Optics Fabrication: Changes, Challenges and Progress

Polishing large optical flats as part of the fabrication process.

BY JUSTINE MURPHY
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Optics and optics fabrication have seen a lot of interesting changes and challenges over the past 25 years.

Aspheres are among them. Once a seemingly impossible task, manufacturing them has since become cost-effective. Precision aspheres are even replacing spherical optics in many applications, as the technology advances and manufacturing becomes more efficient. Aspheric surfaces also play a large role in many IR systems.

But aspheres do not tell the whole story.

Freeform optics design, metrology and manufacturing are among the areas that are becoming increasingly popular for commercial applications. Freeform optics may revolutionize the industry, demanding new technologies for grinding, polishing, measuring machines and more.

Photonics Spectra (PS) spoke with industry experts for their take on the global optics fabrication market — how far technologies and systems have come, some challenges they're seeing, and what the future holds for this segment of the industry.

- **Mike Bechtold**, president of OptiPro Systems LLC, an Ontario, N.Y., developer and manufacturer of precision optical fabrication machines and metrology systems
- **Mike DeMarco**, business manager at QED Optics, developers of optics manufacturing solutions for traditional polishing and metrology methods, based in Rochester, N.Y.
- **John Escolas**, operations manager for Sydor Optics Inc., also located in Rochester, N.Y., which specializes in precision flat optics, parallel optics, wedged optics, glass wafers, borofloat wafers, colored glass filters and custom optics
- **Mark Lifshotz**, CEO of ISP Optics

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Corp., Irvington, N.Y., a vertically integrated manufacturer of IR products, such as high-performance midwave-infrared (MWIR) and longwave-infrared (LWIR) lens assemblies and custom IR optical elements

***Photonics Spectra*: How long have you worked in optics fabrication, and what are the most significant changes you've seen in that time?**

Bechtold: OptiPro began designing and manufacturing optical fabrication equipment in 1990. Over the past 25 years, the optics industry has strived to continuously improve the performance of optical systems, while reducing the cost to make these systems. This effort has pushed technological advancements in optical fabrication equipment. For example, the ability to cost effectively manufacture aspheres, which once seemed like an insurmountable challenge, became achievable in the late 1990s to early 2000s.

DeMarco: My experience in optical fabrication spans almost 30 years. During that time, I believe there have been two major changes. The first is the introduction and adoption of technology, i.e., CNC processing, ion beam, and magnetorheological finishing and single point diamond turning by the optics manufacturing industry. The second has been a strong shift away from artisan-based labor in the polishing/finishing of precision optics. These are of course coupled in some ways, as one begets and/or enables the other.

Escolas: The most significant change that I've seen in my 11 years in the optics industry has been more demanding specifications with tighter tolerances from our customers. Requests for parts thinner than 1 mm, diameters greater than 300 mm and more stringent flatness requirements are becoming more common.

Lifshotz: ISP Optics has been fabricating IR optics for over 23 years. [We] specialize in IR optics in the 1- to 16-µm (SWIR, MWIR & LWIR) spectrums. Twenty years ago … military and aerospace were the main drivers. Commercial applications were limited, and IR optics were very expensive. IR crystals' growth process has since improved significantly: materials became more uniform and homogeneous, with less internal defects. As process improved, along with increased demand, the material price went down. The most significant changes [ISP has seen]: As detector/camera manufacturing processes improved (smaller pixels, larger format, lower price), this [led] to an 'applications boom.' Thermal vision devices started to [be used] more for military applications (stationary ISR, handheld devices, goggles, etc.). Commercial applications also blossomed, [leading] to a necessity to develop fast, high-speed but reliable fabrication and coating processes, while maintaining tight tolerances and high precision.

***PS*: What have been the most significant changes to optics fabrication in the past five years, and how has your company adapted?**

Bechtold: Precision aspheres have replaced spherical optics for many applications. Because of this, their demand in the past five years has never been higher. As the demand increases, so does the need for equipment capable of producing aspheres more efficiently than ever before. Constant efforts to refine both the hardware and software of [OptiPro's UltraForm Finishing]

'Depending on the application, today's optical components can be fabricated from a variety of advanced materials ranging from soft to extremely hard.'

— Mike Bechtold, OptiPro Systems

Edmund Optics

Testing and quality assurance on optics and optical assemblies can be customized to meet project requirements.

The laser scanning projection system enables augmented-reality wearable glasses.

technology have allowed companies to produce finished aspheres in under 20 minutes. OptiPro also brought to market UltraSmooth Finishing, a different asphere finishing technology that smooths surfaces to meet stringent slope specifications. Both solutions have helped companies optimize asphere production.

