KEEPING CURRENT TO STAY COMPETITIVE IN FLEX PCB PROCESSING

TAKING ADVANTAGE OF HIGH-SPEED UV LASER MICROMACHINING TO STAY AHEAD OF YOUR CUSTOMERS' EVOLVING PROCESSING NEEDS.

Designed for Brilliance.
Engineered for Production.

A PCB LASER PROCESSING WHITE PAPER FROM ESI

KEEPING CURRENT IN FLEXIBILE CIRCUIT MANUFACTURING

THREE WAYS THAT THE ADOPTION OF HIGH-SPEED UV LASER PROCESSING TECHNOLOGY
HELPS YOU ADDRESS THE CHANGING TRENDS IN FLEX PCB MICROMACHINING
AND EFFECTIVELY MEET THE EVOLVING DEMANDS OF YOUR CUSTOMERS.

As the market for consumer electronics, wearable devices, medical devices, and automotive and military electronics continues to expand at an ever-increasing rate, there has been a commensurate increase in the demand for flexible circuits. Driven by the demand for smaller, cheaper, and more capable devices, flexible circuits are increasingly being incorporated into a wider array of products than ever before. The reasons why flexible circuits have gained so much popularity are obvious. Given their ability to alleviate some of the packaging difficulties resulting from the move to smaller size constraints, flexible circuits simply allow for more packaging flexibility—both literally and figuratively.

How Do You Stay Current?

As a manufacturer, how do you keep up? How do you remain competitive? How do you stay on the leading edge when it comes to the latest in flexible circuit manufacturing methodologies? How can you take advantage of high-speed UV laser micromachining in your production process? And—more importantly—how does it expand your capabilities for flexible circuit processing and help your operation address a broader set of needs? Those are just the sort of questions this white paper series "Keeping Current" is designed to answer. In this white paper, we look at three ways in which UV laser processing is not only best suited to meet the unique demands of flexible circuit processing, but also why it's necessary, if you are to effectively meet the evolving needs of your customers.

1. The ability to accurately process vias in complex multilayer stack-ups and rigid-flexible circuits.

In order to reduce costs while improving capabilities (generally in the form of more processing power, higher clock speeds, more sophisticated communications technologies and lower power usage), the industry is moving to more complex board stack-ups, more complicated, smaller, and fine-featured shapes, and a higher usage of small blind and buried microvias and ever-thinner materials. Although double-sided flexible circuits are still the most typical construction, complex multilayer stack-ups and rigid-flexible circuits are becoming more common. These multilayer constructions allow the designer to make the flexible circuit more functional. Not only do they allow for more signals to pass through the circuit and the robust placement of chips, they also enable the designer to implement electro-magnetic shielding to prevent noisy high-speed signals from interfering with sensitive signals both inside and outside of the product. Another benefit is enhanced impedance control for both high-speed and RF communications signals. Multilayer constructions such as these come with unique challenges for via processing, which high-speed UV laser micromachining addresses.

Beyond the Limitations of CO2 Laser Processing

Although CO2 laser processing has found a solid place in high-volume manufacturing of relatively large vias in rigid board processing, there are several issues that have limited CO2 tools from being widely used in processing flexible circuits. CO2 technology is often used in blind via processing of rigid copper-clad laminates due to the fact that the CO2 laser's far infra-red wavelength (typically between 9.4 and 10.6µm) is poorly absorbed by copper. Once the top layer of copper is removed, subsequent laser pulses used to remove the dielectric material pose effectively zero risk to damaging the bottom copper layer.

Typical industry practice to enable copper-direct drilling with CO_2 lasers is to pre-treat the top copper layer using a variety of special methods including black oxide, inter-granular micro-etching, and special laser direct drill (LDD) foils. This pre-treatment process adds additional cycle time and capital cost, and typically enables drilling copper layers only up to approximately 12 µm. Given this limitation, CO_2 lasers are effectively prohibited from processing through vias in copper-clad laminates as well as L1 to L3 (and beyond) blind vias in multilayer stack-ups.

