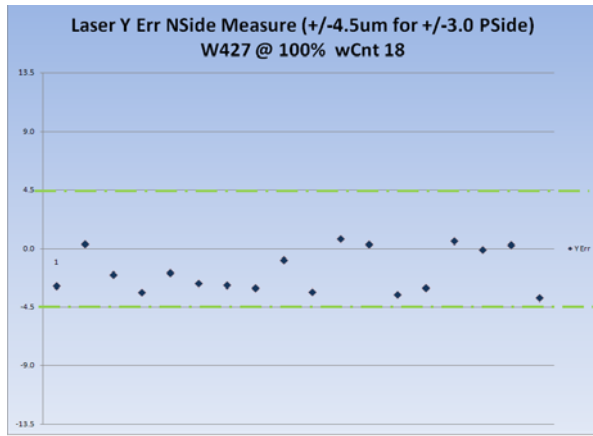


Figure 10 – Y Accuracy Data #427 - 100% $\pm 4.5\mu\text{m}$ N-Side Meas. (Cnt 18)

Summary and Conclusions

This paper shows the continuation work on wafer scale P-Side down eutectic laser attach using a pulsed heat pick tool and steady state heated wafer stage. The topics covered in the paper include:

- Laser die attach accuracy definitions and requirements for P-Side and N-Side measurements.
- Model 6500-WSP machine tool and process description.
- Wafer level consideration testing and results for solder aging and accuracy across the wafer XY area.

The P-Side down AuSn eutectic solder laser attach onto wafer produced results of $\pm 3\mu\text{m}$ in X and $\pm 3\mu\text{m}$ in Y for P-Side measurements on glass substrate. N-Side measurements on the wafer included shifts between N-Side and P-Side but results still indicated $\pm 3\mu\text{m}$ in X and $\pm 3\mu\text{m}$ in Y when N-Side measurements were correlated back to the P-Side. The placement accuracies were consistent across the entire XY area of the wafers.

The effect on solder quality of time at temperature was studied and found to have a minor effect on average shear strength. Additional work has repeated these results.

Follow-on studies are being conducted on the performance and reliability of the before mentioned laser devices.

Additional improvements on the laser materials and lookup camera laser alignment algorithm are planned to further improve Xerr accuracy and overall yield.

Acknowledgments

Palomar Team members who contributed to equipment and process development include Mike Artimez, Don Beck, Tom Boggs, Bill Hill, Dan Martinez, Jim O'Bryan and Andy Wolchinsky.

References

1. Bok, Z. et al, "Micron Level Placement Accuracy Case Studies for Optoelectronic Components", The 41st International Symposium on Microelectronics, Providence, RI, November 2008
2. Dick Otte, Promex Industries, Chair of iNEMI Optoelectronic Technical Working Group (OE TWG) Roadmap draft dated September 26, 2008, p. 16
3. Weiss, S. et al, "Fluxless die bonding of high power laser bars using the AuSn-metallurgy", Electronic Components and Technology Conference, 1997. Proceedings, 47th Volume, Issue , 18-21 May 1997 Page(s):780 – 787
4. Evans, D. et al, "Micron Level Placement Accuracy Case Studies for Optoelectronic Components", The 59st Electronic Components and Technology Conference, San Diego, California, May 26-29, 2009