# Stepping Up To Laser Processing for Flex

How to effectively supplement your flex circuit production capabilities with laser processing

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Engineered for Production.

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# Foreword

*Looking out across the landscape of the electronics value chain, it can sometimes be difficult to anticipate the opportunities and challenges that manufacturers will face next. In the race to better leverage the ever-increasing speed, expanding access and enabling power of the internet, manufacturers of the circuits, components and devices that are such an indispensable part of our daily lives are under pressure to do more, do it faster and do it more profitably. Yet, even though it may be hard to see where the next challenge will come from, one thing is certain; the market pressure on manufacturers to deliver smaller, higher-quality and more-capable devices will only increase. And it will force them to continue to innovate and keep up, or lose out to those that have. ESI has been helping our customers address these challenges and successfully innovate to create value for over 70 years. As the leading provider of solutions for flex PCB laser processing, we continue to offer customers a unique combination of experience, technology and expertise across a wide range of FPC applications.*

*Whether you already have experience with FPC laser processing or are just getting started, I think you will find the information in this eBook helpful. It's meant as a "how-to" guide to understanding the options, trade-offs, challenges and rewards of supplementing your flex circuit production capabilities with laser processing. We look forward to helping you optimize your FPC production as we continue to deliver the tools, solutions and support that enable you to power the innovation that will keep you ahead.*

**Michael Burger**

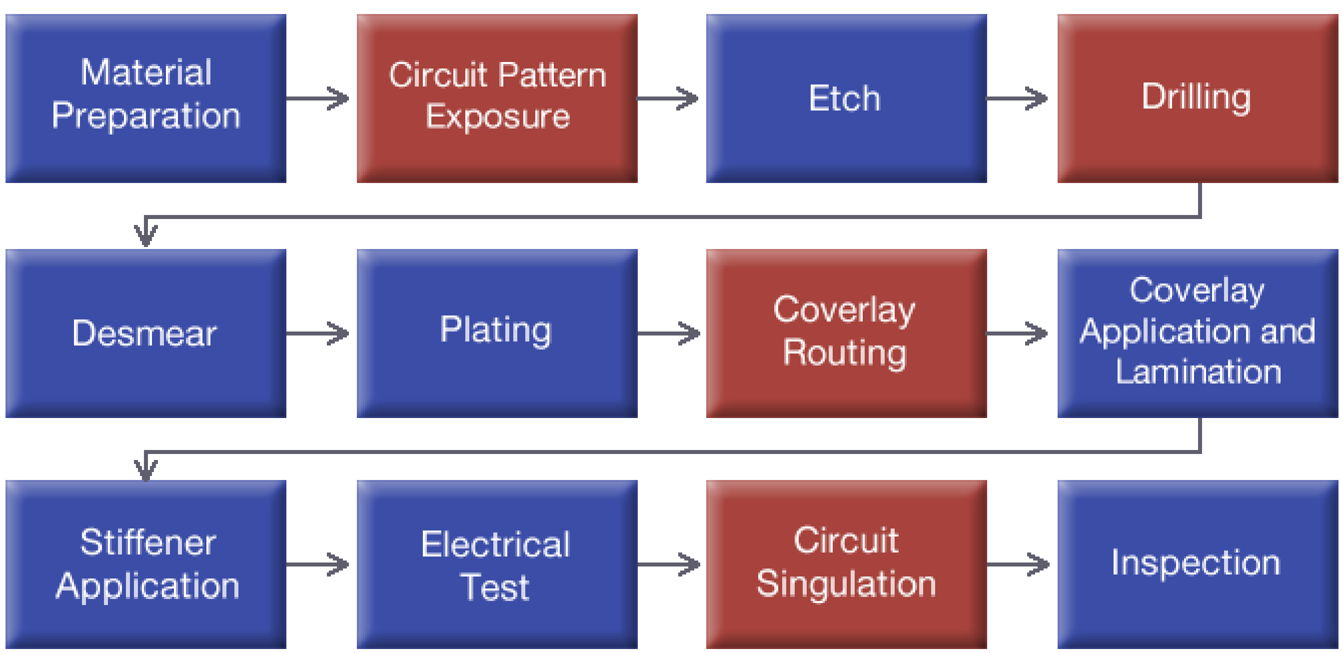
Chief Executive Officer, ESI

# Chapter 1: Laser technology for flex processing
## Manufacturing flow and considerations in adopting laser processing capabilities

Market demand for smaller, faster, wearable, lighter and more powerful devices continues to keep PCB manufacturers scrambling to keep up as they evolve and adapt their manufacturing capabilities to meet changing customer needs. But keeping up with the dizzying pace of change in the world of PCB manufacturing need not be a daunting task. Employing laser technology is one of the best ways to stay current, as it enables printed circuit manufacturers to achieve manufacturing flexibility and agility with more accurate and/or smaller features than is possible with traditional processes. This eBook will arm you with the information you need to understand the opportunities and applications related to implementing flex laser processing and to optimize your results.

Adding flexible circuit laser processing to your production capabilities can pay big dividends. It helps widen the scope of potential customers you can service and extends your reach into additional markets for which you otherwise wouldn't have had a solution.

There are several steps in the flexible circuit manufacturing process where laser processing can add value. This series will primarily focus on the laser micromachining processes related to drilling, coverlay cutting, and circuit singulation using general laser micromachining systems. Keep in mind that many of these same principles are also relevant in laser production of rigid boards and even to LDI.




***Where laser technology fits in the flex processing manufacturing flow.***

## Laser micromachining drivers

Printed circuit manufacturers typically invest in laser micromachining systems when punching, mechanical routing, or mechanical drilling becomes infeasible or is no longer cost effective due to one or more of the following issues:

- Features become too small or complex for drill/routing bit diameters and/or die punch manufacturing capabilities.
- Trace width/spacing requires that the size of via pads be reduced beyond the registration capabilities of mechanical drilling.
- Part tolerances require machining accuracies beyond mechanical processing capabilities.
- The number of vias per panel increases sufficiently to make mechanical drilling less cost effective than laser drilling.
- Customer demand includes blind via processing in thin flex material beyond the depth-control capabilities of mechanical drills.
- High product mix and/or fast turnaround time requirements become incompatible with the long lead times and expense associated with fabricating dies for coverlay cutting and circuit singulation.

If you're facing some or all of these challenges, it's time to consider a laser processing solution. But before launching into that endeavor, take the time to inform yourself about the right way to adopt laser processing capabilities. This eBook will help you understand the implications while answering some important questions related to key topics:

- **Calculating and Optimizing Production: How do you calculate and optimize total system cost of ownership and cost per panel?** We review the high-impact profitability factors in choosing and running your system.
- **Readiness and Site Preparation: How do you ensure that your facilities are ready for the introduction of laser processing?** We address shop floor concerns such as HVAC, temperature control, debris removal capabilities, power requirements and more.
- **Installation, Training, and Initial Operation: How do you get your new system installed and processing those first runs?** We focus on installation best practices, system verification testing, training and safety.
- **Process Development: How do you develop your process library?** We review several best practices, tips and tricks for typical flexible circuit laser processes.
- **Maintenance and Servicing: How do you minimize system maintenance and repair costs while prolonging its useful life?** We highlight best practices and considerations in the "care and feeding" of your laser processing machine.

# Chapter 2: Calculating and Optimizing Production
# How to calculate and optimize total system cost of ownership and cost per panel

## Introduction

When it comes to laser processing for flex PCB, how do you calculate and optimize total system cost of ownership (TCO) and cost per panel (CPP)? While every company has their own methods of making purchasing decisions and controlling expenses, this chapter will review one possible framework for doing both in the context of UV laser flex processing.

## The Basics

Let's start with some basics. Two fundamental equations may be used to calculate TCO and CPP:

$$TCO=C_F+C_R+C_Y$$
$$CPP=TCO/((L\times TP\times Y\times U))$$

where $C_F$=fixed costs, $C_R$=recurring costs, $C_Y$=yield costs, L=production life of system in hours, TP=throughput in panels per hour, Y=product yield, U=system utilization.

Total system cost of ownership takes into consideration all fixed, recurring and yield costs over the course of the system's life. Cost per panel amortizes that cost of ownership over the total number of good panels processed over the course of the system's production life. Now that we have established these equations as our framework, let's dig deeper to understand how UV laser flex processing impacts each of these individual TCO components.

## Fixed Costs ($C_F$)

Aside from the obvious system purchase price and its associated depreciation expense, there are a variety of other – although generally lesser – fixed costs to consider. These can include system installation and personnel training costs, costs to qualify the system prior to running production, floor space allocation or overhead allocation costs, as well as costs related to upgrading facilities to meet the system's site requirements. Of these costs, manufacturers most often neglect to think about the costs associated with upgrading facilities. Those new to flex circuit production will need to consider upgrading their facilities to avoid common and costly issues in production.

Typical areas to watch for in laser system site requirements include electrical, vacuum, compressed air, environmental air, as well as temperature and humidity. Neglecting any of these can result in poor product yield, scrap, or even damage to and downtime on your valuable UV laser system. Poor electrical power quality and sporadic brownouts and blackouts can often result in unexpected system errors, yield issues and, scrap. Vacuum facilities with inadequate pressure and flow can prevent the system's debris removal from doing its job, which includes clearing the panel of extraneous material and preventing that debris from adhering to and permanently burning onto the system's sensitive optics. Furthermore, insufficient vacuum can also be the cause of panel movement or non-flat panel material on the system's vacuum chuck, resulting in yield loss.

## Air Flow and Air Quality

Compressed air is often used on UV laser systems to purge the laser and optics areas inside the system, and in some cases to assist the debris removal vacuum in removing debris from the processing area. Given that this air also flows over and around the system's sensitive laser and optics, not only air pressure and flow are important, but also air quality. While many laser tools will include filters to clean the incoming air, it is possible to negate the benefit of those filters if that air is of especially poor quality. This is equally true of the facility's environmental air quality. Despite air purging designs that are common in UV laser processing systems, environmental air containing high levels of particles and oils can result in high maintenance costs associated with more frequent optics cleaning and replacement. Finally, flex material processing requires strict control of temperature and humidity ranges and stability. The accuracies that are typically required for flex processing coupled with flex material and high-accuracy laser systems' sensitivity to both temperature and humidity changes result in a need for much more stringent environmental control than for other types of PCB processing.

## Recurring Costs ($C_R$)

UV laser flex processing systems are like any other capital equipment in that they have recurring utilities, personnel and maintenance costs. Of these, maintenance costs and personnel costs should be given special consideration.

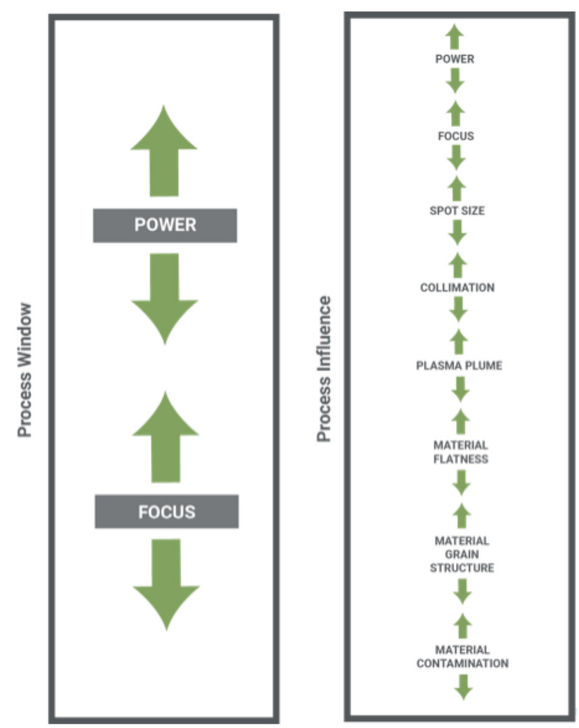
## Consumables

Laser and optics replacement costs dominate maintenance costs for such UV laser systems. Both must be considered consumables. Typical high-power UV lasers used for flex processing have lifespans ranging from 1-2 years, although those lifespans may be drawn out if the laser is not in 24/7 use or the laser power used for processing is much lower than the system's work surface laser power specification. Most optics maintain a similar replacement cadence, which may be longer or shorter depending on the compressed air and environmental air quality, the amount of debris generated by the laser process, the frequency of preventive maintenance optics cleaning, among other factors. The system supplier's highly trained field service engineers generally perform system troubleshooting and major maintenance, while the customer's maintenance team will perform more frequent and simpler preventive maintenance tasks. Most laser system suppliers will work with their customers to identify the best service plan to meet their customers' needs, with consideration for factors such as quantity of systems, usage, location, and budget. Full service plans including or excluding lasers, time and material plans, block labor plans, preventive maintenance only plans and other service plans are all typical options. Many suppliers also include a one-year warranty with their system.

