

## Micron Level Placement Accuracy Case Studies for Optoelectronic Components

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### Abstract

*Ultra high placement accuracies between 1 and 3 $\mu$ m are surfacing in several optoelectronic applications such as Arrayed Laser Print Heads, Multi-channel Optical Communication, and others. Some of the higher performance products are based on either P-Side Down, Edge Emitting, or VCSEL lasers. An overview of the technology, the placement accuracy and attachment method drivers are presented for three cases. With typical placement accuracies of 40 $\mu$ m for surface mount machines, 10 $\mu$ m for die attach machines, and 1 $\mu$ m for ultra high accuracy placement machines, this paper will cover the differences in measurement, material, and process considerations that are required to successfully achieve high placement accuracies of 1 $\mu$ m to 3 $\mu$ m.*

**Key words:** High Accuracy Die Attach, Laser Diode, P-Side Down, VCSEL, Eutectic Attach, Epoxy Attach.

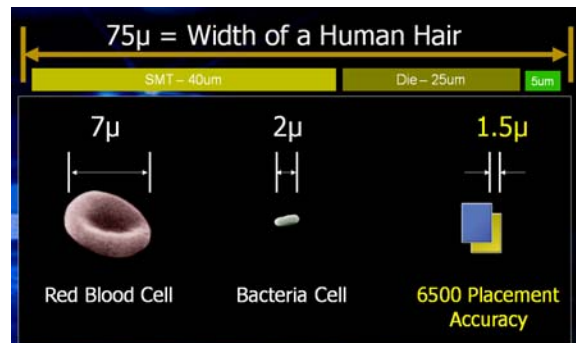
### Overview

The application breakout given in Table 1 is useful to explore general application, attachment, and accuracy requirements for high accuracy die attach. The main breakout is by application product or technology. For the purposes of this paper, each of the applications explored is for specific attachment technologies (Epoxy or Eutectic) and general ranges of required placement accuracy.

**Table 1: High Accuracy Applications**

| Application                     | Attach   | Accuracy             |
|---------------------------------|----------|----------------------|
| LED Laser Print Head            | Epoxy    | $\pm 2$ -5 $\mu$ m   |
| P-Side Down Laser               | Eutectic | $\pm 1.5$ -3 $\mu$ m |
| Active Optical Cables           | Epoxy    | $\pm 2$ -3 $\mu$ m   |
| Lithography/Screen Interconnect | Epoxy    | $\pm 3$ -5 $\mu$ m   |
| Thru Via Die Stacking           | Misc     | $\pm 3$ -5 $\mu$ m   |
| 3D MEMS Stacking                | Epoxy    | $\pm 5$ -10 $\mu$ m  |

Scale perspective is explored by using a 75 $\mu$ m diameter human hair as the starting point, illustrated in Figure 1. Typical SMT equipment can achieve  $\pm 40\mu$ m placement accuracy, while die attach equipment can generally achieve  $\pm 25\mu$ m placement accuracy. Another class of pick and place machines breaks the  $\pm 5\mu$ m barrier, placing to accuracies smaller than a red blood cell. Ultra high placement accuracy pick and place machines achieve accuracies at  $\pm 1.5\mu$ m, which is smaller than a typical bacteria cell.

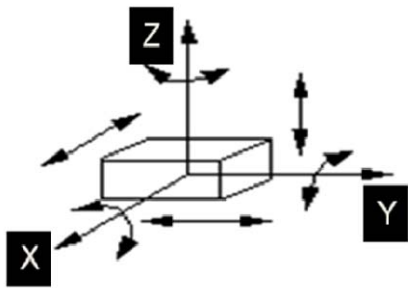


**Figure 1: Accuracy Scale Reference**

### Terms & 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 2. Most pick and place accuracy applications specify Z as a bond line and placement accuracy as X error, Y error, and Theta-Z error. For the purposes of this paper, the specific requirements will be listed for each of the cases studied.



**Figure 2: Geometric Six Degrees of Freedom**

Interconnects are comprised primarily of two methods for optoelectronic assemblies: adhesive (epoxy) or metallurgical (eutectic solder).

