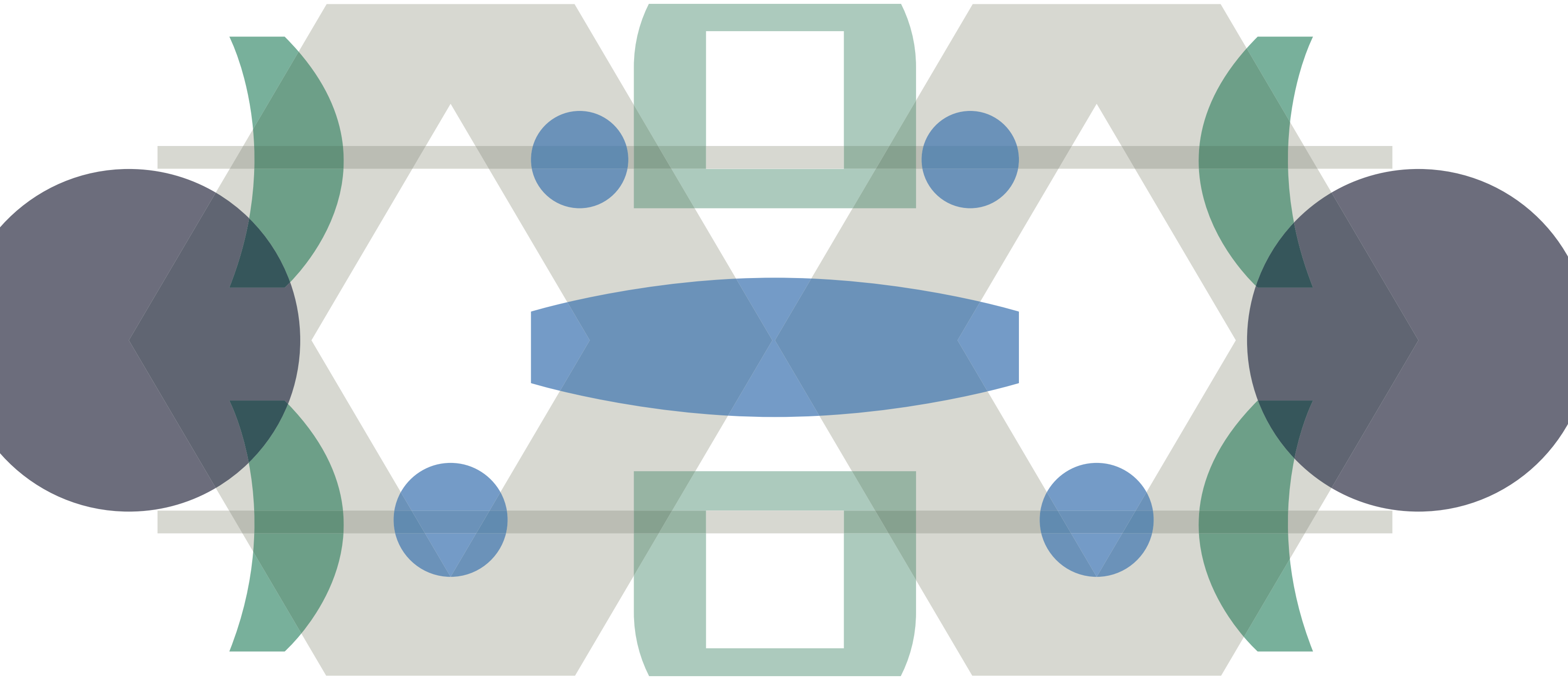


Alternative to Germanium Gaining Momentum for IR Optics

Chalcogenides are fast becoming the material of choice, thanks to advances in system modeling tools and metrology techniques, combined with the efficiencies of precision glass molding.

When it comes to designing IR imaging systems, manufacturers have traditionally worked with crystalline materials such as germanium. To make compact, lightweight systems, fabricators are driven to use aspheric surfaces, which has meant diamond turning. Chalcogenide glasses have emerged as another material option for IR optical elements. Not only do they

A military night vision sensor product deployed in the field.

boast excellent performance, but, even more importantly, they can be fabricated using scalable precision glass molding methods.

Several technologies are converging to enhance the capabilities of IR imaging systems. Advances in detectors provide useful options to system designers from the short-wave infrared (SWIR) through mid-wave (MWIR) and to long-wave (LWIR). System modelling tools are matching that improvement, and it is now possible to predict the performance of complex systems, as well as model intricate surfaces. At the same time, advances in metrology techniques makes it possible to validate individual components and overall system performance at each stage of the development process.

These advances mirror those of optics for visible systems, with the important exception that many key materials that are transparent in the visible are opaque in the IR, so IR systems must use alternates.

