"The TRAILER": A Fully Integrated Assembly-Test-Finish Line for Matrix Array Molded BGA

Bo Soon Chang, Vani Verma
Cypress Semiconductor
3901 N First Street
San Jose CA 95134

Biography

Bo Soon Chang started his career at Fairchild Semiconductor Korea in 1981, where he introduced new standalone automatic die attach machine and wire bonders etc. He was relocated to Silicon Valley in 1986 to join the Fairchild Semiconductor military operations at Mt. View. In 1987 he moved to National Semiconductor as an ASIC package engineer when Fairchild merged with NSC. He joined Cypress Semiconductor in 1991, where he has installed all the new packages for Cypress Semiconductor Philippines factory between 1995-1998. In 2000 he has successfully developed and executed the fully integrated Assembly-Test-Finish line in Cypress Philippines, as factory automation program manager. Currently he is working on additional integrated lines to start production in 2001.

Vani Verma is currently a senior packaging engineer at Cypress Semiconductor, where she is involved in new package technology development since 1996. She has been responsible for the introduction and development of several new package technologies, and recently in factory automation for Cypress. She holds a BS in Mechanical Engineering from University of Pune, India and an MS (ME) from University of Maryland at College Park.

Abstract:

Ever since the start of high volume semiconductor production in the 1970s, there has been a lot of effort in the area of factory automation to help reduce direct labor, improve manufacturing quality, and shorten process cycle time. For a long time factory automation meant 'automated standalone processes or machines'. This has been followed by integrating the automated standalone machines in hardware and/or in software. One of the most important roadmaps was 'assembly-test-finish integration' which would eliminate or minimize human intervention for lot tracking by manual traveller systems. This intergration has been achieved with computer-driven vision cameras and high-tech robotic handling systems. 2D dot matrix on individual substrates has been adopted for an automated lot tracking system and strip mapping is used to provide data communication capability between equipment and the factory host computer.

This paper discusses the historical roadmap of factory automation since the 1970s in Semiconductor back-end manufacturing factories. It then introduces one of the most successful factory automation projects in integrated assembly-test-finish lines. This project, named "The TRAILER" has been executed into production since Q1 2000. The sawn wafers in a cassette are loaded onto this integrated module. Then several automatic material handling systems operate all the (15) process step, and (25) equipment without any human intervention. The final products in tape&reel are ready for shipment in 24 hrs. Production thoughput is 3600 units per hour for a 48pin package. The complete line includes die attach, snap-cure, in-line plasma, wire-bond, post wire bond inspection, mold, post mold cure, ball placement and reflow/clean, package singulation, electrical test, laser mark, package and mark inspection (2D/3D), and finally tape&reel for final shipment to customer.

Finally this paper will propose the ultimate factory automation concept named 'The TRAILER-U' which is designed to achieve the

ultimate goal of "Operator-less Operation" in a Semiconductor manufacturing factory.

Introduction

Conventional semiconductor backend manufacturing facilities, at contract assembly houses as well as several OEMs have a moderate to low level of automation and equipment integration. These lines require several manual steps, and depend upon operator intervention for all operation, maintenance, lot management as well as inspection steps. Since this is a batch type process there is a high level of WIP inventory, as well as higher cycles times. This type of 'build to forecast' model of factory management is suitable for contract manufacturing where flexibility is key, and daily operation requires several changeovers in die, package and leadframe types.

Early efforts in equipment integration and automation resulted in "islands of automation" involving some automation at each individual equipment level, but not a high level of multi-equipment integration. Individual operations steps at each equipment level had been automated, but still required manual inspection, as well as lot movement and tracking. Further improvements in equipment and software capabilities have transitioned these islands to automation cells that handle large chunks of the assembly process. Each cell is a functional area and represents part of the total operation.

All these efforts of automation/integration can be classified as per ref[4]

- Process automation: focussing on automating each process from manual or semi-auto to fully automated. Yield and productivity improvements are the main driving forces.
- Process Integration: focussing mainly on integrating different processes into a single equipment. These include integrating the conveyor/robotic motion as well as vision inspection into each process, and linking this information to a cell controller.
- Cell/Line Automation: focussing on integrating the different processes and equipment into a manufacturing line or cell, coupled with a mechanized intra-cell material transportation system, and controlled by a line or cell controller, which may or may not be linked to an MES.
- MES Integration: focussing on connecting the factory process equipment and cell controllers to the Manufacturing Execution Systems (MES), to achieve a transparent and accurate real time information update to the entire organization. Such access to real time information shall help drive down cycle time, and improve yields.

