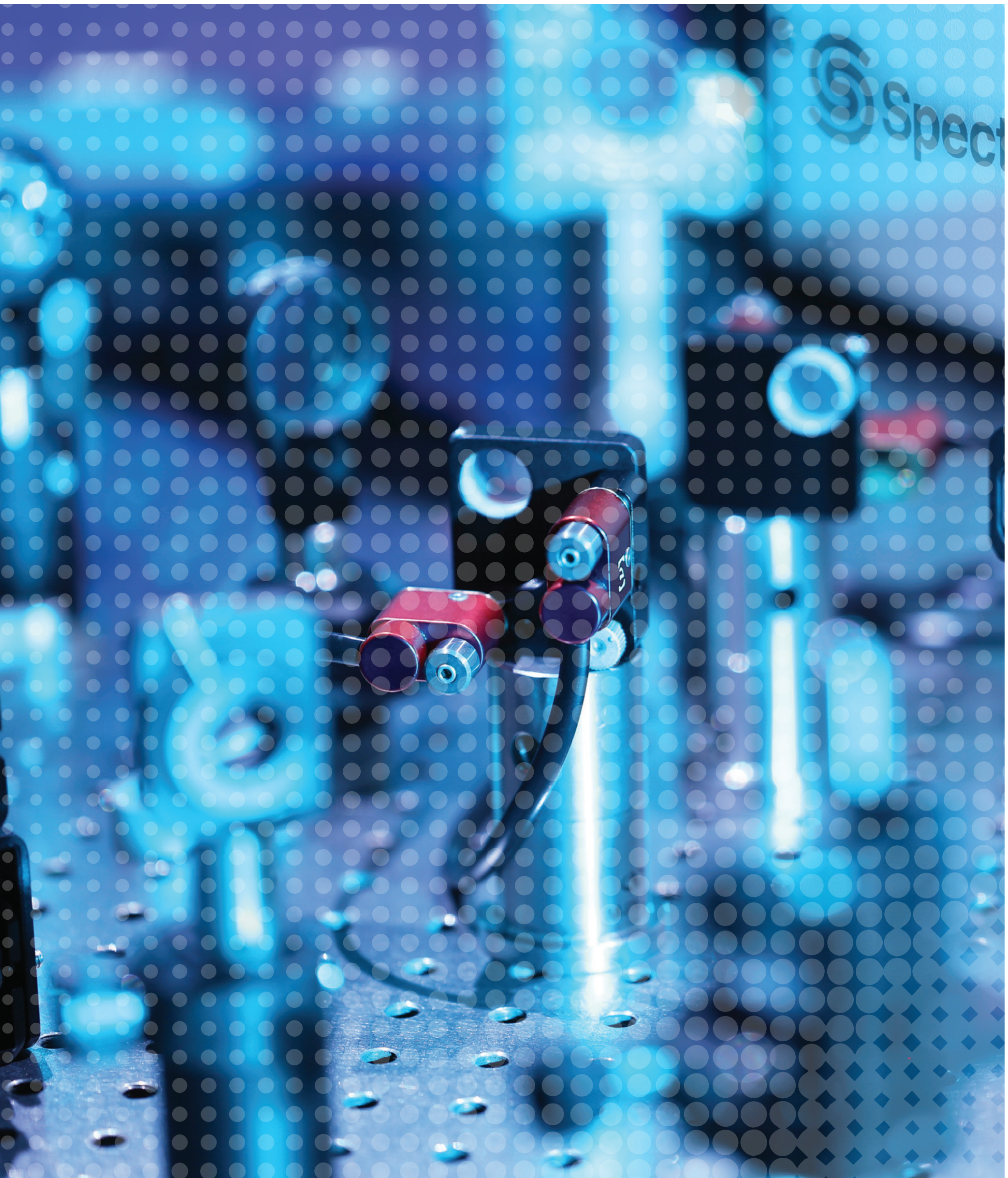
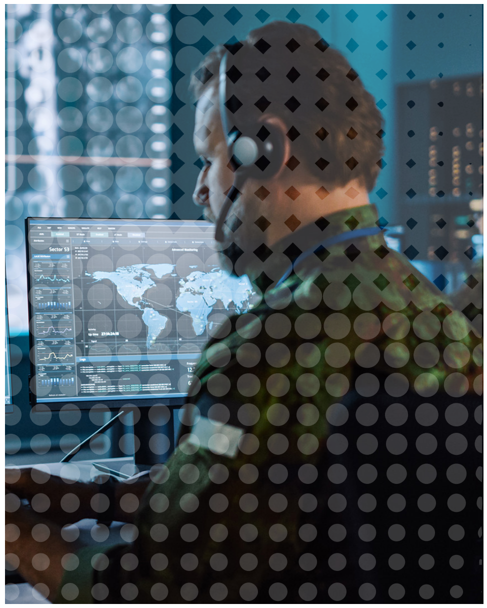
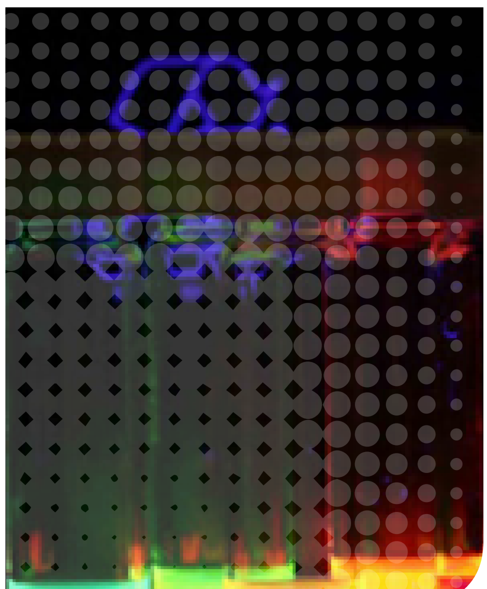
ADVANCING PHOTONICS-BASED QUANTUM TECHNOLOGIES RESEARCH