UV laser processing overcomes many of the limitations that both mechanical and CO_2 laser processing face in meeting the evolving needs of the flexible circuit industry. The UV wavelength (typically around 355 nm for the most common Nd:YAG diode pumped lasers and dropping to below 200 nm for more specialized excimer lasers) has several beneficial attributes that help address these needs.

First, its wavelength is absorbed very well by most common flexible circuit materials, such as copper, polyimide, and various adhesives and resins. This enables UV laser micromachining to be extremely versatile – processing blind and through vias through thick and thin copper-clad laminates, unclad materials, and multilayer stack-ups without any costly and often toxic pre-treatment steps. An example of a multi-layer through via is shown in Figure 2. UV laser tools also can be used to remove layers of copper, excess adhesive, and improperly placed coverlay material, as well as excising complex and fine-featured shapes of circuits and coverlay material.

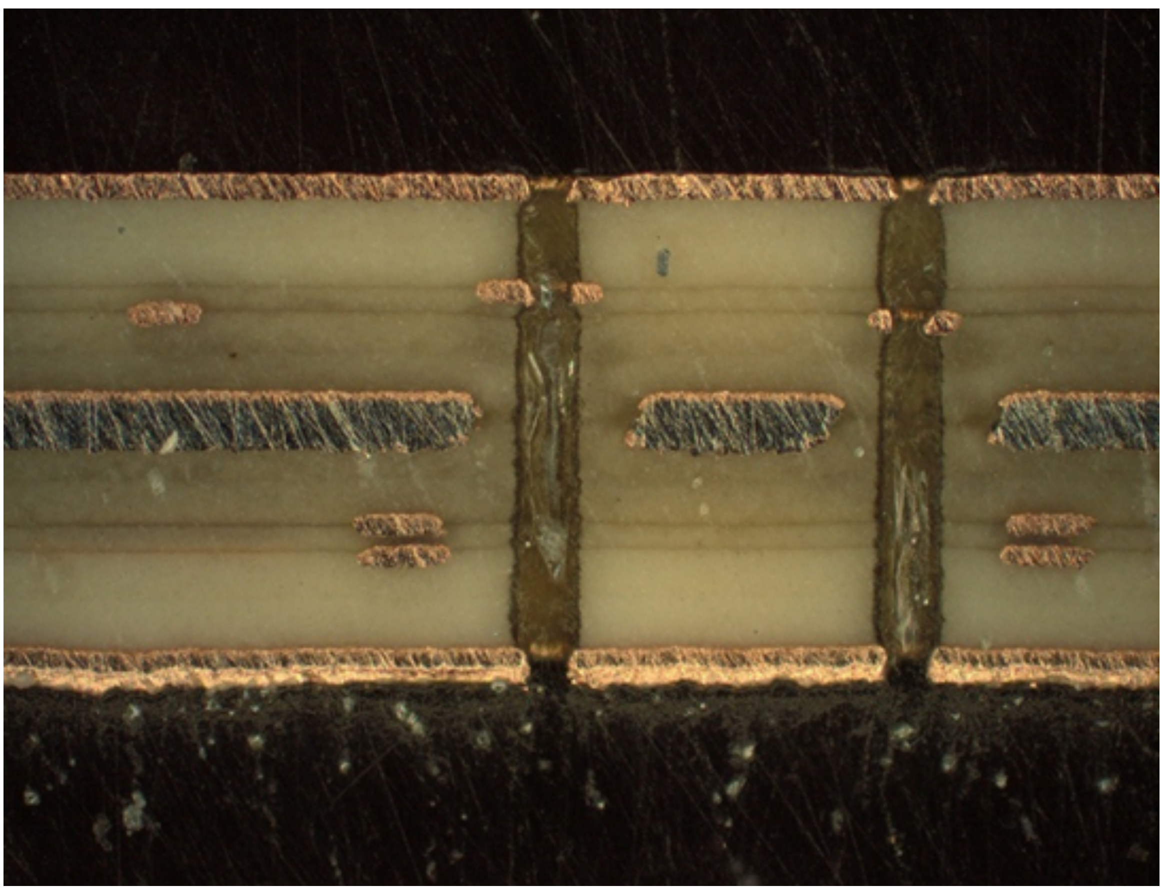

Figure 2 - Through vias drilled by UV laser in a multilayer stack-up

Another benefit of using UV lasers is that most smear and carbonization can be avoided when drilling vias and cutting circuits. As such, much less aggressive desmear or other post-processing steps are needed before plating (if drilling) or reliability testing (if excising the panels). Given UV's short wavelength, typical focused laser beam "spot sizes" are in the 15-25 μm range. That means that with precise beam positioning, features sizes can range from the size of the entire processing area down to that 15-25 μm spot size.

Finally, with proper precision engineering techniques, a UV laser tool can achieve extremely accurate placement of vias and other features. At this time, the most typical tool accuracy specification is ±20 μm, although specialty shops can and do achieve better than ±10 μm with that same tool by maintaining tight control over the tool's and the processing materials' temperature and humidity, as well as enforcing strict alignment, calibration, and pre- and post-processing procedures.

2.

The Ability to Accurately Process Smaller Blind and Buried Microvias to Tighter Tolerances on Ever-Smaller materials.

Given the typical use of flexible circuits to fit into small and difficult spaces and the trend toward smaller and thinner end-user devices, it is not surprising that the shapes and sizes of flexible circuits are becoming more complex, fine-featured, and smaller. These shapes and sizes are beginning to drive a need for more accurate and fine-grained cutting methods for both circuit and coverlay material.