Fig 1 shows a basic module functions for any equipment.

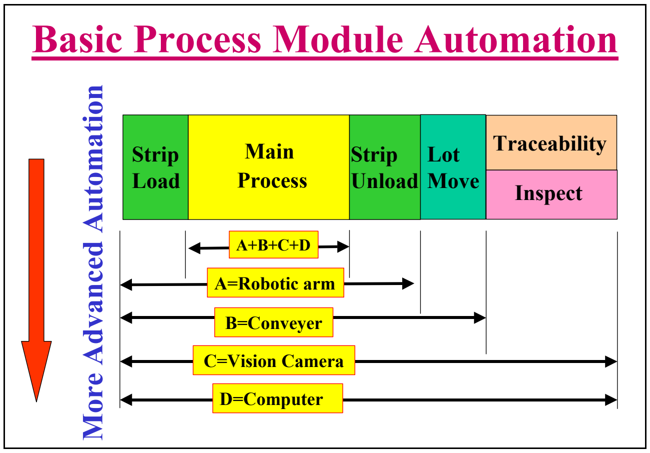

Fig 1 : Equipment Basic Functionality

Taking the example of a die attach machine this figure can be explaines as follows.

- 1970: Individual process was automated but material handling and inspection steps were manual operations.
- 1980: Material loading and unloading was automated, allowing automated indexing.
- 1995: Material transfer between islands of equipment, as well as some some level of machine vision inspection implementation. These islands of automation then grew to a fully integrated hardware link.
- 2000: Final step of software links between all pieces of equipment and their inspection systems hooking up all the information to a central MES system.

Fig 2 shows a simple representation of the historical trend in factory automation in IC semiconductor backend manufacturing.

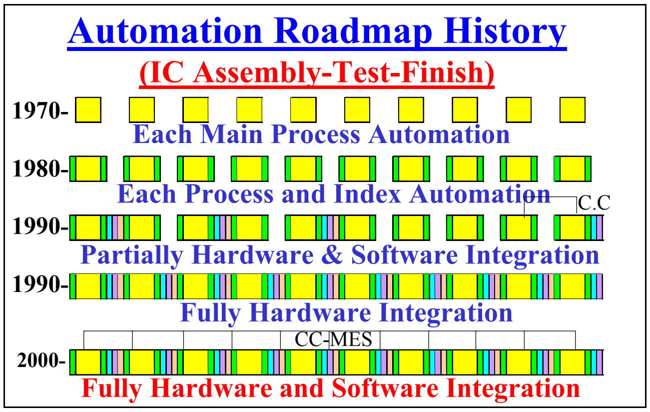

Fig 2: Historical representation Automation Roadmap

Cypress Semiconductor has taken the lead in factory automation by installing one of the industry's most advanced fully integrated assembly and test lines in their Philippines factory to manufacture matrix array molded BGA packages. "The TRAILER" as it is referred to, has integrated the final manufacturing process from die attach up to tape and reel, with a cycle time of less than 24 hrs. This line is a technological showcase module, and is virtually a "hands-free" production line.

Philosophy of "The TRAILER" and Objectives

This "TRAILER" was built with a mission to develop a cost effective advanced manufacturing line, reduce manufacturing assembly and test cycle time. A key goal was to eliminate all human handling of parts to improve the quality as well as yield. Since the line required to be a "true inline" module all offline steps needed to be either eliminated completely or integrated inline. This line would realize the industry objective of a true pipeline operation – allowing reduced WIP and inventory within the line. The reduction in inventory costs has helped lower the unit cost of the parts manufactured in the line. Additionally it also would allow true paperless traveller system in assembly.

Fig 3 shows the comparison in process flow of a conventional assembly line and "The TRAILER".