Traditional IR optical elements are composed of crystalline materials such as Ge, ZnS, ZnSe and Si, which can be diamond turned and conventionally ground and polished. Improved fabrication techniques now allow for creation aspheric surfaces; this allows for compact, lightweight designs. All of these attributes have come together to create growing interest in IR imaging systems, suitable for surveillance, security and guidance.

Single-point diamond turning is a well-accepted and established precision manufacturing method for IR optics, however economies of scale require purchasing additional machines and global production capacity is limited. Designers have been stuck with expensive and slow diamond turning all throughout the production run. Additionally, the ten-thousandth optical element would take almost as much time to produce and validate as the first or the tenth because each part is uniquely produced.

Benefits of precision glass molding

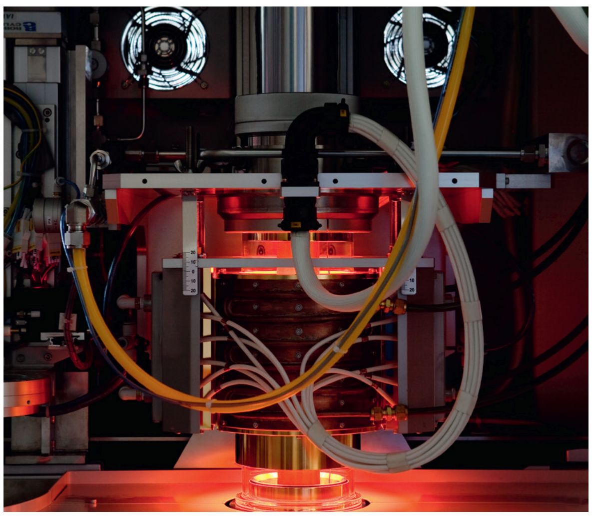
Chalcogenide glass (ChG) optical elements can be diamond turned, but they can also be produced with precision glass molding (PGM). After up-front design, engineering and mold production, PGM elements can be produced quickly, and the ten-thousandth element is identical to the tenth. Once the tool has been validated, the inspection requirements for successive production runs become straightforward.

This opens up the opportunity for designers to take advantage of economies of scale for serial production quantities. That is, they can produce prototype and qualification runs with optical elements composed of traditional materials, and then modify the design for ChG and ramp up to production quantities

But the real opportunity is much more significant. Designers can produce prototypes, qualification systems, and production runs all from the same ChG material. There's no barrier to entry into the streamlined design and production world of chalcogenide glass IR element production other than a lack of familiarity with PGM as a manufacturing method and ChGs as IR materials.

In precision glass molding, glass is heated until it softens and then is compressed between two molds under force. Precision glass molding is suitable for glasses that have relatively low glass transition temperatures. Chalcogenide glasses have an advantage over visible light glasses because they have lower transition temperatures, so molding can be done more easily.

The PGM process cools the glass from its molding temperature down to room temperature. Due to the thermal cycling of the glass, molded optics have what is called "index drop," which



One of FISBA's Toshiba precision glass molding machines with IR heater on.

means the finished optics don't have the same index as the catalog specification for fine annealed glass. The index drop is repeatable and well characterized, so the effect is easily included in design models.

The molds for ChGs are often produced by diamond turning, which means the same precision aspheric surfaces coming from diamond turning an individual part are transferred to each of the many molded copies. Inflection points, tight radii of curvature, and other small design features are usually not a problem. PGM-produced components do have some constraints on their center- to edge-thickness ratio, generally related to factors such as residual stress in the material and shrinkage. Thickness also affects the heating and cooling time and may drive component price. Very sharp corners and rapid thickness transitions can be problematic, but if those types of features are called upon for precision mounting, they can be incorporated with standard post-molding processes.

PGM parts can either be molded to their final diameter or pressed bigger than the finished part diameter and then centered. Diamond turned parts can't get much smaller than 5 mm in diameter, as it becomes increasingly difficult to attach the blank to the chuck, but precision glass molded elements have no theoretical lower limit, although lenses as small as 1,5 mm in diameter are a typical minimum. A reasonable upper limit for molded parts is about 35 – 45 mm in diameter, although larger diameters are possible.

PGM lowers the cost per piece and the component processing time. Initial costs are relatively high because of the Non-Recurring Engineering Costs (NRE) for tooling, but somewhere in the thousand to several thousand part range the reduced per piece costs outpace the initial investment. And when considering going to high volumes, planning for PGM down the line makes it easier to transition from fabrication of prototypes and qualification units into production, because no drawing or material changes are needed.