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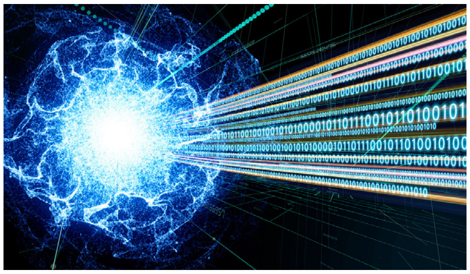


The ability to control and manipulate quantum systems on the atomic and subatomic levels has given rise to quantum technologies that are transforming the world we live in. In particular, the growing mastery of quantum superposition and quantum entanglement has further advanced applications such as:

- Quantum computing
- Quantum sensing
- Condensed matter physics
- Quantum cryptography
- Quantum communication
- Atomic, molecular and optical physics (AMO)

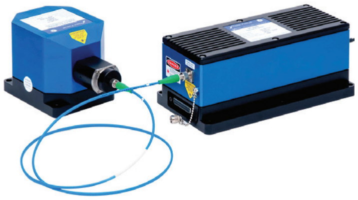
One area of tremendous interest is quantum computing, which promises exponentially faster computing speeds and the ability to quickly solve problems that today's classical computers would not be able to in a feasible amount of time. An industry that would benefit immensely from quantum computing is banking and finance. Not only will a drastically greater number of transactions be possible—an amount not even imaginable today—but the ability to analyze much larger and unstructured data sets will also guide decision-making processes that are inconceivably complex.

Quantum computing also leads to another area of enormous attention, quantum cryptography. Data secured through quantum cryptography will be essentially impossible to crack with classical computers while also being extremely difficult to unlock even with quantum computers. Once again, financial institutions have great interest in this technology, and more importantly, governments and militaries also view quantum cryptography as vital to national security.

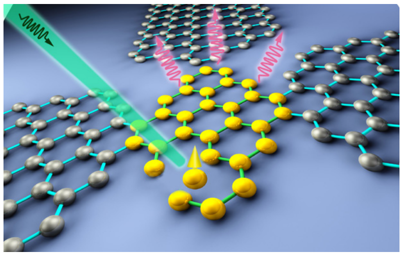
With such vast potential for those who can realize the benefits of quantum technology, funding from both private and public sources is fueling a substantial amount of quantum technology research in academia and the corporate sector.

MKS in International Space Station

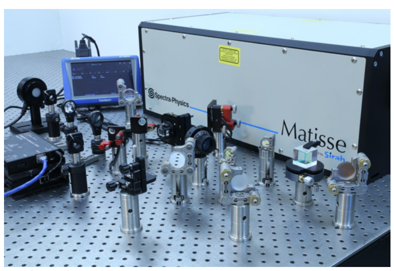
Several New Focus™ Vortex™ Plus external-cavity diode lasers (ECDLs) are installed in the Cold Atom Laboratory aboard the International Space Station, enabling the study of quantum phenomena in a microgravity environment in ways that aren't possible on Earth. These ECDLs were chosen because they feature the narrowest linewidth and fine mode-hop-free-tuning. In a joint collaboration with NASA and JPL, these units were put through extensive shock and vibration testing to ensure reliable performance in a demanding environment.