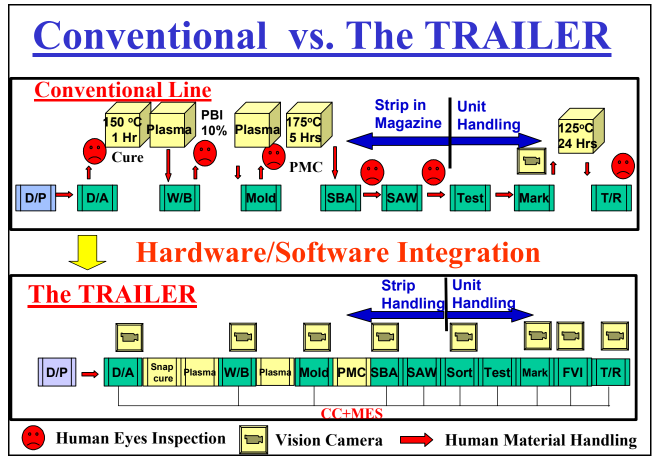

Fig 3 "The TRAILER" Process

In essence this line would better serve the end customers in cost, cycle time and quality. The success of this project also allowed transfer of this learning to conventional lines, allowing overall factory operational improvement, and a potential transition from a 'build to forecast ' to a 'build to order' operation.

What is "The TRAILER"?

"The TRAILER" is an integrated software driven, inline module with a total of 25 machines from die attach through tape and reel with a length of about 120ft, all hooked up with cell controllers to a higher level MES and factory planning information. In effect "The TRAILER" works like a single assembly-test-finish equipment integrating all the individual processes into one assembly step using this software and hardware integration. All these equipment allow a rapid package changeover within similar package size families, allowing flexibility in its production capability.

"The TRAILER" uses automated strip conveyor systems and robotic arms. It has no human handling of strips or units at all, and all human inspection, offline or inline, has been replaced with machine auto-vision. In addition to better inspection quality this also allows QA simultaneously with production except some off-line monitoring like die shear, ball shear and X-ray etc. The overall assembly process has been simplified by eliminating all offline processes, and/or reducing any inline batch processes like curing, plating and dry-baking.

The platform package used for the first line is the matrix array molded BGA. Array based package independent processing lends itself to the goal of automation, and integration. Subsequent lines shall also be based on leadframe package families. Fig 4 shows a picture of the line.

Fig 4 – "The TRAILER"

Technical Description:
In the course of this program Cypress has faced several industry challenges. Some of the hardware, process and software issues were the semiconductor industry's first attempts at solving these issues. A brief description of some of the important procedures used to avert these risks are described below along with the important learnings.

1. **Hardware:**

The line can be divided into two main sections Front of Line (FOL) and End of Line (EOL).

FOL: Die attach, snap cure and wire bond machines are available readily as an integrated module now. However there was no inline plasma clean equipment available until 1999. Since this process step is a key to wire bond reliability for laminate packages, Cypress has worked with equipment suppliers to develop the first individual strip based plasma clean machine which now very easily links in between a standard die attach cure machine and a wire bonder, in a seamless manner, and used the same material transport system.

EOL consists of mold, postmold cure, ball attach, reflow and clean, package singulation, electrical test, laser mark, final visual and final packing. Although most of the FOL equipment was easily available as integrated module, EOL equipment was still modular, and needed substantial improvements in extent of automation as well as in material transport mechanisms. Cypress has worked very closely with the EOL suppliers in both defining and designing these new equipment, to mitigate the risks. One such example would be the package sawing and singulation module. Since conventional saw machines were designed for 8" wafer sawing, the substrate cutting length was limited to 205mm. Cypress has successfully worked with its vendors to enhance the package sawing machines allowing tape-less singulation of molded strips with a length of more than 230mm.. This has helped achieve a higher unit density increasing the throughput of the line.

Both FOL and EOL equipment have been designed to allow package changeovers when required with minimal changeover times allowing the line some amount of flexibility within package families. A typical changeover in the entire line from 7mmx7mm to any other package size would not take more than only 30 minutes.

One of the keys to the success of this hardware integration has been the use of minimum vendors each for the EOL/FOL. This allows for maximum integration at each supplier site rather than at OEM site, allowing better standardization of equipment interfaces, and equipment handshakes. Although presently this may limit the capability of the line to a particular vendor's capability, eventually it promotes equipment enhancements at all supplier sites.

2. **Software**

The main challenge in the software integration of the earlier automation efforts was the unavailability of standard and compatible communication protocols between different suppliers. Equipment suppliers did not open up the protocol and interface software to semiconductor manufacturers , who have had to install their own software "link" increasing the cost of the project tremendously.

