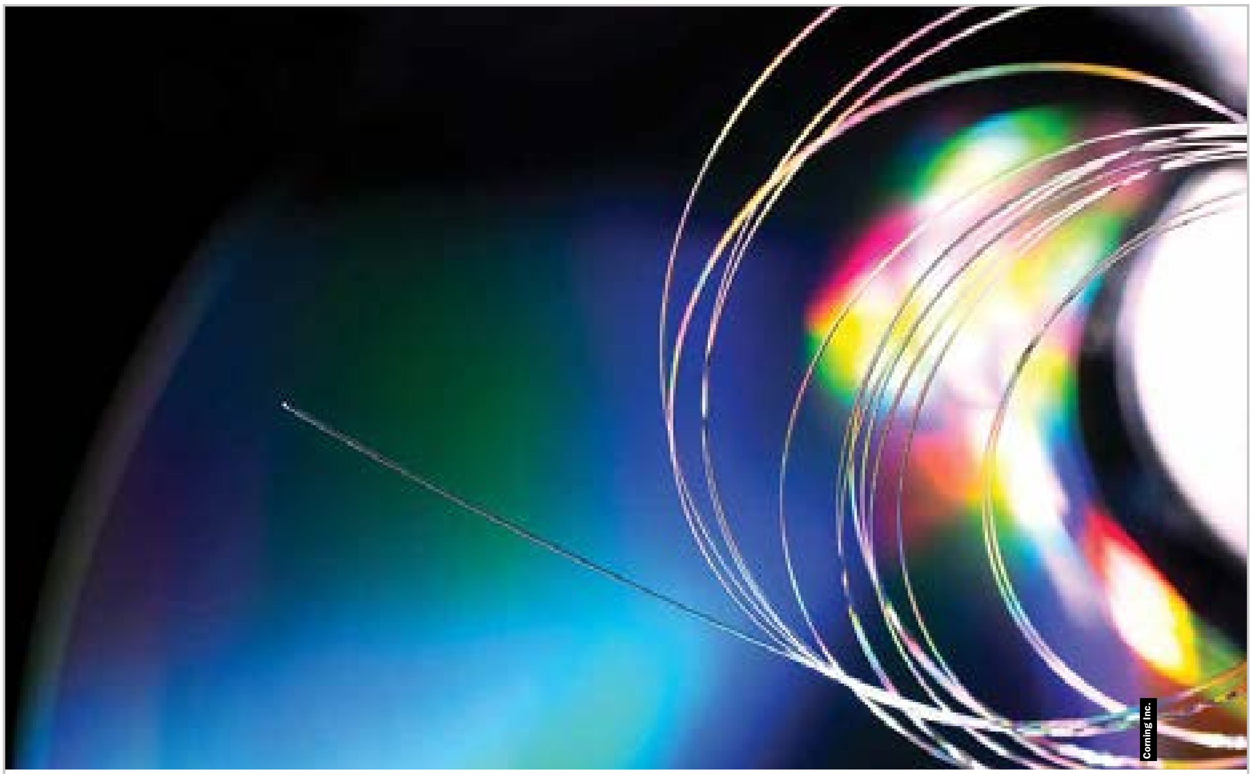

Corning Inc. is working on durable fibers that enable a tighter bend radius, helping to support customer demand for smaller optical components.

Optical Components Pushed to Precision, Tolerance Limits

The rise in low-price, high-power lasers is opening up new avenues in manufacturing and the life sciences, which sets some tough challenges for optical component makers to overcome.

BY MARIE FREEBODY
CONTRIBUTING EDITOR

From materials processing and automotive industries to next-generation inspection of semiconductors and laser surgery, the demand for high-performance optical components has never been greater.

Thanks to the increasing availability of low-price, high-power lasers, innovative industries are demanding more efficient materials processing, smaller components, increasingly detailed inspection, and greater accuracy.

Such pursuits require optical components that can operate reliably under increasingly tough conditions. Optics systems must not only offer greater precision and higher tolerances but also better transmission with fewer wavefront errors.

Optics makers are responding to the challenges with their own pioneering approaches that uniquely address the intended application and type of optical system in operation. At optics, imaging, and photonics technology producer Edmund Optics Inc., significant demand stems from life science applications and materials processing.

"Many laser optics applications are moving toward shorter UV wavelengths for creating very small cuts in processes including laser surgery, printed circuit board manufacturing, and diamond engraving," said Stefaan Vandendriessche, laser optics product line manager at Edmund Optics in Barrington, N.J.

"This surge in UV optics applications has led to a corresponding demand for optical components designed to work at those wavelengths. As laser sources continue to become more affordable and the achievable precision of optical components continues to increase, new applications and markets become viable that weren't previously possible."

With the challenge set, optical manufacturers are refining existing processes, as well as investing in new methods of manufacturing and metrology.

