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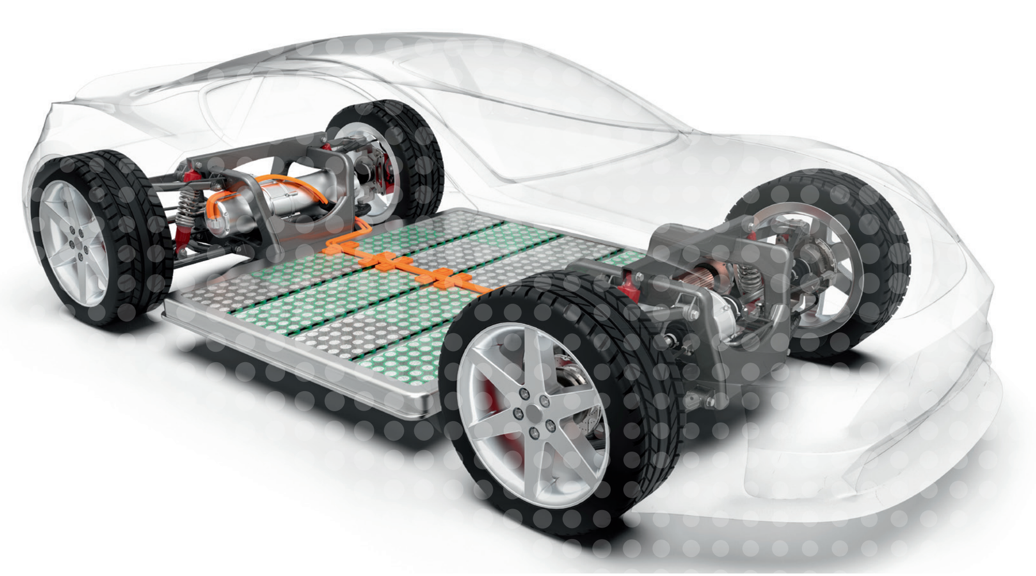
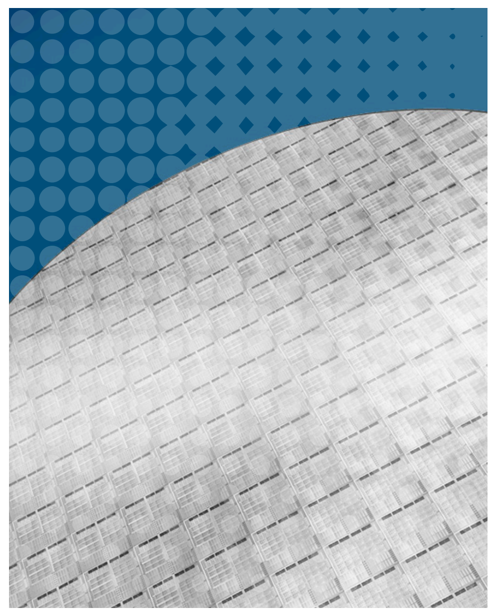
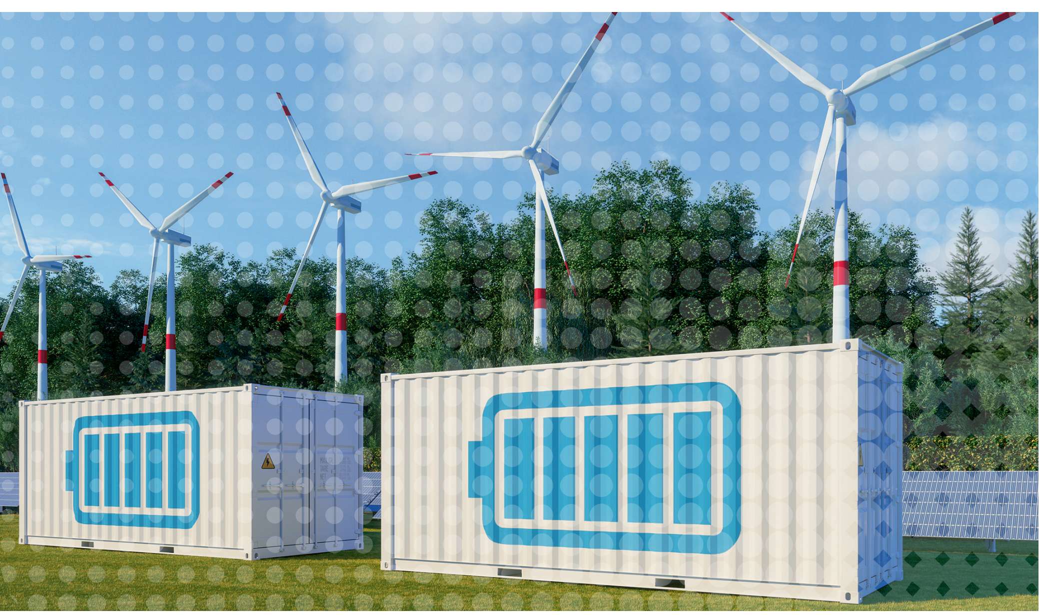
SEMICONDUCTOR MANUFACTURING BROCHURE