Cypress uses a standard SECS/GEM protocol for all equipment wherever possible, allowing smooth flow of data as required. Fig 5 shows a schematic of the line and software heirarchy. Several such lines can eventually be connected to a single Manufacturing Execution System (MES) via equipment Cell Controllers (CC).

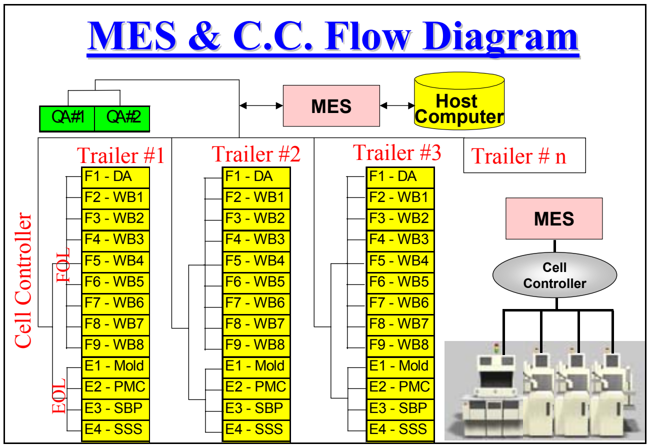

Fig 5: Software Heirarchy

In case of the Cypress line, all FOL equipment are hooked up to a common FOL cell controller (CC) which collects data from each machine using the standard SECS/GEM protocol. Similarly all the EOL equipment, are hooked up to the EOL cell controller. FOL and EOL cell controllers are then connected to a central MES system which is connected to the internal Cypress planning database. All lot movement, and process monitor details are regularly updated to the MES via the CC for every lot, and strip, using a unique code on every strip. This code is a specialized 2D dot matrix code, used similar to a bar code for products. Each 2D code with a size of 2mmx2mm can store upto 19 characters which contain all device and lot related information.

3. **Lot Tracking and Reject Managament (Ref[3])**:

This line is the first in the industry to implement complete and comprehensive strip level tracking and traceability from die attach through test and finish. Two-dimesional codes, otherwise known as Data Matrix 2D symbols are marked on every strip and read at each key process step along the line. Each strip is linked to a unique electronic strip map on the server database using the 2D code. This strip map is used to store information about the strip, its processing history, and defect information, which can be updated at each process step.

Electronic strip mapping systems track defects, maintain device identities, and provide for extensive tracebility at the strip level. The combined technology of 2D Matrix Symbology, equipment interfaces, vision systems and software has thus made it possible to automatically track the lots as well as defects on this integrated line.

An Electronic strip map is a matrix representation of good ("G") and defective or bad ("B") units on a matrix substrate or leadframe in an array-like data structure. Each strip has its own electronic strip map in the database. Fig 6 shows a typical strip map with good and bad sites identified.

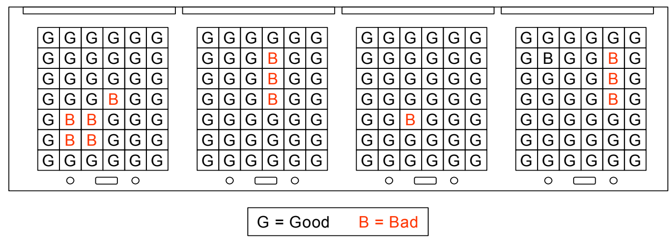

Fig 6: A Sample Strip Map

Each substrate is given a uniques ID, with a corresponding 2D matrix code, marked on each strip using a conventional laser marker. A 2D code reader is installed at the strip entry point of each equipment that will update or use the strip map. When an incoming strip is detected at the strip onload station, a signal is sent to the 2D code reader and the strip ID is read, and its content is used to associate the strip to an electronic strip map in the host database. At each process step, machine vision is used to detect defects. When a defect is detected, the equipment asks for verification of the defect by the operator. For valid rejects it then requests the host system to update the strip map through its equipment SECS interface and changes that specific label for that site on the strip map from good to bad. This helps to eliminate as far as possible wasting of additional raw materials being added to defective units.

The strip map is continously updated at each inspection step, on the strip map server. At the package sawing and singulation step this strip map is downloaded and the information is used to sort out the bad units automatically into a trash can as shown in Fig 7. Fig 8 is an overall representation of reject management in "The TRAILER".

