AUTOMATING OPTOELECTRONICS SOLDERING

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ABSTRACT

The unprecedented growth in the telecommunications sector in the mid to late 1990's saw a high demand in the area of optical packages and optical networks. This sudden growth in demand for optical technology in telecom and data communication applications could not be supported by the existing manufacturing infrastructure; so, to meet the growing volume needs of the industry – the electronics manufacturing sector adopted what was still a laboratory method of assembling technique to high volume manufacturing. Since most of the assembly of the optical component and attaching the component to the board involved tedious manual labor, the process often resulted in a high cycle time and low yields. This drove the need for automated or semi-automated assembly processes that would address these issues and result in a lower cost solution to the contract electronic manufacturer.

This paper discusses one of the National Electronics Manufacturing Initiative's (NEMI) projects addressing this issue. The main purpose of this research project is to identify low-cost, high-yield, data-driven processes such as laser selective soldering and infra-red (IR) soldering to attach non-reflowable optoelectronic packages to circuit boards. Packages whose form factors are currently not standardized will be assembled, placed, affixed to board and connected using automated techniques in order to reduce costs significantly in terms of cycle time, rework, and unreworkable scrap. With the current and foreseeable lack of standard packages formats, the use of data-driven selective soldering techniques hold the promise of maintaining flexibility while replacing the manual assembly techniques that incur high costs and high yields.

This paper will discuss the need for automation – the factors supporting and challenging the needs for the same are also addressed. One of the actions undertaken to quantify and justify the need for an automated process is the creation of a Cost of Ownership (COO) model based on the industry standard SEMI E35. Results from the cost model are discussed in this paper.

INTRODUCTION

The current theme in the OE assembly industry is to drive down costs and many organizations are exploring different ways and means to achieve these goals. The recent downturn in the industry has raised concerns regarding the comeback in the OE sector. Although, this phase is temporary, it is a fact that there will be a constant demand for optical technology in the telecom and datacom sectors. The major driving forces behind this trend are higher speed, higher bandwidth and better cost-to-performance solution. Keeping in mind the current needs to reduce costs and the future demands of high volume – it is just common sense to explore different automated/semi-automated manufacturing techniques. Although changing component trends, lack of standards and standard operating procedures may hinder fully automated solutions; the option of semi-automated solutions is a distinct possibility.

Soldering Techniques for Optoelectronics

Soldering is the typical method of preference to join and connect many components of hermetically sealed OE packages. Most solders tend to require a reducing atmosphere and surface preparation, or a flux to aid adhesion but a flux is not acceptable within optical systems where trace amounts of organic on the optical train can absorb the infra-red (IR) laser radiation. Various adhesives also are used in assembling the optical train; it is essential that these do not outgas, causing contamination. Hermetic sealing is used to exclude moisture, which also can degrade optical components. Although hermetic packages will continue to be used for most long-haul telecommunications, one can expect non-hermetic packaged, SMT-assembled devices and low-cost liquid crystal polymer (LCP) packages finding increased use in OE boards.

Hermetic packages typically are supplied in a "butterfly" format, with a typical package having 14 low-frequency leads. These packages are hand placed, often bolted to the board on thermal grease, and the leads hand soldered; yields resulting are thus poor. Any process heating of the package has to consider not only the fiber, but also many of the other components used in construction. Many packages use low-melting solder or a hierarchy of solders to affix components.

Some of the most common issues in level two OE attach are listed below:

- Manual soldering is high cost and unreliable
- Solder as a joining technique is preferable to adhesive bonding or laser welding in many cases because of the high electrical conductivity, high thermal conductivity, reliability and reworkability of solder.
- Because OE components and modules often require manual mechanical attach prior to or after solder attach, manual soldering is usually performed by the same operator, and the cost is incremental. To completely remove the operator step would also require automating

the mechanical attach process, which may not be feasible because of the diversity of package & attach styles, card thickness, torque requirements, etc.
- Although some devices such as SFF transceiver packages can be reflowed, most OE packages are unlikely to withstand 80^{0}C (i.e. can not be mass reflowed) because of the fiber jacket temperature limit unless the "pigtail paradigm" changes and fiber pigtails are no longer attached. Packages may also contain low-temperature solders and precision aligned components whose alignment may be damaged by thermal expansion.
- Diverse package formats, including through-hole and SMT, may require both bottom-side (or assembly invert) and top-side soldering capability.
- Alternative joining techniques such as selective laser soldering and IR soldering are adaptable to diverse package formats but their performance is not well characterized.

