Automated Precision Assembly for High-Volume HB LEDs

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Abstract
Since the introduction of automated die and wire bonders in the 1980s, equipment manufacturers and process engineers have been challenged to balance speed with repeatability. Today, die bonders can perform epoxy die attach at a rate of 1.5 to 4 thousand die per hour [6]; and wire bonders can interconnect complex packages at speeds of more than 10 wires per second [7]. The advantage of automation is speed and consistency—however, there is one major concern with operating at these speeds: if something in the assembly process is wrong, everything will be wrong. Having tightly regulated assembly processes helps avoid the risk of building a large batch of rejected product.

This paper presents a methodology and process flow supporting High Bright Light Emitting Diode (HB LED) automated assembly, supported by equipment certification, product inspection and SPC data collection methods. The methods presented in this paper have been formulated through extensive work in the high-reliability microelectronics industry and commercial production lines over the last three decades. To ensure time-to-market success in high-volume production, specific methods to achieve throughput and quality are required. This paper will cover the strategies and methods necessary to achieve the ultimate goal of an automated precision HB LED assembly—to blend the requirements of high-reliability and high-throughput to support high-volume commercial production.
Significance
High Bright Light Emitting Diode (HB LED) devices are one of the fastest growing technologies in the world. Industrial, aerospace, utilities and commercial organizations with needs for highly dependable lighting contribute a large part of the HB LED market growth. High reliability and high efficiency are top characteristics to meet when producing high yields of LED applications.

HB LED designs today require maximum thermal transfer to achieve performance specifications. Typically, gold/tin eutectic is assumed for component attach; however, due to the reflow times needed, this process is expensive when compared to more traditional conductive epoxy. A second disadvantage with gold/tin is an inability to perform rework. Recently, adhesive paste manufacturers have designed silver epoxies tailored specifically to replace gold/tin. The processes discussed in this paper assume all components are attached using a highly conductive silver paste. These pastes tend to have thermal conductivity (W/m°K @25°C) of 20 to 40 compared to ~57 for Au/Sn [1]. Traditional silver epoxies are generally 2-4.

Reaching performance and cost targets requires continuous improvements in LED devices and packaging to extract every possible lumen per watt. Both throughput and repeatability are key factors in high-yield production processes. Today, automated die bonders can perform epoxy die attach at a rate of 1.5 to 4 thousand die per hour [6]; and automated wire bonders can interconnect complex packages at speeds of more than 10 wires per second [7]. The advantage of automation is speed and consistency. However, a major concern with high-speed automated microelectronic packaging is that if something in the assembly process is wrong, everything will be wrong. Having a tightly regulated process flow helps avoid the risk of building a large batch of rejected product in a short period of time.

Offshore vs. On-Shore LED Assembly
The majority of light engines are currently assembled offshore—for the purpose of this paper, “offshore” indicates production outside of the United States—which, depending on the supplier, can pose the threat of loosely regulated process flows and an increased risk of rejected products. Shifting assembly to on-shore production (in the U.S) directly addresses these concerns, among others. Depending on the chosen supplier, on-shore contract assembly ensures, but is not limited to, the following points, many of which are important during product development where cycle times are critical:

- Strict USA-governed IP protection laws
- Rapid prototype-to-volume assembly
- Improved communication between contract assembly engineers and the customer organization
- Ability to react quickly to changes
- Access to product during all stages of assembly
- No time loss or delay due to customs
- Ability to perform consistent, complex application

Organizations often revert to offshore assembly with the plan of maintaining lower production costs. This is a misleading concept, as the costs for microelectronic assembly tend to equalize as complexity increases. For example, it is known that light engine assembly costs in China have increased as designs have become more intricate and complex. In 2009, Palomar Technologies conducted a review of LED assembly costs comparing the United States, Europe, China, Singapore, Taiwan and Mexico. In part of the review, the prospective suppliers were asked to quote assembly costs for quantities of 5K, 10K and 20K units per month.

Figure 1 provides an overview of the requested LED module for the original quotes in the LED global cost-comparison review:

1. 8mm X 10mm ceramic LED substrate
   - A ceramic H-frame is epoxy attached using Ablestik 84-3 adhesive
2. Placed within +/- 25µm
3. 25 Cree EZ1000 LEDs epoxy attached using Emerson Cuming’ 84-1LMISR4
   - LEDs placed +/- 12µm
4. Each LED is interconnected using two 32µm gold wires (50 wires per assembly)
5. Wires are encapsulated using GE IVS4632 two part silicone
The results indicated a shift in the world of “on-shore vs. offshore” high-tech complex manufacturing. Mexico (Tijuana) proved to be the lowest cost, with China (Shenzhen, Guangdong) a close second. The results proved an inverse relationship between a high degree of process automation and the importance of labor costs. This review concluded that there is an insignificant difference of $1.25/module in LED assembly costs between the United States and China.