These attachment options can be either in-situ (serial) or batch (parallel). In-situ attachment is completed during the placement operation for each component and will have lower throughput since the attachment time for each component is added to the pick and place time. Batch attachment is completed after all components are placed so the actual attachment can be completed as a parallel process. Batch attachment methods typically have higher throughput compared to in-situ.

Another consideration for the attachment method is its effect on placement accuracy. To understand the effect on batch attachment methods, it is important to measure the pre-cure and post-cure accuracy of the components. In-situ attachment methods can have higher placement accuracy, especially if the design does not include self-centering.

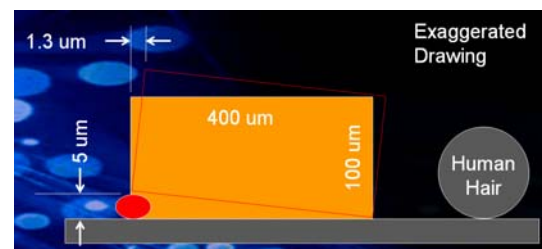
### Material and Process Considerations

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

- Substrate flatness, cleanliness, and fiducial clarity

- Die flatness, cleanliness, and fiducial clarity
- Attach material uniformity, shrinkage, symmetric application, and curing stability

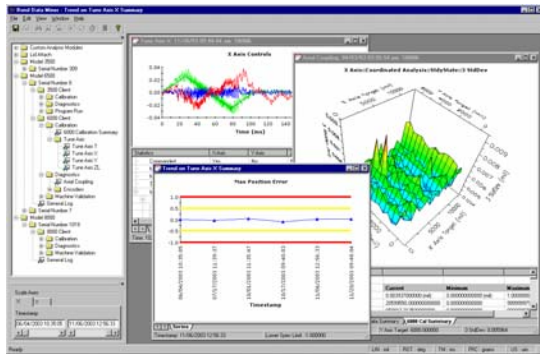
One example of the dramatic impact of contamination on placement accuracy is given in Figure 3. Although not completely to scale, a 400 $\mu$ m wide by 100 $\mu$ m tall component can be shifted by 1.3 $\mu$ m if a 5 $\mu$ m particle is under one edge. Although it is clearly understood that particles must be controlled, this example shows the magnitude of the effect of a thin particle. It may be that contamination is controlled well, but either the substrate or the die has a burr on it or there is an unbalanced particle loading in the attachment material. All factors need to be controlled in order to achieve high accuracy placement and attach.



**Figure 3: Particle Effect on Placement Accuracy**

The clarity of fiducials and dimensional control of parts are important for accurate alignment. However, where part dimensions or fiducials cannot be controlled well in all dimensions, they should be controlled in the primary axis of alignment. Case studies will show specific examples.

The alignment tool should have the ability to diagnose machine capability and to process sub-element capabilities (X move, Y move, Z move, image find errors, etc.) so that alignment issues can be resolved down to operator, material, process, or machine issues. Figure 4 illustrates one example of diagnostics which includes single axis motion, XY axis motion and any cross coupling effects, as well as process capabilities for placement accuracy (as measured by the machine).

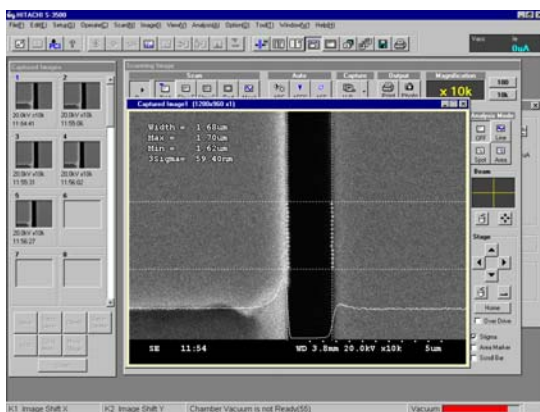


**Figure 4: Process Diagnostic Tools**

The measurement equipment and methods are also critical for high accuracy placement qualification. Typical measurement tools required to measure high accuracy placement include:

- Automated Optical Inspection Equipment (AOI) with  $\sim 0.5\mu\text{m}$  resolution
- Built-in part features such as vernier scales, which allow direct reading of placement accuracy with resolution of  $\sim 0.5\mu\text{m}$
- SEM systems with  $\sim 0.1\mu\text{m}$  resolution

An example of measuring edge-to-edge distance using a SEM with built-in measurement tool is shown in Figure 5. Without automated measurement tools, it would be extremely difficult to achieve a gage repeatability and reproducibility (Gage R&R), required to measure to  $0.1\mu\text{m}$ .