While simple through vias are still the most common method of connecting signals from layer to layer, the push for smaller devices, better signal integrity of high speed signals, and lower capacitance to reduce parasitic power losses is driving higher usage of blind and buried microvias. Chip and circuit sizes are also shrinking, which requires smaller microvias, thinner lines and tighter spacing between signals, and higher placement accuracy to process all of these features. A complication with CO2 lasers, is that they typically leave dielectric residue behind after drilling. And, since the standard dielectric material in flexible circuits is polyimide and the desmear process for polyimide either requires very caustic chemicals or aggressive plasma etch processes, most manufacturers avoid CO2 lasers for flexible circuit drilling. Furthermore, due to the high energies and long pulse widths involved in CO2 processing, a CO2-processed material generally results in significant carbonization, which must also be removed via aggressive post-processing to avoid quality and reliability issues later in the circuit lifecycle. Finally, due to the CO2 laser's long wavelength, such laser systems cannot keep up with the flexible circuit industry's push to smaller and smaller via sizes.

More Accurate and Less Costly Than Mechanical Processing

Typical multi-head mechanical drill benches drill the exact same locations on all panels and do not compensate for the small scaling inaccuracies and deformations that each individual panel typically suffers from. Furthermore, mechanical drilling has insufficient depth control accuracy to robustly drill blind vias in typical flex circuit constructions. Typical flexible circuit copper thicknesses are on the order of (or thinner than) the depth-control accuracy of the drilling tool. These problems will be challenging for mechanical technology to overcome as the flexible circuit roadmap progresses towards smaller circuits, higher accuracy, and smaller microvias.

While mechanical processing methods are typically the most cost-effective means of processing material, they have several limitations when it comes to keeping pace with the latest trends. Die punching or routing the outlines of flexible circuits and associated coverlay material becomes impossible as part sizes and curve radii shrink beyond the capability of the die manufacturer or below the size of the routing tool.

Mechanical via drilling becomes excessively expensive as via sizes shrink due to the higher cost and breakage of small-diameter drill bits. Mechanical drills also suffer from a lack of accuracy. For instance, at smaller diameters, these machines suffer from "drill wander" caused by the higher length-to-diameter ratio of the drill bit.

3.

The ability to accurately process thinner materials.

While the flex circuit industry continues to use double-sided 12 µm Cu / 25 µm PI / 12 µm Cu copper clad laminates, more and more manufacturers are beginning to use thinner materials such as 12/12/12 and 5/13/5 (see Figure 1) copper-clad laminates in production, with some companies experimenting with novel additive technologies. For example, some suppliers are drilling unclad dielectrics and adding an extremely thin copper layer to achieve even smaller geometries at even lower costs. This trend toward thinner and thinner material drives lower material cost and higher flexibility, while increasing micromachining difficulty.

