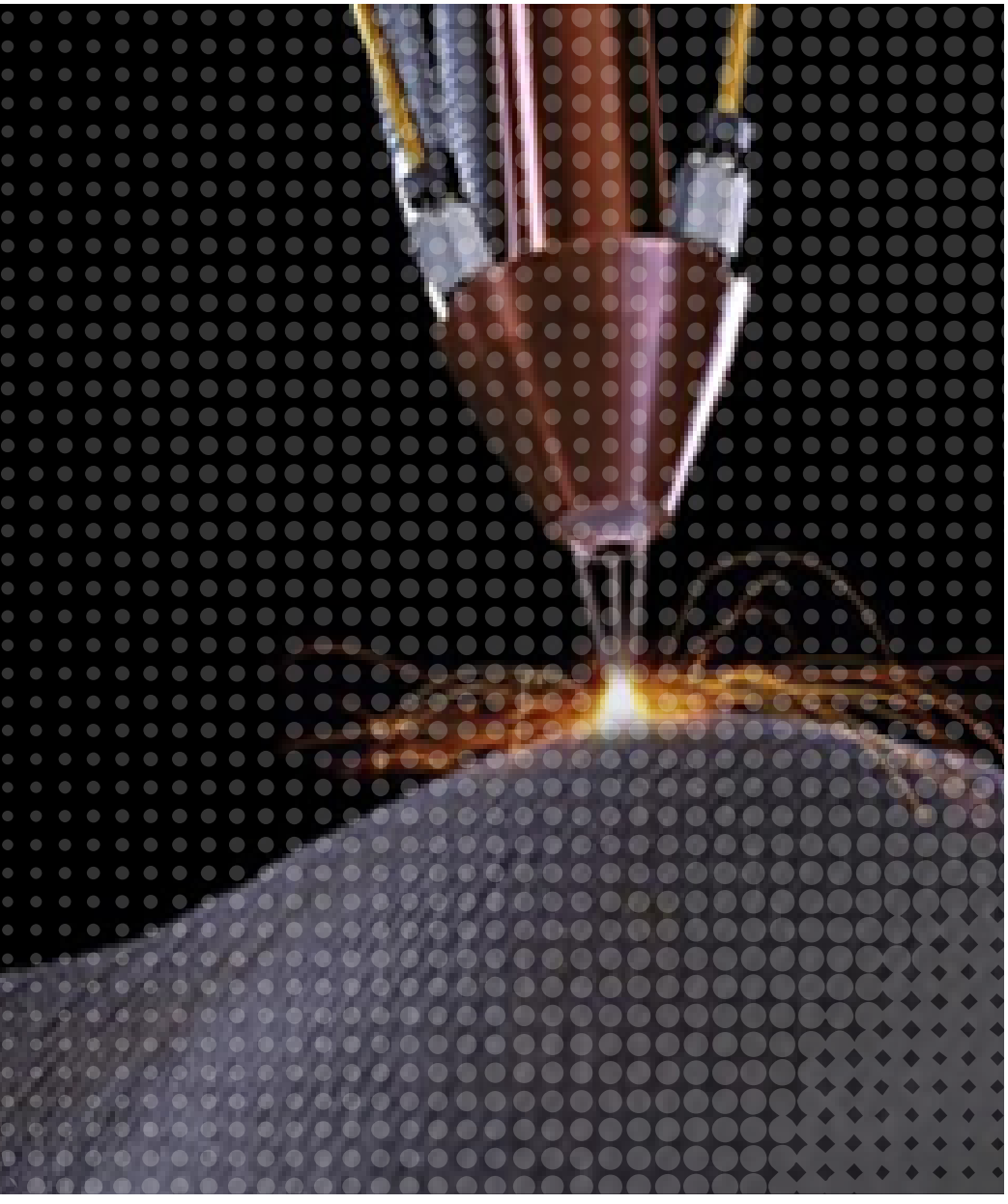
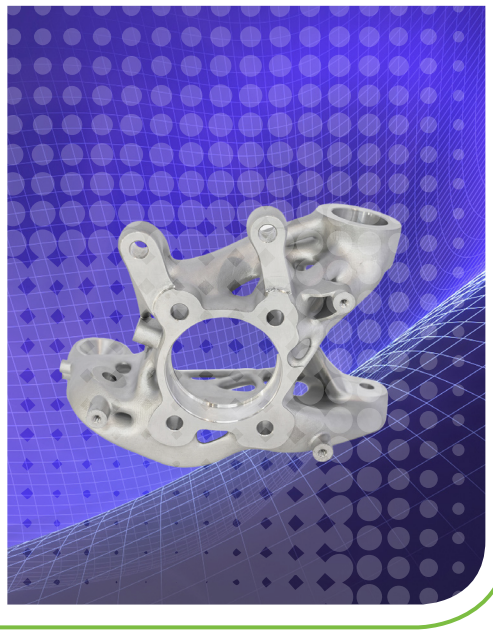
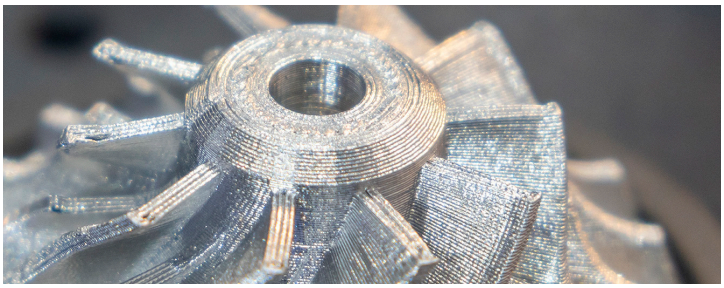
ADVANCING POWDER BED FUSION ADDITIVE MANUFACTURING