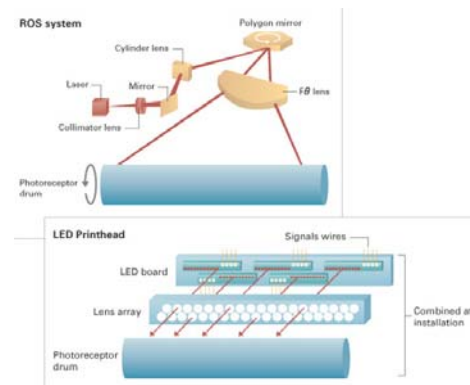
**Figure 5: SEM Measurement Tool Example**

## CASE OVERVIEWS

Three separate case studies are now presented to provide an overview of the various applications, key requirements, and results for micron level placement.

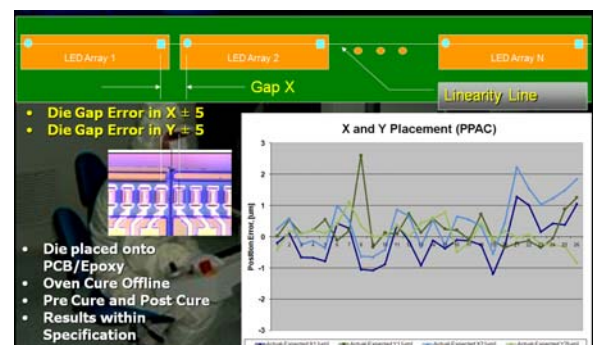
### CASE 1: Arrayed LED Print Heads

Arrayed LED print head technology uses a series (arrayed line) of LED arrays to illuminate the entire length of a photo resist drum at once rather than using a single laser and scanning wheel, as shown in Figure 6. The arrayed LED laser based system reportedly occupies  $1/40^{\text{th}}$  of the volume space required by a raster optical scan (ROS) system.



**Figure 6: Laser Printer Technology Comparison - Single Laser with Scan Wheel versus Arrayed LED (Source Fuji Xerox)**

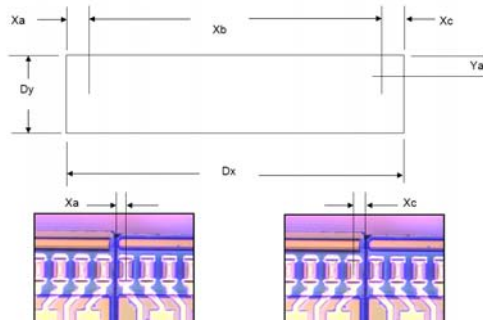
The primary alignment requirement for the series of LED arrays is lateral spacing uniformity (along a line), as shown in Figure 7. Each LED Array die is essentially a singulated die, with LEDs fabricated into a specified number of LEDs at a known fixed spacing, which is determined by the lithography process.



**Figure 7: LED Print Head Requirements and Results in  $\mu\text{m}$**

Individual LED array die are lined up to mimic a continuous array of LEDs. The pick and place requirement is based on placing the outside two LEDs on each die in a uniform spacing within  $\pm 5\mu\text{m}$  in both X and Y from the theoretical line.

Dimensions of the die cut for both ends,  $X_a$  and  $X_b$ , must be controlled (shown in Figure 8) to maintain correct LED spacing as well as to avoid die colliding with each other.