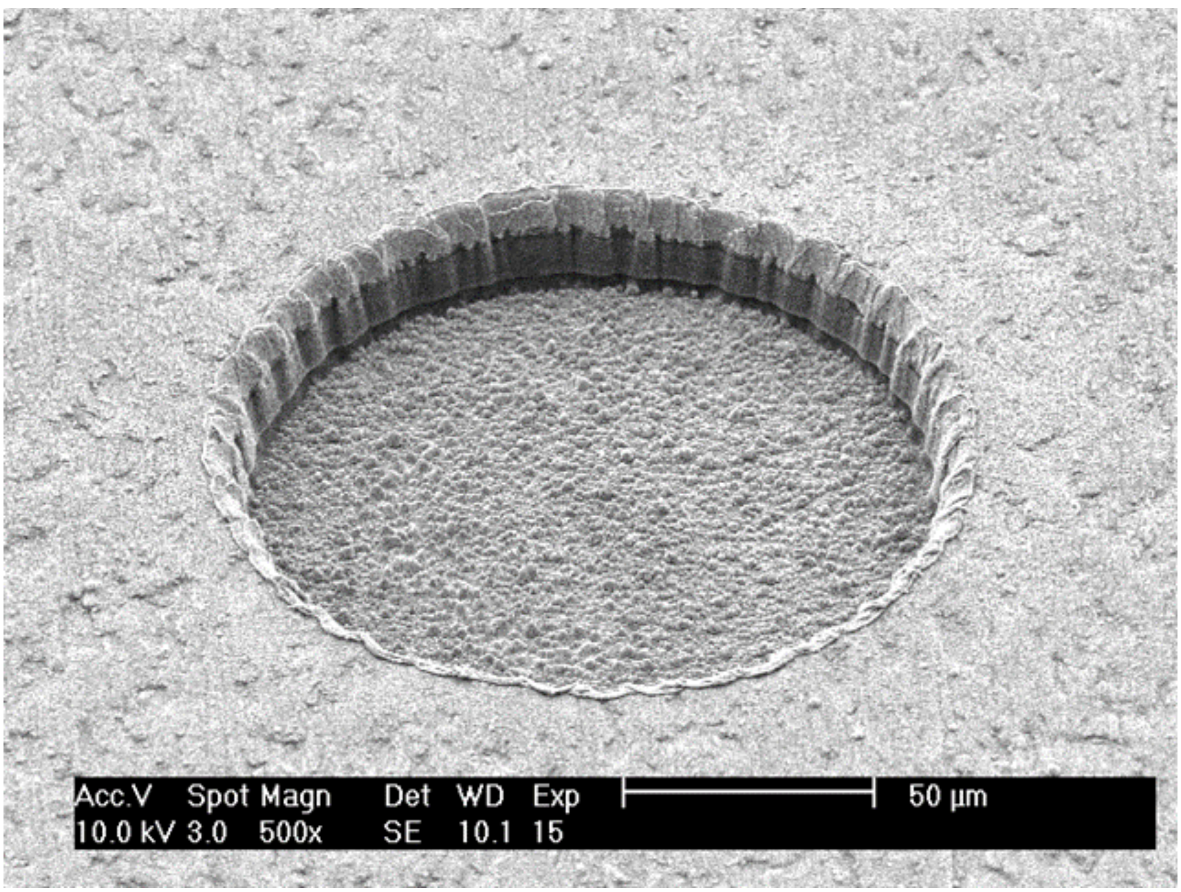

Figure 1 - 150µm blind via drilled in 5/13/5 material

Knowing What Makes the Right UV Laser Micromachining Tool

Lower Cost of Ownership

Beyond having the capability of processing a flexible circuit to customer specifications, the most important factor in deciding on a production tool is cost of ownership. Cost of ownership means different things to different board shops.

