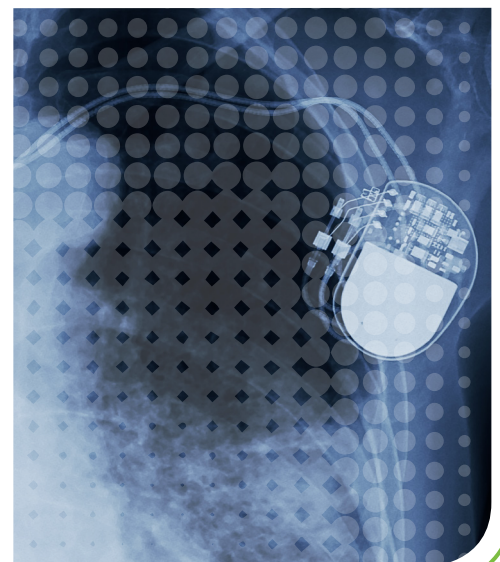
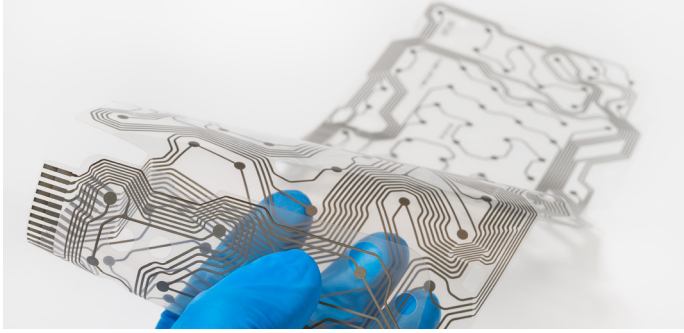


ADVANCING FLEXIBLE PRINTED CIRCUITS MANUFACTURING



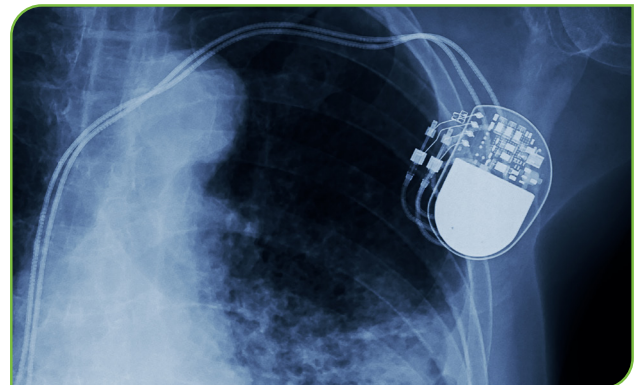
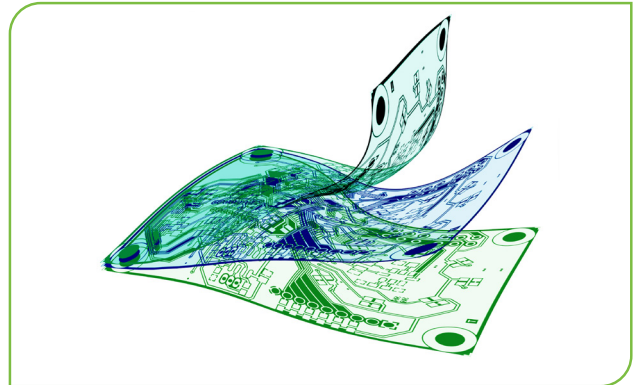