POWERING SiC AND GaN SEMICONDUCTOR MANUFACTURING



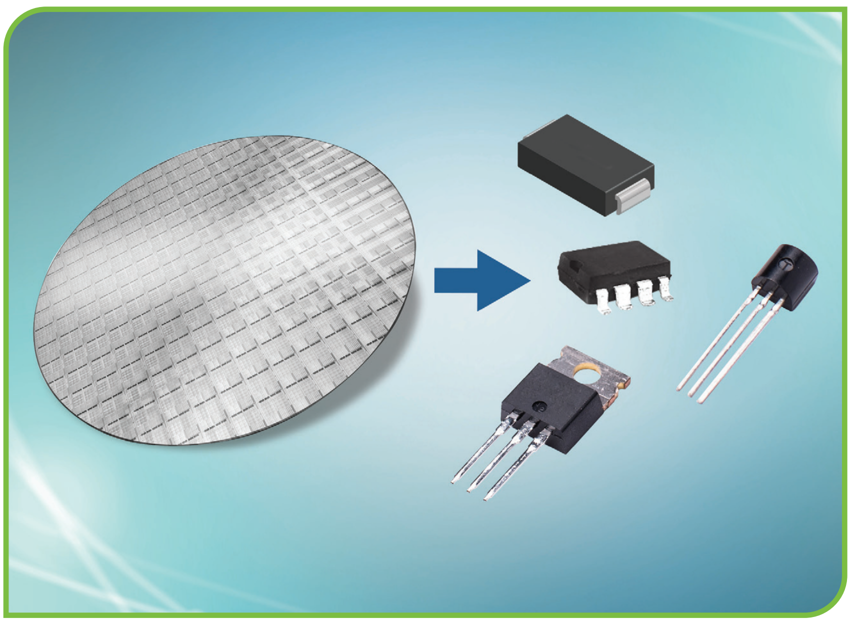




EXPANDING POWER ELECTRONICS
BEYOND SILICON

As the technological transformation of our society continues to take shape, one category of products playing an immense role in this transformation is power electronics. These are devices which convert, control and condition electrical power. Some examples of power electronics devices are diodes, rectifiers, inverters, converters, choppers and transistors. Since the dawn of electronic devices, silicon has been the predominant semiconductor material, and it continues to dominate power electronics devices. However, silicon-based power electronics have limitations that may prevent them from enabling more widespread technological transformations of our society.