## Consistency

A range of factors impact laser processing yield. As discussed earlier, ensure that site requirements are met as your first and fundamental step to ensuring acceptable yield. After this, robust processes must be developed for your particular applications that can accommodate for slight variations in materials, as well as in laser power, laser spot size, laser focus, debris removal, etc.

Material and system variations exist even in the most well-designed, well-manufactured and well-maintained materials and systems. However, beyond developing robust processes to accommodate variability, try to actively reduce variability in the laser-material interaction process. Specifying and achieving lot-to-lot material consistency avoids the need to redevelop laser processes for each new lot. Demanding accurate and responsive laser power control from your laser system will ensure that the process stays consistent over time and over multiple systems. Verifying the laser system's dynamic positioning accuracy and its ability to compensate for upstream panel warping via scaling, rotation, parallelogram, and trapezoidal transforms also ensures that laser processed features consistently align to other features on the board.




***Robust processes actively control for power and focus changes with a robust process window to account for both measurable and immeasurable process influence.***

## Training

Sufficient training for your laser process engineer and choosing a supplier with a wealth of UV laser process development experience will have a direct positive impact on your bottom line. Trade offs must be made between throughput and yield during process development. Choosing a system with a good production track record in processing your specific applications and materials is one step to ensuring that the system will enable high yield and high productivity on your own production floor. Equally important, however, is choosing a reputable supplier that is experienced with your specific applications and materials and able to offer support to your process development team in order to get the most yield and productivity out of your investment.

## Automation

Finally, if you are considering complementing your laser system with an automated material handling solution such as a roll-to-roll handler or stack handler, don't forget that it also has a critical role to play in ensuring high process yield. Especially as materials become thinner and more easily damaged, your material handling solution should be chosen not just on lowest cost, but also on its ability to handle material without wrinkling, scuffing, or other damage at the maximum throughput available through the laser system you are considering.

## Components of Cost Per Panel (CPPC)

Cost per panel amortizes the total cost of ownership over the total number of good panels processed over the course of the system's production life. That number is calculated by first establishing the total number of panels – good or bad – that could be produced by the tool, multiplying the total tool lifespan by the rate of panel production (throughput). Then multiply that number by the yield rate in order to calculate the total number of good panels that could be processed in that time. Finally, multiply that figure by the system utilization rate in order to determine the number of good panels that would be produced in the time the tool is actually in active production. Having alreadydiscussed yield in some detail above, let's review the three remaining components of CPP – system production life, throughput and system utilization.

## System Production Life (L)

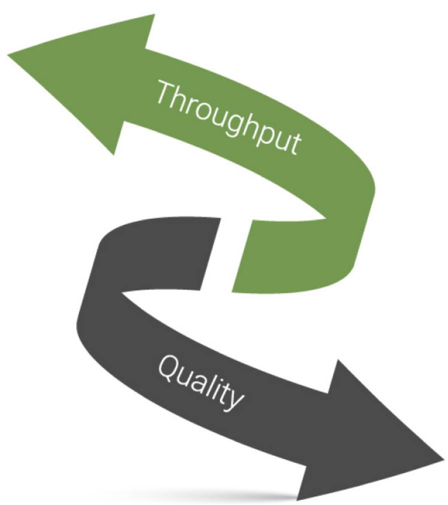
While you currently may just be thinking about the demand spike or latest new application that spurred your need for a new tool, this system purchase is an investment that should last you for many years. As a result, keep the factors in mind that are involved in system production life. Obviously, the tool should not fall apart after the first year, un-repairable and useless. Beyond that, however, are some less obvious factors to consider.

## The Right Service

Judge how likely it will be that your system supplier will be in business and committed to service your tool throughout the tool's expected production life. Does the supplier have a history of long system support? Has it been in the UV laser processing business for many years? Can you expect the supplier to continue to support the training of your personnel throughout the system's life? Beyond your current production application needs, think about the market trends in your business. Verify that the system you plan to purchase will keep up with those evolving market trends. The last thing that you would want is to only get 2-3 years of production life from your investment because it can no longer process the latest materials or applications with sufficient quality or yield. Assuming your company needs to keep up with the latest trends to thinner material and smaller feature sizes, look for systems that have – at the least – excellent power control, fast and accurate beam positioning capabilities for small features and high accuracy.

## Throughput (TP)

Similar to yield, laser process throughput is highly impacted not only by system capability, but also by the process parameters that have been developed for the given material and application. On the topic of system capabilities, laser systems will differ in many ways especially with respect to their beam positioning, controls software, and laser technology and those technological differences will each respond differently to each given application and tool path.




***Processes must be developed with an understanding of the process quality and throughput trade offs.***

On the topic of process parameters, given that each laser system has different benefits and constraints and each material, application, and quality specification will require different processes, each supplier will need to develop new processes for your specific applications. As a result, it is extremely important to compare systems on a mix of several different representative production applications, materials, and tool paths rather than using a simple test grid for throughput and quality comparison purposes.

Your supplier's process development team will typically require the minimum-acceptable quality specifications in order to strike the best balance between throughput and quality. With these real-life applications scenarios, you have the opportunity to test not only the system capability, but also the supplier's process development team capabilities.

## System Utilization (U)

System utilization is the percentage of system time spent in production. It can be calculated via the following formula that subtracts the percentage of time spent on unproductive activities:

$$U=1-T_U/W$$

where $T_U$=unproductive time per week (in hours) and W=168 hours (total number of hours per week).

Unproductive time ($T_U$) consists of scheduled and unscheduled downtime, nonscheduled time, standby, and engineering time. Scheduled downtime can typically be estimated by reviewing the system's preventive maintenance guide as requested from the supplier prior to purchase. Unscheduled downtime, on the other hand, is typically less easy to judge. The supplier's service team should be able to provide reasonable estimates of service event frequency and how long it takes, on average, to perform major interventions such as replacing a laser. System troubleshooting, on the other hand, is often a tricky business that has uncertainties associated with it.

The major factors related to ensuring minimal downtime include the supplier's service team location, training and experience level, as well as the availability of a local spare parts hub that stocks the most critical system components in order to avoid long transit and customs clearance delays. In addition, look for good system logging and diagnostics functionality in order to ensure that system errors can be more easily identified and analyzed both by the local service team and – if need be – by the supplier's remote design engineering team.

Besides system-related issues, facilities can also contribute to unscheduled downtime.

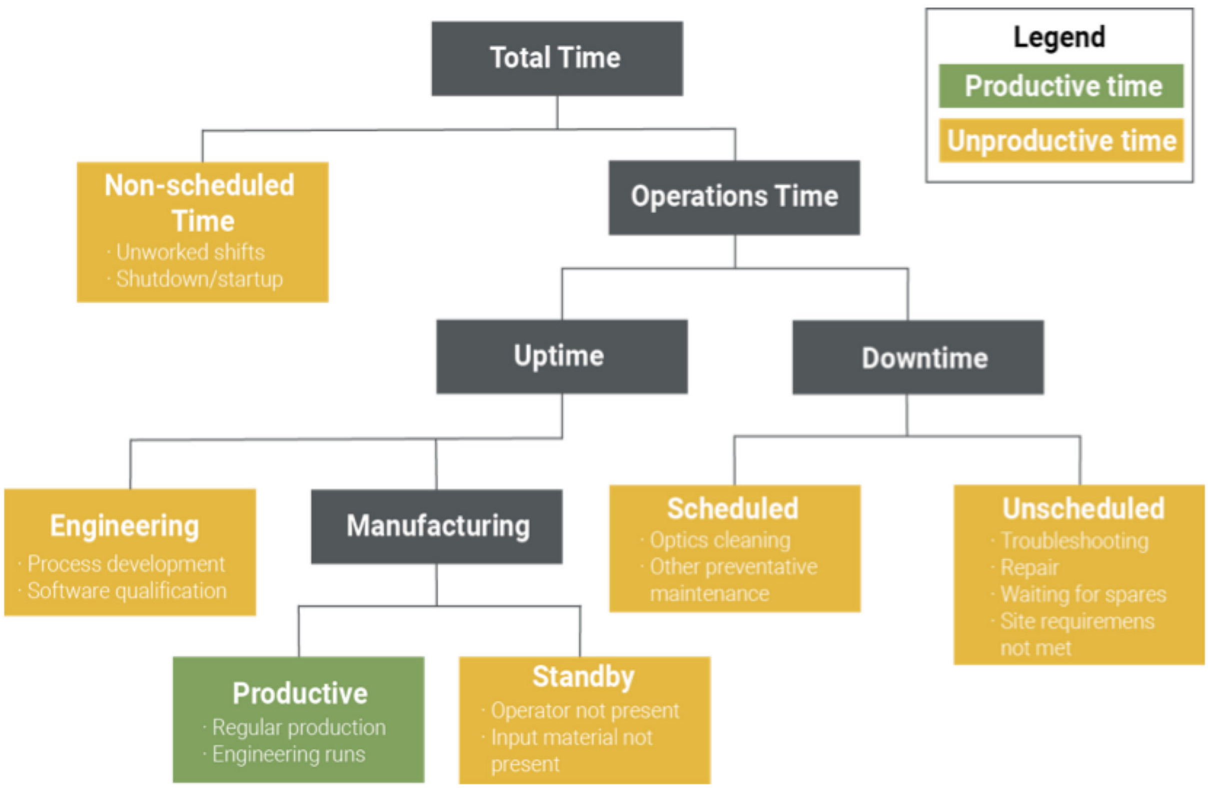
Power outages or brownouts, out-of-tolerance temperature, humidity, vacuum, compressed air, or air quality each can negatively impact the system utilization. Finally, given the fact that it can be difficult to differentiate between a system problem and a process issue when diagnosing yield issues, it is also important that your supplier have an experienced applications engineering team that can help diagnose potential issues with your laser process.

Nonscheduled and standby time will be related to your own business practices, operational efficiency, and level of demand rather than system-specific factors. If running single shifts, non-scheduled time will be significant, while 24/7 operation will minimize that time. Similarly, uncovered lunch breaks, meetings, or unavailability of input material will impact standby time.

Engineering time on laser processing systems is dominated by process development time. Especially when introducing and qualifying new processes to your product mix, process development activities can take days, weeks, or even months. In order to minimize that time, especially if you plan to purchase multiple tools, make sure that the systems are designed and the supplier's service engineers are trained to ensure that the same process can be used across multiple tools. Furthermore, in order to aid and speed process development, look for a system and associated software that has been designed for easy process development, including easy generation of process window tests to ensure robust, high-yield processes.