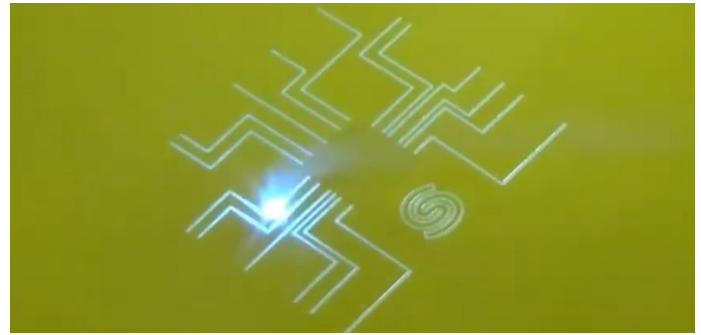
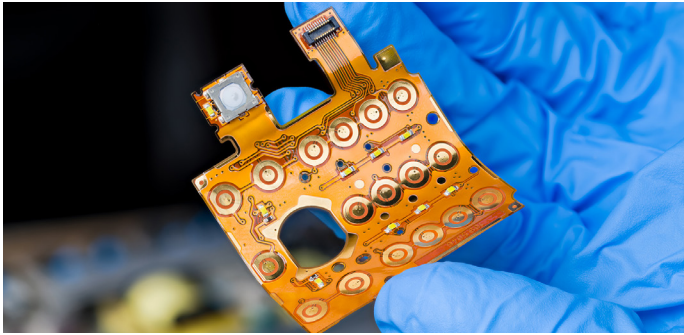
FLEXING FOR A DIGITAL WORLD

Digital technology has become so ingrained in our lives that we take for granted that electronics operate almost everywhere, including within the smallest items we hold and manipulate. Even electronic devices integrated into the clothes we wear or residing within our own bodies are gradually being seen as ordinary. As our society's digital transformation continues, the demand for more powerful electronics in smaller, lighter, and more adaptable packages rises. The traditional FR4-based rigid printed circuit board (PCB) has served us for decades in countless invaluable applications. However, PCBs face limitations in producing the smaller, lighter, more adaptable, and more powerful electronics required in an increasingly digital world.

An alternative to the traditional PCB is a flexible printed circuit, or FPC. As the name implies, an FPC is a circuit board that is flexible and can be bent, twisted, and even folded to a certain extent. By contrast, the traditional PCB is rigid and therefore cannot be bent, twisted, or folded. FPCs are also much lighter than conventional PCBs. Additional benefits of FPCs over traditional PCBs include greater resistance to vibration and movement (due to their flexible nature) and fewer connection points, which may reduce the risk of interconnect or solder failures.

FPCs can be used in countless applications and are already having a dramatic effect on our lives. For example, they enable consumer electronics to become even smaller, more powerful, and more useful, such as with bendable smartphones. In the automotive industry, FPCs are important as cars become increasingly automated and reliant on electronics and sensors. FPCs are especially critical in the medical and healthcare fields—as just one example, they are expanding the functionality and usage of implantable and wearable devices. With the rollout of 5G and the Internet of Things, demand for FPCs will grow even further. This is just a portion of the applications and industries in which FPCs can be used; they are also widely used in aerospace, robotics, AR/VR, and many others.





FLEXIBLE PRINTED CIRCUITS MANUFACTURING CHALLENGES

Lasers are widely used in the manufacturing of FPCs for operations such as singulation (or depaneling), coverlay patterning, and drilling and vias. However, it is important to note that not all lasers are the same, and not all lasers deliver optimal results.

One critical challenge in FPC laser manufacturing processes is to remove as little material as necessary (i.e., reduce waste) so that more circuits can fit on a panel, thereby increasing the net usable area and throughput. Another important reason for removing less material is to enable further miniaturization of FPCs by creating smaller blind via and through-via sizes on thinner substrate materials—dimensions of which are on the order of tens of microns. Commercially available CO₂ lasers are unable to reliably and repeatedly achieve drills and cuts below 30 microns because of their longer wavelengths. Hence, CO₂ lasers are not the best choice for minimizing wasted material or enabling miniaturization, especially in the manufacturing of high-density interconnects.

Reducing FPC part failures can also be challenging because lasers naturally induce a heat-affected zone, or HAZ, into the region of the material being cut or drilled. This HAZ can cause

unwanted changes to the materials used in FPCs, potentially weakening, cracking, or distorting them. Therefore, reducing the size of the HAZ will not only lead to fewer part failures but also to higher throughput. One way to decrease HAZ size without compromising manufacturing efficiency or quality is to employ high-power lasers with short pulses and high repetition pulse rates—features that most commercially available pulsed CO₂ lasers cannot provide.

FPCs are made of varied materials—such as copper (Cu), polyimide (PI), and other dielectric materials—which absorb or react to a laser differently. Thus, an FPC manufacturing system must be able to modify its laser parameters accordingly. For example, when cutting dielectric material, the laser should not damage the bottom Cu layer.

