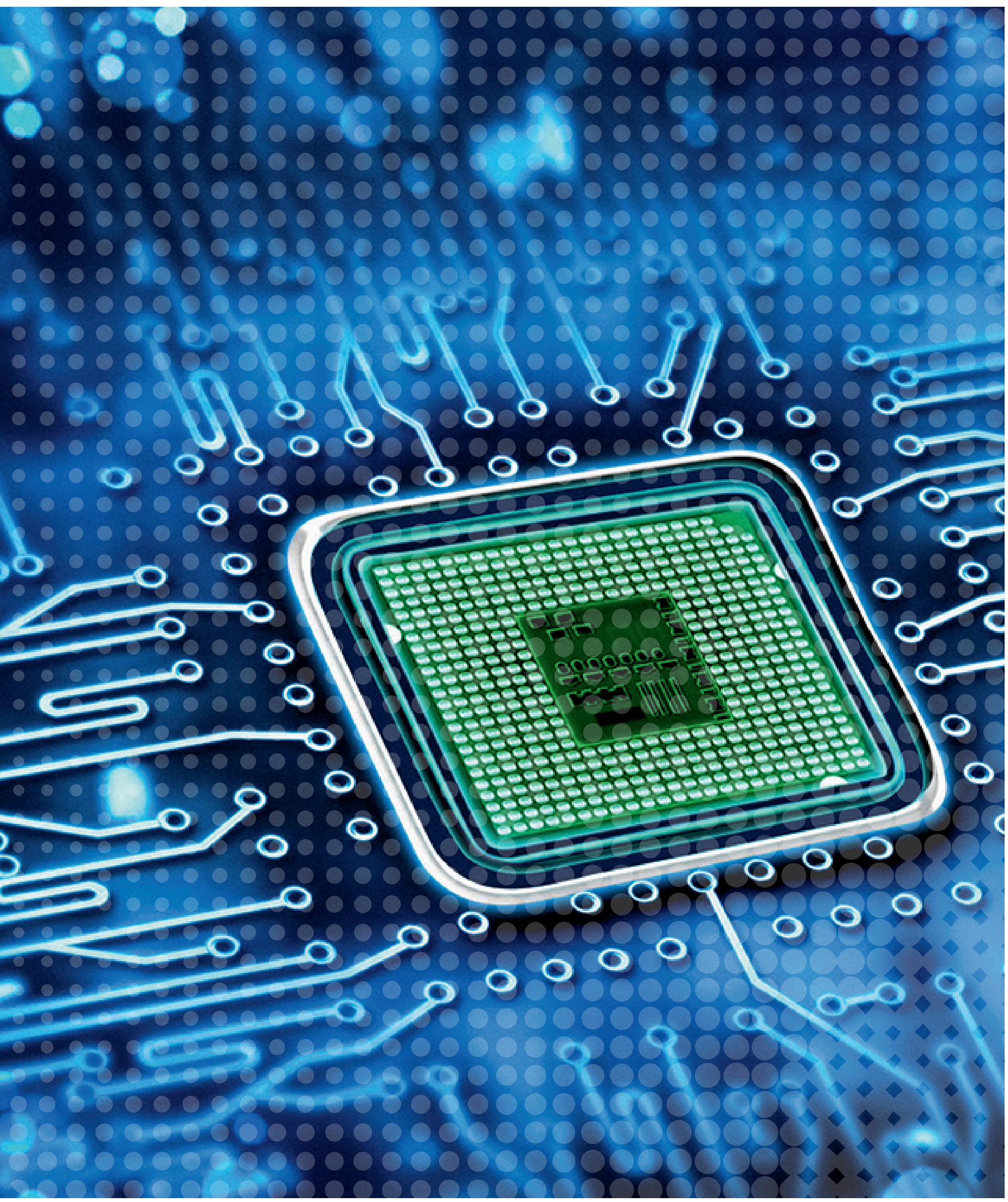
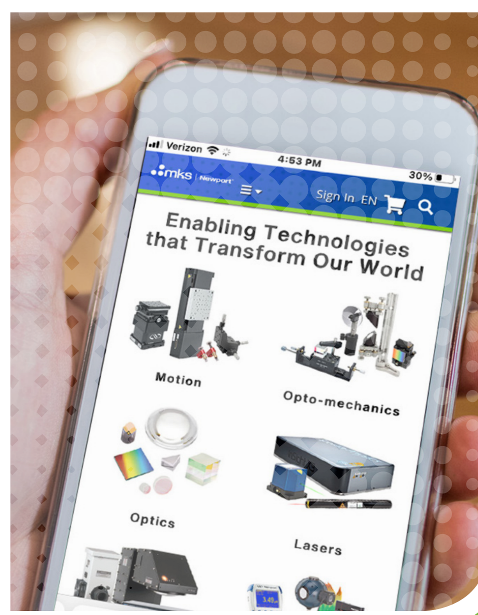
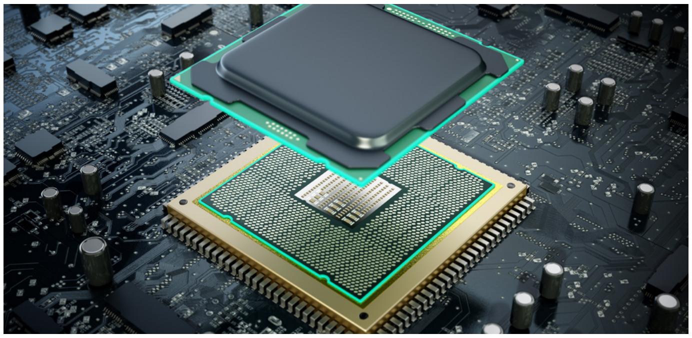
ADVANCING SYSTEM-IN-PACKAGE TECHNOLOGY