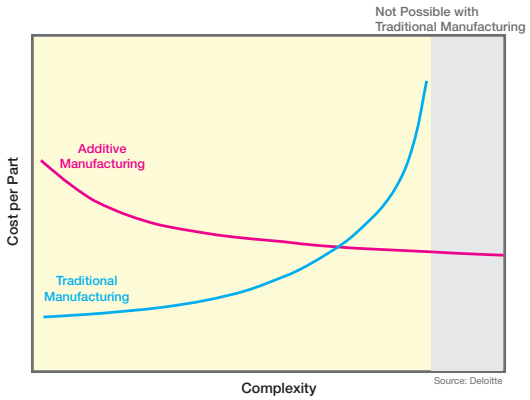
A FUTURE OF OFF-THE-SHELF CUSTOMIZATION

Often referred to as 3D printing, additive manufacturing (AM) is a revolutionary, disruptive approach to traditional industrial manufacturing. It is often thought of as a technique to make complex or lower volume products such as prototypes, concepts and custom one-off parts. But as product complexity increases, AM methods become less costly compared to traditional manufacturing (machining) methods. As such, AM is already used prevalently for production in several industries including aerospace, automotive, healthcare and energy. Demand for AM is predicted to increase further as software, computing power, materials and methods improve over time. In response, engineers will design considerably more products to be crafted specifically by AM methods, including products that are too sophisticated for traditional manufacturing to produce. In time, AM may be able to provide what today is thought of as a contradiction: off-the-shelf customization.

There are many types of AM techniques, and they all have in common the concept of adding or depositing layers of material to create a final object, as opposed to traditional subtractive manufacturing processes that remove material. One AM technique that has achieved commercial success is powder bed fusion (PBF), a method that uses a heat source—such as a laser—to sinter or melt material powder, causing it to fuse together into the desired shape, layer by layer. Popular types of PBF that utilize lasers are selective laser sintering (SLS), direct metal laser sintering (DMLS), selective laser melting (SLM) and direct metal laser melting (DMLM). Another popular type of PBF is electron beam melting (EBM), which uses a high-energy beam of electrons to melt powder.

Benefits of PBF include compatibility with a wide range of materials including metals and polymers, good resolution and minimal or no support structures required when creating new parts. In particular, PBF is an ideal technique for producing metal honeycomb structures, whose properties of high strength at lower weight are extensively utilized for aerospace applications. As PBF further progresses, it will play an even more important role in elevating the norm of current manufacturing.

Product Complexity vs Cost



As products become more complex, additive manufacturing becomes less costly than traditional manufacturing and, eventually, the only option.