The MKS Advantage for Flexible Printed Circuits Manufacturing

As a leader in laser industrial manufacturing for decades, including a wide variety of electronics and packaging applications, MKS has a deep understanding of the challenges faced in designing and processing FPCs. We've turned this knowledge into unique product features that provide an advantage in FPC manufacturing. Some of these features are described here.

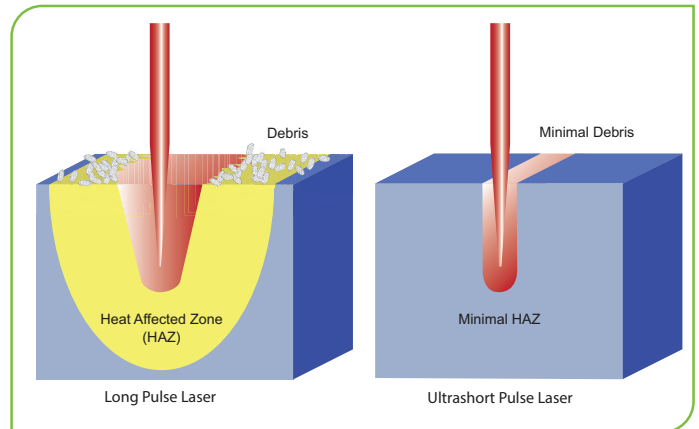
Short-Pulse, High-Repetition Rate, High-Power Lasers

Lasers with short pulses combined with higher repetition rates are advantageous because, in general, the shorter—or faster—the pulse, the higher the quality of a cut or drill will be. Shorter pulse widths can deliver intense peak powers resulting in nonlinear absorption in the sample for instantaneous material vaporization, very minimal heat transfer into the material, and a much smaller HAZ—all of which leads to higher throughput and fewer part failures. While most commercially available pulsed CO₂ lasers have pulse widths in the millisecond or microsecond range and repetition rates up to a few hundred kHz, by contrast, Spectra-Physics® UV diode-pumped solid-state (DPSS) lasers feature nanosecond and picosecond pulse widths and repetition rates ranging from single shots to 10MHz.

Spectra-Physics UV DPSS lasers can also produce high power. This enables faster operations, resulting in higher yields that can help meet FPC processing throughput requirements. At the same time, these Spectra-Physics lasers will not sacrifice operational quality for speed, thanks to the benefits of shorter pulse widths and higher repetition rates.

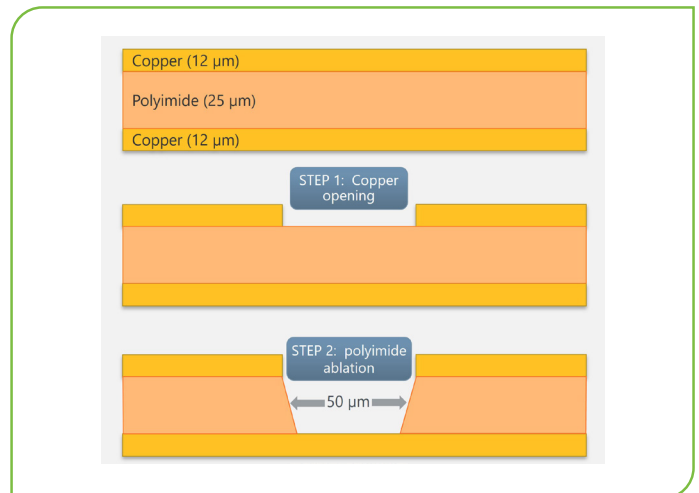
Ultraviolet Wavelength Lasers

Shorter laser wavelengths, such as those in the UV region, allow smaller beam spot sizes and tighter focusing, and therefore higher precision, which is beneficial for FPC processing in several ways. The tighter focus offered by UV wavelengths can remove smaller volumes of material, whether in a straight-line or contoured profile, reducing waste. Moreover, only the tighter focus provided by shorter-wavelength UV lasers can achieve beam spot sizes sufficiently small for drilling the required <30-micron via dimensions, enabling miniaturization of FPCs. By contrast, the longer IR wavelengths of CO₂ lasers prevent them from achieving reliable and consistent <30-micron-level drills and cuts.