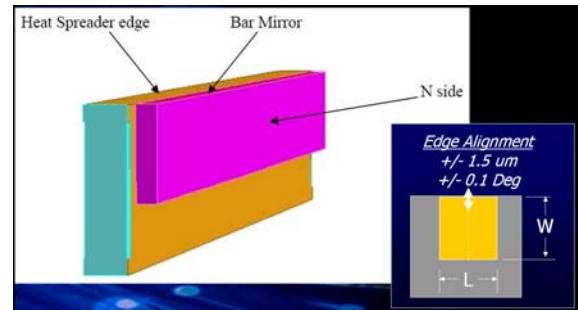
**Figure 8: LED Array Die and Critical Dimensions**

The attachment method specified is electrically conductive epoxy (Epotek H20E), which was cured at  $150^\circ\text{C}$  for 90 minutes (typical) and performed as batch cure after all LED array die had been placed.

Placement accuracy results of the measured gap between LED array die (pre- and post-cure) was well within the  $\pm 5\mu\text{m}$  placement tolerance, as shown in Figure 7.

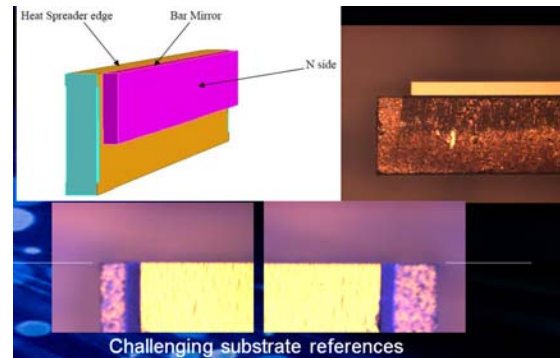
### CASE 2: P-Side Down Laser

Indium Phosphide Edge Emitting Lasers are used in many applications. Most require eutectic attach to maximize the thermal conductivity of the interconnection, primarily for heat removal. To further optimize heat extraction, the laser side with the active region is attached to a substrate heat spreader (P-Side Down). To maximize heat extraction and laser output, the output edge of the laser is tightly constrained with respect to the heat spreader edge to  $\pm 1.5\mu\text{m}$  in Y error and angular alignment to  $\pm 0.1$  degree, as shown in Figure 8.



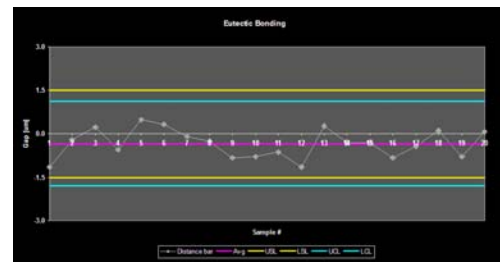
**Figure 9: P-Side Down Attachment Accuracy Requirements**

The P-Side Down attachment images shown in Figure 10 illustrate the laser to substrate edge alignment.



**Figure 10: P-Side Down Eutectic Attach Results**

Eutectic attachment quality is typically specified with a maximum void percentage and/or a shear force requirement, as well as visual defect requirement.

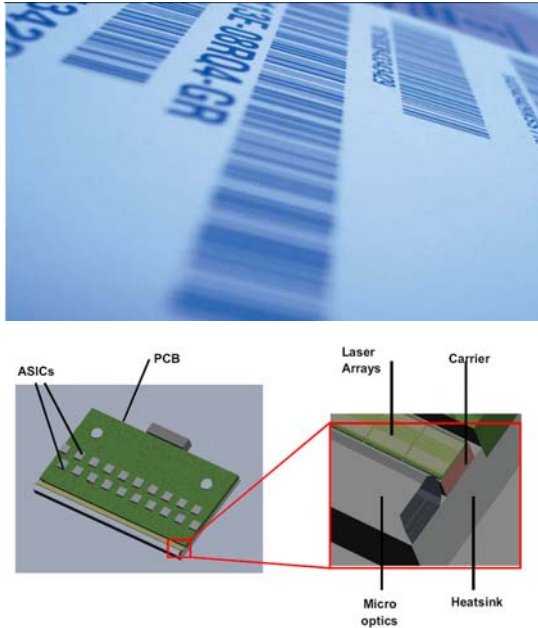


**Figure 11: P-Side Down Pulsed Temperature Eutectic Placement Accuracy**

Placement accuracy results, measured post attachment, were within the  $\pm 1.5\mu\text{m}$  placement tolerance, as shown in Figure 11.