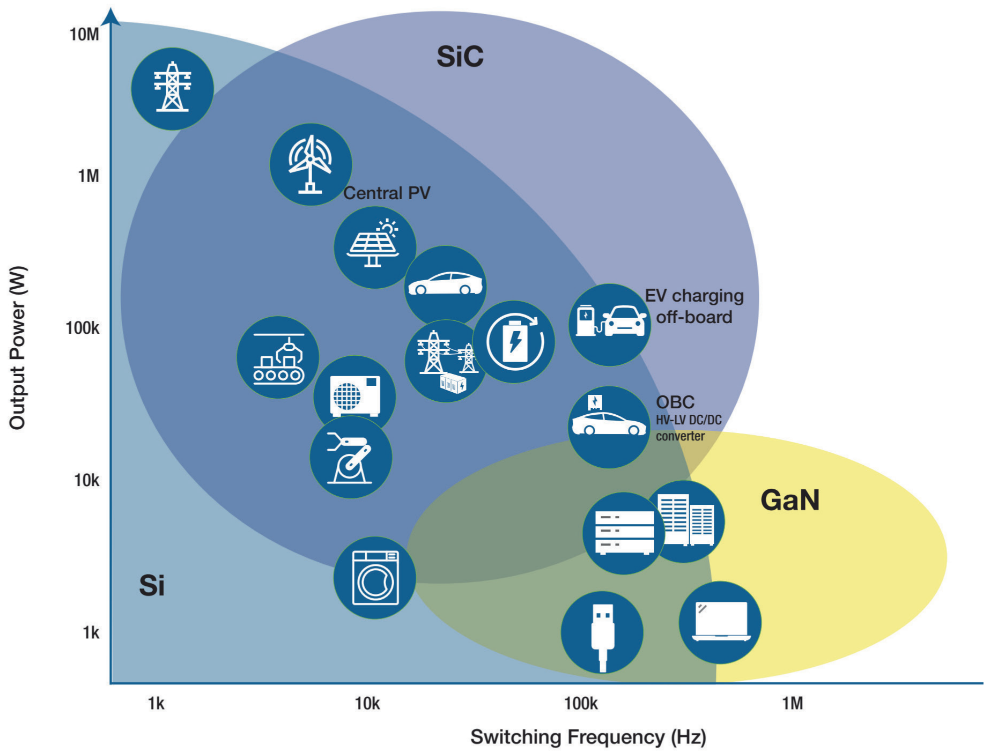
One development requiring higher performing power electronics is the growing adoption of electric vehicles (EVs) and expectations of longer driving ranges and faster charging times. Another trend calling for more advanced power electronics is the shift towards renewable energy sources which rely on efficient power conversion and reduced power losses. Additionally, further advancements in consumer electronics and telecom demand power electronics that can manage higher power densities and faster switching speeds while providing better thermal management.



Silicon-based power electronics are able to serve a portion of the applications described above, but they are mostly suitable for applications such as home appliances, power tools, and less demanding data center functions—for these types of applications, lower to mid-range switching frequencies are suitable, and cost often takes precedence over performance or form factor. But beyond mid-range switching frequencies, silicon-based power electronics fall short due to the inherent bandgap of silicon. Hence, semiconductors with wider bandgaps than silicon are necessary because they can provide higher power, switching frequency, operating temperature, switching voltages and better efficiency. Two materials in particular with wide bandgaps have already proven their worth for power electronics: silicon carbide (SiC) and gallium nitride (GaN). The bandgaps of SiC and GaN are over two and three times greater in electron volts (eV) than silicon's.

SiC-based power electronics are ideal for high-power/high-switching frequency applications. For instance, the potential for EVs with SiC-based power electronics includes longer driving ranges, faster charging times, and lighter vehicle weight. Also, more compact and more efficient energy storage systems may be possible with SiC. While GaN is limited to medium-power applications, it offers the highest operating frequency among these technologies. As such, GaN-based power electronics opens up many new possibilities in consumer electronics and telecom, such as ubiquitous use of wireless charging and faster communication speeds.

It is also important to recognize that all of these technologies overlap in roughly the mid-power/mid-frequency space, creating a "competing zone" amongst them. In this arena, silicon may be preferred when cost is the primary concern. But when higher performance, better efficiency, or smaller-sized products are desired, SiC or GaN should be considered.



Comparison of technologies by power ratings and switching frequencies.

SiC and GaN Manufacturing Challenges

Manufacturing of traditional silicon-based power electronics is well known and established, but SiC- and GaN-based power electronics presents new and more difficult challenges.

SiC as a raw material is much more costly than silicon is, and finished devices are about three times more expensive. SiC wafers are more brittle, thinner, and smaller than silicon wafers are, so handling SiC wafers during the manufacturing process is more delicate, complex, and expensive.

GaN wafers are even more brittle, thinner, and smaller than SiC wafers, so handling GaN wafers is even more complicated and costly than handling SiC wafers. Interestingly, however, GaN-based products can be cheaper than those made of silicon for equivalent power conversion specifications—this is due to GaN's higher efficiency, lower operating costs and smaller footprint.