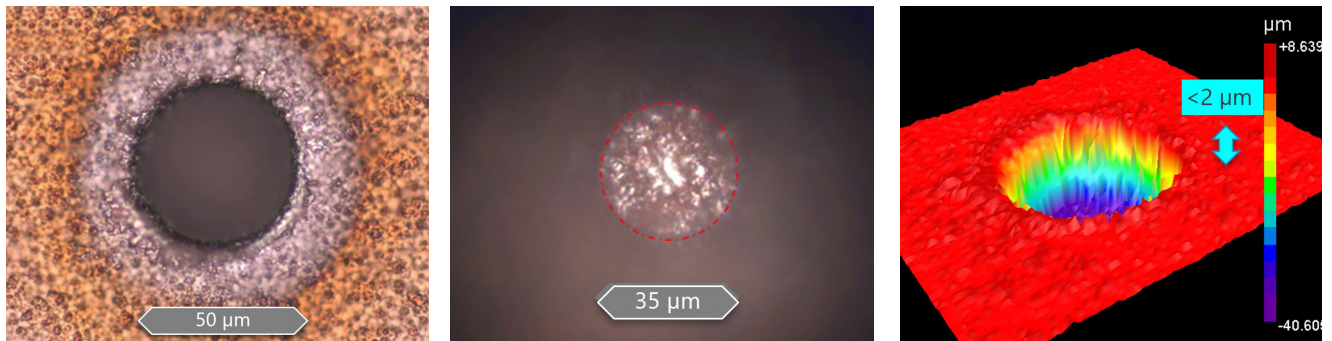


The impact of laser pulse width on machining quality for a long pulse ms laser (left) versus an ultrashort pulse laser (right).

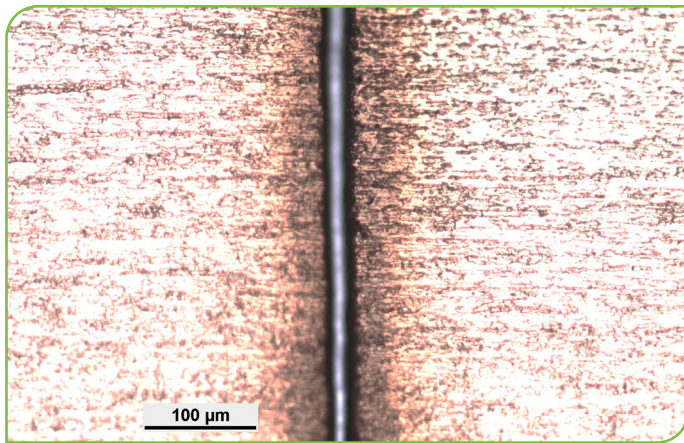
UV wavelengths also contribute to efficient FPC processing, as they are well-absorbed by a variety of materials used in FPCs, including Cu and PI. For example, the high beam intensity with smaller beam spot sizes achievable with Spectra-Physics UV DPSS lasers can efficiently remove Cu. In contrast, a lower beam intensity with the same type of laser can cut dielectric material without damaging the bottom Cu layer.



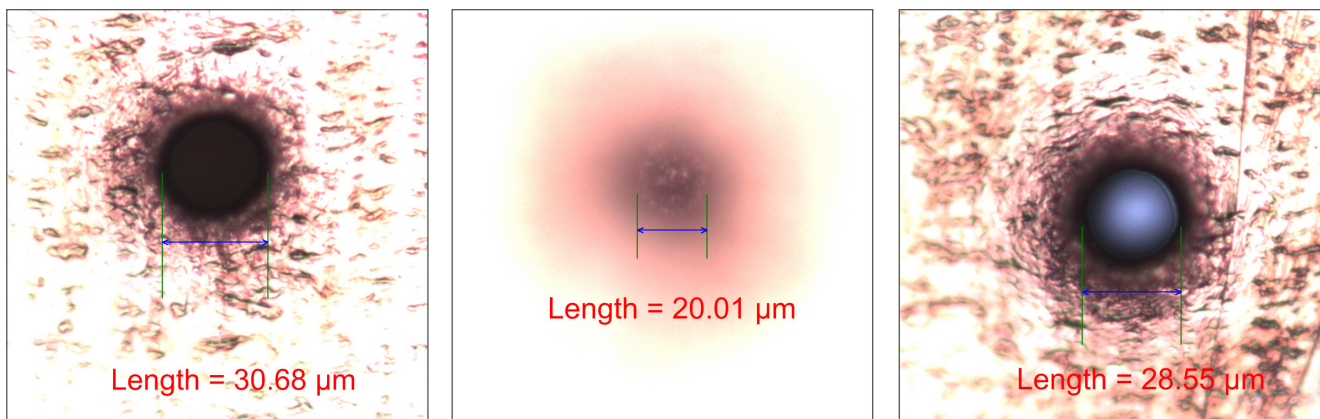
Schematic of blind via drilling in a typical FPC laminate comprised of 12 μm of PI sandwiched between 12-μm Cu layers.



