Advanced manufacturing methods for Chalcogenide molded optics

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Abstract

As Chalcogenide glass and Precision Molded Optics (PMO) have developed and matured to a point of being accepted as replacements for Germanium Single Point Diamond Turned (SPDT) optics; technological research is being dedicated to developing infrared PMO that can be used in a broader application base. These include laser arrays, large aperture molded chalcogenide optics, and molded in mount infrared optics. This paper presents applications for infrared laser arrays and the corresponding optics that must be closely mechanically mounted to avoid clipping the beams. Different molding and mounting techniques will be discussed to solve this issue which include; dicing chalcogenide optic lenses, molded in mount chalcogenide optics and stepped optic shape molding for mounting purposes. Accompanying the research and discussion of these techniques will be experiments and molded chalcogenide glass lenses showing the results and application for each lens type.

Keywords: Chalcogenide glass, Precision Molded Optics, infrared, laser optics, ellipsoid beam, lens array, large aperture infrared optics.

1. Introduction

Chalcogenide glass was introduced several decades ago and has been used for infrared applications since, but because infrared detectors have recently become commercially affordable, a need for more affordable, high volume infrared optics has reinvigorated the interest in chalcogenide materials. The driving factor for this is the cost of the elements required to manufacture the chalcogenide glass. For the purposes of this paper, we will consider LightPath's Black Diamond (BD2) glass which has the material makeup of Ge(28), Sb(12) and Se(60). Germanium is the driving cost element of this glass as it is over twice the cost of the other two elements.

Traditional IR optics are often made from Ge, ZnSe and other similar materials. These materials are unable to be molded which is one of the reasons LightPath uses moldable chalcogenide glass. Two unique distinctions chalcogenide glass has from Germanium are:

- It is significantly cheaper by mass.
- Can be formed to shape by applying heat and pressure without crystallizing the material.

The largest cost of chalcogenide IR materials is the amount of Ge each glass mixture contains. Certain IR non-Ge glasses exist today, but they have a low transition temperature which limits their high variant temperature applications and performance. For the higher ΔT applications, Ge added to the chalcogenide glass enables performance for athermalized designs. With the renewed interest in making infrared optics cost viable for commercial applications and volumes, it is expected that research will continue for a cost efficient chalcogenide material using elements that are cheaper than Ge. With a low amount of Ge present in BD2 glass, it has a lower dn/dt value than pure Ge, which will cause a smaller index change at high ΔT environments. Because of this, athermalization is many times accomplished with the appropriate material choice of the lens holder and careful optical lens design instead of using additional mechanical assemblies to move the optical elements. This makes the opto-mechanical design much simpler and lowers the cost of the IR optic lens assembly without having to introduce mechanical or electro-mechanical compensators for dynamically adjust the optics over the desired temperature range.

While diamond turning Ge to form an IR optic has been the primary manufacturing resource for decades, molding technology for IR optics is a relatively new process. Because of this, diamond turning operations and Ge material efficiency has been through immense lean manufacturing exercises to lower the cost of those optics to industry prices commonly seen from most IR optic companies. The Ge material efficiency is approximately 95% through recycling the material and SPDT has a yield in the same range. In comparison, chalcogenide glass molding is a new technology and the material yield is not close to that of Ge. Even with the increased yield costs, chalcogenide molded optics are cost comparable to Ge optics and the cost saving potential is enormous as most chalcogenide glasses are 20% - 30% Ge by mass and the corresponding materials are 50% - 90% cheaper in unit measure.

One of the largest advantages of molding vs SPDT optic elements is that of capital cost required for high quantity production. While mold pins are manufactured with diamond turning machines, the mold pins can mold several lenses before needing to be remanufactured or replaced whereas SPDT optic elements require the same machine time for each lens as does one optic pin. The throughput of a SPDT machine is much slower than a mold press and the capital cost of each SPDT machine compared to a molding press is exponential. In high volume manufacturing, multiple molding machines can be ran by a single operator with shorter molding times than a single operator manufacturing a single optic on a SPDT machine. As the volumes of infrared optics continue to increase, molding will become a more common method for producing affordable, high volume, high quality infrared optics.