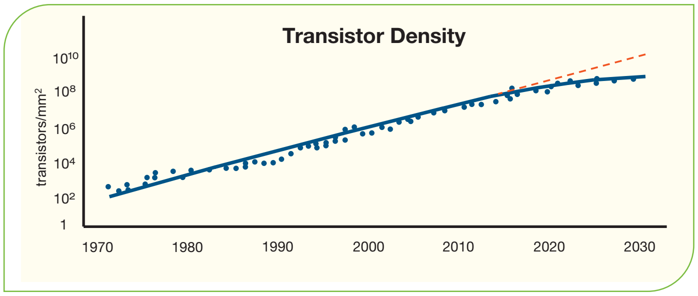


POWERING THE DIGITAL TRANSFORMATION

Maintaining the Pace of Moore's Law

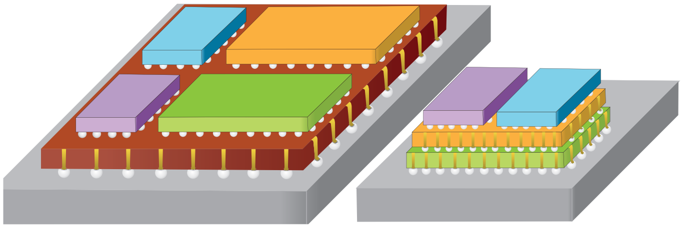
Ever since the first solid-state devices were invented, the rapidly growing demand for electronic components has forced them to become more powerful, at lower electric energy consumption, and physically smaller. A rough way to quantify this is known as "Moore's Law"—named after Intel co-founder Gordon Moore — which states that the number of transistors on a chip would double approximately every two years. This trend generally held steady through the first several decades of electronics, but over time, its trajectory has been slowing down, or "bending," as chip designs began to approach the limits of the physical properties of semiconductor materials. Nevertheless, the desire to maintain the pace of Moore's Law remains, thus requiring new innovations.

One area of innovation lies in chip packaging, and in particular, System-in-Package (SiP) technology. Also known as 2.5D/3D packaging, SiP enables heterogenous integration, which is the packing of individual semiconductor chips with various functions such as memory and logic onto a single, shared printed circuit board substrate to achieve system-level performance. SiP has already become common in mobile consumer electronics such as smart phones, earbuds and other wearables, and it has the potential to continue and possibly exceed the original growth trajectories of Moore's Law for the number of transistors on a chip.