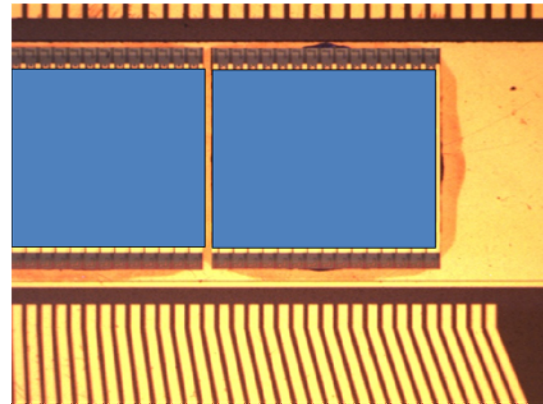
### CASE 3: Laser Marker Head

Labeling is used for product identification and traceability and combines letters, bars, and matrix codes, as shown in Figure 12. Today, nearly everything has a label, including shipped parcels. As security becomes a larger issue, new systems that mark the inside of the paper rather than the surface are gaining acceptance.



**Figure 12: Laser Label Maker Output and Basic Construction (Source: Intense Photonics)**

One configuration of a label print head, as shown in Figure 13, uses groups of arrayed lasers that are evenly spaced to mark thermal paper. These heads require die to be equally spaced with a controlled gap of  $\pm 5\mu\text{m}$  in X and Y on the left and right LEDs of each die, after epoxy cure.



**Figure 13: Laser Label Maker Close-up**

The placement accuracy results shown in Figure 14 confirm that placement results are well within  $\pm 5\mu\text{m}$  of the X and Y placement accuracy requirement, with a maximum error of  $3.2\mu\text{m}$  in X and  $-2.9\mu\text{m}$  in Y. Average placement gap errors of  $-0.5\mu\text{m}$  in X and  $-0.5\mu\text{m}$  in Y, and  $3\sigma$  variation of  $3.8\mu\text{m}$  in X and  $3.6\mu\text{m}$  in Y, show acceptable control for  $\pm 5\mu\text{m}$  accuracy requirements.



**Figure 14: Laser Mark Head Placement Accuracy Results**

### Summary and Conclusions

Three separate optoelectronic application case studies have been reviewed. All three cases required  $\pm 5\mu\text{m}$  placement accuracy or better, using adhesive or metallurgical attachment, as shown in Table 2.

**Table 2 High Accuracy Applications**

| CASE                 | Attach   | Accuracy                      |
|----------------------|----------|-------------------------------|
| LED Laser Print Head | Epoxy    | $\pm 2\text{-}5\mu\text{m}$   |
| P-Side Down Laser    | Eutectic | $\pm 1.5\text{-}3\mu\text{m}$ |
| Laser Marker Head    | Epoxy    | $\pm 3\text{-}5\mu\text{m}$   |

An overview of considerations required to reach high accuracy ( $\pm 5\mu\text{m}$  or better) attachment was presented.

Material considerations include:

- Substrate flatness, cleanliness, and fiducial clarity
- Die flatness, cleanliness, and fiducial clarity

Process considerations include:

- Die presentation format in wafer or gel pack and effect on throughput
- In-situ attachment time or batch attachment time and its effect on throughput
- Symmetry of adhesive and the effect on post cure accuracy

High Accuracy attachment is currently used in production but requires attention to detail for both materials and process.

### References

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### Biography

Zeger Bok is a Senior Applications Engineer for Palomar Technologies and has developed pick and place applications and processes since 1998 with related patents in high accuracy. Zeger holds a MSME/Hogeschool Antwerpen (Belgium) with emphasis on automation and robotics and a MSEE/Vrije Universiteit Brussel (Belgium) with emphasis on controls and power electronics.

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