With the establishment of the cost potential for chalcogenide glasses and glass molding, interest has developed for advanced optic shapes and mounting applications. One application being to characterize the beams of an array of lasers operating in the 3µm - 5µm range. In this application, it is important to keep the packaging of the lasers and their corresponding optics as close together as opto-mechanically possible. To accomplish this, three different manufacturing techniques were identified and experiments conducted showing the feasibility of each method.

2. Experiment

The experiment of manufacturing the different profile of lenses for the array project consists of three different methods. Each of the methods described consists of a Quantum Cascade Laser (QCL) designed chalcogenide lens that LightPath Technologies produces and is available to customers. The object in doing each of these designs was to reduce the mounting space in the x and y directions, thus allowing an array of lenses to be packaged close together. The three methods consist of the following:

1) Dicing – A chalcogenide QCL lens was molded and then diced using a diamond blade.
2) Mold in Place (MIP) – The same QCL lens was molded inside of a metal ring.
3) Stepped Mounting Feature – The chalcogenide lens was molded with a cylindrical step void on the back surface for mounting purposes.

In molding, a key feature that helps ensure the optic surface profile is as accurate as possible is to include a blend feature on the outside of the lens. This area is where the clear aperture of the lens ends and additional diameter is added to the lens for mounting purposes and ease of manufacturing mold tooling. For the purposes of packaging an array of lenses close together, it was necessary to manufacture the lenses with the outside diameter as close to the clear aperture as possible.

2.1 Dicing

For this experiment, a LightPath catalog 390037 BD2 lens was molded and then bonded with ultraviolet epoxy to graphite for dicing on a diamond blade saw. The clear aperture of this lens is ø4.00mm with an outside diameter of ø5.5mm. Typically, it is possible to dice other optical glasses with a chip diameter less than 100 microns caused by the vibration of the blade. Chalcogenide glass is much more brittle than many visible glasses and initial trials of dicing the glass caused the trailing edge of the lens to break with an approximate aggregate size of ø1mm. To give the glass more stability at the exit region of the blade, additional epoxy was added to provide a mass of structural support and the desired results of dicing the lens with <100µm chipping was achieved. After consistently confirming this, it was possible to dice the BD2 lens to a 4.2mm dimension in the multiple configurations as shown.

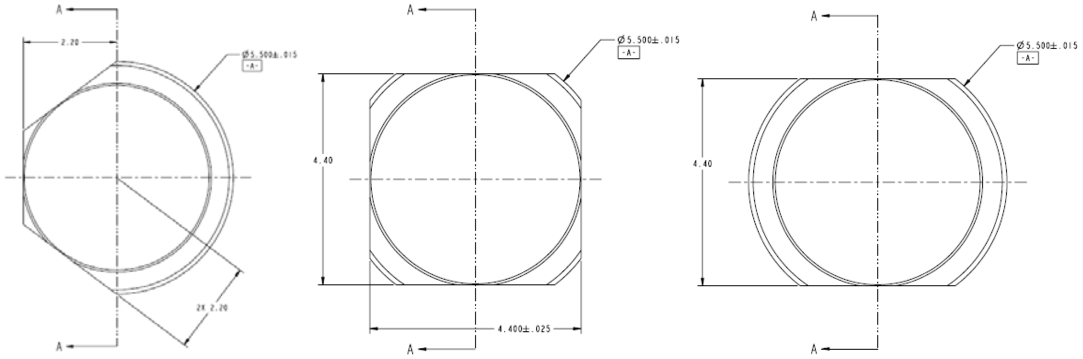


Figure 1: Geometrical configurations of experiment

The other concern was how the AR coating adhesion would react to the dicing process, most notably the possibility of peeling on the cutting edge. Dicing coated lenses engulfed in epoxy and with coating exposed to the blade were both experimented with and there were no adverse peeling or coating defects observed when dicing the exposed coating surface lenses. In addition to dicing the multiple geometrical configurations of the lenses, experiments were conducted using the three standard AR coatings LightPath uses at the following wavelengths; IR1 (1.8µm – 3.0µm), IR2 (3.0µm – 5.0µm) and IR3 (8.0µm – 12.0µm). Chipping of the lenses were still under the 100µm size and no peeling of the three different coatings were observed. Pictures of the diced lenses in the different geometrical configurations are shown below.