Photonics-Based Quantum Technology Design Challenges



The fundamental challenge in quantum technology research lies in observing extremely small changes and characteristics of a material. Examples include how impurities and dopants behave in a matrix or how ions and atoms interact with their lattice and surroundings. Every photonics-based quantum system must manipulate the atom and tune the wavelength precisely, especially to account for Doppler shifts around the atomic transition wavelength. As the number of atoms that need to be manipulated in a system increases, the laser must also be able to deliver higher levels of output power. Thus, choosing the appropriate laser is critical.



Quantum systems are highly sensitive, so the component setup must be extremely stable for long periods of time. Working at atomic and subatomic levels, the slightest amount of noise from vibration or temperature change could affect results. Good vibration control and robust optomechanical components improve the stability of the system.

Just about every quantum technology experiment requires the placement of dozens, and often hundreds, of optical and optomechanical components. Hence, optimal use of an entire tabletop's space is often necessary. Using smaller, or miniaturized, components enables maximum use of table space, as do table tops with double-density component mounting hole patterns.

Another typical challenge with quantum technology research is working with low-light signals. To preserve more of the light for the entire system, use of high-transmission and high-reflection optical coatings is critical. Additionally, balanced photodetectors are designed for extremely low power measurements.

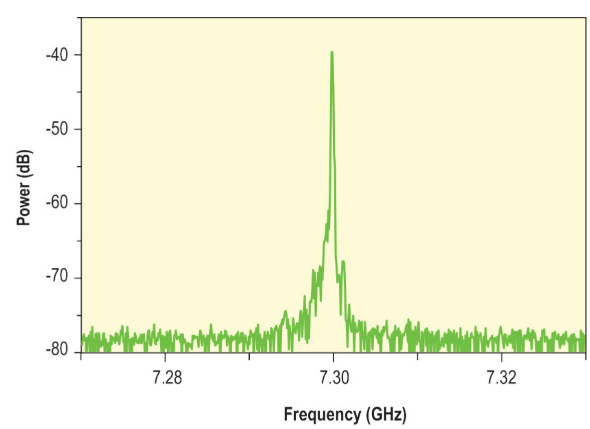
The MKS Advantage for Photonics-Based Quantum Technology

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

Narrowest Laser Linewidth

Laser linewidth is the width of the laser optical field power spectrum, which fundamentally describes the frequency noise behavior of a laser oscillator. Linewidth has a direct effect on the quality of a quantum technology application's results. Narrower linewidths lead to superior trapping of atoms and cooler temperatures, ensuring that atoms are trapped in the correct location and will not leave the magneto-optical trap (MOT). Some practical examples of the benefits of narrower linewidths are more precise atomic clocks, hyper-resolution spectroscopy and better micro-resonators.

When evaluating lasers, it is important to compare linewidth performance over integration times of milliseconds in addition to microseconds. Integration times of milliseconds incorporate mechanical vibrations, whereas intervals of microseconds do not capture how well a system is built to resist vibrations. Vibrations manifest themselves in the data as noise. Spectra-Physics® Matisse® ring lasers and New Focus ECDLs feature the narrowest linewidths on the market, and when the highest power on the market is necessary, ring lasers should be considered.

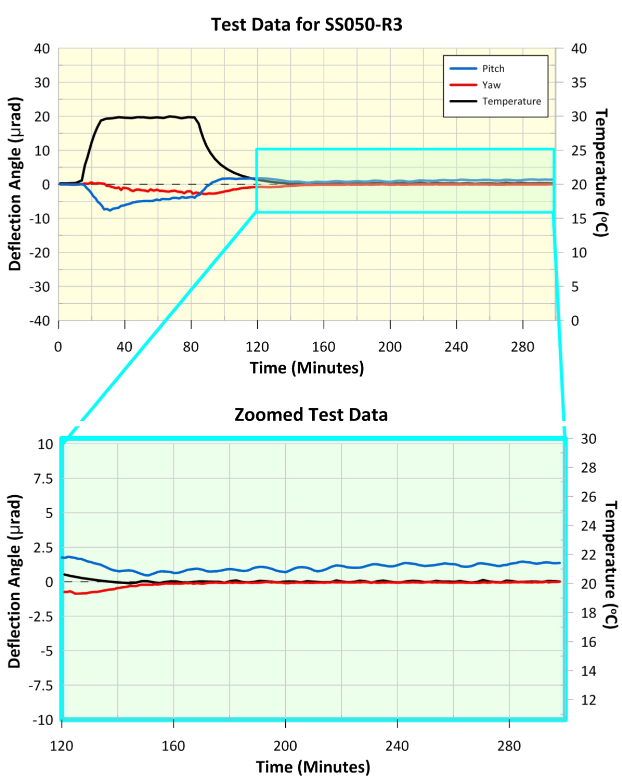


Heterodyne beat note of two New Focus Velocity TLB-6712 lasers, 50 ms integration. Deconvoluted linewidth <200kHz (typically measured performance; not a guaranteed or warranted specification).