12/25/12- μm Cu/PI/Cu FPC blind via drill with Spectra-Physics Talon Ace UV laser results: (1) 50- μm entrance via, (2) 35- μm exit via, (3) <math>< 2 \mu\text{m}</math> Cu edge burr height, and (4) >11,500 vias/sec throughput.



Optical micrograph showing exceptional cutting quality and small HAZ of 12/12/12- μm Cu/PI/Cu FPC laminate processed with Spectra-Physics Talon UV laser.



12/25/12- μm Cu/modified PI/Cu blind via drill with Spectra-Physics IceFyre picosecond UV laser with microscope focus on the top and bottom Cu (left and middle), and through-via imaged at the top Cu surface (right). The blind via demonstrates clean ablation of the top Cu and modified PI layers, stopping at the bottom Cu with minimal damage. Both via types exhibit minimal HAZ and no detectable burr along the edge of the ablated region.

Nanosecond UV and Green Lasers

For the best balance of performance, reliability, and cost in FPC manufacturing, Spectra-Physics Talon® lasers deliver excellent results. While the UV version should be the primary tool of choice for FPC processing, The green wavelength version can also be quite suitable in some areas, such as with less complex FPCs. Based on the Spectra-Physics' It's in the Box™ design, the laser and controller are integrated into a single, compact package, and the Talon laser is manufactured to provide 24/7 industrial reliability.

- Up to >45 W UV and >70 W green power
- Pulse widths as small as <25 ns
- 0 to 500 or 700 kHz repetition rates
- E-Pulse™ technology for superb stability and process control



High-Power Nanosecond UV Laser

The Spectra-Physics Talon Ace UV100 is the highest-powered single mode UV laser in the industry and offers the lowest cost-per-Watt and cost of ownership for high-power nanosecond UV lasers. By enabling the best combination of high throughput and quality, this laser is ideal for FPC manufacturing, especially if speed and throughput are the highest priorities. Designed to provide 24/7 industrial reliability, the laser and controller are integrated into a single, compact package.

- >100 W UV power
- Pulse widths programmable from <2 to >50 ns, plus burst mode operation
- Repetition rates up to 5 MHz for fast processing
- Proprietary TimeShift™ technology for unprecedented pulse control



Ultrashort Pulsed UV Lasers

When quality of results is of the utmost importance in FPC processing, an ultrashort pulse laser should be considered. For the same reason that a nanosecond laser can deliver higher quality operations compared to a longer pulse laser, a picosecond laser can deliver results with even greater quality and even smaller HAZ than a nanosecond laser can. The Spectra-Physics' IceFyre® UV lasers set a new standard for picosecond micromachining and can be used on polyimide-based and liquid crystal polymer-based materials. Based on the Spectra-Physics' *It's in the Box* design, these lasers integrate the laser and controller into a single, compact package and provide 24/7 industrial reliability.

- Up to >50 W UV power
- Typical pulse widths as small as 10 ps
- Single shot to 10 MHz repetition rate range
- Proprietary TimeShift technology for unprecedented pulse control



Laser Thermal Power Sensors

MKS offers a comprehensive portfolio of Ophir® laser thermal power sensors, several of which can measure the optical output power of short- and ultrashort-pulsed lasers such as Talon, Talon Ace, and IceFyre. These sensors have an extremely high damage threshold to withstand the high optical peak power delivered by each pulse. Also included with each sensor is a standard 1.5-meter cable to connect to a power meter or PC, and our sensors support many different data read-outs and interfaces to capture, record, analyze and display data such as the F150 sensor that is often utilized for power. MKS also develops custom sensors embedded in laser-based FPC manufacturing systems to monitor system performance, ensure reliable processes, and save on field service and user costs.

