Molded Infrared Optics 03.06.2015
FISBA

Overview

1. Company
2. Basics precision glass molding
3. Molding of chalcogenide glass
4. Chalcogenide glass comparison with cristalline materials
5. Design recommendations
6. Examples and FISBA capabilities
7. Discussion
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About us

• Leading supplier of optical systems, micro systems and components
• Head office in St. Gallen, Switzerland
• Subsidiaries in Berlin (Germany) and Tucson (USA)
• Turnover: CHF 50 M
• 350 employees
• Privately owned by Hans Huber and the Fischbacher family
FISBA

History

1957  Founding of FISBA OPTIK
1958  Production of optics/mechanics
1961  Development and production
       of optical systems and instruments
1965  Production of micro optics
1982  Computerized lens design

1992–2010  μPhase interferometer
1993–2008  Laser systems
FISBA

History

1999  In house coating
2006  New product line AOC
2006  Precision glass molding
2010  New product line Micro Systems
2012  Inauguration of new production building
2014  Launch of IR molding
Customers from the high-tech industry
- Systems manufacturers
- OEM customers

Markets
- 80 % Europe and Israel
- 20 % USA/Asia

Branch Profile
- Life Sciences (biophotonic/medical optics)
- Security and defense
- Machine and laser industry
- Aerospace
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TECHNOLOGICAL BASICS OF PROCESS

• Deformation of polished preforms at relatively high viscosities
• Usually no polishing of components after molding
• Precision glass molding is an isothermal process (process time much longer compared to non isothermal molding, precision much better)
TECHNOLOGICAL BASICS OF PROCESS
PROCESS AND TOOL DEVELOPMENT

- After initial tool grinding / diamond turning and molding usually one additional iteration is required
- Preform shape: iteration sometimes required
- Tool grinding / diamond turning itself is an iterative process
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PRECISION OXIDE GLASS AND CHALCOGENIDE GLASS MOLDING MACHINES AT FISBA

FISBA has two different molding machine technologies in-house:

1. **Batch machine** with vacuum option
2. **Transfer type machine** without vacuum option

- Technology for your specific request
- Depending on product, autohandler can be applied
- Cleanroom facility with controlled temperature and humidity allows high repeatability of processes
- FISBA always chooses the better
BATCH MACHINE WITH VACUUM OPTION (I)

• Complete process takes place in the same chamber

• Process duration varies from 15 min to 40 min

• This machine type offers a vacuum option which is indispensable for some geometries (nitrogen capture)

• Vacuum option allows a cost optimized preform in certain cases

Source: Toshiba machines
BATCH MACHINE WITH VACUUM OPTION (II)

- Scale up by switching from single cavity tool (used for prototypes) to multi cavity tool.
- For multi cavity molding the process parameters are different to single cavity molding.
- Ramp up from prototypes to serial production needs development time and can lead to slightly different product properties.
TRANSFER TYPE MOLDING MACHINE (I)

Source: Toshiba machines
TRANSFER TYPE MOLDING MACHINE (II)

- Every process step heating, pressing, cooling takes place on a subsequent transfer stage
- Typical tact time is between 4 and 6 min per «transfer stage», typical process time to lens completion is around 30 min
- Only one lens is molded by one tool with the strong advantage of the identical process for prototype and serial production, no additional process development
- Ramp up for serial production is done by using as many tools as stations
- No vacuum option, molding is done in nitrogen atmosphere
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TOOL MANUFACTURING (I)

- FISBA has partnership with various tool manufacturers and material suppliers

- **Ultra precision grinding process** is state of the art and is applied as iterative process (multiple grinding -> measuring-> regrinding) for mold of oxide glasses

- **Single point diamond turning** is typically applied to metal alloys used for molds in chalcogenide molding
Ultra precision grinding on cemented carbides leads to ductile ground surfaces.

Typical roughness for the optimized grinding process is 5 nm rms.

Additional polishing process can reduce roughness down to 3 nm rms.

Usually all tools need to be coated to avoid glass sticking (wetting) and in order to increase tool endurance.
Singel point diamond turning on metal alloys leads to optical grade surfaces.

Typical roughness for the optimized process is 8 nm rms.

Manufacturing of tools with diffractive structures possible.