## Application Engineering

Each manufacturer will have different needs, especially with regard to applications, but also in terms of product mix and volume, personnel costs and plant location. Similarly, each system and system supplier will have different benefits for a given set of applications, product mix and volume, and plant location. As a result, it is imperative to compare system process throughput, quality and consistency using a representative set of real production applications and associated tool paths. Furthermore, given the




***A modified SEMI E10 framework for equipment utilization***

sophisticated nature of UV laser processing systems, make sure your supplier can support you not only with an experienced and knowledgeable service group, but also with a savvy application engineering team in order to support the inevitable process issues that will crop up over the course of your tool usage. In many situations, it is difficult to tease apart system versus process issues. An experienced supplier can help guide you to the quickest possible return to production.

Once you have purchased your system, your quest for lowest cost of ownership and cost per panel has not ended. Ensure that your facilities meet the system site requirements in order to avoid future yield issues and excessive system maintenance costs and downtime. Also ensure that your process development team is sufficiently trained to best optimize your processes for both throughput and yield, as well as to avoid the common mistake of sacrificing process robustness for process throughput.

Whether you are considering a new UV laser processing system or are attempting to improve the COO and CPP of an existing system, keep this framework and these many factors in mind. A holistic approach that considers system, supplier, personnel, and facility costs, capabilities, and limitations will serve you well and ensure you and your company gets the most out of your investment.

## Summary

This chapter reviewed one possible framework of total cost of ownership and cost per panel, including their main components. When reviewing typical UV laser processing systems, upfront costs and maintenance costs make up the largest percentage of cost of ownership, with the majority of maintenance costs related to laser and optics replacement. As such, system and supplier longevity are especially important in order to depreciate these costs over the longest possible period. This longevity includes not just the length of time before the system becomes irreparably broken, but also the supplier's ability to continue to support the tool as well as the system's ability to keep up with the market's evolving needs.

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*Semiconductor Equipment and Material International. "Specification for definition and measurement of equipment reliability, availability, and maintainability (RAM)." SEMI E10-0701. San Jose, CA, 2000.*

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# Chapter 3: Readiness and Site Preparation
# Getting your facilities ready for the introduction of laser processing

**Focus:**

- Electrical power configuration
- Vacuum removal capabilities
- Compressed air availability
- Environmental air management
- Temperature and humidity level controls

It's fairly common for manufacturers to overlook some of the cost factors associated with upgrading facilities to accommodate the addition of new processing methodologies. For PCB manufacturers considering the addition of laser processing for flex circuit production, there is an entirely new set of considerations to be aware of and to manage effectively if they plan to step into flex PCB laser processing. Getting a handle on those issues early helps to avoid common and costly issues once they're actually in production.

In this chapter, we'll consider the factors associated with actually bringing flex laser processing systems on site so you can begin to reap the benefits. Neglecting site preparation can result in poor product yield, scrap, or even damage to — and downtime of — your valuable UV laser system. Furthermore, it is often extremely difficult to isolate process issues from system and site issues once you're up and running. So, it's obviously best practice to ensure that your site fully meets requirements before issues such as lower yield or high scrap affect your production efficiency.

## Temperature and humidity control

Flex material processing requires an environment with stable temperature and humidity levels. Since the laser system and the flex material itself are highly sensitive to changes in temperature and humidity, a much more stringent environmental control regimen is necessary as compared to other flex PCB processing methodologies.

As flex processing continues to push the envelope of finer lines, smaller vias and smaller pads, the level of drilling accuracy must also increase. Given the high-accuracy requirements associated with flex processing, it's necessary to minimize the impact of shifts in humidity and temperature — not only in the drilling room but also for downstream processes.

System accuracy and spot quality can be affected by temperature changes due to a variety of reasons, such as alignment issues associated with the thermal expansion and contraction of the system frame, a shift in optics alignment, thermal errors, etc. Certain optics coatings can also be compromised by shifts in humidity. When combined with the impact of those same temperature and humidity shifts on the dimensional stability of your flex material, accurate drilling requires the control of many variables.

Air conditioning vent placement and associated lack of air mixing is often overlooked when considering temperature control. Your thermostat and temperature monitor might be registering minute temperature fluctuations quite some distance from the air conditioning vents. However, if your laser system is placed directly underneath one of those vents without taking measures to baffle and mix that cold or hot air with the ambient air, your laser system could be experiencing much higher temperature fluctuations! Similarly, be aware of any large heat-generating sources and how they are placed and vented relative to your laser tools.

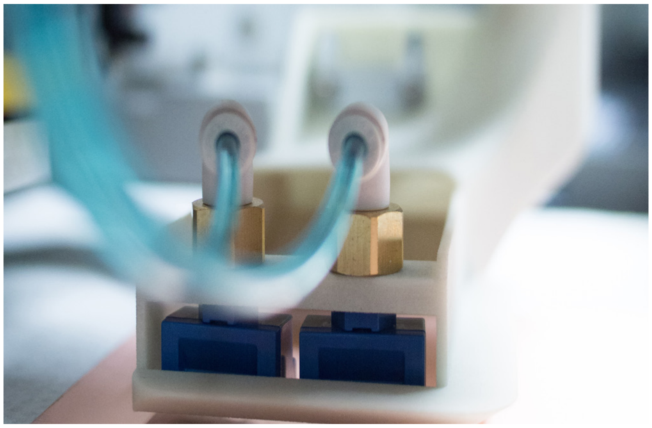
Another commonly overlooked issue is related to the environmental conditions that existed when your system was initially calibrated. If your laser system was installed and calibrated in summer during high factory temperature and humidity levels, you may find that letting the temperature and humidity significantly drop in winter in order to save on utility costs can cause problems. Similarly, if you plan factory shutdowns where you turn off your HVAC or have just moved the system into your facility, make sure to let the system "soak" and stabilize at the set temperature for several hours prior to calibration or processing.

## Electrical power

Poor power quality, not to mention power outages and sporadic brownouts, can result in unexpected system errors, yield issues and scrap. While much of this can be controlled through the use of quality voltage regulators, power conditioners and uninterruptable power supplies (where needed), it's best to start at the source and ensure that clean, conditioned and reliable power is made available to your laser processing systems. While blackouts are perhaps the most obvious contributor to scrap, brownouts and power quality issues can be the most problematic. This is due to the fact that the symptoms of brownouts and power quality issues can look very similar to process and system issues while in fact the root cause is poor input power. Electrical service should be provided by a qualified electrician and should meet local code and regulation.

## Vacuum

Flex circuit laser processing systems typically include debris removal vacuum functionality and a vacuum chuck to hold the flexible, malleable and easily-damaged sheets in a stable and flat position. While many equipment manufacturers offer the addition of a standalone vacuum pump, it is often more cost-effective to use the facility's existing vacuum — especially if considering a multi-system installation. Doing so, however, carries some risks if the implications of multiple systems on a single vacuum line are not considered. When installing your new laser equipment, take time to review your facility vacuum



*ESI model 5335 debris removal nozzle*

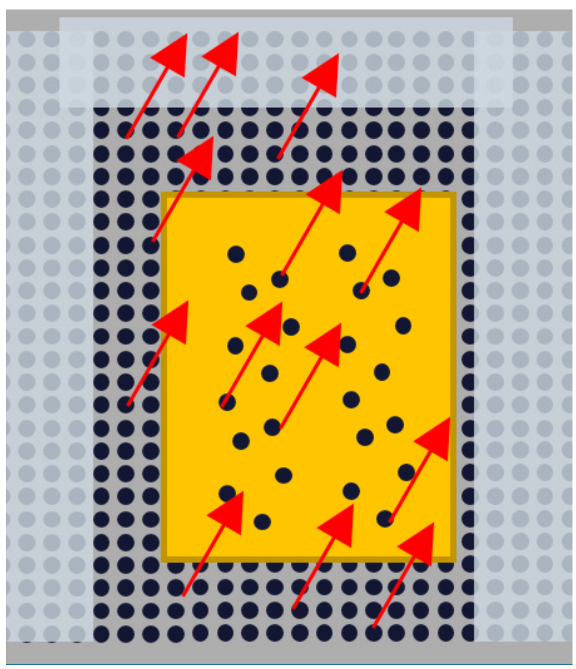
capabilities and plumbing architecture. Before the final step of placing your systems into production, test vacuum pressure and flow rate at each system input when all systems are in operation to verify your facilities under a realistic production scenario.

During equipment capacity expansions, pump and plumbing that may have previously met system requirements might be insufficient given the addition of new equipment. Also, additional vacuum branching after expansion can cause overall vacuum loss that results in insufficient pressure.

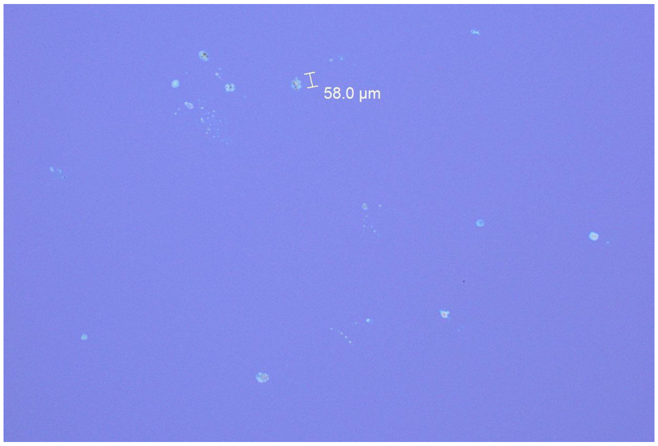
Another common mistake is to test the vacuum pressure and flow when other systems have their debris vacuum off or their chuck vacuum fully covered, both of which do not represent the worst-case production scenario. As a practice, vacuum pressure and flow should be tested again after all equipment is hooked up to the vacuum system and in operation with real panel material — ideally with a production application that exposes the highest number of open vacuum holes on the vacuum chuck.

Vacuum facilities with inadequate pressure and flow can prevent the system's debris removal from doing its job properly. This can result in damage to the system's optics over time since the particles ejected during laser processing are not effectively removed, can settle on the nearby optics, and eventually burn onto those optics. Missing or incompletely-drilled vias can also be caused by poor debris removal due to optics contamination and the debris and processing plasma interfering with the laser reaching the work piece. Finally, insufficient vacuum can also be the cause of panel movement or non-flat panel material on the system's vacuum work table resulting in a decrease in yield.

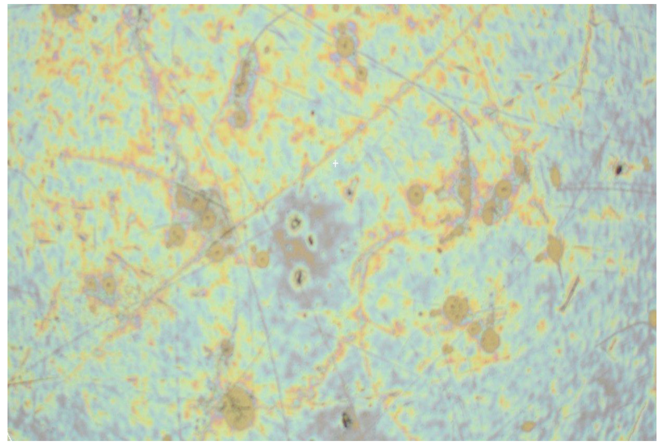
Each of these issues can result in system downtime due to time spent on extra optics cleaning or root cause investigation. Even worse, more frequent costly optics replacement may be necessary if these site requirements are not satisfied.



***Test with worst-case typical vacuum leakage on all system vacuum chucks with debris removal on for all systems***




*Debris that attaches to optics due to poor air quality or insufficient vacuum...*



*...can become a major issue if left unchecked.*

## Compressed air

Compressed air is often used on UV laser systems to purge the laser and optics areas inside the system and — in some cases — to assist the debris removal vacuum in removing debris from the processing area. Given that this air also flows over and around the system's laser and optics, one must take into account not only air pressure and flow but air quality as well. The use of membrane type oil/water separators is essential for ensuring laser-quality compressed air.