Laser Soldering

The key benefit of laser soldering is the ability to apply the right amount of heat, only where needed, and without undue thermal stress on surrounding materials. Once programmed, the laser soldering system can provide repeatable results, run after run. Process control parameter flexibility is an important factor when evaluating an appropriate laser system in a particular application area. With the large variation in OE modules and components, it is difficult to predict future pad and connection geometries. A noncontact laser soldering system that maximizes flexibility will allow precise positioning to handle future needs. To obtain good soldering results without damaging the surrounding devices or materials, it is necessary to be able to manipulate the laser energy being applied.

Focused Light Beam (Soft Beam) Soldering

Here the light from a xenon-arc lamp is converged on a second focus, and the converged light is passed through an optical fiber, which is connected, to a converging lens, which focuses the light beam to a spot diameter of approximately 1 mm. The fiber optic guided light beam from a xenon lamp is used as a heating source for micro-soldering applications.

OE ASSEMBLY OPPORTUNITIES

Level 1 Packaging - Optoelectronic device assembly in packages is complex. Devices may be active (e.g., lasers) or passive (e.g., filters). Thermal transfer is achieved through solder or conductive adhesive die attach for active devices. For passive components, it is achieved through solder, welding or adhesives. Interconnection typically is by wire or ribbon bonding. A typical package may consist of a laser, laser submount, ancillary devices and an optical bench (substrate). The bench may contain other elements such as lenses, modulators, filters, etc., depending on the package type. Devices may be soldered using fluxless solder, such as Au/Sn, or mounted using adhesives. Some devices are soldered and then cleaned using intensive cleaning processes.

Given the technical requirements of OE packaging, the focus has been on meeting performance requirements and not manufacturability, leading to a predominance of gold-plated Kovar hermetic packages with numerous electrical outputs and a fiber "pigtail." The optical pigtail fiber is stripped of its protective coating and glued or soldered into a metal, plastic or ceramic ferrule. The end of the fiber may be ground cylindrically to compensate for the elliptical pattern of the laser diode output configuration. The fiber is introduced through a port in the package, precisely aligned, and then welded, soldered or glued into place using a heated positioner or laser welding system. The active fiber core in a 125 µm area may be only 6 to 9 µm in diameter and, even with the most accurate positioning, only 75 percent of the light can be captured.

Many opportunities for selective laser soldering exist in component attachment to the optical bench, as well as optical fiber ferrule attachment.

Level 2 Board Assembly – The vast majority of assembly operations for an OE to printed circuit board (PCB) assembly consist of standard surface mount technology (SMT) processes, with two major exceptions. The first exception is the attachment of the OE module to the board. Due to its thermal sensitivity, the OE module will typically have to be hand inserted and either hand, wave or selective soldered. The second exception is the handling of fiber. In many OE PWBs the fiber is attached to the OSA in the module. This attached fiber is called a pigtail. The fiber must be handled with care. It cannot be bent around a radius less than about 75 mm and the fiber end must be protected with a cap. Efforts are being made by assemblers to develop techniques to carefully handle the fiber during assembly.

However, the assembly of OE boards is not a big stretch from standard PCB assembly. Typically the vast majority of the assembly is handled in a straightforward SMT approach, such as shown in Figure 1. The OE components will typically be hand inserted and wave soldered, or hand soldered due to their thermal sensitivity near the end of the assembly process.

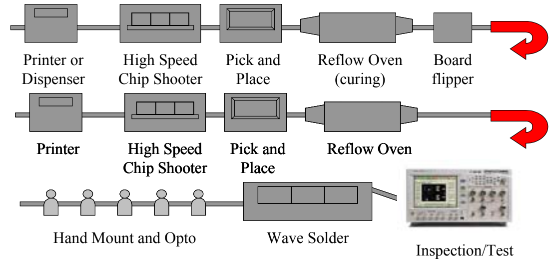

Figure 1. Typical OE assembly line

Laser selective soldering has shown its merits in other packaging and assembly areas through its ability to deliver precisely programmed and directed heat to where it is needed — exactly the conditions required for a heat-sensitive OE package.

Assembly Issues

As with any type of assembly, the problem areas in OE packaging can be broken down into one of the three areas: component, interconnect and design. The quality of the components supplied by the component vendor is not as high as that of the electronics industry – this may necessitate the need for incoming quality inspection to identify the acceptable components and use them for production. The two main methods of interconnecting OE components are using optical connectors and fusion splicing. Contamination and scratches in the connector, and inconsistency in the quality of the splice during the splicing process have contributed to a highly variable process. The high degree of variability in component specifications, the form factors and the lack of focus on design for manufacturability further challenge the assembly process.

