Continuous Improvement through Automation and Enhanced Manufacturing Processes

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The semiconductor industry continuously seeks ways to improve its processes through the use of automation and other tools and techniques. With the increasing demand on quality improvement driven by customers, Amkor Technology Philippines (ATP) constantly evaluates manufacturing processes for automation opportunities. Using a variety of automation tools, essentially every aspect of semiconductor packaging can be taken from manual to automated processing to some extent or another. In fact, the tools themselves are continuously being improved, modified and/or updated.

This white paper will explain some specific automation tools used at ATP and discuss several before /after implementations of automation focusing on quality and Available to Promise (ATP) (on time delivery) improvements. Assembly aspects impacted by automation include: wire bond (WB), data analytics, die attach (DA) cure, die traceability, labeling and test.

**Automation Tools**

ATP has implemented several tools for improved automation of its processes. These include:

- Enhanced computer-integrated manufacturing (eCIM)
- Enhanced statistical process control (eSPC)
- Resource Tracking System (RTS)
- Enhanced Manufacturing Execution System (eMES)

**Enhanced computer-integrated manufacturing** is a system which directly interfaces with manufacturing machines through the SEMI Equipment Communication Standards/ Generic Equipment Model) (SECS/GEM) protocol to provide [1]:

- Real-time equipment status monitoring
- Performance analysis reporting based on the data/information automatically retrieved from each piece of equipment
- Station-specific process controls, including
  - PLS (Program Loading System) interface to ensure correct recipe is used
  - Memory checks to verify whether adjustments made on machine recipe are within tolerance
  - Wire and capillary to ensure correct materials are used
  - Layout and parameter change detection to enforce memory checks
Figure 1 below illustrates the typical interaction of the eCIM architecture.

![Figure 1: Selected aspects of the eCIM architecture.](image)

**Other Automation Tools**

Enhanced statistical process control is an application of statistical methods to control a process to ensure that it operates at its full potential to produce conforming products.

The Resource Tracking System is a centralized resource master maintenance for variety of equipment in ATP that has the following features:

- Preventive maintenance transactions
- Automated line move out/move in process for equipment transfer, return and repair with email notification

Enhanced Manufacturing Execution System is transaction systems used in manufacturing to track and document the transformation of raw materials to finished goods.

The combination of these and other tools into a highly-connected systems approach result in significant progress towards a smart factory.

**The Smart Manufacturing Concept**

The ATP Smart Manufacturing Concept [2], shown in Figure 2, is a new framework for semiconductor assembly operations that relies on a variety of systems:

1. A connectivity system to connect machines to the enterprise network;
2. An In-line Process Control System to provide machine inhibit capability;
3. Error-proofing systems to reduce the potential for variation in product quality and scrappage;
4. A traceability system for process visibility; and
5. A data analytics system to provide quick insight to machine and product performance.
Figure 2: The ATP Smart Manufacturing Concept targets improved cycle time, productivity and quality.

In smart manufacturing, the operation of smart, connected machines occurs through remote commands issued by the eCIM connector. The logic and rules are built into the system to enable control and personalization as shown below in Figure 3.

Figure 3: The eCIM connector provides system connectivity

In-line Process Control Systems such as Advance Process Controls (APC) are developed, configured and deployed to selected assembly process stations to enable machine auto-inhibit capability and real-time feedback for quality controls and machine data collection for data analytics.

Error-proofing systems are developed to prevent mistakes before, during and after lot processing. Two major systems were developed and deployed in assembly manufacturing: (1) a Bar Code Management System (BCMS) to ensure correct materials are used and (2) Lot Control and Certification (LCC) to guarantee and certify each lot prior moving to the next station.
Demonstrated Improvements
After the implementation of Smart Manufacturing systems at ATP, a 55% reduction in quality excursions was achieved (see Figure 4).

![Graph showing 55% Quality Issues Reduction](image)

Figure 4: ATP quality metric results

In addition to improved quality, a 10-15% utilization improvement was achieved after the implementation of ATP’s Smart Manufacturing systems (Figure 5).

![Graph showing 10% - 15% Improvement](image)

Figure 5: ATP wire bond utilization trends
Examples of Process Improvement through Automation

This section shows the demonstrated results from the implementation of automation in wire bond, data analytics, die attach cure, die traceability, labeling and test operations.

Wire Bond Quality Improvement

Amkor Technology Philippine’s lot control and certification deals with the connection, monitoring and control of equipment, material, parameters and personnel. It is a system-level certification process executed during lot movement [1]. ATP can address wire bond quality issues and replace a manual means of qualifying lots. Lot process data is compared from product and process specifications to prevent lot movement transaction to another station. If the LCC requirements are not “PASSED,” it automatically holds the lot in the system.