Standard pneumatics engineering protocols should be followed to allow for proper draining of oil or water from air lines prior to entering the system.

## Environmental air quality

The issue of air quality isn't limited to the quality of compressed air. The facility's environmental air quality is also a factor. Despite air purging designs that are common in UV laser processing systems, environmental air containing high levels of particles and oils can result in high maintenance costs caused by the need to clean and replace optics more frequently.

## Floor vibration

It is also important to minimize floor vibration which can impact system accuracy. Systems can be located anywhere in the manufacturing building from ground floor up to the top floor of a multi-story building. While well-designed systems include vibration-mitigation mechanisms like vibration-absorption foot pads, those are typically designed to only isolate the rest of the factory from vibration from that particular system itself. Obviously, one should avoid placing the laser system near heavy machinery, too close to multiple mechanical drills, or next to other heavy vibration-inducing factory machinery such as the facility vacuum pump, air compressors, or backup generator — especially if you are placing the tool on a higher floor. Typically, the placement of multiple laser systems in the same area does not cause issues, and it is common to find single shop floors containing as many as 40–50 laser systems.

## Summary

With so many processes to keep track of in a flex manufacturing line, it can be easy to get lost in the details and begin to rely on your suppliers to address any issues that might crop up. However, given that laser processing equipment and flex materials are both impacted by your facilities, your attention to and investment in clean, stable, and robust facilities and support equipment will quickly pay off in less downtime, higher yield, and — perhaps most importantly — fewer headaches!

# Chapter 4: Installation, Training and Initial Operation
## How to get your new system installed and processing those first runs

With your factory now prepared, let's review the issues associated with getting your new system installed and running properly so that you can start processing your first runs.

### Focus:

- Installation best practices
- System verification testing
- Training
- Safe system operation

### Getting it there

As with any large piece of manufacturing equipment, just getting it onsite can be the first challenge. Your system supplier should be able to help coordinate transportation of the system to your facility. Working together with your supplier, your shipping/logistics partner and, if necessary, a local rigging company will ensure a smooth delivery and setup process.

***Poor handling during shipment can result in severe equipment damage***

The International Commercial Terms (Incoterms) associated with your system purchase will outline the tasks, costs and risks associated with the system's shipment. It's a document providing details regarding the location to which the system is being delivered and includes the point at which final transportation and any associated insurance become your responsibility.

Due to liability concerns, you will typically need to take responsibility for movement of the system once it reaches your facility. Unless you can provide your own in-house rigging, it is a good practice to stage the equipment at your local rigging company's facility. This is especially beneficial if multiple systems are expected to arrive at different times. This will minimize the production interruptions typically associated with systems being repositioned on the production floor. Such off-site staging is also useful if you do not have an interim storage facility that meets the system storage environmental requirements. For instance, laser systems can become damaged as the result of being exposed to conditions such as high humidity and extreme temperatures or — even worse — being stored outdoors in pouring rain!

Once the system has arrived at your facility — and before moving the uncrated system into position on the production floor — it is wise, and often required as part of the supplier contract, to perform a thorough post-shipment inspection of both the crate and system before taking ownership; noting any damage and comparing the system's condition with the pre-shipment inspection. Since poor handling of the equipment can also result in less-visible system damage to the sensitive optics, the laser, and other precision components, many equipment manufacturers will apply shock and tilt sensors to the shipping crates or the equipment itself in order to document the proper handling of the equipment in transit. If anything looks out of order — whether it be a tripped sensor or obvious physical damage — make sure to get photographic evidence and alert your supplier as soon as possible in order to sort out a recovery plan.

Final system uncrating and unpacking should be done in the presence of your supplier's service team. In addition to inspecting the system for damage after uncrating, you should verify the presence and condition of the sealed environmental barrier bag that was used to prevent the contamination of the system's optics during shipment.

After system uncrating, inspection, and subsequent move to the system's ultimate operating location, system installation/commissioning will typically be performed by your supplier's field service team. This will consist of placing and leveling the system and connecting it to the services that have been prepared for the system's arrival. Electrical power, compressed air and vacuum services should have already been made accessible at the system's ultimate location and those services should be consistent with the system's site requirements.

## System and site verification testing

After the system has been connected to the required facility services, your supplier will typically perform a thorough set of compliance, safety and diagnostic tests designed to verify that both the installation site and the system itself meet the agreed-upon requirements.

## Site requirement compliance

These tests will ensure that the installation site complies with the system's requirements as discussed in the Chapter 3 of this eBook. These verify environmental factors meet specifications such as temperature and humidity. They will also ensure the availability and quality of services such as vacuum, compressed air, etc.

## Safety

At a minimum, safety tests will ensure that the system's laser beam is safely confined to the processing area inside the system and is not escaping through any gaps in the system's cabinet when the shrouds and doors are closed. They also ensure that safety interlocks are functional and trip at the appropriate time and that all Emergency Machine Off (EMO) buttons are operational.

***A typical EMO button***

## Major subsystems

Verifies the proper functioning of subsystems such as computer, power supplies, sensors, debris removal, etc.

## Laser and laser chiller

Verification of laser and chiller functionality, including laser power levels, chiller temperature stability and chiller coolant levels. This ensures that the laser will continue operating according to its specifications and avoids premature service interventions.

## Optics quality and alignment

Laser spot quality and laser power transmission through the optics path can be affected by optics that may have become contaminated, damaged or misaligned during shipment. Given the importance of laser spot quality and spot size in high-quality via formation, verification of items such as optics alignment, beam diameters and laser spot quality is critical.

## Motion/accuracy/kinematics

Verification of stages, galvanometers, and camera accuracy calibrations as well as motion and control loop functionality ensures that the process features will be placed accurately and formed correctly with precise beam positioning.

## Laser power stability and control

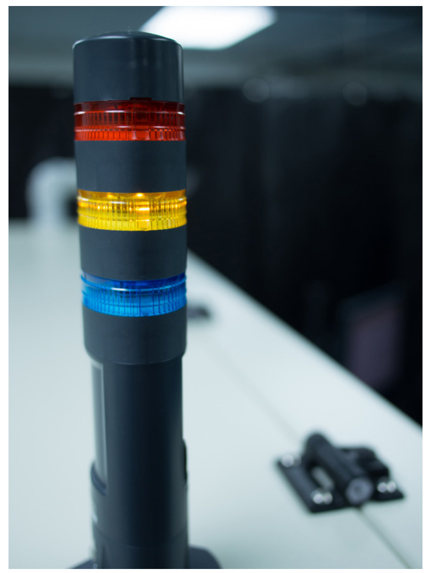
Correctly calibrated and functioning power control ensures the best possible yields, especially for blind vias and other depth-limited processes on sensitive materials. At an absolute minimum, calibration of the system's power measurement sensors against a certified, calibrated external power meter is required.

Other tests related to system laser power control and laser power stability further verify how much laser power variability your process engineers will have to build into their process development calculations.

Assuming these tests completed and no issues are documented, the system has met the supplier's own system specification criteria. If demonstration applications had been developed by your supplier prior to the system sale, this is often a good time to verify that the applications show similar quality on the system that you are purchasing as compared to those previously seen in the demonstration results. After the completion of these tests, the system will typically be released for your use.

## Training and safe tool operation

Now that the system is ready for use, how do you use it? At a minimum, your operators will require training related to basic tool operation. On-site operator training is typically offered by your supplier's service or applications team, complementing a copy of the operator guide. These should cover safe operation of the tool, including laser, electrical, mechanical, chemical safety, functionality and the proper use of safety interlocks and EMOs. This should also involve an explanation of how the system shows that the interlocks are defeated — indicating dangerous Class 4 system status, rather than safe Class 1 operation. Furthermore, system startup and shutdown should be covered, including how to put the laser into standby mode and understanding the time required for the laser to warm up and stabilize after returning from standby. A review of the operator interface — how to log in, how to initialize the system and process panels, how to start and stop jobs, and other production features — will similarly be covered in a typical training.



***Example of an LED light tower with operation status (red, yellow, blue) LEDs***

Beyond operator training, assuming you will not exclusively use the system for a single application for the life of the tool and have already been given the production process for that application, it is important to train your process engineer or process engineering team on the development of new processes. This is equally important if your team is new to laser processing or if you are switching from one laser supplier or system model to another. Each system will have different operating characteristics and capabilities that impact the process, as well as different software functionality for process development.

There will always be certain guidelines that can be followed for flex laser processing, some of which will be discussed in more detail in the next installment of this series. A typical applications training outline might include the following concepts:

## Tool overview

How does the laser energy get from the laser output to the work piece? How is power controlled? How is the material kept flat and in place during processing? How does the debris removal mechanism work, how is it used, and what is its importance in consistent processes and optics lifetime?

Creating a laser drill file from a CAD file: How does one define alignment points, offset, rotation, and scaling methods? How does one set laser focus? How are process parameters and tooling motions (e.g. circles, spirals, punches, routs) added and modified?

Developing processes for blind and through vias, routing, and/or patterning: What are the available knobs to affect the process, such as tooling motions, laser power, laser repetition rate, process velocity, and laser focus? How does one best combine various tooling motions for any given process? How do blind and through processes differ, and what are the associated tradeoffs between throughput and quality/yield? What is fluence, and how does it affect material removal? How does one ensure a high yield process with a robust process window?

For both operator and process engineer training, there are many important details to cover. Make sure that the personnel to be trained can fully focus on the training. At a minimum, they should be relieved of other engineering or production responsibilities during the training times, and ideally, distractions such as the use of mobile phones should not be allowed in the training room.

## Summary

With your systems in place and your operators and process engineers fully trained, your team is now equipped to start developing and running production processes. However, it is common for questions to arise as you start operating the tool. Don't hesitate to stay in touch with your supplier. Especially for those new to laser processing, questions are normal.

# Chapter 5: Process Development
Tips and tricks for developing effective flexible circuit laser processes.

## Focus

- Developing a process library
- Best practices

## Choices, choices, choices. What defines a good process?

An important point to consider is that the definition of a good process may vary between companies, the product being processed, the phase of a project and/or production backlog, and even from individual to individual. In theory, there are always trade-offs to be made among variables such as process development duration, cycle time, quality and yield.