"Bending" of Moore's Law

SiP Manufacturing Challenges



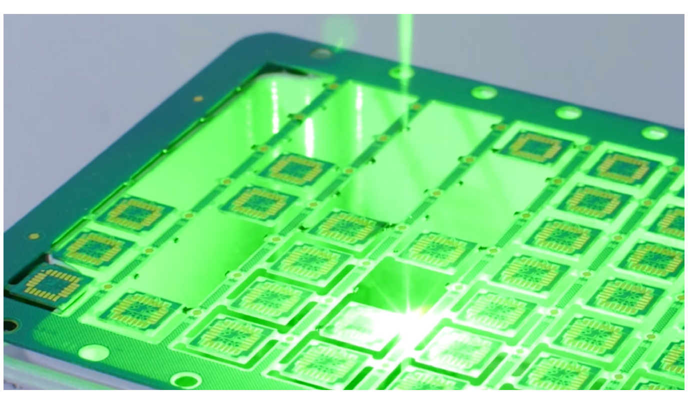
Illustrations of 2.5D (left) and 3D (right) chip packaging

As SiP packages contain two or more chips stacked vertically as well as horizontally, micro-vias with typical diameters ranging from approximately 200 to just a few microns are used to provide vertical electrical connections among them. These micro-vias may be present either in an interposer (which is also referred to as an IC substrate) layer or within the chips themselves. Formation of micro-vias is commonly accomplished through chemical etching, but this process has limitations. Although chemical etching is a proven methodology for silicon and glass, etching cannot be used with ceramics or organic materials. Additionally, the waste management required for chemical etching processes presents extra complications and costs.

Cutting various materials as part of the SiP manufacturing process is also a very delicate process. Whether cutting an interposer, depaneling a package substrate or scribing and dicing a silicon die, the size of the cuts can be extremely small and must be made with the highest precision and minimal surrounding damage. As chip designs become even more advanced and miniaturized with higher densities, the type of cuts required will also become more complex.

Furthermore, as the materials become thinner, contact-based mechanical methods could cause damage such as cracks and tears, so therefore, a non-contact laser process will improve yields and throughput.

The assorted types of materials which SiP packages comprise—for example, ceramics, organic laminate and glass—respond differently to different manufacturing processes. To further complicate matters, some materials are inhomogeneous, such as ABF and FR4, which contains glass fibers and epoxy resin, and some laminates, which are embedded with copper traces. Traditional manufacturing processes including mechanical saws and etching may work well with some materials but not as well with others. The same is also true with laser manufacturing processes, as not all lasers are the same. Furthermore, tradeoffs in areas including speed, precision, surrounding damage and cost are always present when comparing manufacturing processes.



Depaneling with ultrashort pulse laser

The MKS Advantage for SiP Manufacturing

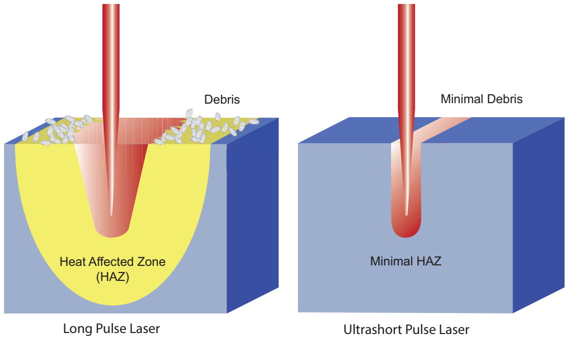
MKS has a deep understanding of the challenges faced in designing and building SiP manufacturing systems. We've turned this knowledge into unique product features that provide an advantage when used in SiP manufacturing. Some of these features are described below.

Ultrashort Pulse Lasers

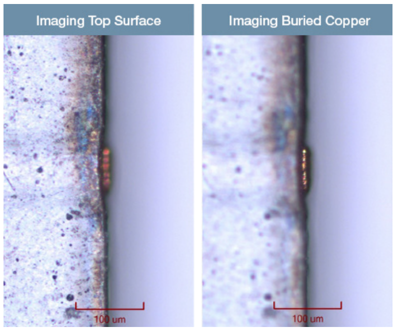
One of the challenges for laser materials processing—including cutting and drilling—is removing only the desired material, usually through localized heating, while at the same time minimizing the extent of the heat-affected zone (HAZ) to any of the remaining material. Delivering laser irradiation with near-perfect beam quality precisely to the target region is a necessary step to achieving this desired result. Shorter wavelengths and, in particular, shorter pulse widths are advantageous to achieving higher-quality results.