- Spectral ranges from UV to mid-IR
- Power ranges up to a few hundred Watts
- Apertures from 16 to 30 mm diameter
- Response times 1 second or less for most applications



Beam Profiling Cameras and Beam Attenuators

An effective way to analyze beam profile is with a camera-based system. Ophir beam profiling cameras allow real-time viewing and measurement of a laser beam's size, shape, quality and modal content. Camera-based systems can also measure cross-sectional intensity of the laser and provide a complete 2-dimensional view of the laser mode. The power of lasers used in FPC manufacturing must usually be attenuated by several orders of magnitude in order to be profiled properly. For this, MKS offers Ophir beam attenuators with compact, easy-to-use optics designed to reduce beam power to measurable levels without compromising beam integrity—Ophir LBS-300s series attenuators are recommended for most FPC manufacturing laser profiling applications.

- Spectral ranges from UV to mid-IR
- High-resolution, real-time viewing
- Highest accuracy measurements
- User-friendly BeamGage® software with extensive analytical features included

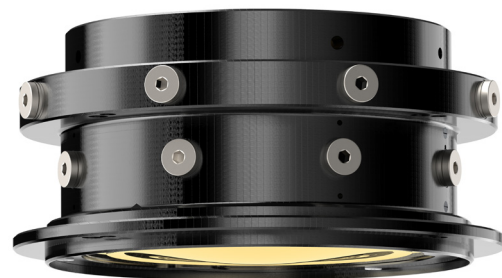
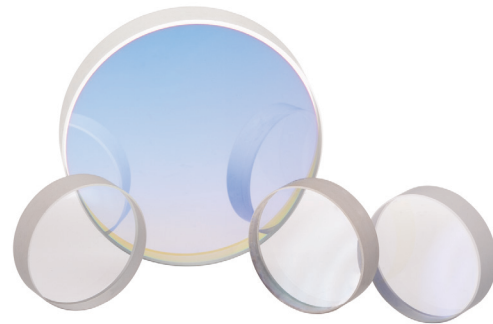
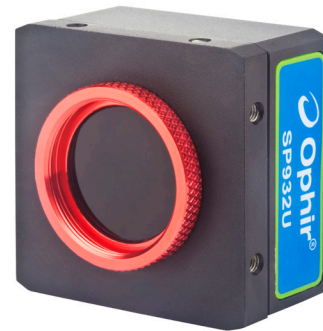
High-Energy Laser Optics

Dozens of Newport™ standard catalog optics are designed to operate with high-energy lasers such as those used in FPC manufacturing. Mirrors, lenses, beam splitter cubes, and waveplates are readily available in many sizes and shapes whose substrate materials and coatings are optimized for the 355-nm wavelength. These high-performing optics can withstand high laser fluences to enable many solutions for FPC manufacturing.

- Mirrors, lenses, beam splitter cubes, waveplates
- Optimized for 355-nm wavelength
- Extensive ultrafast optics selection
- High LIDT (Laser Induced Damage Threshold)

CO₂ Laser Scan Lenses

If using CO₂ lasers for FPC manufacturing (e.g., with >30- μ m vias), MKS also offers Ophir scan lenses. These scan lenses are customized for advanced, high-resolution 9.4-micron laser micromachining applications, including via drilling for FPCs. Used in conjunction with galvos, Ophir scan lenses can deliver highly telecentric converging ray bundles with small spot sizes to the scanning area.



- Customized for advanced, high-resolution 9.4- μm laser micromachining applications
- Small spot sizes with tight tolerances
- High telecentricity
- Unique AR coatings for high-incidence angles

Optimize the InterconnectSM

MKS combines Atotech[®] systems technology and chemical processing expertise with ESI[®] via drilling systems, forging two pioneering technologies in PCB and FPC solutions. This synergy drives the development of adjacent PCB and FPC processing technologies and pushes the boundaries of the interconnect. This industry-leading approach is creating solutions for complex PCB, FPC, and package substrate manufacturing, satisfying current requirements and those needed for future roadmaps.