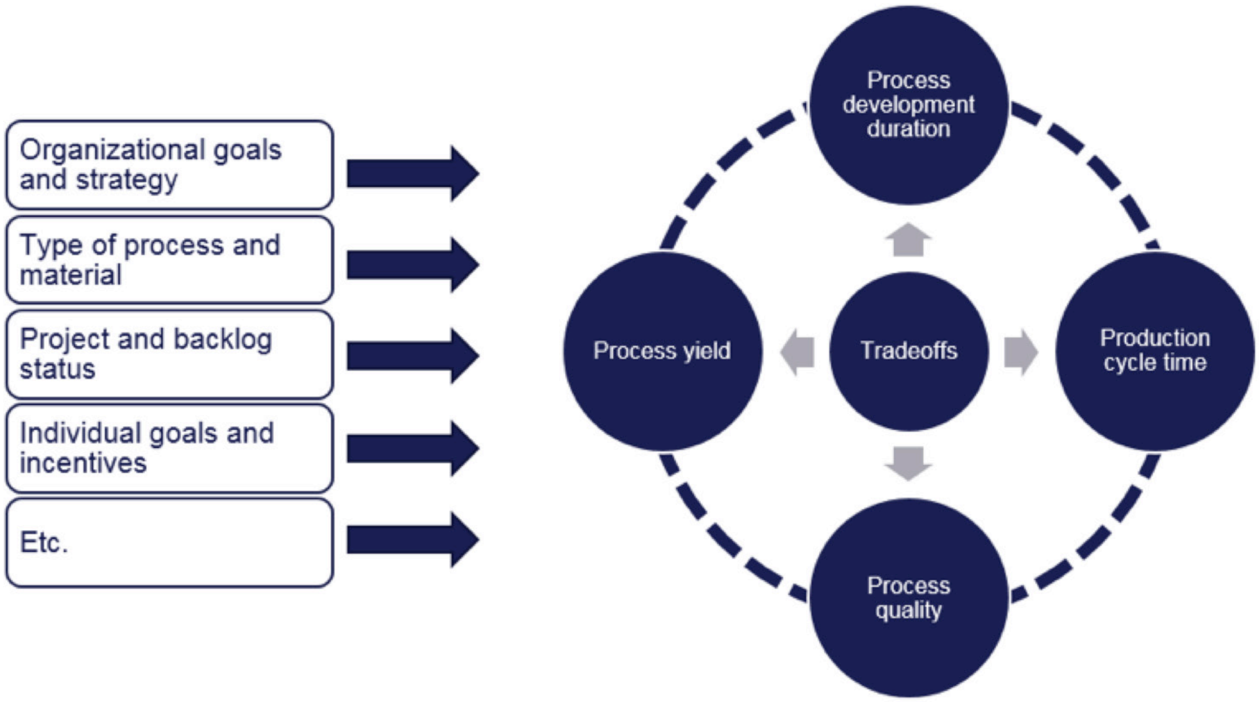
Looking at this question from an organization's perspective, the process should support the organization's goals and strategy, each of which have an impact on company priorities. One company may prioritize speed to market over yield and process throughput cost. For this company, a good process might be defined as the first process to meet the minimum product requirements, allowing the company to quickly deliver on their commitments. Another company may prioritize quality and yield over other factors. For this company, a good process might be defined as one which exceeds certain stringent quality and yield requirements, despite higher process cycle times. Yet another company may prioritize process cycle times or other factors. Which model does your company fit?

The product being processed can also have an impact on how a good process might be defined. For complex multilayer build-ups where yield loss in the final product can skyrocket, a "good" laser process may require a focus on higher quality than an equivalent double-sided FPC laminate process. Alternatively, the product material might be more expensive on one product than another, in which case yield might be prioritized higher. The phase of a given project or the level of production backlog may similarly impact the priority of quality and yield, productivity, or time to develop such a process.

At a human level, one can even think about how different employee roles and responsibilities impact this question. Depending on organizational incentives, management structures, etc., different individuals may have different personal priorities that can influence their perception of a good process. A process engineer being pushed or incentivized to get the finished product out the door and qualified as quickly as possible may prioritize process development speed over yield or process cycle time. The factory manager, on the other hand, may be watching over total production costs and total production output and, therefore, prioritize these factors differently. Ideally, in a well-run organization, all employees will be aligned to the organization's goals and strategies and be cognizant of the product, project phase, and product backlog. Often that is not the case and needs to be continuously monitored and worked on.

## Why are there tradeoffs in process development?

As discussed above, different circumstances will impact the relative priority of process development duration, process cycle time, process quality, and process yield in defining a good process. The reasons why it's not possible to deliver equally on these factors may not be clear to everyone.




***Many factors impact process tradeoff choices..***

## Process development duration

It takes time to develop processes. In an ideal world, one would have access to a library of canned processes for every possible combination of via size, material, depth, quality, and target drill time. The massive diversity in process requirements and continuous evolution of the market prevents a single such library from being developed. Furthermore, developing processes for more demanding applications — whether due to sensitive materials, unusual feature characteristics, or stringent process quality, yield, or cycle time requirements — often requires significant trial and error to meet all the success criteria. As a result, each manufacturer will need to develop processes that best suit their needs — developing their own process libraries based on their unique set of products, customer requirements, cost profiles, market conditions, goals, and strategies. In building up such libraries and making use of known-good processes, process development duration can be reduced over time.

## Process cycle time

Laser processing cycle time can be broken down into a few categories: time spent drilling features (drill time), time spent moving the laser between features (move time), time spent aligning to features (alignment time), time spent placing and removing the material on the system work table (handling time), and any time that the system spends performing additional tasks. Process development will generally affect drill time, sometimes also move time, but generally none of the other factors which are mainly characteristics of the system and handling methods.

## Process quality and yield

Process quality specifications differ between flex manufacturers. This can be traced back to both the diversity in company priorities as well as the diversity in downstream processing. Different downstream processing, such as types and effectiveness of patterning, desmear, etch, plating, and other processes, will all impact the laser drilling quality characteristics necessary to achieve a given end-product yield.

Similarly, yield requirements — the required percentage of product output meeting quality specifications — can differ between flex manufacturers. While all manufacturers prefer high laser processing and end-product yields, sometimes the cost profiles of yield loss versus process cycle time will favor a faster process over a few percentage points in yield.

## Example tradeoffs

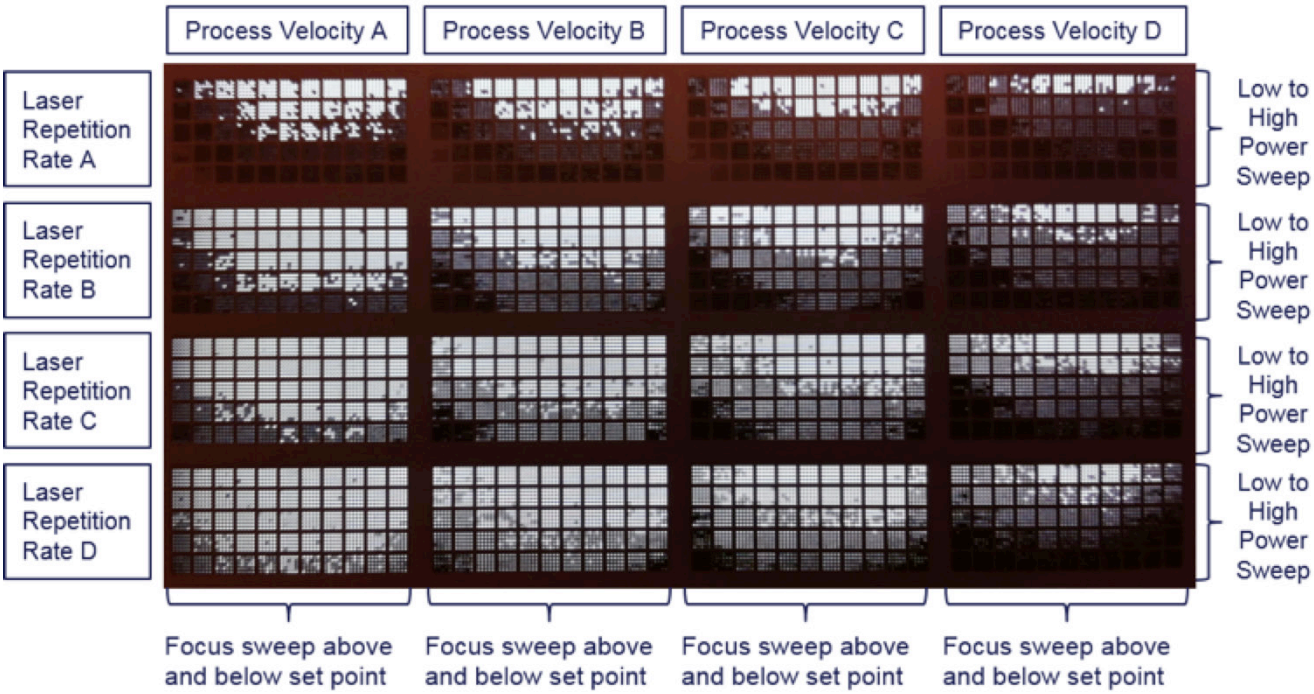
In an extreme example of the tradeoff between cycle time, process development duration, and process quality/yield, a process engineer might choose to use a single laser pulse for a large-diameter through-via process. It would be an extremely fast process (cycle time) and have been very quick to develop (process development duration) but be very unlikely to meet any of the process quality or yield requirements for this application.

In an alternative extreme example, favoring process yield and extremely stringent process quality requirements, a process engineer might spend years making adjustments before meeting the necessary quality requirements, running thousands of panels through the entire manufacturing process flow to understand and improve on the end-product yield.

In practice, process development activities fall somewhere in between these extreme examples, balancing the relative priorities of each of these key criteria.

## Flex laser processing basics: Developing a process

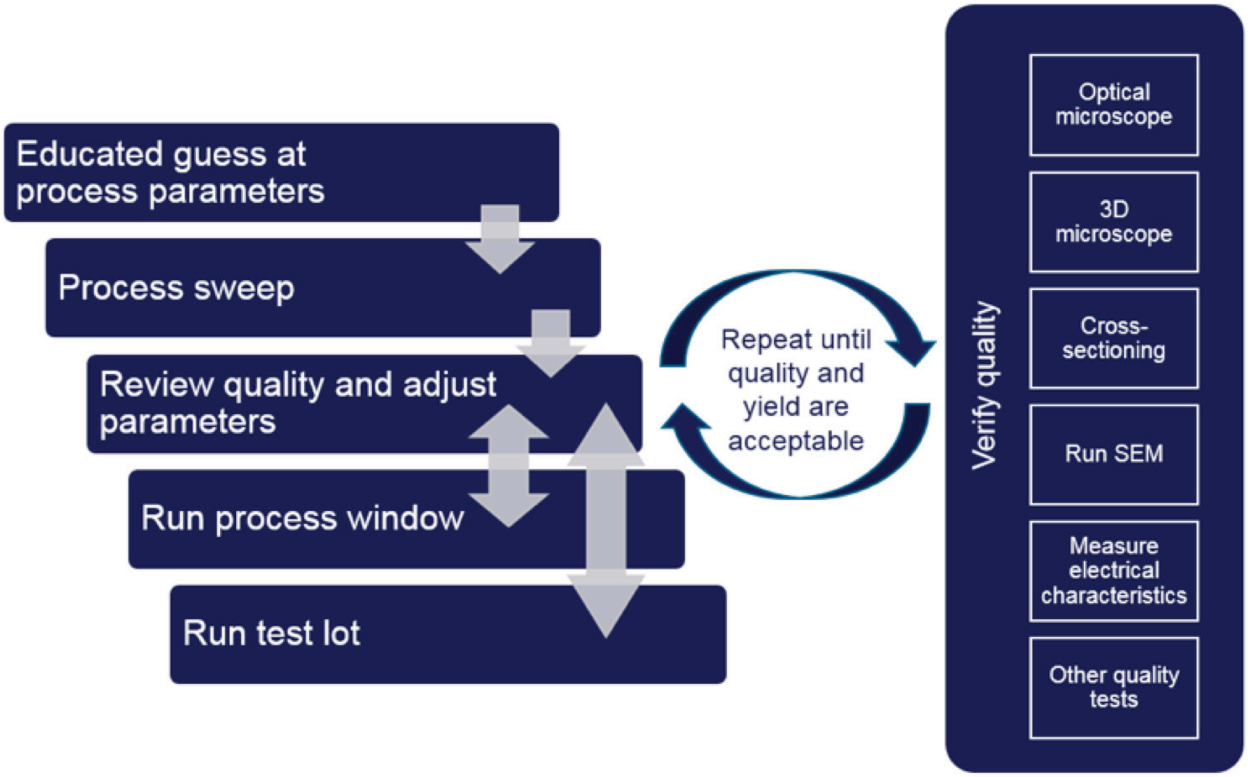
Although you may already have some idea of a process starting point, each new material and application generally has unique, unforeseen challenges. As a result, it is generally a good idea to generate several test grids on unpatterned materials to perform a broad sweep of the process space around that process starting point. For very new applications where the starting point is less clear, that process sweep can be an extensive design-of- experiments (DoE) around laser power, laser focus, laser pulse repetition frequency (PRF), process velocity, number of process steps, and tooling motions. For more well-understood applications, this process sweep might be limited to varying laser power and focus.