Stainless-Steel Optical Mounts for Long-Term Stability

It is essential for the optics in a quantum technology research system to maintain their alignment. They should not move, since misalignment can lead to system errors and possibly downtime. One source of instability is thermal drift, which can be a problem because lasers may heat the optic and its mount. One way to address thermal drift is to choose proper materials for the optical mounts. Stainless-steel mounts, with a lower coefficient of thermal expansion than aluminum, offer the best stability over a wide temperature range.

0.5-in. clear-edge Newport Suprema™ Stainless Steel Mirror Mount

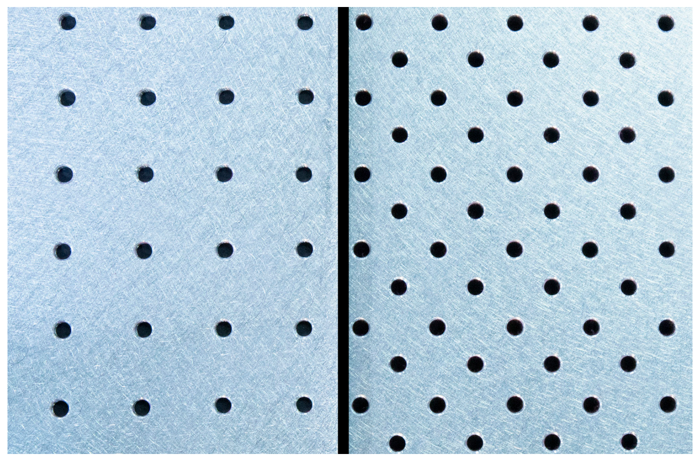


The maximum deflection of the Newport Suprema SS050-R3 mirror mount during peak temperature was 8 µrad in pitch and 3 µrad in yaw, and a shift in reflected beam position after temperature cycling was < 2 µrad in pitch and < 1 µrad in yaw.

Double-Density Hole Pattern

The standard hole pattern on tabletops and breadboards is a 1-inch grid. Newport offers twice the number of mounting holes with our double-density pattern. This is ideal for applications that require dense mounting of dozens or hundreds of components, such as laser cooling, atomic physics and quantum optics.

Double-density hole patterns are available on some Newport standard tabletops and breadboards, and they can also be supplied as custom products.



Standard hole pattern (left) vs. double-density hole pattern (right)

Non-Magnetic Materials

Some quantum technology experiments utilize high magnetic fields, such as a trapped ion quantum computer. In these cases, it is undesirable to use materials or components that may become magnetized, as this may interfere with the experiment and its measurements. MKS offers Newport table tops constructed with non-magnetic 316 stainless steel, non-magnetic vibration isolators and non-magnetic opto-mechanical and positioning components.

Non-magnetic Newport table top and non-magnetic Newport pneumatic vibration isolators

MKS Products for Quantum Technologies Research

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

High-Power Ultra-Narrow Linewidth Tunable Ring Lasers

The Spectra-Physics Matisse C tunable ring laser is the ultimate solution for quantum technology research. It delivers the industry's highest output power, the narrowest external linewidth and the broadest mode-hop-free tuning range with a single optics set. When coupled with the Spectra-Physics Millennia® eV™ pump laser, the Matisse C can produce the industry's highest output power of over 7.2 W. Several advanced design features also make Matisse an ultra-stable laser.