For singulation of SiP devices, lasers in the ns pulse width regime at UV and green wavelengths, such as the Spectra-Physics® Talon® laser, may be suitable. However, challenges arise if excess heating cannot be tolerated, especially as these devices become further condensed and more densely packed. This leads to an interest in laser processing with even shorter pulse durations for reduced HAZ. Such may be the case if there are encapsulations that use a heat-sensitive bonding media, such as solder or adhesive, which may fail under excess thermal loading. Moreover, the presence of copper traces embedded within the SiP laminate, which can become excessively hot and result in the potential for layer delamination, can create additional difficulties.

To meet these challenges and to enable the advancement of SiP technology, ultrashort pulse (USP) lasers, like the Spectra-Physics IceFyre® laser, can be employed. Ultrashort pulse widths in the ps and fs regime yield intense peak powers that result in nonlinear absorption at the sample for instantaneous material vaporization, very minimal heat transfer into the material, and a negligible HAZ. The result is a fast, high-precision, high-quality cut or drill which leads to higher throughput and fewer part failures.



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

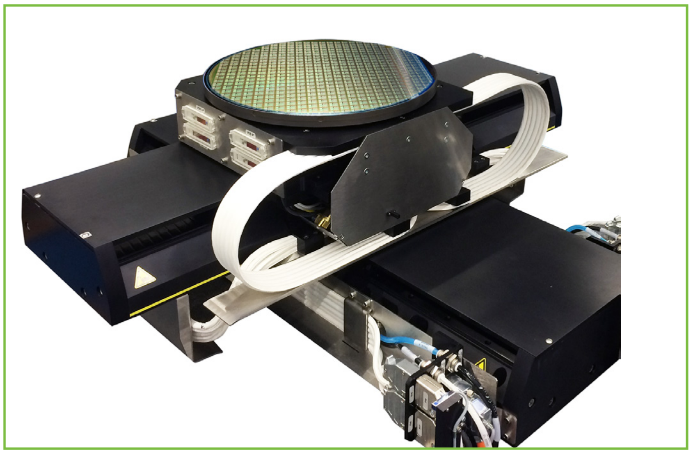


Entrance side microscope images of green ps laser pulses cutting ~100-µm thick FR4 with polymer solder mask protective layers and intermittently embedded coper trace lines.

High-Precision, High-Speed Industrial Grade Positioners

The target for a laser materials process—for instance, a silicon wafer for scribing and dicing—will often have to be positioned for the laser to perform its operation. The positioning requirements for SiP manufacturing can be extremely challenging. Accuracy in two dimensions is typically on the order of microns, as is the repeatability to ensure consistent results. To meet throughput demands, the required speed can be up to 1 meter/sec.

These performance requirements must be achievable in a demanding production environment. Thus, only high performing motorized positioners designed for continuous usage in industrial environments, like the Newport™ IDL series linear positioners, should be considered.

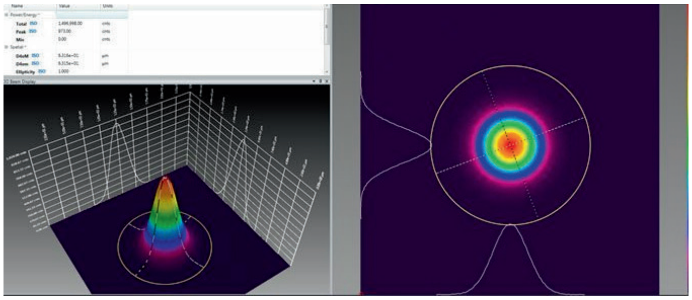


Two Newport IDL positioners stacked for high-precision, high-speed positioning of a wafer.

Beam Analysis

Even with the advantages that lasers have over traditional tools, laser systems can still degrade over time. Some causes of degradation include thermal effects on a laser system's internal components, vibrations or shock and debris near the processing site. These issues could affect laser performance in a number of ways. First, output power may be reduced, causing the laser to be less efficient. Another problem that may be caused is a change in the focus or other profile of the beam, which may lead to a cut or drill to be off target, too deep, low quality or possibly damaging to another part of the material.