Using eCIM, ATP, eSPC, RTS, eMES, LCC and other tools, details of the problem categories were defined for existing systems. This served as basis for the triggering and holding of lots. Any non-conformance was considered a failure.

Demonstrated Improvements

From the baseline of 19.75% for ATP overall, the lot rejection rate was reduced to 6%, as shown in Figure 6. In addition, internal quality barometers indicate a 67% reduction in WB issues due to LCC.

Figure 6: Sample zero line lot rejection improvement
Further Wire Bond Quality Improvement

Previously, wire bond quality monitoring and detection control mainly depended on operator intervention [3]. This intervention was conducted during in-line monitoring inspection as well as through machine alarm events. When called, the technician would identify the root cause through Out of Control Activity Plan (OCAP) and manually record the findings and corrective actions performed in a logbook. The manual human interventions were prone to error and non-compliance that could lead to quality excursion and low yield events.

WB machines had the capability to detect most of the common wire bond defects with the most common failures received from customers being broken stitch, non-stick on lead (NSOL) and non-stick on pad (NSOP). Once a defect was detected, the machine provided an alarm for the operator or technician to assist or repair. However, the operator or a technician can continue running the machine without doing anything and without proper documentation of the actions performed.

To correct this situation, a closed-loop system was designed so a separate software application controls the machine every time it encounters an alarm. The system auto-inhibits the machine from running production after reaching a user pre-set number of errors. At this point, the operator or a technician will be forced to conduct an investigation on the problematic machine. The investigator will also be required to fill-up an electronic OCAP system to release the machine back to production mode.

Demonstrated Improvements
After the activation of NSOL and NSOP alarm limits, sufficient data on the electronic OCAP was retrieved and analyzed. Corrective and preventive actions were formulated based on the data feedback from the operators and technicians themselves. A significant improvement on Lifted Stitch defect parts per million (PPM) trend was achieved on a monthly basis as shown in Figure 7.

<table>
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<th>Date</th>
<th>Dec'16</th>
<th>Jan'17</th>
<th>Feb'17</th>
<th>Mar'17</th>
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<tr>
<td>Lifted Stitch PPM</td>
<td>202</td>
<td>151</td>
<td>114</td>
<td>91</td>
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</table>

Figure 7: Lifted Stitch defect PPM monthly trend
The results shown in Figure 7 correlate with the reduction of NSOL out of limit alarm occurrence on a monthly basis. See Figure 8. Shifting from manual to automatic control by implementing the machine auto-inhibit function and electronic OCAP release have demonstrated a major influence on the reduction of Lifted Stitch defect PPM. Additionally, the NSOL alarm occurrences were also reduced.

Figure 8: Improvement in NSOL out of limit alarm occurrences

**Data Analytics**

Data analytics is a process used to enhance productivity and improve business efficiency that leads to smarter business decisions [4]. This process uncovers hidden patterns and reflects the increasing significance of data to draw conclusions about the information they contain.

The use of data analytics and effective data visualization have demonstrated an increased efficiency and success in identifying downtime, yield and cycle time patterns or behaviors. Data analytics also provide a way to easily diagnose chronic issues relative to both equipment performance and execution problems.

In ATP's data analytics system, shown in Figure 9, data was captured from several in-house databases and processed for analytics reports. Visualization creators were given the desktop version of the software to design interactive reports that were deployed through the web viewer page. A separate web portal was provided to users with read-only access to reports.
Demonstrated Improvements
With the integration of Manufacturing Data Analytics in ATP, an improvement of 10% to 15% was realized in the wire bond process. (Refer to Figure 5). The integration of cycle time analytics provides a quicker and easier way to track lots including hold lots before their due date to avoid delinquencies. This enabled the production and planning teams to proactively strategize lot execution in the manufacturing floor.

As the result of the integration of data analytics in the factory, there was an improvement of 94% in productivity based on Assembly and Test operations deployment. Therefore, the implementation of data analytics significantly improved operational indices translating to improved quality, efficiency, on time delivery (OTD) and margins.

Die Traceability System
A die traceability system (DTS) can be very important for advanced and automated detection of problems prior to shipping to the end-customer [5]. DTS captures die coordinates/position from the site on the wafer where it was picked in parallel with the location of the die on the substrate using eCIM technology. DTS also provides/reflects the location of rejected units from the previous process, which reduces human intervention from manual rejection of units that were rejected but not removed by the machine during processing. DTS produces a strip map for every strip ID after the die attach process.