For high-volume board shops, cost of ownership will typically mean cost per panel over the course of the system lifespan, taking into consideration upfront and maintenance costs, as well as tool productivity, part yield, and system uptime. For quick-turn shops or specialty research institutes, cost of ownership will be more influenced by how flexible the tool is in processing many different types of materials and features as well as how easy and fast it is to develop new processes for new applications. In order to achieve the best cost of ownership, UV laser micromachining tools – supported by the supplier's service and applications engineering organization – must both incorporate the most optimal laser for the end-user's application as well as be able to harness the full capabilities of the lasers.

Precise Power Control

Micromachining with lasers operates by laser ablation, whereby material is removed by an absorptive interaction between laser photons and the material being machined when the laser fluence (energy per unit area) exceeds the material's ablation threshold. The characteristics of most UV lasers – small spot size, excellent absorption in most flexible circuit materials, and relatively high pulse repetition rate (number of laser pulses per unit time) – require precise energy dosing and fast and accurate beam positioning to fully take advantage of their capabilities. That becomes even truer given industry trends to thinner materials and smaller vias with increasing accuracy requirements.

Precise and well-distributed energy dosing is very important as shown in Figures 3 and 4 to reduce or avoid quality issues such as damage to the bottom copper layer and adhesive or polyimide residue in blind vias, etch back of via sidewalls, fiber protrusion in rigid-flex constructions, and copper splash, to name a few.

Especially with the trend toward materials with thinner copper foils, precise power control is extremely important to avoid yield issues. The drill tool must employ methods that keep laser transients from reaching the material to ensure consistent process quality. Since typical via sizes are larger than the UV laser spot size, consistent beam positioning with flexible motion paths (e.g. spirals, circles, etc.) must be available for robust process development. For multi-revolution processes, pulse distribution methods should be used to avoid localized ablation.