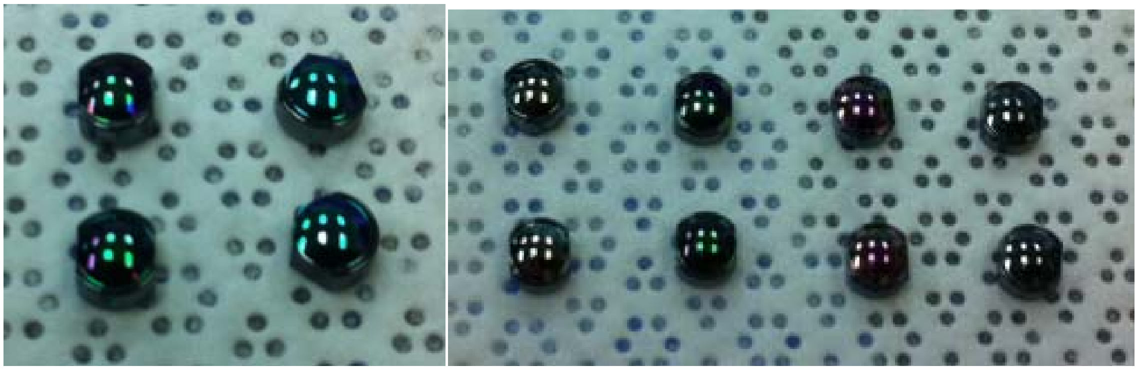


Figure 2: Different geometrical and AR coatings of diced lenses

2.2 Mold In Place

Mold in Place (MIP) is a technology originally patented by LightPath (formerly Corning Glass Works) in 1993 and is used with many of our visible glasses. The technique involves molding a glass lens inside metal ring for the purposes of:

1) Producing a hermetic seal
2) Optic inserted into material that can be welded or assembled without bonding
3) Protect the optic surface

In choosing the material for MIP manufacturing, care must be taken to select a material with a similar coefficient of thermal expansion (CTE) as the glass you are molding. If care is not taken to select the correct material and size it accordingly at the molding and intended use temperatures, stresses can occur in the optic decreasing the optical performance or resulting in material failure. Many laser applications for this type of lens require a hermetic seal for the entire optical system. When assembling the MIP subassembly inside the laser assembly, many times the ring is laser welded into the laser mount and testing from previous customers have indicated a seal impervious to gases. For the purposes of this experiment, a study was conducted based on the Tg temperature of the BD2 glass and the correlation of CTE's of metals and glass at that temperature. The suitable metals are identified below.