DeMarco: The most significant change has been the widespread adoption of deterministic polishing methods, which in turn has resulted in a pull for improved metrology to drive said methods. Since our core business is selling capital equipment, namely subaperture stitching interferometers and magnetorheological finishing (MRF) machines, we have adapted by improving our offerings to meet the ever-changing needs of the industry. On the metrology front we introduced our own interferometer, the QIS, which has been optimized for use in our ASI platform, and on the polishing side we have introduced the Q-flex line of polishing machines that provide high-precision deterministic finishing in a production-worthy platform.

Escolas: More and more, customers are requiring inspection data packages for each shipment and higher quality control standards regarding part handling and cleaning. As a result, we have added personnel and equipment to keep up with the demand. We've added additional ultrasonic cleaning and spin-rinse drying capabilities paired with cleanroom vacuum packaging to provide customers with the best quality parts.

Lifshotz: Machinery and metrology equipment have advanced. Today it is hard to imagine an IR system without aspheric/diffractive surfaces, so diamond-turning processes from state-of-the-art equipment become a workhorse of optical fabrication. CNC grinding and lens polishing machines become more and more popular for IR crystals fabrication because of the need for a reliable and fast process. Hard protective coatings become a norm. ISP Optics has invested in fully automated coating chambers, and designed and developed in-house high-durability antireflective, diamond-like carbon (DLC) and hybrid coatings.

Metrology has improved significantly. Overall, ISP Optics has invested $3M in modern equipment in the last four years.

***PS*: What are the newest materials being used to fabricate lenses — both lens and process — and what are the challenges they bring?**

Bechtold: Depending on the application, today's optical components can be fabricated from a variety of advanced materials ranging from soft to extremely hard. The properties associated with optical ceramic materials such as AlON, PCA, Spinel or sapphire provide incredible durability, making them ideal for applications such as aerospace and defense, among others. However, because of their hardness, machining these materials poses challenges such as accelerated tool wear, excessive tool load, reduced processing speeds and less than desirable surface quality if inadequate machining methods are utilized.

DeMarco: I don't know that there are a lot of truly "new" optical materials making an impact in the industry today. A number of materials have had their recipes modified to minimize the use of rare earth materials and heavy metals, and this requires some modification of process steps for sure. Truly new materials that we have experienced, however, have been few.

Escolas: The newest material that we are working with is silicon. Lapping and polishing silicon has some specific challenges, so in order to be more efficient, we invested in new equipment and refined our process. We use fixed abrasive diamond pellets for lapping, which has resulted in much faster processing with less polishing.

Lifshotz: New materials for lenses in SWIR, MWIR and LWIR imaging applications are amorphous/chalcogenide materials (IG/IRG series, BD2, etc.). Recently reborn exotic crystals to make lenses from are potassium bromide and sodium chloride, cadmium telluride and KRS-5. New materials for lens fabrication depend on the fabrication process. Chalcogenides are very difficult to manufacture because the material is brittle and, at high temperature, is susceptible to cracking and breaking. In addition, the challenges for coating are caused by crystals' weak-bonded and less robust structure that results in low adhesion between the surface and thin-film layer. Water-soluble crystals

TechSpec laser-line coated precision aspheric lenses are designed to maximize performance in high-power Nd:YAG laser applications.

(including KBr, NaCl) are not traditionally the easiest materials to handle — no diamond grinding, centration or water contact is allowed, polished surface is harmed if breathed on, and there are difficulties on finishing operations. Removing stress of the material allows it to achieve less complex final lapping, more stable surface shape form and better surface quality. This leads to a possibility to manufacture more complex parts from such kind of material.

PS: What are some key market drivers of new lens materials and lens types? How have changes impacted your business?

Bechtold: The high performance qualities of hard optical ceramics have made these materials ideal for applications where durability is crucial. As this market continues to grow, the ability to minimize the challenges associated with machining and polishing optical ceramics has become imperative. OptiPro has made a focused effort to provide optical manufacturers with a cutting-edge solution that delivers unprecedented machining efficiency for challenging materials.

In recent years, extreme advances in computing power and optical design software have created an interesting dilemma; freeform optical designs, which were once impossible to conceive, are demanding the requirement for new manufacturing technologies including grinding, polishing and measuring machines. Just as aspheres changed the way optical systems were designed and manufactured 15 to 20 years ago, freeform optics will revolutionize the optics industry because of their vast capability. With freeform optics increasing in popularity for commercial applications, we have invested countless R&D hours to develop equipment and software capable of not only grinding and polishing freeform optics, but for metrology as well.