While SiC and GaN wafer fabs share many steps used in silicon wafer manufacturing, there are some notable differences. For example, SiC and GaN wafer ingot slicing is typically performed by lasers instead of mechanical diamond saws to improve wafer yields and lower costs by reducing material waste and scrap. Also, an existing silicon wafer processing line cannot be used as is on SiC or GaN wafers—one reason is that wafer handling equipment developed for silicon may not be appropriate for SiC or GaN wafers.

The good news is that MKS has decades of experience with silicon wafer processing from the front-end to back-end and can work with you to develop and build the best solution for your SiC or GaN needs.

Comparison of SiC and GaN Power Electronics Manufacturing with Traditional Silicon (Si)

	Si (base case)	SiC	GaN
Device Cost	$	$$$	$
Wafer Brittleness			
Typical Max Wafer Ø	300 mm	200 mm	150 mm
Typical Max Wafer Thickness	0.4-0.5 mm	0.35-0.5 mm	0.25-0.3 mm
Manufacturing Complexity			

The MKS Advantage for SiC and GaN Manufacturing

As a leader in silicon wafer processing from the front-end to back-end for decades, MKS has a deep understanding of the challenges faced in designing and manufacturing power electronics. We have turned this knowledge into unique product features that provide an advantage when used for SiC- and GaN-based power electronics. Some of these features are described here.

High-Precision Lasers

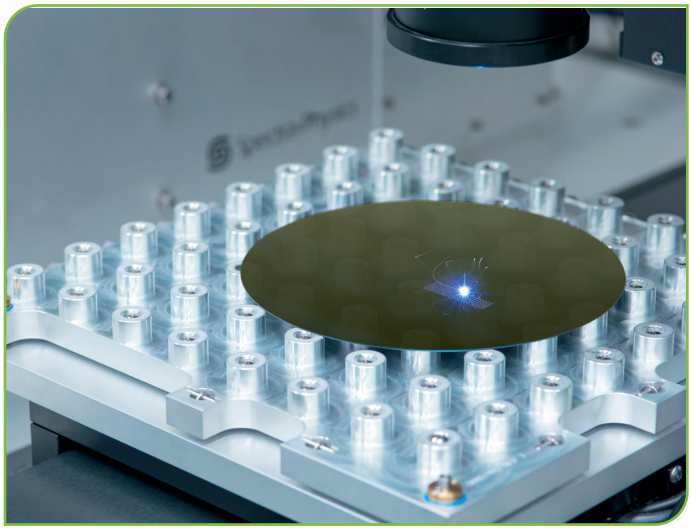
Lasers are superior to traditional mechanical methods such as blades and drills in applications including ingot slicing, scribing, grooving, dicing, and marking. For example, the time-consuming process of slicing a SiC ingot with a mechanical diamond saw can waste up to 75% of the material. Moreover, as SiC is a significantly harder material than silicon is, a blade will be worn faster, leading to increased replacement costs and more frequent downtime. By comparison, laser ingot slicing for SiC and GaN results in minimal material loss, and there is no tool wear. And by employing the appropriate laser and slicing methodology, laser ingot slicing can be considerably faster than mechanical slicing.

MKS' lasers are very high-precision devices, so they can cut and drill accurately and repeatably on the order of microns with ease, which may not be the case with mechanical tools. SiC and GaN wafers are already more brittle than silicon and must be handled more delicately, and as SiC and GaN devices become more complex, they might be even more difficult to produce solely through mechanical means. In addition to the high precision, lasers also offer more flexible patterns for cutting and drilling, which further enables more complex designs and higher performing devices to be made.

Another important advantage that lasers present over traditional processes is the quality of their results. With slicing, scribing, grooving, and dicing, lasers produce fewer burrs and less damage to the surrounding areas than mechanical cuts do. This results in higher manufacturing yields, as less of the material is wasted. Additionally, laser operations result in fewer latent defects and cracks compared to mechanical operations, which can lead to better quality and reliability of the product in the field, as not all of these types of issues are discovered before products leave the factory.