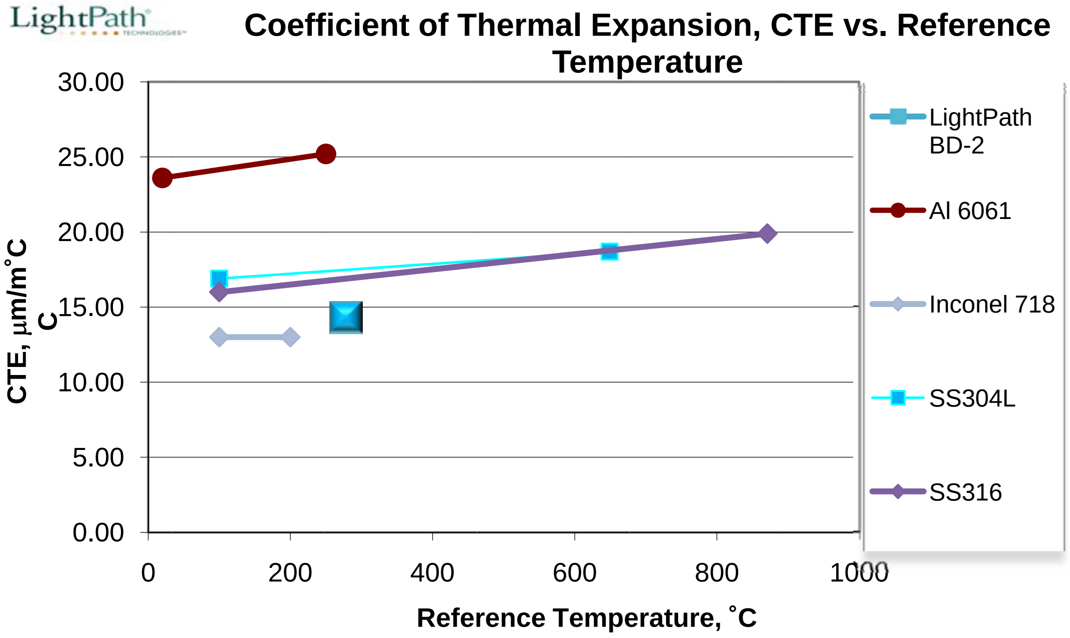
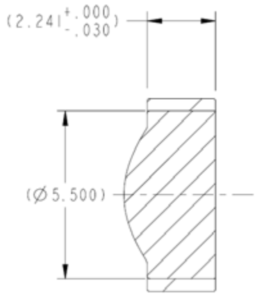


Figure 3: CTE of BD2 glass and suitable metals

Once the appropriate metals were identified, calculations were made to correctly size the inside diameter of the MIP ring to the outside diameter of the lens without inducing large amounts of stress. Generally the height of the MIP ring is the same as the length of the outside diameter of the lens, shown in Figure 4, but it can be extended to protect the sag height of the lens or provide additional mounting surface. If this is done, the molding complexity increases, so tooling design can limit this and consideration needs to be taken to ensure the lens surfaces can evenly be coated with the appropriate AR coating. Additional mechanical features



design

can be present on the outside of the MIP ring if desired. These can include adding threads on the outside diameter, a tab for locating of clocking purposes during assembly or whatever feature may prove useful for the end user. Four metals were identified as plausible matches for the BD2 material in this experiment and multiple lenses were molded in each of the materials as shown in Figure 5.

Figure 5: BD2 glass molded inside a MIP ring

2.3 Stepped Mounting Feature

Another method to achieve a high ratio of the clear aperture to the outside diameter of the lens was to eliminate the blend radius which makes your mold tooling more complex and to add a step feature to the back of the lens which would accommodate mounting of the lens without adding to the diameter. For a collimating laser application, this can be done on the back surface of the lens because its' clear aperture is much smaller than the front surface as shown in Figure 6. Adding this feature allows the lens to self locate itself in an array mechanical fixture and can be held in place by bonding or mechanically restrained. To produce the stepped feature, significant SPDT machining is required in either making the mold or an individual lens. One significant advantage molding has over SPDT for a design such as this is that molding uses one set of molds to repeatedly manufacture lenses of this shape where as SPDT would require the same amount of machining for each lens. Also, the optical axis and stepped mounting features are all controlled on the same mold so consistency of quality assurance is repeatable for the life of the mold.