***Example of a broad process sweep to find a robust through-via process.***

This process sweep would typically be followed by an iterative process of verifying quality, adjusting parameters, running process window tests, test lots, and eventually going into production.

For processes to eventually be used with patterned material and small internal-layer capture pads, the process developed on equivalent unpatterned material would then be revalidated on this patterned material in order to validate accuracy and any process shifts due to the different thermal response of the smaller pads. If that patterned material is scarce, evaluate smaller process shifts using selective processing of individual circuits on the panel.




***Example flowchart for process development.***

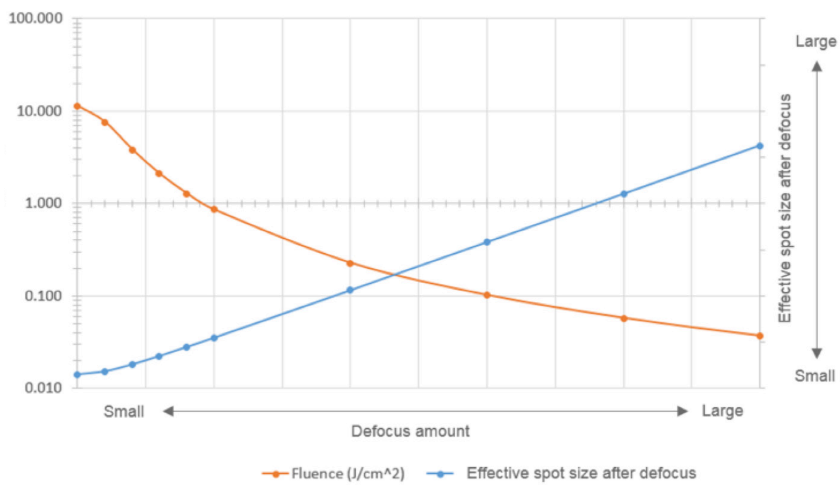
## Process robustness verification

At this point, we can introduce key process development concepts surrounding process robustness. Process robustness can be defined as the process' ability to meet the process quality specifications across the design tolerances in system characteristics as well as slight changes to system and material characteristics due to environment changes, handling, and contamination over time. Different manufacturers and even different product models each might have different tolerances on collimated beam size, laser spot size, focus accuracy, power control, and work table flatness as a few key examples. Similarly, the system, the material, and the process will be impacted by extrinsic factors such as facility temperature and humidity, facility vacuum, and compressed air pressure and flow rate, etc. that can impact process quality if not managed properly.

In short, process robustness is a key factor in ensuring high yield processes with consistently high quality. The alternative to spending time developing robust processes is accepting lower yields, system downtime and the expense associated with constant system adjustment and cleaning, and the higher expense associated with more stringent environmental control.

## Process windows

Process windows are a key method of quantifying the process robustness. Process window tests typically measure how much laser fluence (laser energy per unit area) change the process can tolerate before the process no longer meets quality specifications. Fluence is used as an evaluation metric due to its vital role in material ablation (removal). Furthermore, each of the system tolerances listed above (e.g., spot size, focus accuracy, power control, etc.) have an impact on either the laser energy or area over which that energy is delivered. Some manufacturers measure process window by varying laser focus above and below the process setpoint for the specified application. Some manufacturers measure process window by varying laser energy above and below the process setpoint for the specified application. Others do so by varying both laser focus and laser energy. No matter the precise method, it is critical to validate that the chosen process can withstand real world manufacturing conditions, considering the fluence control accuracy and stability of the system you have purchased.




***Laser focus has a significant impact on both effective spot size and laser fluence.***

## Laser focus

For most laser processes, it is critical to find laser focus accurately. The reason for this is again related to the importance of laser fluence for material ablation. Not only will an out-of-focus laser spot be larger and therefore lower fluence, most lasers also suffer from lower beam circularity and higher beam distortion the further the laser spot is out of focus. This can result in poorer-quality and less predictable processes.

Note that it is equally critical to find and verify laser focus accurately both during process development and during production. If the process was developed in focus, but processed out of focus — or vice versa — the process quality will suffer significantly in production. Note as well that the more accurately and consistently your laser system can find focus , the more consistent your process will be.

There are times that it is acceptable and even desirable to process out of focus, such as in clearing dielectric material from a blind via using the top copper opening as a conformal mask. However, even in these circumstances, in order to ensure a consistent process, it is important to have found the focus point accurately before purposely defocusing the beam by a known amount.

## Tooling motion choice

While every laser tool manufacturer may have slightly different options and names for tooling motions, common choices include punches, circles, spirals, and routs. Each tooling motion has unique characteristics that result in different typical uses.

Punches may be used when the feature size is approximately equal to the laser spot size and are generally the fastest via formation method when it is possible to use them.

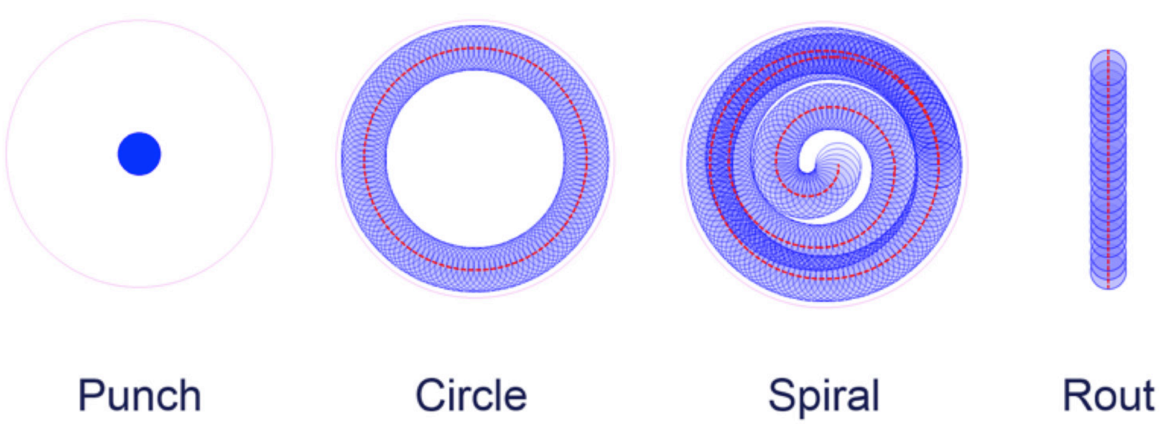
Circles can be used effectively when the via sizes are larger than the laser spot size. Since circle tooling motions only ablate the perimeter of the circle, it is often necessary to follow up with inset circle processes to remove more of the internal material to achieve a robust process. Such multi-circle processes are described in more detail later.

Spiral tooling motions can similarly be used when the via sizes are larger than the laser spot size. Spirals can be used in place of multiple inset circle processes for more process flexibility.

Finally, rout tooling motions are best used for cutting out or ablating any non-circular shapes. Pulse overlap and material removal rate are two important characteristics to consider for routs. Special process development attention should be given to areas with small turn radii, given the tendency for heat to accumulate in those areas.

## Depth-limited vs. through processes

There are distinct differences in process development best practices for depth-limited processes such as blind vias and soldermask removal versus processes that cut completely through a material, such as through-vias and excising parts. For depth-limited processes, one needs to be very careful about cutting too deep into the material and damaging the underlying substrate. On the other hand, for through processes, it is possible to develop much more aggressive processes since one does not have to worry about damaging the underlying material. These differences result in greater difficulty to develop optimal




***Common tooling motion choices.***

depth-limited processes — one needs to weigh cycle time vs. yield/quality tradeoffs between aggressive and more conservative processes.

In general, to ensure the most robust and high-yield process, it is important to completely clear the top copper using an in-focus spot before proceeding to the dielectric clearing step. Another best practice is to develop blind via and multilayer processes one step at a time. Test out and evaluate process parameters for each step of the via formation process.

For example, perhaps you have a three-step blind via process, cutting the top-copper perimeter with a circle tool first, then removing the interior top-copper slug with a second circle tool, and finally cleaning up the polyimide dielectric with a spiral tool. In such a case, develop and evaluate all three steps individually. Verify that the first perimeter cut fully cuts through the top copper without penetrating the bottom copper. Then, after optimizing the first step process, verify that the central copper slug removal is complete. Finally, after optimizing the second step process, verify that the dielectric removal does not leave any residue and does not cause bottom copper damage.

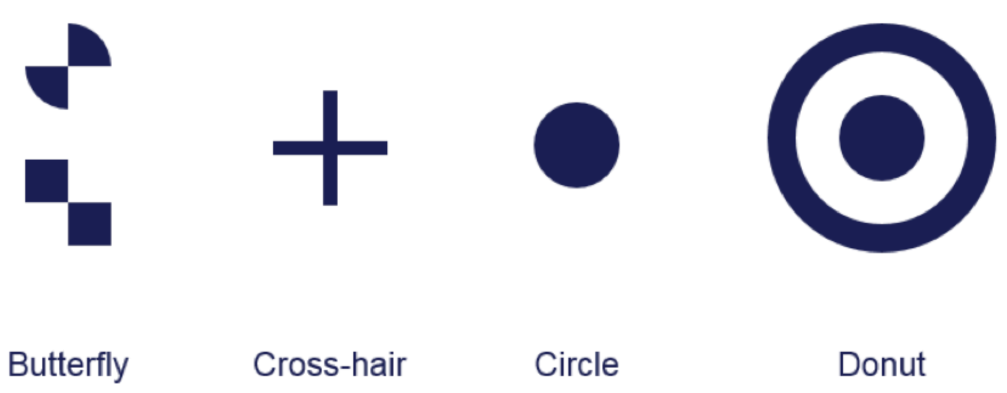
## Alignment points and geometry transforms

There are many factors beyond the scope of this article that affect the registration accuracy between via holes and the landing pad. However, a few common-sense best practices can be followed to improve your registration today.

First, use the same alignment points for all processes, such as laser drilling, patterning, and drilling the tooling holes for layup — this results in the least amount of inconsistency.

Second, use the most accurate tool/process to create the alignment points — in many cases, this will be your patterning process or laser drill. While laser  drills will often take more time, and have a higher cost per hole than a punch or mechanical drill, the registration accuracy will be higher.

Third, use the same scaling methods and geometry transforms (e.g., parallelogram, trapezoid, etc.) for




***Common types of alignment targets.***

your drilling and your patterning processes — this again results in the least amount of inconsistency.

Finally, make sure your alignment points are high contrast, highly consistent, and have a well-defined center at the small scale commensurate with the accuracy that you are trying to achieve. Patterned butterfly-type targets best meet these criteria. However, when used appropriately, cross-hair, circle, and donut targets can be used effectively as well.

## Summary

Optimizing PCB laser processing for production requires a holistic view of the laser processes and their place in the production line. Taking the time to understand how those factors interact allows you to make informed decisions about where to focus your efforts and helps you to create a production process that effectively supports your organization's unique set of operational goals. But since process development is iterative and always ongoing, you will need to devote the necessary time to test, document, adjust and improve your process library.

Following basic process development principles and best practices with a focus on constant improvement will not only allow you to be more flexible in response to changes in requirements but the resulting production processes will be better aligned to your business goals.

# Chapter 6: Maintenance and Servicing
# How to minimize system maintenance and repair costs while prolonging useful life

In the previous chapters, we've addressed topics such as what to look for in a flex PCB laser processing system, an overview of flex laser systems, cost-of-ownership issues and a comparison of various process development strategies. In this sixth and final chapter, we will look at the ongoing maintenance and upkeep of your system. While it is not meant as an exhaustive overview of required maintenance, it addresses several best practices related to the proper care and feeding of your system — detailing some of the reasons for what might seem like arcane or unnecessary activities to those who are new to flex laser processing. You should always refer to the maintenance documents provided by your system supplier for a full and accurate picture of the required and recommended maintenance activities for your specific systems.