"The goal is to increase the precision of optical components by improving achievable surface tolerances," Van-

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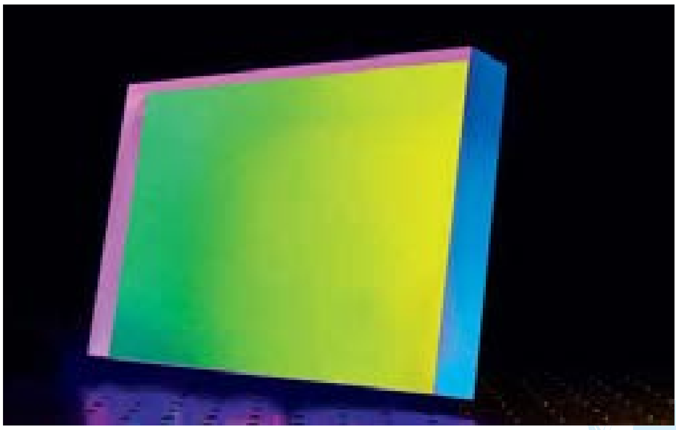


Laser Components GmbH

Large-laser optics is needed to handle the power densities of lasers that become more powerful. Laser Components deposits homogeneous, high-power, and low-GDD (group-delay dispersion) coatings on optics up to a diameter of 390 mm.

Edmund Optics Inc.

Laser materials processing is driving a significant amount of growth in optical components.

dendriessche said. “Recent advances have allowed component manufacturers to produce optics with improved surface quality, surface flatness, power, and irregularity.”

Production techniques

One technique that is facilitating production of high-precision flatwork and lenses is magnetorheological finishing (MRF). This approach is a deterministic process using a precise interferometrically documented subaperture tool to correct waveform errors by selectively removing material under a controlled and predicted process.

MRF removes the need for many of the fine-finishing steps that are normally achievable only by highly experienced technicians.

“Improvements in metrology also contribute to us being able to deliver tighter specifications,” Vandendriessche said. “A higher availability of precise metrology and improvements in sensors allows manufacturers to verify tighter specifications. If you can’t measure it, you can’t make it. This is especially important for applications in laser optics and UV optics, as those applications require tightly controlled tolerances.”

Another leading laser optics manufacturer, Laser Components USA Inc., is addressing some of the challenges that emerge when optical components are subject to high-power lasers.

“The development of higher peak power lasers drives many components to the edge of what is possible in terms of LIDT [laser-induced damage threshold], therefore the beam is enlarged,” said Huyen Vu, sales director of laser optics, diodes, and modules at Laser Components, based in Bedford, N.H.

A larger beam requires larger optics, which adds some new complications to the manufacturing process, such as flatness after coating, as well as homogeneous coating over a larger aperture. Efforts to mitigate this effect involve improving the coatings by altering chamber parameters and modifying the coating design.

“On the substrate side, we try to improve the surface quality by varying the polishing process and parameters,” Vu said.

On the other hand, the availability of high-power, continuous-wave lasers leads to a different set of difficulties. These include making substrates with low absorption and developing coatings to reduce thermal-lensing effects.

“The main target is to reduce the absorption, which is already in the ppm range, but it needs to be further improved,” Vu said. “This can be done by selecting different substrate material, [different] substrate polishing processes, and by [different] coating processes.”

Aspheres perform the job of many

Driven by emerging opportunities in artificial intelligence, the Internet of Things, and autonomous vehicles, the demand for high numerical aperture deep-UV (DUV) lens systems in the semiconductor industry gets tighter and therefore more challenging for the lens system and its optical components.

“Today, semiconductor equipment manufacturing customers ask for cost-effective, high-performance optical components in their desired next generation of optical inspection or lithography lens systems,” said Thomas Ganz, key account manager of the optics business unit at Jenoptik Optical Systems GmbH in Jena, Germany. “Keeping the costs reasonable for the next generation, new ways have to be found, like high-end aspheres or simple freeform optics.”

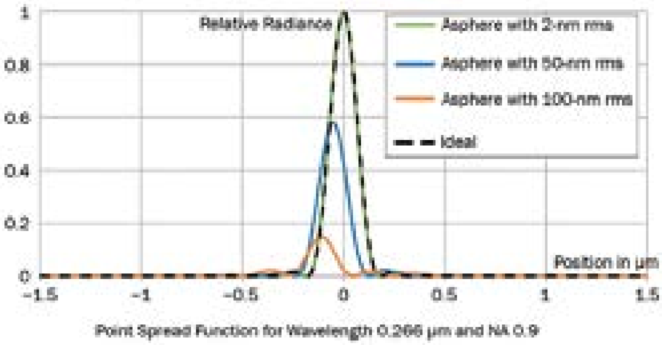
Traditional optical designs that include spherical optical components created lens systems that were increasingly large and heavy. Associated costs significantly rose and implicated a more complex supply chain management.