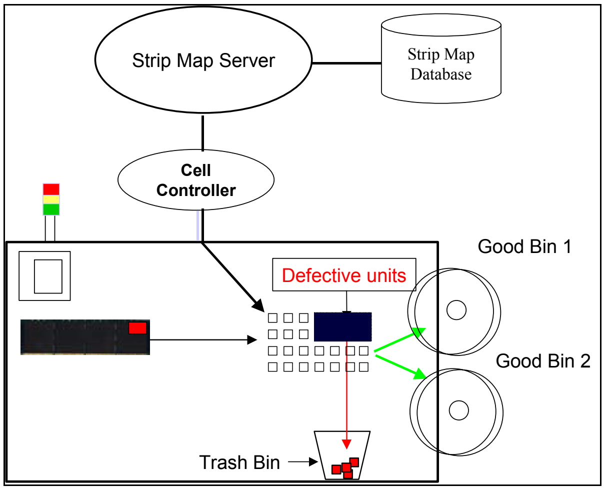

Fig 7: Reject sorting after Singulation

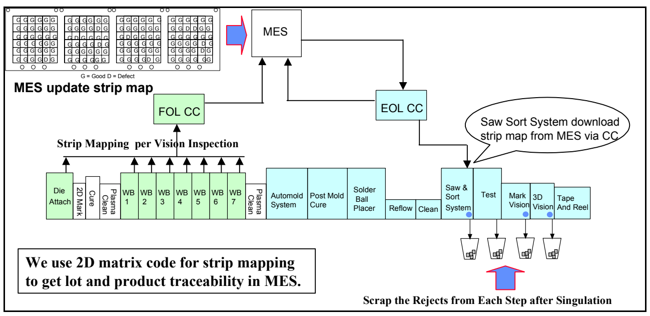

Fig 8: Reject Management Representation

In addition to just defect information, a strip map also contains information about the strip's processing history, including material and equipment details. Strip-level traceability is achieved with this map, and prevents mixing of devices. Added benefits are better defect analysis by showing exact areas within a strip, or equipment numbers which are linked with repeating defects. This feature can be used to enhance the SPC system to potentially predict failures.

Electronic strip mapping has several other advantages, details of which can be obtained in ref[3].

4. **Process:**

Fig 9 shows a schematic representation of the process flow used in "The TRAILER".

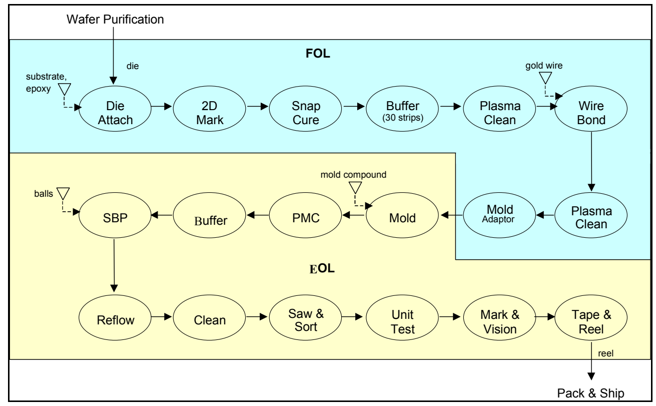

Fig 9 "TRAILER" Process Flow

"The TRAILER" process uses the standard matrix array molded BGA process flow used at most of the assembly houses with some process simplification and improvements. Some key process enhancements were in die attach cure and plasma clean, as well as in the elimination of dry bake on the packages.

D/A: Since all offline processes needed to be eliminated or minimized, standard batch type oven cure after die attach has been replaced by inline snap cure, which completes the proces in less than 90 seconds. This process also been optimized for a variety of die sizes. Material enhancements in the die attach chemistry have helped achieve this requirement.

Plasma: Standard batch type plasma clean process was replaced with inline strip plasma. Significant improvements in the plasma clean process were achieved due to uniform plasma action on both sides of strips, in a very repeatable fashion. Variability of plasma action both over a strip, and amongst several strips was shown to be extremely low, and the process is a highly controlled, and repeatable one.