## Maintenance should not be an afterthought

Today's maintenance managers are constantly managing the trade-offs between higher machine availability (asset utilization) and lower maintenance costs (cost control). In their balancing and prioritizing of these competing concerns, they need to consider such factors as maintaining aggressive production schedules, the level of investment in capital equipment, safety and health concerns, and environmental regulations. And to make everything work, they need to ensure availability of properly-trained technicians, spare parts and tools (resource allocation).

Although it's exciting to get your new flex laser processing system installed and processing panels, you shouldn't wait until you are up and running before you turn your attention to the topic of system maintenance and upkeep. Planning for ongoing maintenance should be a priority. If this is your first foray into laser processing, keep in mind that, although many general maintenance concepts are shared with mechanical-based systems, there are maintenance needs that are unique to laser-based systems.

Having the proper maintenance mindset from the beginning will ensure that your laser systems continue to safely and effectively deliver the performance you require and the longevity you expect, thus maximizing their lifetime value and return on investment.

## Scheduled downtime vs. unplanned downtime

Your preventive maintenance schedule should include planned downtime to check, clean, adjust, and/or calibrate the subsystems of your laser system as per the manufacturer's recommendations. Having the machine scheduled to be off-line for a short period during preventive maintenance will not only make sure that the maintenance is performed but will also help minimize any unplanned processing disruptions and maximize the system's future uptime. This is especially important when interventions require support from the system manufacturer's off-site service engineers.

As with most production equipment, the costs associated with the extended unplanned downtime or degraded performance of your laser systems can be a multiple of the costs spent on maintenance. That multiple can be very high when one looks beyond decreased system efficiency to the loss of productivity and the associated scheduling and yield impact on downstream processes.

There are also situations when preventive maintenance and scheduled downtime may need to be more frequent. If your application involves more debris-intensive processes — such as large through-holes or routing — or if you are operating your systems in a less-than-optimal environment, maintenance frequency should be adjusted accordingly. Similarly, operating your systems 24/7 for extended periods of time will dictate more frequent planned maintenance. Finally, more challenging applications with more strict quality controls and yield requirements will also dictate an accelerated maintenance schedule. This situational or process-dependent maintenance planning will help ensure that your system is delivering the level of performance and precision you need for such applications.

In an environment where equipment replacement costs continue to rise, proactive preventive maintenance is an easy way to extend the equipment lifecycle of your flex systems. This extension of your systems' service life better positions you to postpone or defer budgetary issues associated with capital outlays for new systems.

## UV laser system preventive maintenance overview

Your laser-based flex systems have a unique set of maintenance requirements. In addition to proper operator training to reduce system downtime related to misuse, it's important to follow a scheduled maintenance regimen in order to run at peak efficiency. This generally includes caring for and updating calibrations of the laser and optics subsystems and beam positioning subsystems, maintenance of the cooling and pneumatic subsystems, general system cleaning and a variety of other activities specific to your system. Regular system performance validation tests can also become a useful component of your preventive maintenance system. These tests can preemptively identify system issues that might affect production yield and should be built into your process flow.

## Laser and optics subsystems

In order to maintain high-quality, high-yield via formation it's important to minimize the presence of contaminants that can come into contact with the optics, such as mirrors, beam expanders, galvanometers, scan lens, etc. These are the components that transmit, deflect and shape the laser beam. Proper calibration of the laser power, along with the removal of contaminants from the optics path, will help ensure that the system delivers the desired laser power, spot size and spot quality. In some circumstances, checking the alignment of elements in the optics path is also necessary to ensure that the laser is providing the spot size and quality required for high-quality via formation and delivering maximum yields.

## Beam positioning subsystems

The precise, coordinated motion of a number of beam positioning components such as linear stages, galvanometers, and more advanced components is necessary for your flex system to precisely position the laser beam and provide optimal process productivity and quality.

As with any piece of equipment that has moving parts, periodic cleaning and lubrication will keep things moving smoothly. Flex laser processing systems are no different. Depending on your shop floor's environment, the materials being processed and the application you are running, this could mean more frequent maintenance actions are necessary. Scheduled maintenance should include the cleaning and lubrication of the x and y stages, and the removal of any debris that can affect the smooth operation and motion of the components.

Beam positioning subsystems such as the galvanometers and related vision subsystems may also require periodic tuning/recalibration to ensure optimum performance and accuracy.

***Example of pneumatic filters and pressure regulator.***

## Pneumatic subsystems

Most laser systems include some level of pneumatic subsystems. These are used for functions such as providing the sensitive optics with pressurized clean air to avoid debris contamination, aiding debris removal during processing, actuating doors, etc. To ensure optimal performance of these functions, it is typically recommended to check pressure and/or flow, clean the air dryers and water/oil separators, and clean or replace any clogged filters.

## Cooling subsystems

A typical UV laser system used for flex circuit processing will include a laser chiller, various fans and possibly other cooling mechanisms. The performance of these cooling components is crucial to maintaining the laser power, beam quality and pointing stable. It also extends the longevity and performance of the system's other components.

To keep the laser at the optimum temperature for stable performance, most laser systems include a self-contained recirculating chiller. For such recirculating chillers, the level of fluid (generally water) must be maintained at the recommended level. Water will build up algae and other particulates over

*Example of laser chiller with water level gauge.*

time. Thus, to avoid blockages from restricting flow and causing temperature and pressure spikes from damaging the laser or reducing its performance, it is important to replace the water at the manufacturer-recommended intervals and — if specified — add algaecides and anticorrosive additives to the water.

System fans, especially in poor environmental conditions, will build up dust that must be removed by vacuum to ensure effective operation and longevity.

## General cleaning

It may seem obvious that sensitive, high-value applications such as flex PCB processing and their processing systems would benefit from clean processing areas. However, not all operators pay close attention to such cleaning. Periodic vacuuming of the processing bay and work table, and even regularly checking the debris vacuum lines for debris build-up is a quick but high-value activity.

## Regular system performance validation tests

While typically not required by some system manufacturers, regular verification of process quality for one or more well-characterized processes, critical system calibrations, laser power statistics and other leading indicators of potential system issues can become a powerful tool for getting ahead of unscheduled downtime, quality and yield issues.

## Importance of operating environment

If you are operating your laser systems near environmental pollutants or the airborne byproducts of adjacent manufacturing/processing, you'll need to adjust your maintenance schedule accordingly. If the current environment does not meet the system's site requirements, place a high priority on improving the conditions or consider relocating your systems to a less challenging operating environment.

## Laser safety

If you are new to laser processing, laser safety is something you'll need to be prepared for. Take the time to familiarize yourself with the safety guidelines provided by your system supplier. While operating and performing maintenance on the system, you should make sure that proper safety guidelines are in place and that operators and maintenance personnel are properly trained. If servicing the laser system with the laser on, protective eyewear rated for the laser in use is a must. For the protection of others, sufficient, appropriately-rated laser safety panels must be used during such service activities. Consult the operating guide and safety information that came with your system, and follow the guidelines suggested in the guide.

## Partnering with your supplier

Your system supplier will typically provide a comprehensive preventive maintenance guide, which lists maintenance checks, describes the suggested maintenance processes and lays out appropriate maintenance intervals. Although it sometimes assumes a lower priority, documenting preventive maintenance and keeping an up-to-date maintenance log — together with the system-generated log — will ensure that potential problems are identified before they impact your processing operation. Also, documenting service issues unique to each system helps give your supplier's service organization a more accurate assessment of your systems' condition over time.

## Summary

In this chapter, we have discussed flex PCB laser processing systems and addressed some of the maintenance topics that are unique to those systems. Proactive preventive maintenance plays a significant role in minimizing production disruptions, extending the equipment life cycle of your flex systems, and maximizing the value that can be extracted from those systems. Since these systems represent a substantial investment in capital equipment on your production floor, extending their useful life, as well as ensuring their efficient and effective operation, should be a high priority.

# Chapter 7: Automating Flex PCB Laser Processing

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## Introduction

In their drive to aggressively cut costs out of their business, manufacturers are looking for more creative ways to optimize production, increase efficiency and improve yields. All factors that affect a lower cost of ownership for capital equipment.

One of the ways flexible printed circuit (FPC) manufacturers have been effective in staying ahead of the throughput/cost curve is through the deployment of appropriate automation. Yet, although automation may be one of the low-hanging fruits for flex PCB processors, its application should be viewed in the context of a production flow that may already include other innovations.

## The need for automation

Demand trends for virtually all electronic products point to the need for manufacturers to dramatically improve their accuracy in the fabrication of high-volume electronics. Especially as it relates to their proficiency at processing extremely thin films, flexible glass and other fragile substrate materials. To stay ahead and successfully compete in global markets they must produce precision-quality electronics that incorporate novel materials and nanotechnology-level accuracy. In this environment, automation isn't a luxury; it's a requirement.

Automation can mean different things to people in different manufacturing environments, and numerous material handling technologies are available that address myriad production challenges. In this article, however, we will focus primarily on automation in the context of flex PCB and interconnect material handling.

## Roll-to-roll web handling automation

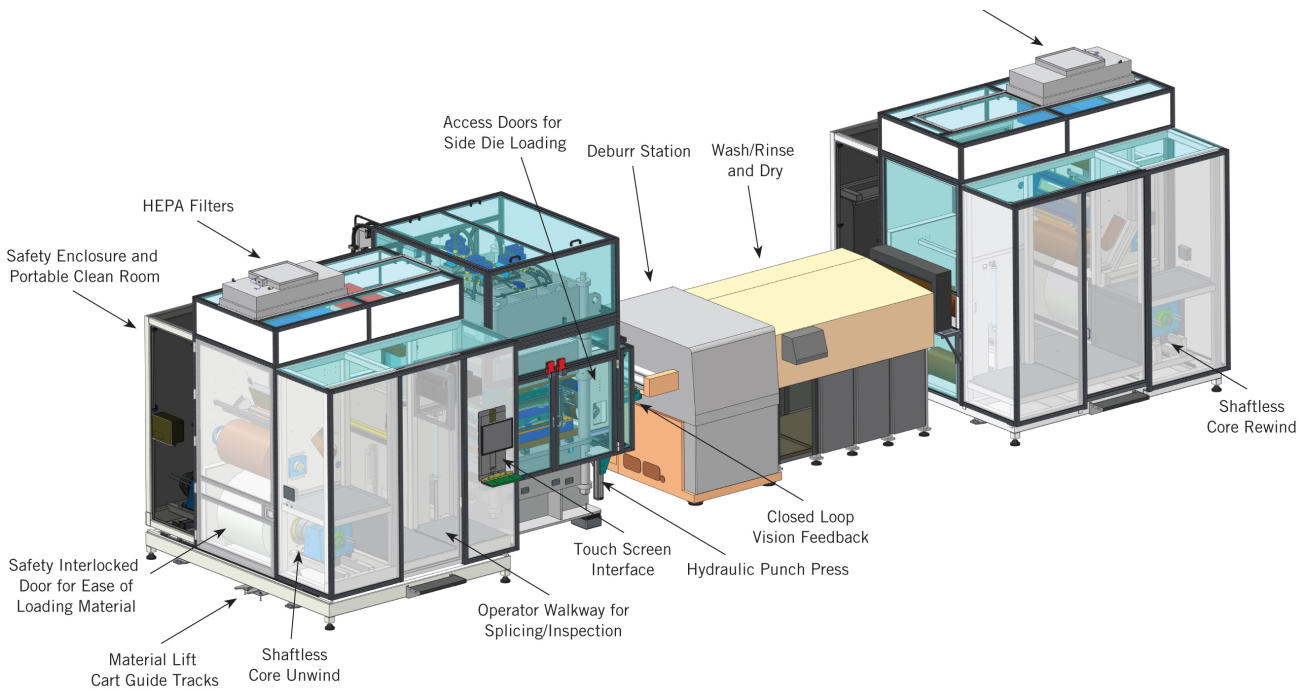
The good news in this discussion of production challenges is that, given the flexible nature of FPCs, the vast majority of flex processing can be performed in roll formats using web handling automation technologies. There are numerous advantages to keeping roll-to-roll materials in this format through as much of the manufacturing process as possible.