And like laser ingot slicing, laser scribing, grooving, dicing, and marking are contact-free operations, so there is no tool wear, and the replacement downtime is exceedingly infrequent compared to mechanical methods.

Taken all together, SiC and GaN processing with lasers will enable the production of devices that are mainstream enough to complement and compete with silicon-based electronics.



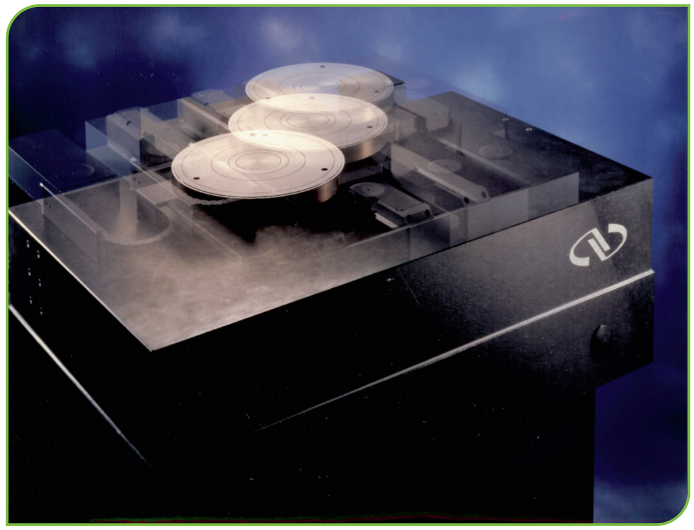
MKS laser scribing a GaN wafer

Nanometer Scale Wafer Positioners

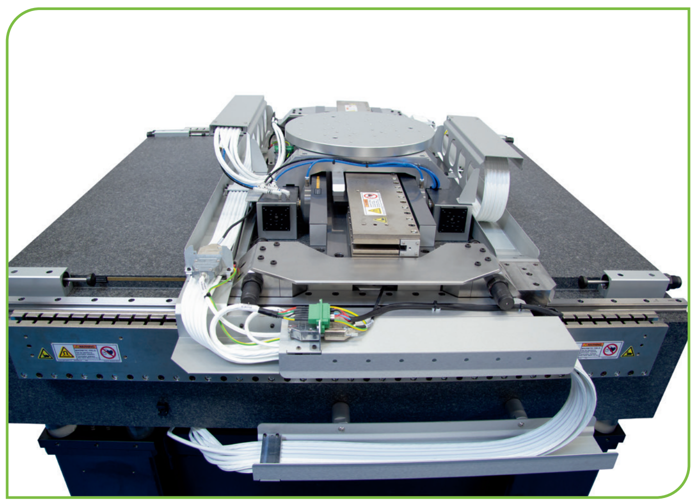
Wafer positioning performance for processes including lithography, inspection and dicing can be partciularly challenging, often with sub-micron and even nanometer scale accuracy and repeatability required. Moreover, this very precise level of operation must be delivered quickly, with speeds up to 1 m/s, to maximize throughput.

To address the wafer positioning demands of the semiconductor manufacturing industry, MKS developed the Newport DynamYX® series positioner, a high-throughput, high-accuracy solution based on air bearing and linear motor technology. With over 20 years of field-proven success in more than 1,000 systems installed worldwide, DynamYX provides the highest level of commercially available positioning performance. Additionally, MKS offers the Newport HybrYX® series positioner, a hybrid air and mechanical bearings system with linear motors, that also delivers high throughput and accuracy.

All DynamYX and HybrYX systems are custom-designed, so the techniques and solutions developed for silicon processing can be adapted and applied to SiC and GaN processing.



DynamYX Air Bearing Wafer Positioning Stage

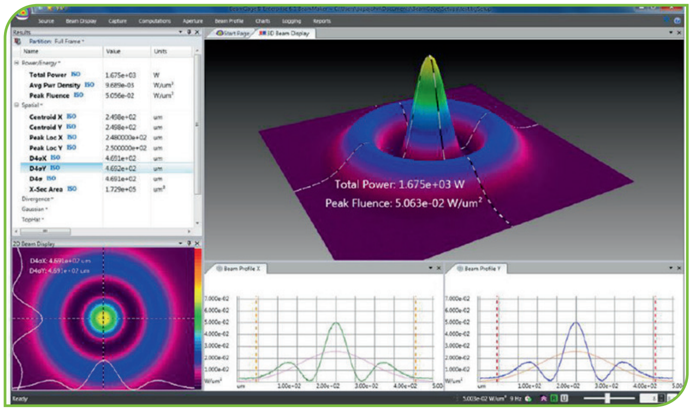


HybrYX Air and Mechanical Bearings Wafer Positioning Stage

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 SiC and GaN wafers 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 characterize the laser while handling its maximum output power level.