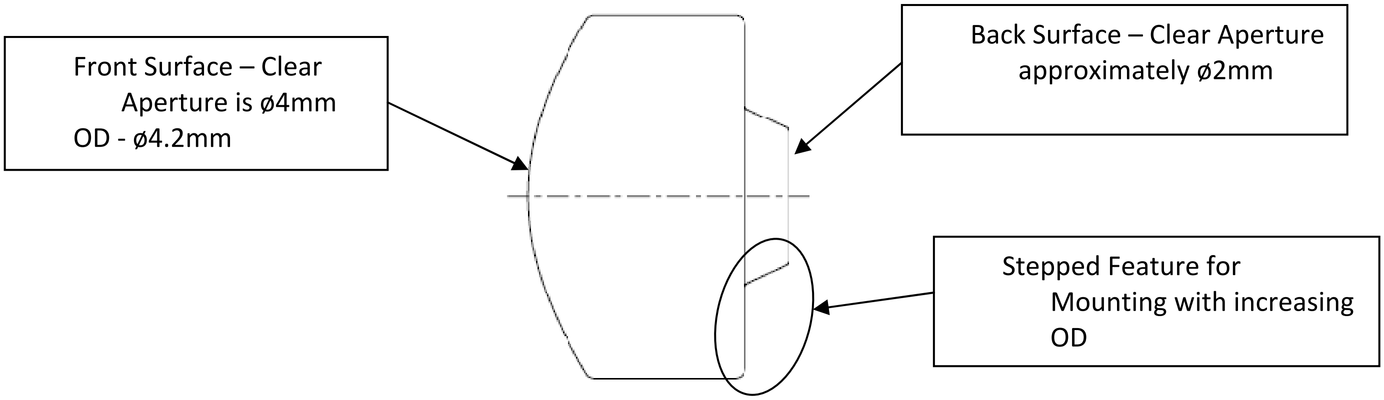


Figure 6: Stepped feature lens design

When an application would require a lens with a stepped feature such as this or some other geometry differing from a standard spherical/flat/aspherical surface there are some limitations per the flow properties of glass. The two key areas of concern would be that the lens geometry is concentric and that it is as close to the largest mass of glass as possible. Chalcogenide can crystallize if taken above a certain temperature during molding and if not cooled correctly. The main concern with molding this lens was the possibility of trapped gas on the back surface as the mold forming this surface was recessed. As the glass formed to that surface, it was designed to form from the axis of the lens outward as to promote the air to escape from the OD of the lens and not get trapped between the mold and lens surfaces. Shown below in Figure 7 are some molded, uncoated lenses.

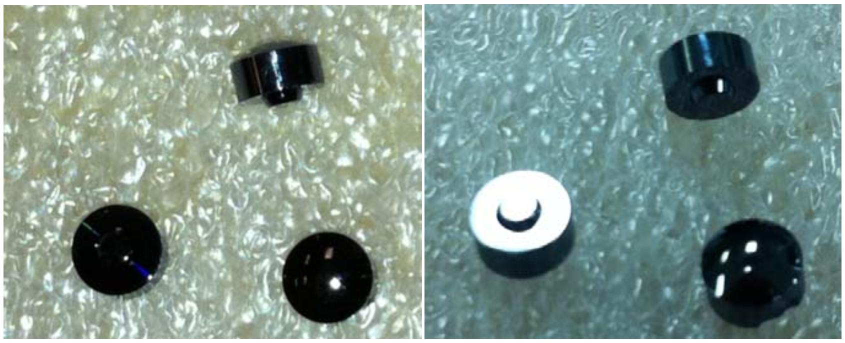


Figure 7: Molded BD2 glass lenses with stepped feature

3. Conclusion

As the need for commercial quantities of infrared optics become greater, more cost competitive options will be needed. Molding requires significant initial costs associated with tooling and engineering to begin production for a lens, but those costs can typically be absorbed in the lens unit costs within the first few hundred lenses. Chalcogenide glass can be molded whereas other infrared materials such as Germanium cannot. This paper has discussed three different lens designs and manufacturing techniques which are conducive to producing a lens with a clear aperture close to the outside diameter, a lens that is hermetically sealed and can be laser welded in a module and a diced lens which can be shaped in a variety of way and be used to characterize non-uniform beams while saving mechanical mounting space. There is follow up research being conducted based on the results of this study and it is believed more complex lens shapes can be molded while maintaining commercial pricing.