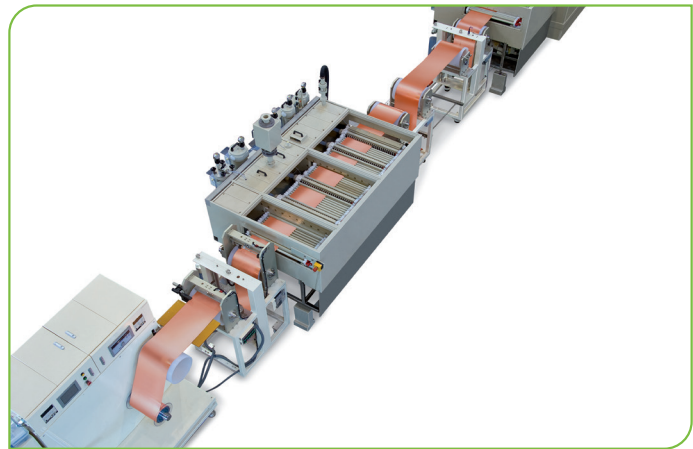
MKS' comprehensive suite of Optimize the Interconnect offerings delivers integrated solutions to improve reliability, productivity, and performance amid evolving PCB and FPC complexity and miniaturization. Our combined solutions offering includes:

- Atotech plating systems
- ESI via drilling systems
- Surface treatment
- Desmear and metallization
- Electrolytic copper filling

FPC Laser Processing Systems

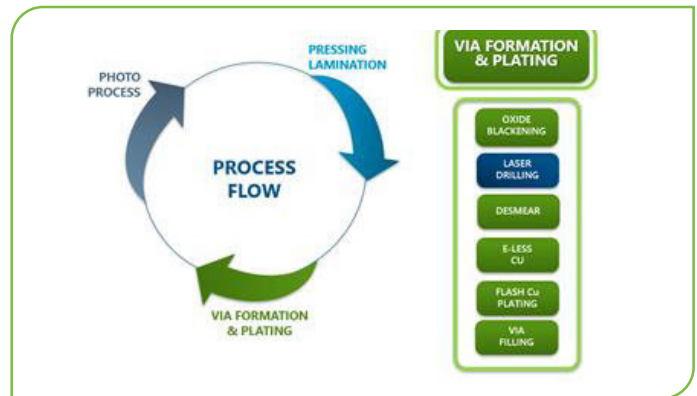
Under its ESI brand, MKS also offers complete FPC laser processing systems for applications ranging from advanced high-speed blind via drilling, circuit patterning processes, and coverlay cutting. As a leading innovator in FPC laser processing, MKS delivers systems that excel in accuracy, power control, reliability, and productivity, leading to higher throughput and quality output, and lower overall cost of ownership.

- Fastest blind via processing times in the industry
- Up to 10,000 mm/s maximum drill velocity
- Process a wide range of current and next-generation materials
- Blind via drilling, through via drilling, routing, patterning, skiving, coverlay routing



Atotech Plating Systems

Atotech plating systems provide an industry-leading transport system and reliable process control features, using fully-automated systems and analysis equipment to ensure that the optimal process parameters are always maintained. The combination of our Atotech plating systems, ESI drilling systems, and chemistry solutions enables MKS to Optimize the Interconnect by providing the complete production system from oxide treatment, laser direct drilling, desmear, electroless copper seeding to electrolytic copper plating and via filling.



MKS Products for FPC Manufacturing

MKS offers many products that are broadly utilized in FPC manufacturing. For more information, please visit www.newport.com or call +1 877-835-9620. Also, visit www.spectra-physics.com and www.atotech.com

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MKS INSTRUMENTS, INC. enables technologies that transform our world. We deliver foundational technology solutions to leading edge semiconductor manufacturing, electronics and packaging, and specialty industrial applications.

We apply our broad science and engineering capabilities to create instruments, subsystems, systems, process control solutions and specialty chemicals technology that improve process performance, optimize productivity and enable unique innovations for many of the world's leading technology and industrial companies.

Our solutions are critical to addressing the challenges of miniaturization and complexity in advanced device manufacturing by enabling increased power, speed, feature enhancement, and optimized connectivity. Our solutions are also critical to addressing ever-increasing performance requirements across a wide array of specialty industrial applications.

Additional information can be found at www.MKS.com