Beam profile displayed and analyzed with Ophir BeamGage® beam profiling software

MKS Products for SiC and GaN Manufacturing

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

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 scribing, grooving, and dicing SiC and GaN wafers. 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

Nanosecond UV and Green Lasers

For the best combination of performance, reliability, and cost in SiC and GaN manufacturing, Spectra-Physics Talon lasers deliver excellent results. The UV version can be the primary tool of choice for marking, scribing, grooving, and dicing, and the green wavelength can also be used for wafer dicing and ingot slicing. 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 small as <25 ns
- 0 to 500 or 700 kHz repetition rates
- E-Pulse™ technology for superb stability and process control

Ultrashort Pulsed Lasers

When quality of results is of the utmost importance in SiC and GaN manufacturing, an ultrashort pulse laser should be considered to ensure the cleanest cuts and smallest heat affected zones (HAZ). Spectra-Physics IceFyre® lasers set a new standard for picosecond micromachining. For scribing, grooving, and dicing, the UV version is ideal, while the green version can also be used for grooving and dicing. The IR version of IceFyre works best for ingot slicing. For an even more advanced level of ultrashort pulse laser performance, IceFyre FS femtosecond lasers deliver even higher quality results than the IceFyre picosecond laser. The UV and IR versions of IceFyre FS work extremely well for scribing, grooving, and dicing, and the IR version can also perform ingot slicing. Based on 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.

IceFyre Features:

- Up to >50 W power (UV, Green and IR)
- Typical pulse widths as small as 10 or 13 ps
- Single shot to 10 MHz repetition rate range
- Proprietary TimeShift™ technology for unprecedented pulse control

IceFyre FS Features:

- Up to >50 W (UV) and >200 W (IR) power
- Typical pulse widths <500 fs
- Single shot to 3 MHz (UV) and 50 MHz (IR) repetition rate range
- Proprietary TimeShift™ technology for unprecedented pulse control

Air Bearing Positioning Systems

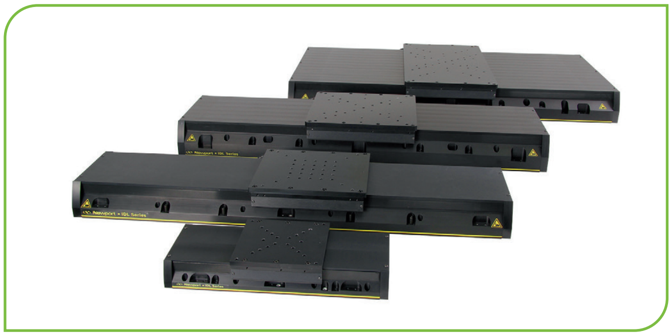
Newport DynamYX is a high-throughput, high-accuracy positioning solution delivering the highest level of commercially available positioning performance. Featuring air bearing and linear motor technology, DynamYX provides sub-micron accuracy and nanometer scale repeatability at speeds of up to 1 m/s for applications including wafer and reticle inspection, lithography, mask writing, and wafer dicing. Over 1,000 DynamYX systems have been installed worldwide.

Another type of Newport air bearing platform is the HybrYX-HD with Soft Isolation, which uses an air bearing for one axis of motion, mechanical ball bearings for the other axis, and linear motors for both axes. HybrYX can deliver speeds of up to 1.5 and 2 m/s, sub-micron accuracy, and nanometer scale repeatability. More economical than DynamYX, HybrYX-HD with Soft Isolation is ideal for wafer dicing and may also be used for wafer inspection.