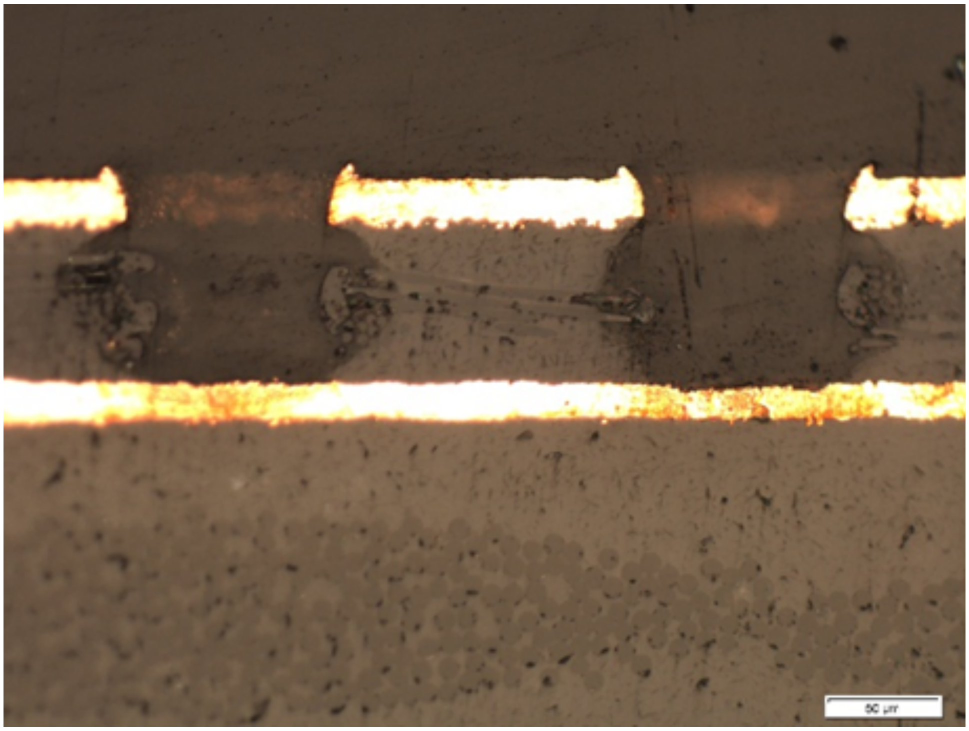

Figure 3 - Poor etch back and fiber protrusion with poor energy dosing

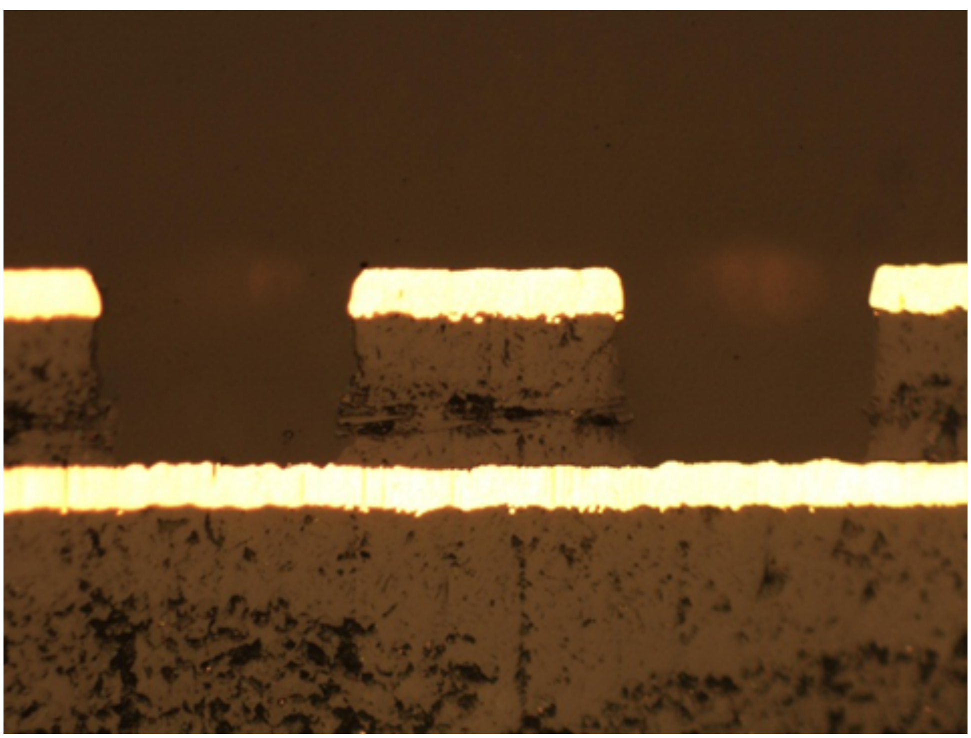

Figure 4 - Minimal etch back and fiber protrusion with good energy dosing

Compound Beam Positioning Increases Accuracy and Efficiency

Fast and accurate beam positioning is equally important to avoid quality issues, while also ensuring maximum productivity. A must-have for any UV laser micromachining tool is a telecentric lens. As shown in Figure 5, a telecentric lens ensures that the laser beam always strikes the material at a 90-degree angle, thereby creating a perpendicular via or cut anywhere the machine processes the material.