Elimination of Dry Bake step by using Post Mold Cure as Dry Bake: In order to achieve the cycle time reduction target, final package dry-bake step required elimination. Cypress has achieved this by using the standard PMC process as a baking step. Although there are a few wet processes after PMC moisture absorption in these processes has been shown to be lesser than current shipping moisture level in standard MSL3 dry-baked package.

In the line molding is followed by a post mold cure cycle consisting of 175C bake for 5 hours and a 20min annealing process to reduce strip warpage, and allow mechanical stress relief. Since the total cycle time of all the EOL processes after PMC is very short, this line allows eliminating final dry-bake process step for all packages, independent of their shipping moisture level.

An experiment was run to compare moisture content in these packages after 24 dry bake at 125C, to PMC at 175C. Figure 10 shows the results of the test. Moisture content at the end of PMC is same as seen in a dry bake sample.

Since there is no dry bake step after PMC, simulation tests were also done to measure actual possible moisture absorption after PMC, especially during the wet package sawing process. Figure 11 shows the results for this post PMC moisture absorption test. It can be seen that under normal processing condition (wet package saw, followed by short 1 min bake in the test boat) moisture absorption is negligible. This supports the theory that most of the moisture absorption at this stage is on the package surface alone, and a quick bake removes all the moisture.

Current shipping moisture level allowed on existing standard parts has also been measured, with allowable 9 hrs exposure after dry bake, indicating current MSL3 shipping moisture content to be 38% of 0.35% of package. "The TRAILER" PMC followed by all the EOL processes shows maximum moisture ingress of only 0.06% of package weight, which allows complete elimination of dry bake step for "TRAILER" standard process. This is one of the key process improvements allowing major reduction in total assembly cycle time to less than a day.

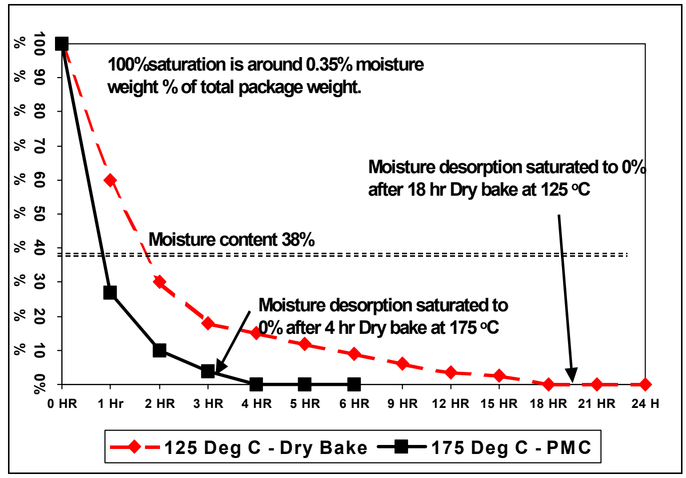

Fig 10: Moisture Desorption Comparison during Dry-Bake and PMC.

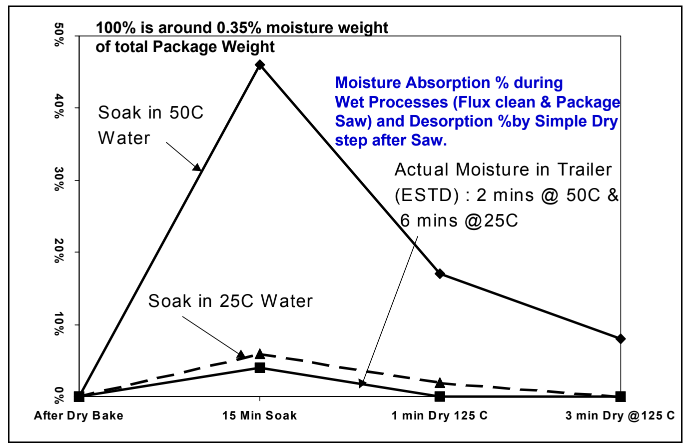

Fig 11:Moisture Absorption after PMC

5. Vision Inpection

"The TRAILER" uses machine auto-vision inspection after all major process steps. These include die attach, wire bond, molding, ball attach, and sawing. Conventional assembly equipment typically has several operators performing QA checks for post process inspections in the assembly line, requiring a considerable amount of handling of in-process substrates, while slowing down the assembly process.