The reason: most Chinese-assembled light engines occur in Shenzhen where labor costs have steadily risen. That combined with the fact that U.S.-based microelectronic assembly is performed by automated equipment and not by hand helps equalize costs in this market. Figure 2 shows a graphical overview of the LED assembly costs per module among the six regions/countries examined for this review.

![Figure 1: Sample LED assembly for global cost-comparison review](image1)

![Figure 2: Global LED assembly cost comparisons](image2)
Palomar Technologies Assembly Services™ LED Production Strategy

Palomar Technologies Assembly Services™ (“Assembly Services”) is the on-shore contract assembly, process development, prototyping and test division of Palomar Technologies, providing a low-cost alternative to purchasing capital equipment. Assembly Services has developed a rigorous process flow ensuring high-reliability of automated precision assembly for high-volume HB LED, supported by equipment certification, product inspection and SPC data collection methods. Figure 5 illustrates Assembly Services’ proven process flow of high-yield HB LED automated assembly. Not all LED assemblies require the level of detail and strict regulation employed by Assembly Services; however, the division abides by this process flow to ensure high quality for LED applications.

Each validation and certification checkpoint can take between 2 to 10 minutes, depending on the process. The Palomar Technologies die attach and wire bond equipment used in the contract assembly of HB LEDs perform diagnostic tests that evaluate the performance of each motion and servo system. Palomar Technologies’ motion validation test takes only about 20 seconds and scans hundreds of data points, grading them green, yellow or red. This process consistently catches degrading performance and therefore reduces future production downtime and allows scheduled correction before the process or machine fails.

A Few Words on Die Attach

One key aspect of the LED light engine resides in the medium used for component attach. There is no question that using Au/Sn yields the highest performance, although assembly costs may increase via cycle time. The majority of high-volume light engines use silver epoxy as this provides the highest throughput.

Recently, Palomar Technologies has been working with Indium Corporation to evaluate Au/Sn preforms and Au/Sn solder paste. Following months of testing, the following results were discovered:

1. LEDs attached using Au/Sn-backed alloy (like the Cree EZ1000) may be attached using flux with no pressure, but this may yield a high void bond line
2. LEDs attached using Au/Sn preforms require constant pressure during reflow (see Figure 3), which restricts design and process options.

3. LEDs attached using Au/Sn solder paste and no pressure yields a very good bond line with few voids (see Figure 4)

Since uncovering these results, Palomar Technologies launched additional studies to determine the most effective process for Au/Sn solder paste and how that process compares to silver epoxy. After evaluating several different methods for transferring solder—including screen print, auto dispense and pin dot transfer—auto dispense was found to be most effective. This is key since one would also use auto dispense to transfer silver epoxy. In this flow, one would only add reflow into the process when comparing to silver epoxy LED attach.

There are several ways to reflow Au/Sn solder that includes belt furnace reflow, vacuum reflow and a Pulsed Heat System (PHS) reflow. Each method is effective, but the PHS process is much faster and limits the LED exposure beyond 300°C. This is important since most LED components degrade beyond that temperature. A traditional PHS reflow cycle is completed in approximately 30 seconds and is above 300°C for only a few seconds; a traditional belt furnace cycle is approximately 20 minutes and above 300°C for several minutes.

Since the PHS process is typically supported on the die attach platform, time would be lost during the reflow cycle. However, the time impact is significantly diminished by continuing component attach of one part while the first part is being...
reflowed. A typical flow would consist of the following:
1. Dispense Au/Sn solder paste using a separate auto dispense system (as one would for silver epoxy)
2. Pick and place all LEDs for part 1
3. Transfer part 1 onto the PHS stage and initiate reflow
4. Pick and place all LEDs for part 2
5. Transfer part 1 onto completed work pallet and continue cycle for all remaining parts

Additional information pertaining to this study may be found in our joint paper entitled “Evaluation of Test Protocol for Eutectic Die Attach Using High Power LEDs”.