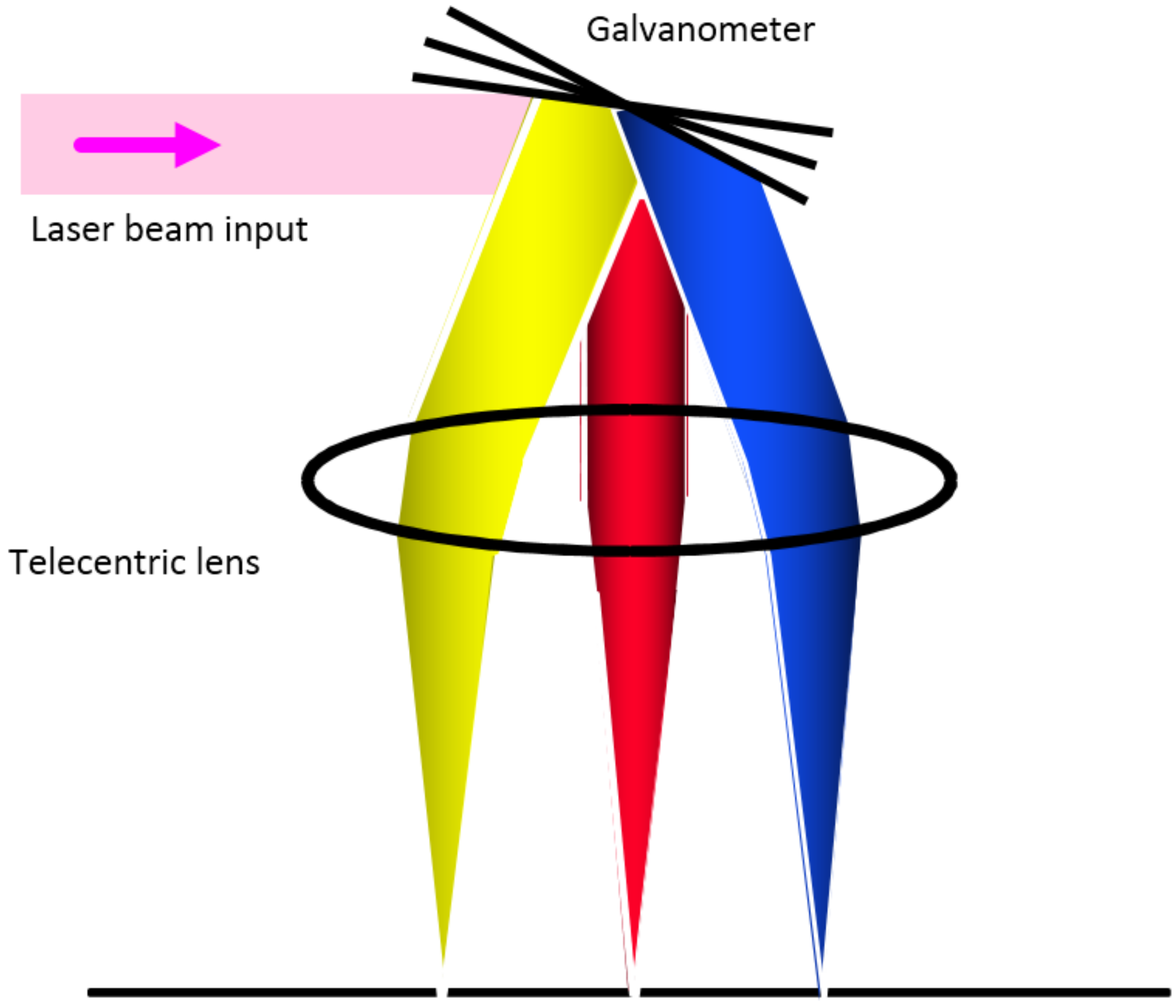

Figure 5 - A telecentric lens restores the laser beam to vertical no matter the galvanometer angle

Typical UV laser tools use a combination of linear stages and galvanometers (motorized mirrors) to position the laser beam on the part being processed. Many manufacturers use a move-then-process method to cut the full panel area – moving the stage to an area on the panel within the galvanometer field, processing that area, stopping the laser, moving to the next area, processing, stopping, etc. This results in a lot of non-value-add time since the laser is off during each long move. In addition, due to small galvanometer and linear stage errors, as well as due to optics aberrations, that method can result in incongruous cut lines where one galvanometer field touches the next.

The method of compound beam positioning resolves both of these issues by moving all beam positioning devices at the same time in a manner similar to hand-writing. For a stage-plus-galvanometer beam positioning system, one can think of the stage as the arm making the large and slow motions to cover the entire page at the same time as the galvanometer acts as the wrist and hand, making the small, precise, and fast motions to form the words. This method ensures high productivity given that very little time is wasted with the laser not processing, as well as avoiding quality problems caused by galvo field incongruities since the laser is continuously processing while moving.