The testing of OE technology is more challenging than other technologies, primarily because of the rigorous performance requirements of OE systems. There are a number of other factors that increase the difficulty of testing including the high cost of test equipment, the length of each test cycle, and the high speeds at which test processes are carried out given the stringent conditions. In addition to tests performed to estimate splice loss the finished boards are subject to functional testing at speeds that include temperature-biased conditions. Testing is often the bottleneck in the process thus requiring many test sets to reduce cycle time. Moreover the test "suites" required for OE boards and systems are typically a completely new skill set. Hence, it is almost impossible to enter this part of the business without a team of engineers with expertise in OE testing.

Is Automation the answer?

The electronics manufacturing industry has enjoyed automated production systems for many years due to diligence engineering complemented by standardization of components, production systems and metrics. Moreover, the Design for Manufacturing (DFM) handoff from the Original Equipment Manufacturer (OEM) to the Electronic Manufacturing Service Provider (EMS) further solidified automation in electronics manufacturing. Contrastly, the opto business still remains fragmented and labor intensive with only islands of automation seeming apparent. Unfortunately, the disparate segments of the OE industry barely employ DFM today; moreover the high margins enjoyed by businesses leaves little room to consider automation. The lack of standards for component, module, PWB and system assembly and test, also inhibits the growth and quality of product in the OE assembly industry. Although there is enough consciousness in the industry among groups such as NEMI, IPC, NIST, and IMAPS to initiate roadmaps and guidelines and many initiatives that would work towards standardization.

Given the current economic conditions, cost is the most important factor in making emergency broadband services attractive and affordable. To be able to offer these services at a lower cost and make it more widespread there has to be an immediate need to reduce costs and streamline the entire process. This necessitates the use of automated processes to manufacture the optical modules and the assembly of these modules onto printed circuit boards. An important factor in reducing costs for OE devices and the entire assembly is a higher level of automation. Automation will facilitate the high volume production of components, improve manufacturing repeatability, reliability and yield and result in lower cost per device, as well as reduced footprint and time-to-market.

Inspite of the decline of the global OE component market from \$8.9 billion in 2000 to \$7.6 billion in 2001, most analysts predict a rebound in the near future, and automation will be the key driver of the recovery. As the demand for bandwidth continues to increase worldwide at over 50% per year, there is significant opportunity for suppliers of OE components. The OE industry is today where the semiconductor industry was twenty-fice years ago, with many of these modules being assembled largely or partly by hand. This entails placing discrete components, such as electronic ICs, active OE components, such as the laser diode and photo diode, and truly optical components, such as filters, lenses, and fiber, into a single functional block.

The design for higher volume assembly is especially critical for lower-end OE modules, including those that are used in metro or LAN applications. Here, the higher volumes are critical to meet market demand and to drive costs down further. At the same time, the somewhat relaxed performance requirements of these markets also allow completely different packaging approaches.

In high-end modules, high data rates and high optical coupling efficiencies are usually the primary design constraint. However, in lower-end modules, both the requirements are less stringent. The change in packaging approach impacts both material usage and component requirements

COST of OWNERSHIP (COO)

The current economic situation coupled with the collapse of the telecommunication sector has made the contract assemblers to focus on cost effective manufacturing methods and systems. This can be achieved by reducing cycle time, increasing first pass yield and moving towards automated or semi-automated manufacturing processes. However, although the inherent benefits of automation are too basic to be listed and any investment in automated systems has to be justified given the cost-consciousness enforced by today's market conditions. Therefore it is necessary to perform a cost-benefit analysis of the proposed manufacturing process with the existing operations. The mathematical model used in this study is based on the Semiconductor Equipment and Materials International (SEMI) E35 standard for calculating the cost of ownership of automated manufacturing equipment. Adoption of a common standard such as the SEMI E35 allows access to the same decision making tools for the equipment manufacturer and the end user of the equipment. Besides this, the basics of the model are quite simple and the COO can be calculated by dividing the total costs by the total number of good parts produced. A few factors that sum up to the total costs are the fixed costs, labor costs, cost of consumables and other materials, cost of yield, rework and many more. The total number of components produced is a function of cycle time, equipment utilization, uptime, first pass yield etc. Some of the input parameters may be easily obtained than others. Figure 2 shows some of the elements in terms of the difficulty associated in establishing various costs.