These advantages include:

- Large-volume rolls of material are easily and safely transported between process machines
- Much shorter panel-to-panel move times as compared to swapping individually-cut panels manually or with robotic stack handlers

- Material moves between process machines with constant tension and automated precision positioning, both of which can be critical to meeting requirements for fine-line accuracy
- Tension and position control for step-and-repeat processes such as laser drilling, testing, blanking, printing, photo lithography, etc.
- Tension, positioning, and speed control for continuous processes such as wet process develop, etch, strip, plating, printing, coating, lamination and so on

For the remaining process steps or for products that must be individually handled in panel formats such as multilayer FPCs, coverlay, or rigid-flex circuits, robotic stack handler systems can be used to increase the level of automation. Standardized and custom solutions cover almost all segments of the processing flow, thus making it possible to accommodate a wide range of product-specific requirements and sizes.




***Example of turnkey web integration of multiple processes.*** *Courtesy of Northfield Automation Systems*

## When does it make sense to automate?

Many factors can spur FPC manufacturers to consider automating parts or all of a production line.

Key considerations include:

- Yield loss due to operator material handling, material contamination, and operator errors
- Low equipment efficiency due to high levels of operator interaction, variability, standby, and non-scheduled equipment time

- Continuously-shifting bottlenecks in a production line due to cycle time variability
- High operator labor costs that could be alleviated through handler automation

In general, low-mix, high-volume manufacturers tend to get the most value from automation with the least amount of investment. For such manufacturers, investments in web handling automation can often provide sufficient increases in throughput, uptime and yield on existing process machines to obviate the need for additional investment in capacity.

However, even high-mix, low-volume manufacturers are finding that the cost-benefit analysis is beginning to favor automation technology as wages rise globally, materials become more susceptible to damage from manual handling, and accuracy and quality requirements become more stringent. And, as noted above, the macro trends in wearables, medical devices and other electronics devices point to greater use of thinner, more fragile materials, which can only be processed cost-effectively with automated web handling solutions.

## Automation: the low-hanging fruit?

The move to automated web handling systems, while not trivial, often proves to be relatively easy to implement for many of the processing tools used in most FPC manufacturing operations around the world. This is especially true for tools such as laser-based processing systems that incorporate communications interfaces capable of supporting integrated handlers. In such cases, the resulting gains in yield, throughput, and efficiency lead to rapid returns on capital equipment investments. Of course, the ideal scenario for rapid ROI is a turnkey automated process solution, such as when setting up a new or expanded process.

As materials become thinner and more sensitive, it becomes more and more difficult to prevent material damage from occurring during the normal course of manual material handling operations. As damage problems and risks mount, significant yield improvements can be realized from the use of web handlers with automated positioning and automated tensioning control that virtually eliminate damage and wear to flex materials during the manufacturing process.

Let’s take a look at some of the problems with manual panel-based processes with modern flex materials.

## Panel damage

Moving the panels is a challenge since the slightest bend or uneven tension applied to materials can result in permanently bent edges and wrinkled substrates.

## Operator handling

Even the slightest physical contact with the material surface can cause scratches or surface contamination, as all too frequently occurs during the course of manual panel handling by operators.

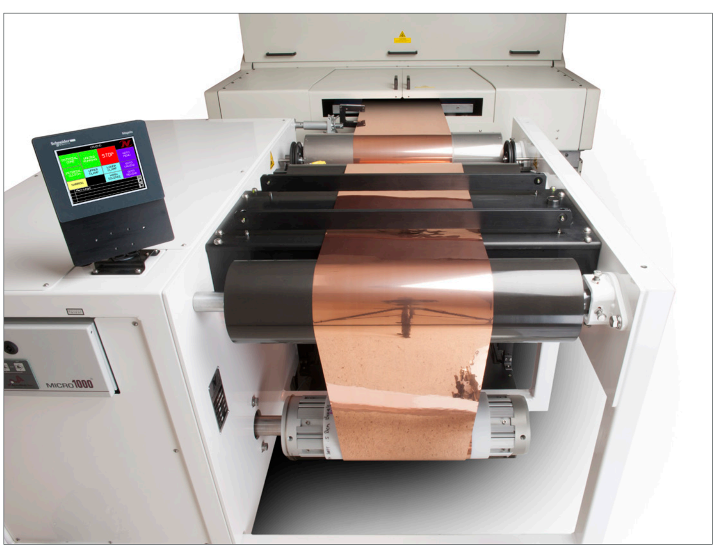
## Machine calibration

Manual operator material handling requires significant user-machine interaction. Each interaction presents an opportunity for errors to be introduced. With web automation, closed-loop feedback can assure that error tolerances are not accumulated through the processing of even a large roll of production material.

## Material contamination

In roll-to-roll processes, contamination problems are almost completely avoided. Rolls of material can be wrapped for protection when moving between processes, and portable clean room enclosures can be used to enable machine tools to process the exposed web in a clean environment. By limiting user interactions to a single, automated lot of rolled material, yield loss due to operator errors are minimized as well.

Rapid equipment efficiency benefits can also be achieved through greater automation. Tool load and unload time are greatly reduced when moving from panel handling to web handling. Processing equipment typically requires safety doors to avoid harm to operators. Web handling equipment is designed so the flex materials can travel through very narrow slits that are inaccessible to operators. As a result, no time is lost due to the need to continually open and close safety doors.




***Roll-to-roll automation of flex material***

## Example: Replacing an operator-panel-loaded process with a web handling unwind and rewind

Prior to automation, panel removal, placement and readiness required an average of 12 seconds per panel between process machine cycles. With the unwind and rewind systems installed on that same process machine, the panel removal, placement and readiness within the web was reduced to two seconds between machine cycles.

The increased 10 seconds of machine up-time per panel raised that machine's throughput enough to deliver a web handling unwind and rewind ROI of six months.

Another process advantage is that material webs have effectively near-zero distance between the edges of one panel to the next. Movement time is reduced given these shorter distances for the material to travel. Efficiency is further improved by reducing the amount of inefficient operator interaction, reducing system standby time due to absent or busy operators, and reducing non-scheduled equipment time due to unworked shifts. For certain applications and processes, it is possible to start a job at the end of a day shift and have it finish overnight in time for the beginning of the next day shift. Also, some process machines can support two webs running through in parallel, giving twice the throughput with the same investment of one process machine.

Planning can often also be simplified by reducing cycle time variability caused by differences in operator-tool interactions. If this variability is causing continuously-shifting bottlenecks in a production line, it may be due to the difficulty of accurately planning material movement and product delivery schedules. Handling automation improves cycle time consistency and eases production planning.

Labor costs can often be reduced through the use of handling automation. These labor costs show up in various forms. Obviously, when automation reduces the amount of operator-equipment interaction, fewer operators can do the same amount of work. One operator can support multiple roll-to-roll manufacturing lines. Less obvious benefits include higher operator satisfaction that results in less employee turnover as well as fewer operator injuries. Both of these benefits can be achieved due to the less-repetitive work that is generally further distanced from the dangerous parts of process machinery.

## Example: Minimizing operator handling and related defects

Prior to automation:

- 30 seconds required to load and unload each thin panel into a rigid frame for processing through wet process
- Required three operators (frame, load and unload)

After moving to roll-to-roll format: Operator handling removed from the process

- Requires less than one minute to load a 1,000 foot roll — 1,000 panel equivalent
- A single operator supports up to three roll-to-roll process lines
- Yield improved from 84% to 99% for material handling related defects
- The throughput, yield improvement and labor reduction combined to deliver an ROI of only three months

## Selecting an automation supplier

Regardless of production needs and scenarios, it’s important to work with an automation supplier who has the process experience necessary to design and manufacture a turn-key solution that will ensure product quality, maximize efficient throughput, deliver meaningful data outputs, and is user-friendly for operators.

Going a step further, the supplier should be able to demonstrate the expertise necessary to enable the seamless movement of materials across the entire manufacturing process. Additionally, suppliers should demonstrate a willingness to partner with FPC manufacturers to both maximize efficiency and maximize quality.

In cases where manufacturers are adding new processes and tools, it’s often advantageous to consider solutions that already have the right processing platform paired with the right high volume production-oriented automation.

## An incremental automation step that pays big efficiency dividends

Although the implementation of web handling automation is a great way to gain efficiencies in FPC manufacturing, it doesn’t require drastic changes to one’s processing technology roadmap. As an incremental technology change to the process flow, most of the existing flow is maintained with the only change being the automation of the web handling component. It is also possible to incrementally convert process steps to roll-to-roll processes using stand-alone web-to-panel process tools as the overall process flow is converted. The web-to-panel tool moves further down the process flow as the conversions are made downstream. Also, the use of wider web widths can still be maintained in the upstream processes for further production efficiency. In such cases, the wide web is slit into narrower widths using a web slitter in order to support production webs in the downstream processes.

In this sense, web handling automation can be seen as an incremental step but a step that delivers major gains in efficiency and yield without adding significant systems management overhead. The resulting increase in total processing up time also helps maximize investments in the laser processing tool.

A strong case can be made for adding web handling automation, but it needs to be viewed in the context of the overall process flow. As part of a broader automation roadmap, the minimal disruption, ease of implementation, and the resulting operating efficiencies gained through roll-to-roll automation make it worth considering. The increase in capacity with less capital and labor expense not only benefits the bottom line but also positions FPC manufacturers for long-term success.


*Roll-to-roll automation integrated with ESI GemStone laser processing system*

***Web slitter*** *Courtesy of Northfield Automation Systems*

# Conclusion

As the consumerization of electronics continues to power the market demand for mobile devices, wearables and Internet of Things (IoT) devices, suppliers and manufacturers at all points along the electronics value chain are presented with a new set of challenges. This market demand brings with it a set of evolving requirements for the underlying circuits and components that drive such devices. These requirements are primarily related to functional attributes such as speed and functionality, and to form factor constraints such as size, build quality and durability. At the same time, the big brands — the manufacturers' customers — are not only battling to differentiate themselves among myriad alternatives but are also striving to be the first to address new and broader markets with a wider range of devices.

Flex PCB laser processors are squarely in the middle of this confluence of market demands, customer requirements and evolving technology. Effectively responding to these new requirements — and doing so profitably — requires that they continually innovate, but with a focus on maintaining processing quality without sacrificing throughput or increasing costs. As they are forced to adopt new processes, new techniques and new technologies, ESI is there to help our customers navigate the myriad FPC technologies and applications, to apply the solution most appropriate to the unique challenges they face.

## About the Author

Patrick Riechel is Product Manager for Flexible Circuit Micromachining tools at Electro Scientific Industries (ESI). He has over ten years of experience in the design and manufacture of electronics, having held positions at Symbol Technologies, Motorola Solutions and ESI. Patrick has an MBA degree and a Master of Science in Systems Engineering from the Massachusetts Institute of Technology (MIT) as well as a Bachelor of Science of Electrical Engineering from Brown University. As the inventor of seven patents and the catalyst for bringing industrial head-worn computing to Motorola, he was the recipient of the Robert Noyce Fellowship at MIT for his contributions to the field of electronics.

## About ESI

As the recognized leader in flex PCB laser processing, the systems in ESI's Flex Processing Family represent the broadest range of options in the industry, and have been the solution of choice for the world's top FPC processors for over a decade. Regardless of your application, material, throughput requirements or automation needs, there is an ESI flex system that fits.

Find out how at https://www.esi.com/solutions/via-drilling/

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