Usually all tools need to be coated to avoid glass sticking (wetting) and in order to increase tool endurance.
FISBA History in Precision Glass Molding

- 2006 - first molding machine and production of oxide glass lenses for medical endoscopes (VIS)
- Continuous extension of product range, including cylindrical arrays, off-axis aspheres and off-axis cylinders
- Lenses for beam shaping and imaging optics in VIS, NIR and SWIR
- 2014 – substantial investments in chalcogenide glass molding for thermal IR applications
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WHY AND WHEN PRECISION GLASS MOLDING OF CHALCOGENIDE GLASS?

Chalcogenide feasible / advantageous?
  no ➔ Christalline materials lead to a non molding option
  yes ➔ Can the lens be spherical?
    yes ➔ Go for a conventional process with polishing
    no ➔ Is the quantity low?
      yes ➔ Go for SPDT or polishing
      no ➔ Medium or high quantity needed?
        yes ➔ Check feasibility for Precision Glass Molding
        no ➔
Main differences between oxide glass molding and chalcogenide glass molding

- Chalcogenide glasses are molded at significantly lower temperatures
- Chalcogenide glasses have higher CTEs compared to oxide glasses
- Chalcogenide glasses are more brittle
- Typical geometrical tolerances of oxide glasses are much tighter compared to chalcogenide glasses, due to the difference of the application wavelength
Advantages of molded chalcogenide glass lenses from FISBA

- Extensive experience with precision glass molding technology, optical design and manufacturing of components
- Independent sourcing of the best material for the project
- Strict OEM approach
- Experience in long-term relationship with partners in demanding applications
- Manufacturing capabilities in Switzerland and the US
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General properties of chalcogenide glasses

- Due to its amorphous nature it is moldable
- Good transmission from SWIR to LWIR
- Can also be processed by single point diamond turning (for example for prototypes)
- Fits to all available sensor technologies (Micro-Bolometer, MCT, InSb, QWIP, InGaAs)
- Less expensive raw material compared to Ge and ZnSe and many other crystalline materials
Table of popular chalcogenide glasses

<table>
<thead>
<tr>
<th>Composition</th>
<th>Schott</th>
<th>Vitron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge33 As12 Se55</td>
<td>IRG-22</td>
<td>IG2</td>
</tr>
<tr>
<td>Ge30 As13 Se32 Te25</td>
<td>IRG-23</td>
<td>IG3</td>
</tr>
<tr>
<td>Ge10 As40 Se50</td>
<td>IRG-24</td>
<td>IG4</td>
</tr>
<tr>
<td>Ge28 Sb12 Se60</td>
<td>IRG-25</td>
<td>IG5</td>
</tr>
<tr>
<td>As60 Se40</td>
<td>IRG-26</td>
<td>IG6</td>
</tr>
</tbody>
</table>
Transmission of popular chacogenide glasses

Source: Schott
Chalcogenide glass properties compared to Germanium

- Lower $\frac{dn}{dt}$ 😊
- No thermal darkening 😊
- Lower costs 😊
- Some materials completely free of Germanium 😊
- Lower abbe number in the LWIR 😞
- Less transmission in the LWIR 😞
Chalcogenide glass properties compared to Silicon (I)

- Much better transmission in the LWIR 😊
- More expensive 😞
Properties compared to Silicon (II): Refractive index

<table>
<thead>
<tr>
<th>n</th>
<th>Ø Si</th>
<th>IRG22</th>
<th>IRG24</th>
<th>IRG26</th>
</tr>
</thead>
<tbody>
<tr>
<td>3µm</td>
<td>3.434</td>
<td>2.518</td>
<td>2.627</td>
<td>2.802</td>
</tr>
<tr>
<td>5µm</td>
<td>3.424</td>
<td>2.510</td>
<td>2.619</td>
<td>2.791</td>
</tr>
<tr>
<td>8µm</td>
<td>3.420</td>
<td>2.503</td>
<td>2.613</td>
<td>2.783</td>
</tr>
</tbody>
</table>
Comparison of abbe numbers (approximations) of various materials