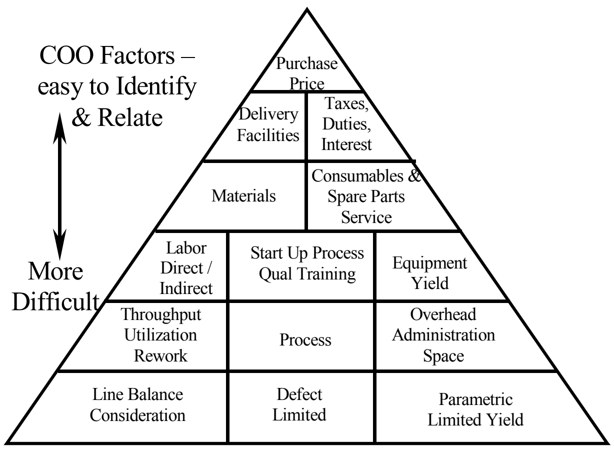

Figure 2. Difficulty of some of the elements of cost

The numbers obtained from a cost model are only as good as the input provided; therefore it is very important to share information between the equipment manufacturer and the end user.

CASE STUDY

Let us consider the assembly of a butterfly package onto the board – typically the process would consist of three distinct processes – mechanical attach to the board, optical connection and the electrical connection. In most cases these operations are done manually which usually results in large process variation, low yields, and thus high cost. In this case let us compare a proposed semi-automated process that would automate the soldering operation only. So, the existing workstation that has two manual operators will be replaced by the semi-automated process that will require one operator. The following items listed in Table 1 highlight a few input parameters in the model:

Table 1. Few input parameters

Cost of Component being manufactured ($)	1500
Equipment Cost ($)	150000
Operator Labor Cost ($/hr)	25
Process Engineering Cost ($/hr)	100
Operational time (hrs/year) @ 2 shifts/day, 6 days/week	4992
Yield	60%-Manual, 91%-SemiAuto
Cycle Time (parts/hr)	4-Manual, 8-SemiAuto
Total Cost of Consumables per year	32500
Useful life & Depreciable Life of Equipment (yrs)	5
Employee Productivity	0.977
Equipment Utilization	0.88

The labor rates and rates for floor spaces are based on North American rates. It is assumed that no parts are scraped and 100% of the defective parts are reworked. Also the line is assumed to be functioning at full capacity thus producing around 39,800 components per year. Thus based on the above-mentioned parameters the total cost of ownership of a workcell that would consist of an operator and an automated equipment would be $8.523 per part as compared to $17.846 in a fully manual process.

The following graph (Figure 3) shows the contribution to the costs for these assembly techniques. In the figure below Y corresponds to yield costs, L+R corresponds to labor and recurring costs and F is the fixed cost.

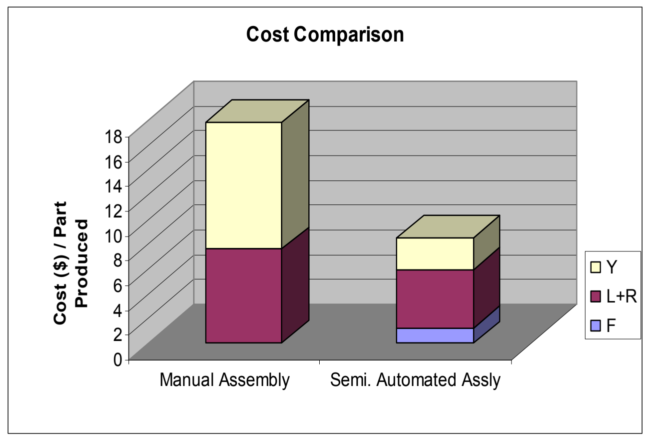

Figure3. Contribution of different factors to the total COO

It is seen in the above figure that there are significant cost savings with a small step towards automation. The labor cost in the semi-automated process comes from the manual assembly required for the non-soldering operations.

Furthermore, cost savings is seen with a minor improvement in yield as seen in Figure 4.

Figure 4, compares the yield costs – the costs due to low yields in a manual process is almost four times more than the yield costs of a semi-automated process.

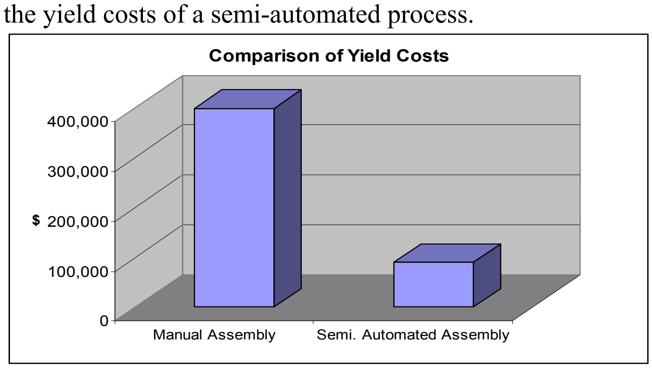

Figure 4. Comparison of Yield Costs

A model is only as good as the input provided to the same, every effort has been made to provide realistic numbers in this case, although the actual numbers may be tough to obtain.