Group 16

In 1932 two German scientists, Wilhelm Blitz and Werner Fischer, proposed the name " chalcogen" for the elements in Group 16 on the periodic table. Those elements include oxygen, sulfur, selenium, tellurium and polonium. Sulfur (S), selenium (Se) and tellurium (Te) are the chalcogens that form chalcogenide compounds that can be made into IR optical glass. Chalcogenide glasses are comprised of Chalcogen compounds arranged in an amorphous network with no long range order. Dual element glasses such as As2Se3 have a "3D-like" structure held together by Van der Waals forces, while ternary or more complicated ChG glasses are crosslinked by stronger interatomic bonds.

The unique chemical and physical properties of chalcogenides make them attractive candidate materials for IR optics. The five to seven mainstream industrial "flavors" of chalcogenide glasses all have high transmission over a wide wavelength range (from about 1 µm to 12 to 14 µm), an index of refraction broadly comparable to traditional IR materials, and lower melting and glass transition temperatures than visible glasses — so they are an excellent fit for PGM. The physical properties of the material also make them workable with diamond turning and conventional grinding and polishing methods. There are some variations among nominally identical chalcogenide glasses from different suppliers, primarily depending upon how much the suppliers purify the arsenic, selenium, or other elements prior to synthesizing the chalcogenide. These different formulation processes don't modify the material properties significantly, except for extending the long-wave transmission window cutoff from 12 µm to 14 µm in certain cases.

Another key advantage chalcogenides hold over germanium is the lack of thermal darkening. Heated above 65 °C Germanium becomes opaque in the IR. ChGs are stable to + 100 °C or greater depending on the composition. Mechanical hardness is about the only area where ChGs aren't advantageous over germanium, but with hard coating, chalcogenide glasses can be just as robust.

Component designers need to incorporate the PGM index drop into their models, but that's not as complex as it might appear. Although the heating and cooling cycle of molding lowers the index of refraction from that of the fine-annealed raw material, there's not much difference between the index profiles for parts created with different cooling profiles. The actual cooling profile tends to be dominated by the very low thermal conductivity of chalcogenides, self-limiting the cooling rate and evening out differences between distinct PGM parts. The bottom line: as long as designers include the index drop in the material description of their modelling program with measured data available, the design and simulation will be accurate.

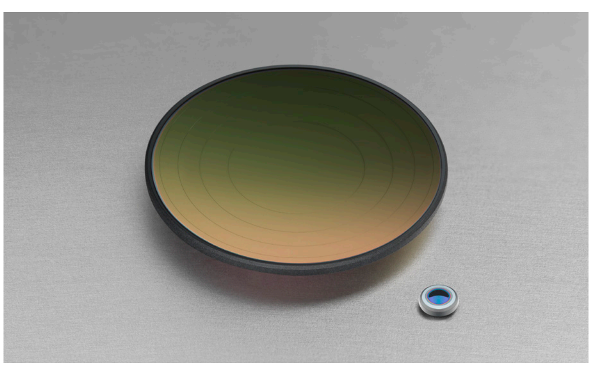
Precision molded IR lenses and a ball preform made from chalcogenide glass.

Large-scale product of detailed

Precision glass molding is not often cost-effective for spherical surfaces – custom tooling for grinding and polishing is usually the way to go for spheres. PGM excels for moderate- to large-scale production of complex and detailed parts. For example, if an optical element has two aspheric surfaces, the proper relative orientation of the two surfaces is critical to reach performance goals. With traditional fabrication and metrology methods, the orientation of each surface must be individually measured and controlled. With PGM, once the tool (the mold) has been qualified, the job is done.

IR diffractive optical elements (DOEs) are also excellent candidates for PGM-fabricated chalcogenides. Small and sharp features are cut into the tool with diamond turning, and then those features are reproduced in each part. The same advantages apply to freeform components – once the tool has been qualified, production runs are efficient and straightforward.

IR system design is inherently a complex and intricate process, and optical component design is often the most critical element of an entire project. Performance predictions must be validated with prototypes, then manufacturing protocols must be verified with qualification units, and finally the performance of the qualification units must be transferred to large-scale production units.



An IG6 molded aspheric diffractive lens with AR coating (~ 25 mm) and a 2,5 mm IG5 biconvex collimation lens.

When designers incorporate production-phase requirements into their prototype designs the overall process becomes dramatically simplified. There is no question that moderate- to large-scale production runs are more efficient with precision glass molded chalcogenide glass components. Keeping that endpoint in mind, designers can make prototype ChG parts with diamond turning or traditional grinding and polishing, but with design features that seamlessly transition to PGM.Foresight in early stages eliminates many of the hurdles of changeover from qualification to production, improves efficiency, and reduces cost over the entire product lifecycle.

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