<table>
<thead>
<tr>
<th>GLASS</th>
<th>&quot;Abbe-number&quot; LWIR</th>
<th>LWIR Transmission</th>
<th>&quot;Abbe-number&quot; MWIR</th>
<th>MWIR Transmission</th>
<th>&quot;Abbe-number&quot; SWIR</th>
<th>SWIR Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRG22</td>
<td>111</td>
<td>68%</td>
<td>197</td>
<td>68%</td>
<td></td>
<td>68%</td>
</tr>
<tr>
<td>IRG23</td>
<td>168</td>
<td>60%</td>
<td>154</td>
<td>60%</td>
<td>35</td>
<td>60%</td>
</tr>
<tr>
<td>IRG24</td>
<td>175</td>
<td>66%</td>
<td>198</td>
<td>66%</td>
<td>49</td>
<td>66%</td>
</tr>
<tr>
<td>IRG25</td>
<td>109</td>
<td>64%</td>
<td>173</td>
<td>64%</td>
<td>47</td>
<td>64%</td>
</tr>
<tr>
<td>IRG26</td>
<td>160</td>
<td>62%</td>
<td>169</td>
<td>62%</td>
<td>41</td>
<td>62%</td>
</tr>
<tr>
<td>Germanium</td>
<td>942</td>
<td>90%</td>
<td>96</td>
<td>70%</td>
<td>19</td>
<td>50%</td>
</tr>
<tr>
<td>SILICON</td>
<td>1869</td>
<td>20%</td>
<td>241</td>
<td>95%</td>
<td>80</td>
<td>95%</td>
</tr>
<tr>
<td>Quarzglass</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td>17</td>
<td>95%</td>
</tr>
<tr>
<td>N-BK7</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td>19</td>
<td>90%</td>
</tr>
</tbody>
</table>
Infrared transmission spectra for 2.2 mm thick uncoated, polished HiTranTM silicon and 2.0 mm thick uncoated, polished prime Czochralski silicon.

Oxygen concentrations for prime Czochralski silicon and HiTranTM silicon is 6x10^{17} \text{cm}^3 and 5x10^{15} \text{cm}^3, respectively.

Measured transmission at 8.92 \text{µm} and at 13.5 \text{µm} as a function of the uncoated sample thickness for HiTranTM silicon.
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As large interdependencies between the individual parameters exist, the given values cannot be seen as an absolute limit or be guaranteed in every case.

Wider tolerances, in particular in the areas of form errors, irregularities and cleanliness, lead to lower costs.
# Generic Shapes

<table>
<thead>
<tr>
<th>Form</th>
<th>Feasibility</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planar Convex</td>
<td>++</td>
<td>If rotational symmetric: no major advantage to biconvex</td>
</tr>
<tr>
<td>Biconvex, one side aspherical</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>Biconvex double asphere</td>
<td>++</td>
<td>Only slightly more expensive compared to one sided aspheric</td>
</tr>
<tr>
<td>Meniscus (spheres or aspheres)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Biconcave and spherical on steeper side</td>
<td>-</td>
<td>Conventional post polishing possible if necessary</td>
</tr>
<tr>
<td>Biconcave aspherical</td>
<td>--</td>
<td>Risk very high, only worth a try if steepness is very low</td>
</tr>
</tbody>
</table>
### Design recommendations chalcogenide glass lenses

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Standard Values</th>
<th>High Standard Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>3 – approx. 25 mm</td>
<td>3 – approx. 30 mm</td>
</tr>
<tr>
<td>Tolerance for lens Ø &lt; 5 mm</td>
<td>± 0.015 mm</td>
<td>± 0.005 mm</td>
</tr>
<tr>
<td>Tolerance for lens Ø &gt; 5 mm</td>
<td>± 0.025 mm</td>
<td>± 0.010 mm</td>
</tr>
<tr>
<td><strong>Center thickness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerance</td>
<td>± 0.03 mm</td>
<td>± 0.01 mm</td>
</tr>
<tr>
<td><strong>Form figure error</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspheric figure error</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Irregularity</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Wedge</strong></td>
<td>5’</td>
<td>2’</td>
</tr>
<tr>
<td><strong>Decenter</strong></td>
<td>± 0.015 mm</td>
<td>± 0.005 mm</td>
</tr>
<tr>
<td><strong>Surface Quality (MIL)</strong></td>
<td>60-40</td>
<td>20-10</td>
</tr>
</tbody>
</table>
Selection of glass types

As of June 2015, the following glass types are available:
- IRG 26, IRG 24 or their equivalents (IG6 and IG4)

We are working on molding capabilities for the following glass types:
- IRG 22, IRG 23, IRG 25 or their equivalents (IG2, IG3 and IG5)
- Remark: Please consider index drop* in your design
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Optical Lens and System Design

- Analysis of the optical task
- Conceptional design of the optical path
- Computer-based calculation of lenses and optical systems
- Simulation of optical systems and components
- Selection of suitable glass materials
- Design software: CODE V, OSLO Premium, ZEMAX, GLAD and LightTools
- IR components design capabilities
Coating experience

- Wide range of high quality coatings
- Coating of small optical components and micro optics
- Stable mass production
- High process reliability
- Temperature-stable and long lasting products
- High expertise in specification of coatings based on in-house capabilities and experience
- LWIR and MWIR coatings are sourced from external suppliers
Metrology

- Full set of standard measurement equipment for R+D and quality assurance in VIS-NIR
- Special equipment for IR
  - Decenter measurement equipment
  - Tactile and contact free measurement of surface parameters
  - Various types of interferometers
  - UA3P-5H tactile profilometer for lowest measurement forces
FISBA operates a new **UA3P-5H type profilometer** from Panasonic.