- Designed for the semiconductor manufacturing industry
- Air bearing and linear motor technology for high-throughput, high-accuracy performance
- Applications include wafer and reticle inspection, lithography, mask writing, and wafer dicing
- All systems custom-designed

Industrial Grade Linear Positioners

For more traditional positioners, the Newport IDL-LM series 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 excellent for SiC and GaN 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 Talon Ace, Talon 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.

- 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

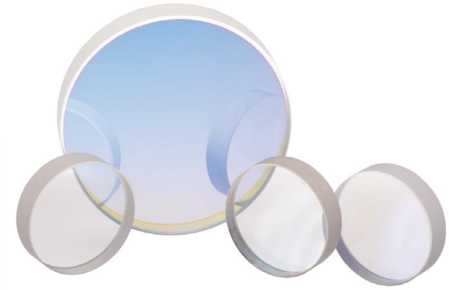
Beam Profiling Cameras

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 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 SiC and GaN 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 SiC and GaN manufacturing.



- Mirrors, lenses, beam splitter cubes, waveplates
- Optimized for 355, 532 and 1064 nm wavelengths
- Extensive ultrafast optics selection
- High LIDT (Laser Induced Damage Threshold)
- Various sizes and shapes High-Energy Laser Optics

Opto-Mechanical Components

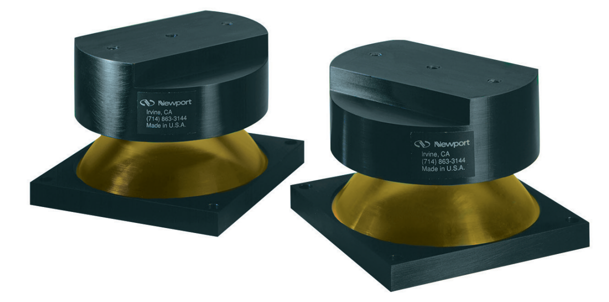
Whenever optics are part of a laser system, they will have to be precisely positioned and steadily held over lengthy periods of time. MKS offers the most comprehensive line of opto-mechanical components in the industry. Hundreds of optical mounts and positioners at various levels of performance and cost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

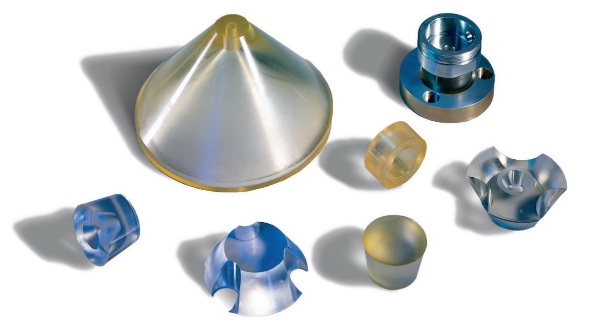
- Mirror mounts, lens positioners, and other optical mounts
- Linear and rotary positioners
- Post and pedestal assemblies
- Stainless steel and aluminum

Vibration Isolation

MKS offers industry-leading Newport vibration isolation solutions that can be integrated into SiC and GaN wafer positioning systems. Our NewDamp™ series of elastomeric isolators, available as standard catalog products or custom designs, is ideal for supporting and damping the high acceleration amplitudes produced by very high-throughput wafer positioners such as the Newport DynamYX. Additionally, MKS can provide custom pneumatic isolator solutions available individually or in sets. For custom vibration isolation, MKS will work with you to understand your machinery characteristics such as load, shock response and resonance modes, and the isolators can be built into your equipment's isolation supports.

- Elastomeric and pneumatic isolators
- Standard catalog products or custom solutions tuned specifically to your system
- Can be built into equipment isolation supports
- Scalable quantities





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

Newport Corporation
1791 Deere Ave.
Irvine, CA 92606
Tel: +1 949-877-9620
Tel: +1 877-835-9620

Spectra-Physics
1565 Barber Lane
Milpitas, CA 95035
Tel: +1 408-980-4300
Tel: +1 800-775-5273

Ophir
3050 North 300 West
North Logan, UT 84341
Tel: +1 435-753-3729

MKS Corporate Headquarters
2 Tech Drive, Suite 201
Andover, MA 01810
Tel: +1 978-645-5500
Tel: +1 800-227-8766 (in USA)

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