Therefore, to ensure the highest quality of manufacturing SiP chips and to minimize the possibility of production down-time, it is crucial to monitor the laser beam frequently with appropriate instruments–like Ophir® power sensors, power meters and beam profilers–that can operate at the laser's wavelength while handling its maximum output power level.



Beam profiling graphical user interface

MKS Products for SiP Manufacturing

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

Picosecond UV, Green and IR Lasers

Spectra-Physics IceFyre picosecond lasers set a new standard for picosecond micromachining and can provide the ultimate solutions for SiP manufacturing. The UV version enables premium quality drilling of micro-vias through ceramic, organic and glass interposers. Both the UV and green versions are great for cutting ceramic interposers, depaneling and scribing and dicing silicon dies. Additionally, the IR version can be used to cut glass interposers. Based on Spectra-Physics' *It's in the Box*™ design, the laser and controller are integrated into a single, compact package, and IceFyre is manufactured to provide 24/7 industrial reliability.

- Up to >50 W power
- Typical pulse widths as short as 10 or 13 ps
- Single shot to 10 MHz repetition rate range
- Proprietary TimeShift™ technology for unprecedented pulse control

Nanosecond UV and Green Lasers

For the best combination of performance, reliability and cost in SiP laser manufacturing, Spectra-Physics Talon lasers deliver excellent results. Talon works exceptionally well for cutting ceramic and organic laminate interposers, depaneling and scribing and dicing silicon dies. The UV version in particular is also able to drill micro-vias through ceramic and organic interposers. The Talon provides high quality results, but its cuts and drills may not be as pristine as the IceFyre's. Talon's advantage over IceFyre, though, is that it can cut and drill faster. Based on Spectra-Physics' *It's in the Box* design, the laser and controller are integrated into a single, compact package, and Talon is manufactured to provide 24/7 industrial reliability.

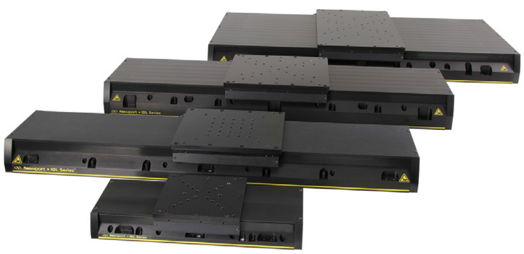
- Up to >70 W power
- Pulse widths as short as <25 ns
- 0 to 500 kHz or 0 to 700 kHz repetition rates
- E-Pulse™ technology for superb stability and process control

High-Power Nanosecond UV and Green Lasers

Other lasers highly suited for SiP manufacturing are the Spectra-Physics Quasar® and Talon Ace™ nanosecond series of lasers. The Talon Ace UV100 is the highest-powered single mode UV laser in the industry, so it delivers fast micromachining and provides 24/7 industrial reliability. Like the IceFyre and Talon, the UV and green versions of the Quasar and Talon Ace can also be used for depaneling, scribing and dicing dies. And like the UV version of the IceFyre, the Quasar UV and Talon Ace UV can also drill micro-vias through ceramic, organic and glass interposers.

- >100 W (UV) and >95 W (Green) 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

Industrial Grade Linear Positioners



Newport IDL-LM series positioners are industrial-grade positioners with an ironless linear motor and recirculating ball bearings that offer the highest speed and load capacity of all linear motor stages. With an accuracy on the order of microns and sub-micron repeatability, these positioners are ideal for SiP manufacturing. To further add to their design for production environments, all IDL-LM positioners feature a hard top cover, wear-resistant, flexible side bands, air purge and directed debris path.

- 100 mm to 1.2 m travel range
- 2 m/sec speed
- 450 to 2,000 N max load capacity
- Micron level accuracy and sub-micron repeatability
- Designed for the most rigorous demands of precision industrial laser microprocessing

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 IceFyre, Talon, Talon Ace and Quasar. These sensors have a very high damage threshold to withstand the high optical peak power delivered by each pulse. Ophir sensors and meters meet the ISO/IEC 17025 standard for calibrated devices.