Powder Bed Fusion Challenges

Each type of AM technology has a specific set of benefits and challenges. Fabrication accuracy and reproducibility are important challenges that PBF systems face. PBF may already provide high resolution, but the quest to create parts with even tighter accuracy and finer details continues, with sub-millimeter and even micron-level precision often required. These demanding accuracy requirements apply not only to the part being made, but they also pertain to the next parts to be produced and extend to all PBF machines in the entire production system.

Despite the non-contact operational nature of lasers, laser systems still degrade over time. Some causes of degradation include thermal effects caused by the laser's energy, debris at the processing site, vibration and shock. These issues could lead to decreased laser power at the machining plane, resulting in subpar sintering or melting of the powder.

Just as important as a laser's power level is its focus quality, or changes in focus position over time. The focus spot location can shift up to several millimeters as the optical train of the laser system heats up. This can directly influence the quality of

laser sintering, because if laser power is too low or not applied long enough, the grains of powder will not melt properly—this will cause the metal to become porous and weaker. On the other hand, if too much laser power is used or applied for longer than necessary, then the laser will drill into the fused powder, reducing the density of the structure. Moreover, if the focus spot location of the laser is before or behind the build plane, or if the distribution of power is not optimized, then inadequate melting of the metal powder may result, causing structurally compromised parts. Ultimately, poor focus quality will lead to higher costs. Therefore, a beam profiler such as the Ophir® BeamWatch® AM should be used to ensure that the laser is performing optimally each time it is activated to avoid inaccuracies.

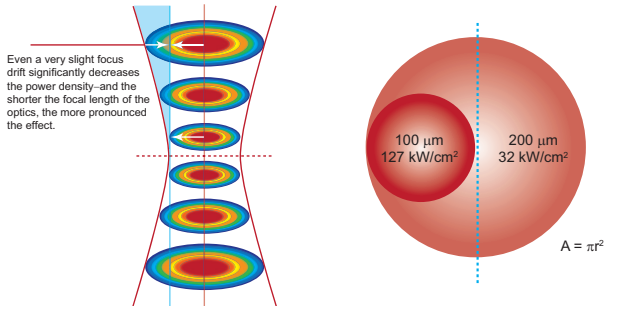


Illustration depicting how focus shift influences power density and how doubling the focus beam diameter results in a four-fold reduction in power density

The MKS Advantage for Powder Bed Fusion

MKS understands the challenges faced in designing and building PBF systems. We've turned this knowledge into unique product features that provide an advantage when used in PBF. Some of these features are described here.

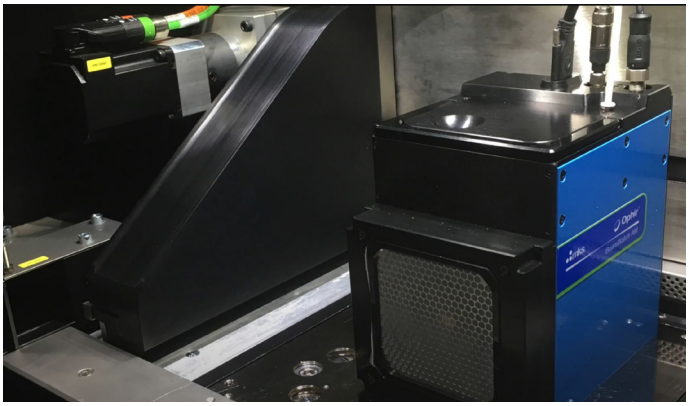
High-Power Laser Sensors

To measure the power of a PBF laser at the machining plane, a sensor that is compatible with the laser wavelength (typically IR) and can handle the laser's power, which can be in the kilowatt range, is necessary. Additionally, so as not to hinder the process, the sensor should be placed in a way that does not add unneeded physical space, it must quickly communicate results, and in some cases, it should not be water-cooled. The Ophir Ariel™ is an ideal sensor designed for industrial applications like PBF.