"The TRAILER" has been set-up to eliminate this human inspection completely, and replace it with a sampling inspection using machine vision. This 'GOOHEI' (Get-Out-of-Human-Eye-Inspection) has been implemented in several steps. Fig 12 shows a schematic of the Auto-Inspection Development flow.

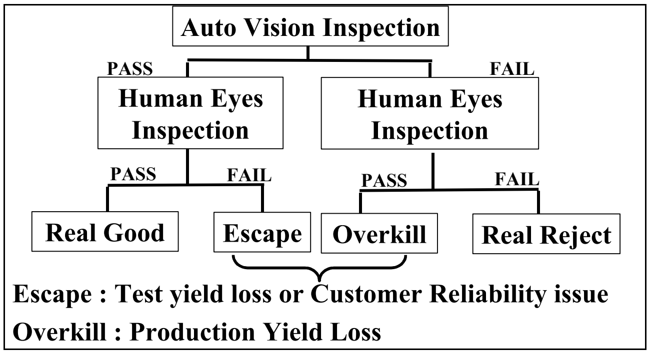

Fig 12: Auto-Vision Inspection Correlation

Initial phase consisted of performing 100% inspection using both machine vision as well as human inspection. Extensive data was collected over several weeks to compare and co-relate human inspection data with machine auto-vision. The number of a) escapees, and b) overkill was monitored, and these results have been published within Cypress. With equipment fine tuning, as well as vision inspection software calibration, the extent of both overkill, as well as escapees was reduced to virtually zero, and the present QA escape rate at PBI is lower than that seen in the conventional line.

A great deal of time has been spent in this effort, since there is no outgoing final QA check on the units from this line. The key to the success in achieving desired outgoing quality was the accurate calibration of the vision inspection systems, and their linkage to the software database for accurate reject sorting. To a great extent the development of accurate machine vision has allowed the success of the line by allowing all inspection to be automated. Manual inspection during assembly had been one of the major roadblocks to some of the earlier automation attempts.

6. **Operation:** .

This assembly line is dedicated to a great extent based on package family, for high volume runners. Some people would think that since the entire line runs as a single black box, it would be based on the "Weak Link" theory. The automated module will be only as good as its weakest link. Once the weakest link breaks down, the entire module would shut down. This would reduce production capacity immediately to zero, this shall require tying up a team of skilled technicians to bring the module back up.

However since the line does not have any need for manual operations, the minimal operators required are chosen to be these skilled technician/maintenance personnel too. This line has been designed to require about 3-4 operators/technicians only.

"The TRAILER" has started operation in Q1 2000, and has now ramped up to a target volume of 350K/week on a regular basis, based on the 7mmx7mm 48 lead matrix array molded BGA, with a total cycle time of less than 24hours/lot.

7. **Project management:**

One of the major project risk initially was the skepticism felt by both the internal management and factory, as well as the equipment vendors. This project was approved and launched in Q2 1999, and with the help of a corporate wide cross-functional project team it was successfully implemented in a less than a year. Project status and milestones were continuously monitored using the formal project review process in place at Cypress. Since this was a new technology for Cypress in-house assembly, a dedicated core engineering development team was formed, dedicated 100% of their time towards this project. Key items for development were material development and vendor selection, equipment design and selection, process development and optimization, and finally operation execution for production.

Substantial amount of process and equipment development was done at the vendor site, while the Cypress equipment was being manufactured. This greatly helped in a joint development effort for the project, and greatly reduce rework time on equipment.

Monthly design reviews were used to monitor equipment and material design progress. Additionally, Cypress package engineers were stationed at the vendor site for an extended period to overlook equipment development, and simultaneously work with them to develop and optimise the assembly processes. Most of the process development presented here is a result of joint development efforts by Cypress Package Engineering, equipment and material vendors.

What's next? "The TRAILER U"?

Now that we have discussed the existing "The TRAILER" line we would like to propose a further enhancement, taking the assembly automation to its ultimate goal, a true 'lights out' and hands free operation. This module shall be referred to as "The TRAILER-U", the ultimate in factory automation.

"The TRAILER-U" shall be a modular assembly line, with the only connections to the outside world as

- Material input of all direct and indirect materials
- Facility connections, for power, water, etc
- Material output in the form of final packed boxes ready for shipment to customer.