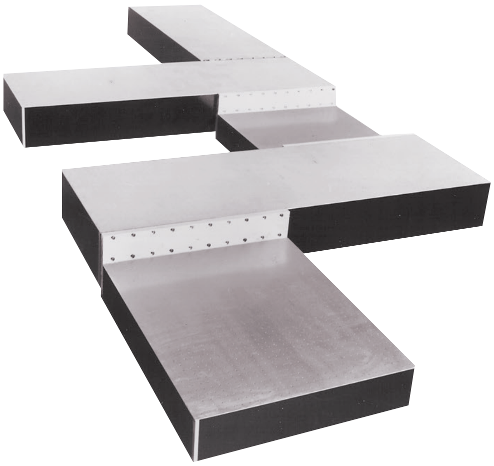
- Mode-hop free tuning ranges from 668 to 1068 nm
- Max output power >7.2 W
- Linewidth <20 kHz rms
- Amplitude noise <0.1% rms

Widely Tunable and Precision Finely Tunable ECDLs

New Focus ECDLs feature one of the narrowest linewidths available on the market and true mode-hop free tuning. The Velocity™ series is capable of both wide and fine wavelength scanning, and the Vortex Plus series is the highest performance precision finely tunable ECDL. They are designed for demanding 24/7 OEM applications, with several Vortex Plus lasers operating in the Cold Atom Laboratory aboard the International Space Station. These lasers are easy to use, and an integrated turn-key, fiber-coupled option is also available.

- Linewidth <2.5 kHz @ 5 µs, <200 kHz @ 50 ms
- Wide mode-hop free tuning ranges from UV to mid-IR, or
- Fine mode-hop free tuning ranges from ~455 nm to IR
- Fiber-coupled option

Doubled and Custom Optical Tables



In addition to our industry-leading Newport standard optical tables, MKS has the expertise to supply doubled or custom optical tables. Through our modular approach, any size, shape and quantity of table sections can be assembled. Newport combined tables function as a single monolithic structure and are dampened accordingly for superior performance over typical multiple-table assemblies. Several types of materials are available, including non-magnetic materials to avoid interference in applications with high magnetic fields such as trapped ion quantum computers.

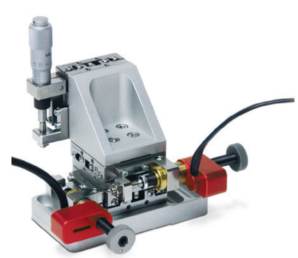
- Any size, shape or quantity of table sections
- Double-density or standard hole patterns
- Dampened as one finished, monolithic table for superior performance
- Various materials available, including non-magnetic

Stainless-Steel Optical Mounts

For long-term stability and thermal performance, the Newport Suprema series of stainless-steel mounts are the best in the industry. They allow exceptionally fine resolution adjustment of the optic and feature lockable positions to further ensure stability. The Suprema is available in dozens of configurations, with different options for size, adjustment resolution, optic mounting style and other features.

- 0.5-, 1- and 2-in. diameter versions
- 50, 100, 127 and 254 threads-per-inch adjustment resolution
- Lockable adjuster versions for more stability
- Options for clear-edge optic mounting, front- or rear-loading and right- or left-handed configurations

Piezo Linear Actuators



The Picomotor™ series of piezo linear actuators utilize patented technology to offer extraordinarily small step sizes of less than 30 nm when automating movement of positioners and mounts. They are ideal for quantum technology research that aims to observe extremely small changes and characteristics. Picomotor actuators will not move when there is no power applied, therefore, long-term positioning stability is ensured. Their standard-sized mounting options allow them to be easily integrated into standard micrometer mounting holes.

- <30-nm minimum incremental motion
- Set-and-forget long-term stability
- Compact design
- Closed-loop versions available for high repeatability

Broadband Metallic Mirrors

Metallic-coated mirrors provide a good combination of performance and value over broad spectral ranges. Over 100 Newport standard catalog metallic mirrors are available that vary in size, shape, substrate material and coating. Our aluminum, UV-enhanced aluminum, silver and gold coatings deliver average reflectivity performance from >90% to >96% for UV, visible and IR wavelengths. For more specialized performance requirements, MKS offers additional standard catalog mirrors and custom optics design and manufacturing capabilities.

- 0.5- to 8-in. diameters
- Square, elliptical, D-shaped and concave shapes
- Aluminum, silver and gold coatings covering UV to IR
- >90% to >96% reflectivity, insensitive to polarization and angle of incidence
- CW damage thresholds of 100 W to 1 kW/cm^2

Balanced Photodetectors

The Newport Nirvana™ series of balanced photodetectors are ideal for optical detection applications requiring sensitive measurements and increased signal-to-noise, such as heterodyne detection. Our patented circuitry effectively eliminates background noise for extremely low power measurements, resulting in fast measurement of signal power with 50 dB less noise for the 400-1070 or 800-1700 nm wavelength ranges. Free space or fiber-coupled optical input options are available.

- 400-1070 or 800-1700 nm wavelength ranges
- Reduces common-mode noise by up to 50 dB
- 3-μs rise time
- Free space or fiber-coupled optical input

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 Light & Motion 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**