Ophir Ariel laser power sensor inside a small build chamber

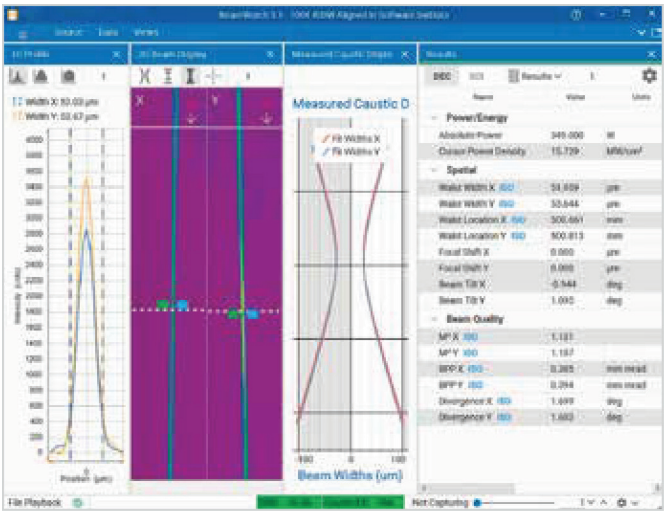
High-Power Beam Profilers

Finding a beam profiler to monitor focus quality can be quite difficult for PBF due to the high power levels and densities of the IR lasers used, which typical beam profilers cannot always handle. To provide a solution specifically for PBF, MKS created the Ophir BeamWatch AM, a high-power beam profiler featuring our patented non-contact measurement technique based on Rayleigh scattering. Non-contact beam profiling offers several crucial advantages: the measurement technology itself has no power limitation, every focus shift is immediately registered and displayed, and there is no need for active cooling. BeamWatch AM can measure a variety of critical beam parameters including focus spot width and location, drifts in focal shift, M^2, beam divergence and absolute power.



Ophir BeamWatch AM high-power beam profiler integrated into a PBF system

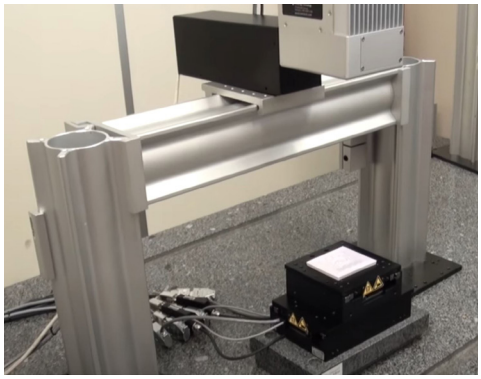
A camera-based system can also analyze beam profile, and in addition, it can measure the cross-sectional intensity profile of a beam. However, not all camera-based beam profilers are able to survive the high output powers of PBF lasers. To meet this challenge, MKS developed the Ophir BeamPeek™, which combines a laser beam profiler camera, power meter, beam dump, beam splitters and optics into a single device.



Ophir BeamWatch graphical user interface

Motorized Positioners

A common device used to steer PBF lasers very quickly to fuse patterns in the powder is a galvanometer scanner, or galvo. Although galvos can produce steering speeds of up to several meters per second with sharp corners, they have a limited field of view (FOV), on the order for 100-200 mm, and limited focal spot size of around 10-20 microns. By contrast, motorized linear positioners provide for a large FOV and allow for tight focal spots. Combining galvos and motorized positioners in a PBF system—by having positioners move the target or move the galvos—can take advantage of each of their features. A combined galvo-motorized positioners system enables "stitching," which is a method where galvos are used to process smaller cells within the work plane, and then positioners place the next cell for the galvos to work on. MKS offers not only a full range of Newport™ motorized positioners but also Newport motion controllers that can synchronize the motion of galvos and positioners for high accuracy, precision and speed.

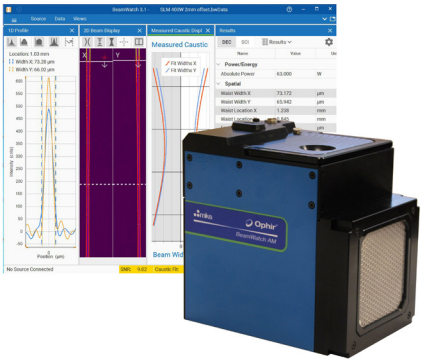


Example setup of a Newport motion controller producing synchronized motion from galvo scanners (top) and Newport linear positioners (bottom) for laser processing applications.