Third Dynamics™ Beam Positioning for Accuracy at High Processing Speeds
Precise beam positioning at high velocities is more difficult. It is crucial to maintain adherence to part dimensional tolerances, as well as to avoid localized heating quality issues by moving the beam fast enough to spread out laser pulses even at high laser pulse repetition rates. Accurate high-speed beam positioning becomes also becomes important as feature sizes shrink, and thinner and more heat-sensitive materials are used.

Here, good tools set themselves apart. It becomes much more difficult to maintain precise beam positioning at high velocities for small features and tight curves given the high accelerations that the beam positioning components must overcome. One method of overcoming these challenges is to include a solid-state device as part of the beam positioning mechanism since such solid-state devices have effectively zero inertia. ESI's Third Dynamics™ patented beam positioning technology is one such example. By coupling a first level of linear stage motion with a second level of galvanometer (motorized mirrors) motion, as well as a third level of solid-state device motion, it is possible to achieve well-placed laser pulses at very high beam velocities, even when processing vias as small as 25 μm as well as right-angled features.

Accuracy not only is achieved through precise beam positioning, but also through panel scaling and warping compensation. Given that materials and drilling systems expand, contract, and otherwise warp due to thermal and humidity fluctuations, post-etch relaxation, roll-to-roll handler tension, and other factors, achieving high accuracy relative to existing features requires alignment to those same features and calculated adjustments to the drill locations to compensate for those factors. With good alignment between upstream and downstream processes, it is possible to enable tighter part tolerances as well as reduce the size of via landing pads.

Achieving the best tool cost of ownership involves finding the fastest process that consistently meets the given application's quality specifications, reducing non-value-add time during which the laser is not processing, as well as reducing the system's maintenance costs.

Optimizing for Laser-Material Interaction
In order to find the fastest process to meet quality specifications, a flexible circuit manufacturer must understand the basics of laser-material interaction and ideally also the latest techniques for processing a specific application. A good UV laser tool supplier will have a knowledgeable applications engineering team available to help teach these methods and provide advice on how to optimize the processes for the given application requirements and tool capabilities. Furthermore, the tool itself should have features that facilitate easy process development for rapid deployment of new processes and log process changes for quality control.

Non-value-add time can be reduced in a number of ways. Automation, whether through roll-to-roll handlers for high volume flexible circuit manufacturing or through stack handlers for medium-volume manufacturing, can reduce operator error and speed up loading and unloading procedures. Automated vision alignment routines are another way to reduce operator involvement and speed up alignment time. Good debris removal and optics protection mechanisms can reduce both preventive maintenance and unexpected maintenance procedures and minimize laser and optics consumption to reduce maintenance costs.

Reliability

Maintenance costs and system downtime can also be reduced when the supplier has well-trained service support teams for preventive maintenance and troubleshooting support. On-system logging and diagnostics features aid rapid turnaround of fixes with targeted solutions (rather than the alternative approach of replacing parts to see what fixes the problem). Finally, given that the laser will be one of the highest-cost consumables, the supplier should have chosen a reliable laser to help achieve the lowest possible cost of ownership over the course of the system lifespan.

Summary

In this article, we have explored some of the market trends that are driving more and more flexible circuit usage, as well as more difficult-to-process materials and features. We evaluated three different processing methods—mechanical, CO2, and UV laser processing—in terms of their ability to help you meet the evolving needs of your customers in the flexible circuit market, and showed how UV laser processing is the best-equipped of those three to meet changing market need. Finally, we explored some of the most important factors to consider when choosing a UV laser processing tool. This is an exciting and evolving time for the electronics industry—and for flex circuit manufacturers in particular. Make the most of it. Continue to educate yourself on what you might be able to achieve, given the right tools and processing methodologies. At the confluence of processing technology evolution, the consumerization of electronics, and ever-smaller devices sits the flexible PCB. And, your ability to efficiently process flex materials isn't simply a nice-to-have…your customers will demand it!

About the author

Patrick Riechel, MSc MBA, is product manager for flexible circuit micromachining tools at ESI, with over ten years of experience in design and manufacturing of electronics.