Demonstrated Improvements
DTS was introduced to improve wafer level traceability in ATP that allows the customer to determine the identification of Device 1, Device 2 and Device 3 or more stacked die requirements. Since all information is recorded, the specific die coordinates and position on the wafer and the strip allows manufacturing to easily trace the device location for each lot.
Labeling

Labels play a key role in the life of a packaged product and is a critical part of the product packaging process [6]. Incorrect labeling can lead to mixed product, wrong shipments and other quality problems. Since automation minimizes or reduces human intervention in many processes, it was chosen as the solution to the inconsistencies that can occur with operator-involved labeling. For system information to be automatically applied to label printouts, eMES was used to automate processes. The fully automated Traceability Label Automation (TLA) system replaces a manual labeling process. It has:

- Quantity automatically printed on the label based on production engineering (PE) enrollment
- Label information linked in eMES
- Maximum of five CLNs (Customer Lot Number) allowed per label
- QR (Quick Response) Code used to validate lot number content

Demonstrated Improvements
By implementing the TLA system label sticker:

- No operator non-value added activity of label cutting.
- Printed information can be easily read using matte type label material.

In addition to reducing the operator’s non-value added activity by 82% and providing a considerable cost savings, label-related quality problems were essentially reduced to zero as shown in Figure 10.

![Figure 10: Zero label quality occurrences after full implementation of the TLA system](image-url)
Die Attach Cure Automation

Die attach cure automation was pursued to improve quality and manufacturing productivity by eliminating manual transactions as well as program-dedicated machines.

The DA cure process allows the bond epoxy to reach its optimum stable state. Cure conditions, such as temperature and time, depend on the type of epoxy. Manual checking of cure conditions could cause the use of the wrong program. With a Smart Console System, lots to be processed are validated and upon successful transaction, the oven will turn on automatically based on the conditions required by the lot. The Smart Console is a system used in manufacturing transactions in ATP for Move In (Operation In), Track-In (Machine In), Track-Out (Machine Out) and Move Out (Operation Out).

Demonstrated Improvements

PLS (Program Loading System) uploading in the eCIM client ensures correct programs uploaded per condition code. Uploading of the cure pattern is performed by process engineers and qualified/counter-checked by the Quality Assurance (QA) Team. If a process engineer uploads a wrong pattern on a given condition code, this will be trapped by QA during qualification, thus assuring the quality of the profile.

After implementing DA Cure Automation in Assembly, no quality issues and misoperations were noted. Refer to Figure 11.

![Quality Data for DA Cure](image)

Figure 11. Quality data for DA Cure shows no more quality and misoperations after the implementation of an automated process. (CIR – Customer Incident Report; MRB - Material Review Board).

Automated oven processing eliminated the manual selection of programs, thus minimizing quality issues such as wrong program used. This also increased the productivity by eliminating the program-dedicated ovens, since programs are already qualified and saved in the system.
Test

The cost of test is a significant portion of final manufacturing cost [8]. To address this challenge and reduce cost, the common strategy is to increase the number of test sites. However, in testing a large number of sites, there are difficulties of contacting the pad geometries of the newest generation of small form factor packages. Assembly parameters such as unit movement after saw, sticky tape distortion on full sawn film frame technology, and pad dimensions or location must be considered, since they determine the suitability of implementing multiple site testing. Contact failures are more evident when an increased number of test sites are implemented and a good contact is required to fully verify the functionality of the device under test.

To reduce high contact failures, a Contact Optimization Process System (COPS) was developed (see Figure 12). The automatic alignment strategy compensates for the assembly parameters that impact multisite testing. This procedure has no limitations on the maximum number of test sites that can be achieved.

![Figure 12: Automated test equipment (ATE) in COPS](image)

**Demonstrated Improvements**

Testing indicated a reduction from a maximum of 14% to an average of 1% contact failures without COPS versus with COPS, respectively. By observing the without COPS implementation, it was obvious that the contact performance was erratic and inconsistent (see Figure 13). The COPS performance averages 1% failures and removes the unpredictable results.

![Figure 13: Demonstrated reduction in contact failure rate](image)
Using COPS effectively optimizes the device contact for high parallelism and increases the number of devices tested by more than three times. The increase in the number of devices tested means an increase in units per hour (UPH) production capacity, providing a productivity increase to more than 257%. In addition, the total volume shipped also increased. As a result, COPS saved almost $1M in capital expenses.

Conclusions

Automation has been used in numerous aspects of semiconductor packaging and testing to improve quality and on time delivery and to reduce costs. When implemented through a well-established and highly-integrated enhanced computer integrated manufacturing approach, the demonstrated results are highly sought after in other phases of assembly and rather easily duplicated.

References