Validating and Testing Materials
Assembly Services begins LED assembly by first validating all materials at incoming inspection. Material validation is based on standard guidelines, usually including standards for automated processes where the recipe is static to eliminate varying process parameters. Common material validations include:
- ICs – attach to coupon and perform wire bond tests
- Substrates or packages – high-temperature wire bonding tests
- Adhesives – dispense tests from one syringe from each lot/batch

All equipment is verified against minimum performance guidelines. Off-line visual and in-process inspections are conducted to ensure the assembly process does not drift. This also offers an instant indication of any material or equipment issues before beginning production. Assembly Services uses a 2” x 2” gold-plated test coupon for material validation, which is defined per a material specification or drawing. Since key decisions are made based on this coupon’s performance, the coupon’s quality must be known.

Figure 5: Palomar Technologies Assembly Services™ HB LED process flow
**Kitting and Build Documentation**

Assembly Services has developed a reliable paperless manufacturing software system called Automated Data Management and Analysis (ADMA), which directly communicates with Palomar Technologies die attach and wire bond machines [5]. ADMA begins by importing data from a travel document and ends when parts are shipped. Benefits to the paperless laboratory offered through contract assembly with Assembly Services include:

- All information is stored and is accessible via a common network
- Material inventory and kitting may be performed at any workstation
- All work instructions are defined for each operation, with the ability to include descriptive image
- Data may be accessed directly from equipment to validate process consistency
- Operator sign-off steps create a timestamp indicating the exact amount of time required by each operation
- Valuable assembly progress reports are available via remote access (i.e., ability to check on HB LED assembly, even while not in the office)

**Adhesive Certifications**

The Assembly Services process flow documents and tracks key parameter changes, which are then transferred to production. Minimum standards for each adhesive are defined and tested using a 2” x 2” gold-plated test coupon. The epoxy dots are automatically measured and reconciled against the originally defined standards. Any changes needed to support variations in adhesive lots are then transferred to the production process and verified using real application parts.

**Component Attach Certifications**

Component attach certifications are used to validate pick-and-place accuracies. Assembly Services validates component attach expectations by first loading a calibrated glass die onto the workstation. An automated program utilizing pattern recognition transfers the die onto the stage. The position of the die is verified using “Post-Placement Accuracy Check” (PPAC) software through a high-magnification lookdown camera.

Palomar Technologies developed Bond Data Miner™ (BDM) to track trend and machine calibrations, aggregate run data and timestamp data sets. BDM is used to export test die placement analysis details to an Excel™ database in the ADMA program. BDM works in concert with ADMA to provide a more comprehensive and centralized data management and analysis system.

**Wire Bond Certifications**

Assembly Services performs an automated wire-bonding program on a 2” x 2” gold-plated test coupon. The wire-bond test involves a minimum of 50 wires and 10 Free Air Balls (FABs). The FAB test monitors consistency to form a ball by Electronic Flame Off (EFO), while tracking Bonded Ball Diameters (BBD) measurements monitors the bonding process (force/ultrasonic). Destructive wire pull and ball shear tests may also be included depending on the type of process being certified.

**Visual and In-Process Inspection**

Once a process is certified, Assembly Services defines crucial in-process checkpoints during which the assembly process is paused and applications are inspected with an equipment camera. The part remains in process during this inspection. The operator decides to either stop or continue the LED assembly based upon the instructions defined in the traveler—this is a key reason descriptive images are included. Off-line visual inspections are performed prior to each new part run and then switched to sampling as the process matures (typically 2.5% AQL) [4].

**Summary**

Palomar Assembly Services™ (“Assembly Services”) is a California-based (on-shore) contract microelectronic assembly division of Palomar Technologies, providing a low-cost alternative to purchasing capital equipment. Many misconceptions of on-shore assembly exist, with the major discriminator being cost. However, reviews show that not only is on-shore assembly equivalent in cost, but there are other benefits including secured IP confidentiality and quick access to production progress reports.

Assembly Services offers a highly regulated process flow to ensure consistency and high-reliability when performing automated precision assembly for high-volume HB LEDs. Detecting defective materials, processes and product is key when using high-speed automation. Testing materials and equipment before the assembly of deliverable hardware increases quality and reduces manufacturing issues.

Outsourcing to an offshore production can no longer be assumed as the best choice. There are cases where on-shore (production in the U.S.) assembly is nearly as competitive on price and will outperform offshore options in terms of lead-time, response time, IP
control and traceability. This paper covers the ultimate goal of an automated precision HB LED assembly—to blend the requirements of high-reliability and high-throughput to support high-volume commercial production.

References:

5. MIL-STD-38534 Hybrid Microcircuits General Specifications