There is no doubt that there is a significant cost benefit associated with automation. However, taking in to account the current economic conditions and given the relutance of organizations to invest in automation it is important to assess the benefits taking into account the current manufacturing volumes. The following graph (Figure 5) shows the decreasing cost per part produced with respect to the increase in the total number of components produced per year.

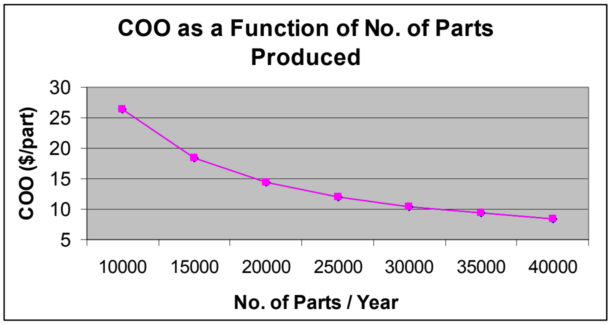

Figure 5. COO as a function of number of parts produced

MANUFACTURING OVERSEAS

The dramatic drop in sales revenue in the electronics industry over the past two years has driven drastic restructuring and a huge move to outsource manufacturing operations to the far east, particularly China.

However, despite its less expensive manufacturing base, China' research, development, and design expertise may fall short in the area of OE. Traditionally, cost reduction in this area is addressed through automation. Today, as much as 60-70% of the passive components are manufactured in China, but there is no indication of moving the production of active components.

A quick check with near approximate values for labor rates shows tremendous cost savings if boards were assembled in China. As trivial it may seem, the move to assemble OE boards in China requires developing an entire supplier base, educating the engineers and training the operators to mention a few obstacles. However, it is very important to understand that although labor costs are significant the most significant parameter is perhaps the yield, which essentially reflects to the quality of training provided, infrastructure and adherence to procedures in a manufacturing operation.

NEMI INITIATIVE

The National Electronics Manufacturing Initiative (NEMI) has numerous technical initiatives that address the above-mentioned issues, primarily aimed at providing guidelines for standardization and developing new processes for the future. A short survey of NEMI members regarding automating the soldering operation showed keen interest in the subject and at the same time it also highlighted the need for justifying investment in capital equipment. The COO model created as a result is discussed in the preceding pages and is made available to NEMI members.

Future work regarding the same will involve evaluating alternate joining techniques such as laser, IR soldering, hot bar bonding etc.

CONCLUSION

The OE industry is at a stage where there are several routes forward. As we drag out of the "tech-wreck" and survey the telecom/datacom infrastructure business, we can see signs of recovery but no rapid ramp-up in the immediate future. This has a number of ramifications for the industry as it prepares to restaff and retool.

First, much of the future production will continue to use existing technology – butterfly packages, fiber loops, splices, and connectors. It's relatively expensive but flexible. Semi automated systems are being designed for assembly, but manual intervention is still the common practice, and it is difficult to develop full automation systems without standardization. Standardization is necessary for automated assembly and test systems to be developed, and to generate customer acceptance of a new technology. Although automation of parts of the process is feasible and economic we will continue to have "island of automation" in a manual assembly environment.

Secondly, it is very important to close the communication gap between automation solution providers, end users and the component manufacturers – this is because the near future will increasingly use "pluggable" formats like Xpak where the optical assembly is separate from the electronic assembly. Multi-source agreements (MSA) have been established for a broad family of the resulting lower cost modules, such as transceivers and transponders. MSAs are available for small form factor (SFF), parallel optical, Xenpak, Xpak, and a host of other module configurations. Since package standardization offers cost reduction through fewer part numbers, more volume per part and standardized assembly processes, it seems likely that the more complex function, high-end modules will utilize these packages. Many datacom modules are now being designed to simplify assembly – modules with connector receptacles are now widely used. Such modules offer the promise of eliminating pigtail fiber management at the board assembly level.

NEMI's work on "making OE mainstream" is appropriate to all these technologies – fiber management, signal integrity, splicing, automated selective soldering, and board technology, plus their comprehensive roadmap review will be published in the near future. IPC has also been tremendously active with the IPC-STD-0040 and their roadmap which has similar conclusions but from a different perspective.

ACKNOWLEDGEMENTS

The authors sincerely thank Peter Arrowsmith from Celestica and Sundeep Nangalia from JDS Uniphase for their valuable input and technical guidance.

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