However, high-end aspheres are featuring more in lens systems where space is at a premium. By using an asphere, high-performance lens systems can be made with fewer optical elements and increased throughput as well.

“Having less optical elements means less optical surface where transmission losses happen,” Ganz said. “Using an asphere, we can decrease the number of lenses in the lens system [and] have less optical surfaces.”

It’s not an easy shortcut, though. The surface of an asphere must be manufactured to the highest surface quality to perform as it should. A measure of surface quality — known as the root mean square (rms) of the wavefront irregularity (rmsi) — needs to be below 10 nm to achieve the high resolution and high throughput of a lens system required today.

“Combining current manufacturing and measuring technologies is necessary to achieve cost-effective, high-performance optical components,” Ganz said. “Without feedback from the measurement data, it is not possible to proceed correctly with the next manufacturing step. Understanding the complete technology chain is the key



Jenoptik Optical Systems GmbH

Comparison of the point spread functions of the high-performance apshere with 2-nm rmsi, standard available asphere with 50-nm and 100-nm rmsi, to the ideal point spread function.

Laser Components GmbH

An ion-beam sputtering (IBS) coating chamber. Laser Components uses IBS coating technology to reach highest reflection and transmission values, from 248- to 3000-nm wavelength range **(left)**. To reach the best possible results for high-quality laser optics, Laser Components controls the surface roughness by using white light interferometry **(right)**.

for producing high-performance optical elements and lens systems."

Today, Jenoptik offers serial production of large-diameter optical components of different materials with an rmsi below 3 nm, up to a diameter of 70 mm. Ganz cautions, however, that every step below 2-nm rmsi is a new challenge and needs an entire understanding of the complete technology chain.

"Simple freeform optics produced by robotic polishing may be already used within the next generation," he said. "Complex freeforms have been demonstrated over a small area with different production techniques but are still too expensive and not yet ready for large-area and serial production. Forecasting the future might be difficult, but we assume that within the next five years, major breakthroughs in freeform optics will highly influence the challenges of tomorrow."

3D printing and metamaterials

Investment in new technologies is crucial to keeping up with demand. There is much interest in 3D-printed optics and metamaterials, and experts predict that, at some point in the future, one of the 3D printing or metamaterial technologies will mature into something more generally applicable to a wide range of functions.

"A lot of work is being invested into new technologies such as 3D-printed optics and metamaterials," Edmund Optics' Vandendriessche said. "These will eventually end up finding a place in optics applications, but as of yet no single technology has developed to a point where it is generally applicable in precision optics applications."

Polarization-directed flat lenses are one example of a promising alternative lens technology that could be one to watch. These thin-film lenses utilize some of the unique optical effects generated by plasmonic metamaterials. They function differently than typical spherical lenses because their focal length is defined by a holographically recorded wavefront profile rather than by the curvature of the surfaces.

The lens is a 0.45-mm-thin flat window with a complex photo-aligned liquid crystal polymer (LCP) film deposited on the surface. By varying the geometrical phase shift spatially, the LCP achieves near-perfect diffraction efficiency of the holographically recorded wavefront.

In particular, when the lens is oriented with the LCP surface facing the light source, left-hand circular polarization (LHCP) light will focus with the positive focal length of the lens, whereas right-hand circular polarization (RHCP) light will diverge with the negative focal length. The opposite holds true when the lens is oriented with the LCP surface facing away from the light source.

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The Changing Direction of Fiber Optics

Ten years ago, when the first fiber lasers came on the market, rumors abounded that this revolutionary technology would trigger the demise of demand in laser optics. This has proved not to be true; in fact, quite the opposite. The market for high-quality laser optics is increasing, and an emerging perfect storm could lead to even greater demand.

"Consumers [have an] insatiable desire for greater bandwidth to stream data and store content wherever and whenever," said Michael Jordan, advanced optics product line manager of specialty fiber and glass polarizers at Corning Inc.

He added that the simultaneous clamor for data centers, fiber to the home, and 5G build-out is creating a unique surge in demand for optical components, in particular for smaller transceivers that save space.

"Space is at a premium and maximizing space efficiency saves our customers money, which ultimately saves the consumer money," he said. "To help meet these demands and support our customers, Corning continues to develop durable fibers with a tighter bend radius. That issue is a particular focus for our specialty fiber team this year."

The Corning Titania-Clad Optical Fiber was released just this year. The benefit of the titania outer cladding is that it enables a bend radius as small as 2.5 mm, which allows for significantly less signal degradation when the fiber is deployed in a shape other than a straight line.

"Tighter bending allows for more design options for component designers who need to couple fiber to a device," Jordan said, "because they know the signal will still be strong."

Edmund Optics Inc.

Polarization-directed flat lenses have less weight and volume than comparable spherical lenses, making them ideal for space-constrained applications.