Specified accuracy (minimized Abbe-error):
- $\pm 0.05 \, \mu m / \pm 30^\circ$
- $\pm 0.08 \, \mu m / \pm 45^\circ$
- $\pm 0.15 \, \mu m / \pm 60^\circ$
- $\pm 0.15 \, \mu m / \pm 70^\circ$

Range of diameters
- 200 mm

Available stylus:
- 2 \, \mu m
- 500 \, \mu m

Available options:
- Decenter jig
MEASUREMENTS II: CONDITIONS FOR UA3P MEASUREMENTS

UA3P-5H is operated in the new building in a well adapted measurement environment:

- Humidity & Thermostatic at 22±0.5°C
- Temperature variation < 0.1°C/h
- Room cleanliness level < 15,000 (particle’s diameter < 5µm)
- Vibration acceleration criteria D1 (i.e. < .5-2cm/s²)
MEASUREMENT III: LAYOUT OF THE UA3P-5H MEASUREMENT TIP

⇒ No Scratch on glass optics, thanks to extremely small force

Z-axis measurement laser
Micro displacement detector
Semiconductor laser for focus servo
Mirror
Micro slider
Micro spring
Stylus
Measured object

75°

Measurement force: 0.15mN (15mgf)
MEASUREMENT IV: UA3P-5H MEASUREMENT WORKFLOW

Input design formula

Auto centering and measurement

Measurement Data

Data alignment

Result output
MEASUREMENT V: DECENTRATION ON ADVANCED OPTICS

Front to back decentration and alignment measurements of advanced optical surfaces such as aspherical or optical wafers are possible by using the available Decenter jig.
FISBA experience with PML in VIS and SWIR assemblies

- Application of precision molded aspheres in low weight, high aperture (F# 1.2) assemblies for aerospace applications
- Application of molded aspheres in imaging applications with limited space
- Application of molded aspheres in broadband assemblies from VIS to SWIR
Samples of IR components made by FISBA (I)

- Shape: Meniscus
- Diameter: 25 mm
- Center thickness: 2.75 mm
- Irregularity: 300 nm
- Cosmetics:
  60-40 (PER MIL-REF-13830B)
Samples of IR components made by FISBA (II)

- Shape: Meniscus
- Diameter: 25 mm
- Center thickness: 2.75 mm
- Irregularity: 300 nm
- Cosmetics: 60-40 (PER MIL-REF-13830B)

\[ \varphi(r) = \frac{1}{\lambda_0} \left( C_2 \cdot r^2 + C_4 \cdot r^4 \right) \]

Spherical
Radius 90.596 ±0.1%

Diffractive
\[ \lambda_0 = 10\mu m \]
\[ C_2 = -3.1563557E-4 \]
\[ C_4 = 0 \]
Step Height 5.662\mu m

<table>
<thead>
<tr>
<th>RING</th>
<th>ZONE RADIUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.629 ±0.05</td>
</tr>
<tr>
<td>2</td>
<td>7.960 ±0.05</td>
</tr>
<tr>
<td>3</td>
<td>9.749 ±0.05</td>
</tr>
<tr>
<td>4</td>
<td>11.257 ±0.05</td>
</tr>
</tbody>
</table>
Example of a FISBA hybrid design

- Hybrid design of a silicon sphere and a molded chalcogenide asphere
- Main advantages:
- Cost reduction because of cheap spherical silicon lens with a relatively small chalcogenide lens
- Color corrections based on the usage of two materials with a significant difference of the abbe number
- Disadvantage: limited transmission of the Silicon lens in the LWIR
- Promising concept in the MWIR
Current status and typical timeline for a project

- Full project capabilities for (refractive+diffractive) components according to design capabilities – Q3/2015
- Readiness for serial production – usually 4 months after completion and acceptance of prototypes
- Willing to take R+D projects with shared costs
Discussion / Questions