This module shall be a mobile/movable module which can plug into any wafer fab as a last step in manufacturing. Wafers after sort shall be sent into the line for all assembly steps from backgrind to final packing. Standard "The TRAILER" assembly shall follow inside this module and final packed units shall come out of the output end of the module.

Why "The TRAILER-U"

Fig 13 shows the comparison in the assembly-test-finish flow used today by most semiconductor manufacturers in the conventional factories, and the proposed "TRAILER-U" flow.

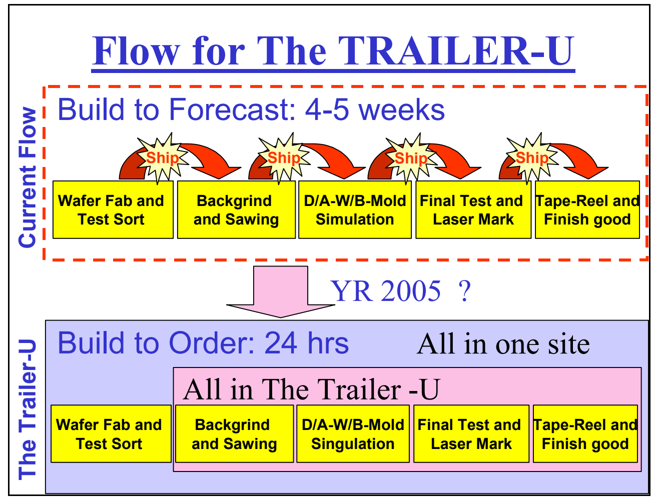

Figure 13: Flow for the "TRAILER-U"

Taking an example for a typical lot manufacturing, today a wafer may be fabricated in USA, shipped to Philippines for wafer backgrind, shipped over to Korea for assembly, shipped to Taiwan for test, shipped to Philippines for finish and tape & reel, and then finally shipped to Asia, Europe, or USA to customers. Since the total cycle time for all these operations may easily be 4-5 weeks, most of these operations are 'build to forecast' .

The proposed "The TRAILER-U" shall be a module for these operations in the wafer fab itself. Wafers coming out of fab shall be fed into the module. All the assembly processes shall then follow using an integrated line, and final product coming out of the end of this module ready for shipment to customers, within 24hours. This shall allow quicker response to customer demands, allowing 'build to order' operation.

“The TRAILER-U" shall be designed to be operator-less-operation (O-L-O), with 100% software control of the line for all operations. All equipment shall be intergrated for process from wafer-in to tape&reel. There shall be no hard changeovers. This is possible since package roadmap is moving toward array based package like matrix array molded BGA and Microleadframe package (MLF, QFN or SON) etc which require only equipment soft-changeover to convert from one package type to another.

Although the semiconductor manufacturers may not be ready for this concept today – the authors would like to leave the discussion open on whether such a "The TRAILER-U" is indeed probable, and practical in the future.

Conclusion

"The TRAILER" as it is today has been successful with the joint development by Cypress Semiconductor with its supliers.

This paper wishes to generate discussion and motivate such further common development in the industry, that would support the realization of a true cost effective automation/integration project similar to "The TRAILER-U". Future automation solutions shall be required by all semiconductor manufacturers to compete in the global marketplace.

References:

1. T. Olson, "Package-less Strip Designs Explode in Popularity", Semiconductor Magazine, Vol 1, Issue 4, April 2000, P58
2. L. Estacio, "Cypress Semiconductor Leads the Way with Advanced Strip Level Tracking", Semiconductor Magazine, Vol 1, Issue 4, April 2000, P60
3. J. Pedro, L Estacio, "Using Electronic Strip Mapping for Tracking Defects in a Fully Integrated Assembly and Test Line",
4. C. T. Choon, K. R. Vadivazhagu, N. H. Sieng, "Automation / Integration Program in TAP Reality Vs Vision", Test Assembly & Packaging 1999.

Acknowledgments:

The authors would like to acknowledge the Cypress project team and management in Philippines, and San Jose for their contribution and support to this project. They would also like to thank all their equipment and material suppliers, with special thanks to ASM Technology-Singapore, Advanced Systems Automation-Singapore, Icos Vision Systems-Belgium, EO Technics Co, March Instruments-USA, Agilent Technologies-USA, Disco Hi-Tec Japan and Shinko Electric-Japan for helping make "The TRAILER" successful.