MKS Products for Powder Bed Fusion

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

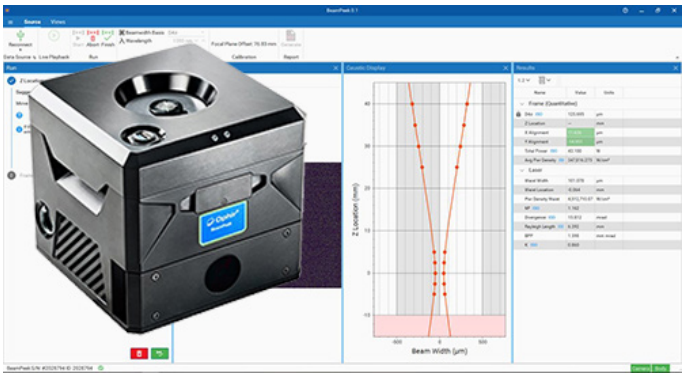
Integrated Non-Contact Laser Beam Profiler



The Ophir BeamWatch AM integrated beam profiler is a fully automated measurement system designed specifically for laser-based AM. It combines our non-contact laser measurement technology based on Rayleigh scattering with a NIST-traceable power sensor to provide real-time measurement of very high-power IR lasers without disruption of the beam. Parameters that can be measured include waist (focus spot) width and location, focal shift, divergence, M^2, absolute power and others. Short measurement times allow laser beams to be checked quickly. As the beam is simply passed through the instrument with no contact or moving parts, BeamWatch AM can measure up to 1 kW for 2 minutes without the need for water cooling, and no maintenance is required.

- Patented non-contact measurement for real-time monitoring of critical beam parameters
- 1060-1080 nm spectral range
- Measure up to 1 kW for 2 minutes without water cooling
- NIST-traceable power sensor

Camera-Based Laser Beam Profiler



A more familiar way to analyze beam profile is with a camera-based system. The Ophir BeamPeek combines a laser beam profiler camera, power meter, beam dump, beam splitters and optics into a single device that allows simultaneous beam profiling, focal spot analysis and power measurement. Furthermore, camera-based systems are able to measure the cross-sectional intensity profile of a beam. Utilizing a revolutionary beam dump cartridge which fully absorbs the laser heat (eliminating the need for fan or water cooling), BeamPeek can measure up to 1 kW for 2 minutes, which typical camera-based systems cannot handle. Additionally, BeamPeek can also measure M^2. Developed with AM field technicians in mind, BeamPeek's reliable, easy-to-use and fast results are ideal for both field service and integration into production lines.

- 1030-1080 nm and 532 nm spectral range
- Measure up to 1 kW for 2 minutes without water cooling
- Measure M^2
- Fits into most AM chambers

Industrial All-in-One Laser Power Sensor

Designed for use in closed AM production chambers, the Ophir Ariel is a compact, self-contained, all-in-one, power meter for high power laser measurements. Its sensor can measure high power industrial lasers of up to 8 kW within seconds. As Ariel makes measurements with a short exposure to the beam, the total amount of heat absorbed is small, so there is no need for water cooling, and a number of measurements can be performed in succession. Battery-operated with a built-in display, Ariel may be used as a stand-alone device. It can also connect to a smart phone app via Bluetooth® or to a PC through USB. Additionally, Ariel's rugged design is dust- and splash-resistant.

- 900-1100 nm, 450-550 nm, 2.94 µm and 10.6 µm spectral ranges
- Up to 8 kW power range (up to 500 W continuously)
- 3 seconds to display results
- No need for water cooling

Industrial Linear Motor Stages

Newport IDL-LM series linear motor translation stages are industrial-grade positioners that offer the highest load capacity and speed of all linear motor stages. They utilize an ironless linear motor and recirculating ball bearings for fast, smooth motion with micron-level accuracy and sub-micron repeatability. Designed for production environments such as

AM, IDL-LM stages feature a hard top cover, wear-resistant, flexible side bands, air purge and directed debris path. Over 20 different models with various dimensions and travel ranges are available.

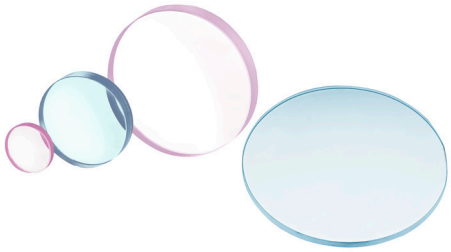
- 100-mm to 1.2-m travel ranges
- 450 to 2,000 N load capacities
- 2 m/sec speed
- Micron-level accuracy and sub-micron repeatability

Universal High-Performance Motion Controller

Newport's high-performance XPS-D series of motion controllers can control up to 8 axes of motion and offers movements ranging from basic to complex position-velocity-time, or PVT, motion trajectories through high-speed Ethernet TCP/IP interface. With its extensive analog and digital inputs and outputs, it can also monitor or synchronize with external events, including synchronizing galvos and motorized positioners for AM.