- Spectral ranges from UV to mid-IR
- Power ranges up to a few hundred Watts
- Apertures from 16 to 30 mm diameter
- Response times of a few seconds or less
- Not water cooled

Virtual Power Meters

A sensor's output will have to be processed through a power meter. Another option is to use a PC as a laser measurement station. This can be accomplished by connecting the sensor to the Ophir Juno+ virtual power meter, which then connects to a PC via USB. This cost-effective approach also allows multiple power meters to be run on a single PC. To control and monitor a sensor remotely through the "cloud," the Ophir EA-1 Ethernet adapter allows that, as Telnet, HTTP and UDP protocols are supported. MKS user-friendly application software is included with features including extensive graphic displays of data, advanced measurement processing and data logging for future review.

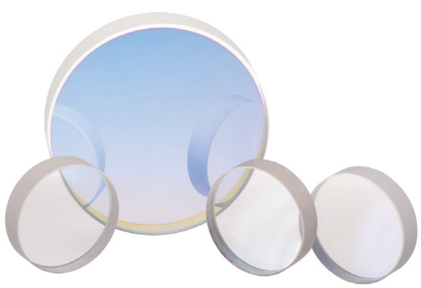
- Connect sensor to a PC via USB
- Connect sensor to the "cloud" – Telnet, HTTP and UDP supported
- Data logging
- User-friendly application software with extensive features included

Beam Profiling Cameras

An effective way to analyze beam profile is with a camera-based system. Ophir beam profiling cameras allow real-time viewing and measuring of a laser's structure in high resolution. Camera-based systems can also measure cross-sectional intensity of the laser and provide a complete 2-dimensional view of the laser mode.

- Spectral ranges from UV to mid-IR
- High-resolution, real-time viewing
- Highest accuracy measurements
- User-friendly application 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 SiP laser manufacturing. Mirrors, lenses, beam splitter cubes and waveplates are readily available in various sizes and shapes whose substrate materials and coatings are optimized for the 355, 532 and 1064 nm wavelengths. These high-performing optics can withstand laser fluences in the Joules and sometimes tens of Joules of pulsed energy per square centimeter to enable many solutions for SiP processing.

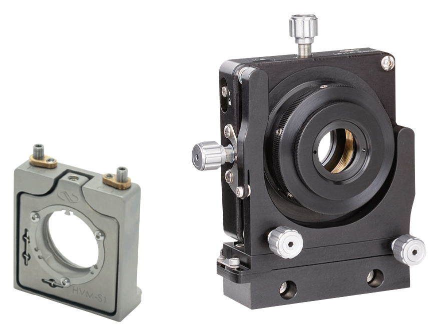
- Mirrors, lenses, beam splitter cubes, waveplates
- Optimized for 355, 532 and 1064 nm wavelengths
- Extensive ultrafast optics selection
- LIDT (Laser Induced Damage Threshold) of Joules and tens of Joules per cm^2
- Various sizes and shapes

CO2 lenses

For SiP operations that utilize CO2 lasers, Ophir low-absorption CO2 laser lenses are specially designed to be used with high-powered 10.6-micron CO2 lasers of up to several kilowatts. These lenses absorb up to 50% less CO2 laser energy than standard anti-reflection coatings, resulting in higher efficiency, superior performance and longer lifetime.

- Optimized for 10.6-µm CO2 lasers up to several kilowatts
- Absorption rates as low as <0.13% of laser power
- Transmission >99.3%
- 1.1- to 2.5-in. diameter, plano-convex and meniscus shapes

Opto-Mechanical Components



Whenever optics are part of a laser system, they will have to be precisely positioned and steadily held over long periods of time. MKS offers the most comprehensive line of opto-mechanical components in the industry. Hundreds of optical mounts and positioners at various levels of performance and cost are readily available.

- Mirror mounts, lens positioners and other optical mounts
- Linear and rotary positioners
- Post and pedestal assemblies
- Stainless steel and aluminum

WHY MKS?

CRITICAL TECHNOLOGIES

World-class technology and development capabilities for leading-edge processes

PROVEN PARTNER

Recognized leader delivering innovative, reliable solutions for our customers' most complex problems

OPERATIONAL EXCELLENCE

Consistent execution across all aspects of our business

COMPREHENSIVE PORTFOLIO

Largest breadth of product and service solutions for the markets we serve

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