DeMarco: One major driver has been a shift in the defense and security sector from LWIR applications in the $\lambda >$ 10-µm range, to SWIR ($\lambda \sim 1$ µm) and multispectral systems, with IR and visible channels sharing a common path. This has changed the subset of available materials and driven a significant tightening of tolerances. The former has resulted in more of these applications being designed with materials that are MRF-compatible, and the latter has resulted in many of these components requiring finishing after single-point diamond turning, and metrology beyond the prevalent 2D profilometry.

Escolas: IR camera development. These cameras used to be primarily used by the military, but we now see security and police purchasing these products more and more. In order to meet the IR testing requirements of our customers, we recently invested in an IR interferometer and upgraded its capabilities to measure parts up to 14 in. in diameter.

Lifshotz: Commercialization of IR optics (automotive, [unmanned aerial vehicle] application, commercial night scopes) is driving the cost down of LWIR uncooled cameras and, at the same time, demands low-cost athermal lenses. Hence the need for chalcogenide glass materials that are moldable. The obstacle for traditional glass optics manufacturers to enter into the chalcogenide optics business is real. ISP Optics, an expert of optical manufacturing with IR crystals, is smoothly transitioning into this market. We are in the perfect position to partner up with companies that manufacture molded optics with chalcogenide materials. ISP Optics also plays a critical “bridge” role between proof-of-concept and mass production by offering the industry an economically feasible solution for prototyping with any IR materials including chalcogenides.

PS: How are optics trends driving changes in fabrication machinery and equipment?

Bechtold: The aforementioned material trends prompted OptiPro to develop the OptiSonic series of ultrasonic machining centers, ideal for efficient processing of optical glasses and ceramics. OptiSonic technology involves ultrasonic frequency of the cutting tool, while the tool rotates to yield rapid material removal, maximized tool life and improved surface quality. As a result, OptiSonic allows optical fabricators to enhance their overall throughput and surface quality when manufacturing optical components out of hard ceramic materials or standard glass types.

With optical systems beginning to shift toward incorporating freeform optics, OptiPro recognized the importance of developing software that can streamline manufacturing of complex geometric shapes.

DeMarco: Enhanced software and increased computing power have enabled the optical design community to develop new, and refine existing, designs by more readily employing components that have proven challenging to manufacture in the past, such as aspheres, off-axis components and even freeform shapes. These new shapes require novel solutions for all aspects of the fabrication process, but especially in the polishing and metrology areas.

Escolas: Customers are requesting larger parts, so we've allocated most of our capital improvement investments toward larger double-sided polishing machines.

Lifshotz: The need to assemble IR lens systems faster and more reliably leads to the change of lens configuration — mounting steps and flat bevel (especially on convex side) are the popular changes in today's IR optomechanical design. Chalcogenide glass that requires DLC coating (coating chambers) needs to be modified to adapt.

_PS_: What do you think will be the next significant trend in optics and optics fabrication?

Bechtold: There is an extreme amount of focus and effort on freeform optics design, manufacturing and metrology. The numerous advantages of freeform and conformal optics are driving the technology. These new optical systems are still in need of robust solutions, and improvements in hardware and software will be critical to solving these challenges. There is still a lot of work to be done, including collaboration on developing standards and better understanding for what the actual component specifications need to be.

DeMarco: We believe and are hopeful that the next major trend will be a move toward design for manufacturing. Traditionally the design and manufacturing communities, even those residing in the same building, often performed their respective work in a vacuum. As the novel materials and shapes being used, and the need for tighter tolerances, become prevalent, designers and manufacturers need to become partners in the process of producing optical components. This requires that manufacturers actively describe their capabilities, challenges and limitations so the designers can account for them in the design activity. The result is a better performing system design that is comprised of components that are known to be manufacturable: a win-win for both partners.

Escolas: That's one of the great characteristics of our industry, no one really knows. If you find someone that does know … have them send in a resume!

Lifshotz: Self-driving cars and commercial drones need to "see" day and night, so the commercialization of IR optics will continue. Wider use in security and surveillance as prices come down, extending to consumer markets; amorphous materials may gain a momentum with 3D printing; IR optics shall gain greater use in [quantum cascade laser] applications as they come down in price. All of this will lead to more automation of lens fabrication process and less operator interaction. Combining visible and IR images into one system will lead to a combination of old (Ge, ZnSe, ZnS, CaF_2, KBr, NaCl, CdTe) and new (chalcogenide) materials to be used together.