- Can synchronize galvos and positioners
- Up to 8 axes of high-performance, complex motion trajectories
- Extensive analog and digital I/O
- High-speed Ethernet TCP/IP interface

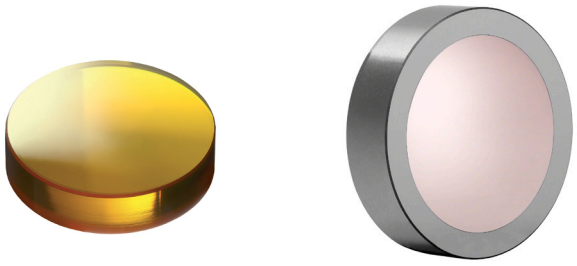
1-Micron Optics



Utilizing advanced manufacturing methods, MKS produces Ophir 1-micron optics specifically for use with high power IR fiber lasers. These optics' high laser induced damage threshold (LIDT) coatings on high-purity UV grade fused silica substrates can withstand up to 20 J/cm^2. Fiberlens™ aspherical lenses in various shapes can be provided in custom configurations. Conventional singlet and doublet spherical lenses and protective windows are also available. In addition, collimating and focusing assemblies and motorized zoom lenses for laser cutting heads are offered as standard products or as OEM custom designs.

- Spherical and aspherical lenses
- Protective windows
- Collimation and focusing assemblies
- Motorized zoom lenses for cutting head
- Damage thresholds up to 20 J/cm^2

CO_2 Laser Optics

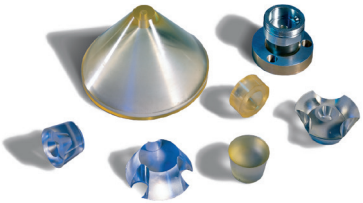


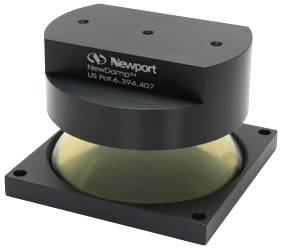
MKS also applies similar advanced manufacturing methods to produce Ophir CO_2 laser optics that are compatible with all major laser systems in the market. They are designed for the highest durability and accuracy to assure complete uniformity, repeatability and consistency. Our CO_2 focusing lenses can absorb up to 50% less laser energy than standard anti-reflective coatings, leading to superior performance and longer lifetimes for cutting heads. Zero- and 90°-phase shift,

telescopic and absorbing thin-film reflector (ATFR) mirrors with very high reflectivity and tight phase shift tolerance are also available. And to protect sensitive optics or for separating areas with different gas pressures, MKS offers high transmittance, low absorption windows for CO_2 lasers.

- Compatible with all major CO_2 laser systems in the market
- Low-absorption meniscus and plano-convex focusing lenses
- Beam delivery mirrors
- Protective windows

Vibration Isolation





To improve PBF system performance, platforms may be mounted with vibration isolation. As the leader in vibration control and isolation, MKS offers Newport elastomer and pneumatic isolators that can also be built into equipment isolation supports and even custom machinery feet. A comprehensive set of standard catalog products are available, or MKS can work with you to understand your machinery characteristics such as load, shock response and resonance modes to design and provide a custom solution. Quantities can be scaled as needed through our world-class manufacturing capabilities.

- Elastomer dampers
- Pneumatic isolators
- Custom solutions and standard catalog products
- Scalable quantities

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 Newport 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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Newport is a brand within the MKS Instruments Photonic Solutions division. The Newport product portfolio consists of a full range of solutions including precision motion control, optical tables and vibration isolation systems, photonic instruments, optics and opto-mechanical components. Our innovative Newport solutions leverage core expertise in vibration isolation and sub-micron positioning systems and opto-mechanical and photonics subsystems, to enhance our customers' capabilities and productivity in the semiconductor, industrial technologies, life and health sciences, research and defense markets.

For further information please visit **www.newport.com**