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ABSTRACT

The development of the ability to routinely "machine" glass materials to optical tolerances is highly desirable and, in particular, could provide new degrees of control over the precise shape of complex and unusual optical surfaces. Of particular interest in this regard is the formation of non-spherical shapes where there is a need to fabricate both inexpensive, low-precision optics as well as specialized high-precision aspheric components. This work describes the initial feasibility tests of the machining of a new type of glass, lead indium phosphate (LIP), a material which transmits from the visible to 2.8 μm (for thin samples). Glossy surfaces were produced with a root-mean-square surface roughness of less than 100 nm (with 200 μm filter). The results indicate that this approach offers the potential for producing high-quality aspheric optical shapes based on the use of LIP glass.

Keywords: optics fabrication, optical materials, asphere, lead indium phosphate

1.0 INTRODUCTION

There is interest in the capability to machine glass optical materials.¹ A greater degree of control over the precise shape and surface figure would provide greater design flexibility to these two important qualification parameters. The fabrication of high quality spherical shapes is simpler than for nonspherical shapes and there is consequently a need for both inexpensive, low-grade as well as high-precision aspheric optical fabrication methods. Single-point diamond turning for the latter purpose has received some attention.^{1,2,3} This report describes some feasibility tests of machining of lead indium phosphate glass. The results indicate that there is the potential that high quality aspheric shapes can be applied to this glass.

2.0 BACKGROUND

Brehm and Haisma¹ investigated the use of several types of cutting tools and as expected, the best results were obtained with a diamond tool. Of the glass types they investigated, a lead-iron glass gave the best results, yielding a root-mean-square (rms) surface roughness of 450 nm. This glass was not transparent. They obtained the best results when using a chlorinated paraffin as the lubricant since, evidently, an iron chloride (FeCl_3) results which decreases friction between the tool and the workpiece. They were only able to achieve transparent, non-matt surfaces by diamond-turning at high temperatures, near the softening point of the glass.

Schinker and Doell² describe a theoretical model backed by experimental results which indicate the

conditions under which successful machining may produce transparent and nearly stress-free surfaces. An enabling arrangement must be such that glass removal occurs by microshearing in a viscoelastic manner. A negative rake angle for the machine tool is suggested. When this occurs, there is localized melting and annealing as opposed to brittle shearing of glass microchips and crack propagation. The technical requirements to effect this are difficult to achieve.

It may be noted that a number of infrared optical materials can be diamond-turned.³ Some examples are germanium, zinc selenide, and cesium iodide.

3.0 MATERIAL PROPERTIES

A new glass system based on lead-indium-phosphate composition has been developed.^{4,5} The physical, chemical, and optical characteristics suggest that the material may be used to satisfy many types of electro-optic needs both in the visible and infrared. The material exhibits a high index-of-refraction (1.7-1.9), moderate dispersion (typical Abbe number about 30), wide transmission range (300 nm to 2800 nm), and high coefficient of thermal expansion (10 to $12 \times 10^{-6}/^{\circ}\text{C}$). The material is chemically durable and radiation resistant. This glass has been used recently in the fabrication of high numerical aperture ($\text{NA} \sim 0.9$) optical fibers, both plastic- and glass-clad types. Biconvex, plano convex, and rod lenses have been manufactured from the glass by the usual grinding and polishing method. Preliminary tests suggest that high quality optics may be produced by casting. This is rendered feasible by the low melt viscosity as well as low preparation temperature (about 800°C) of the material. The material dissolves rare-earths readily and this characteristic made possible the demonstration of a Pm^{3+} laser in a lead-indium phosphate host⁶. Since the thermal expansion coefficient essentially matches that of many metals, the material may be useful for applications requiring metal-to-glass bonds and seals. The fabrication of microlenses is under investigation as well as the production of aspheres.

4.0 RESULTS

The Nanoform 600 single-point diamond turning machine used for this effort can produce nanometer-smoothness and is described in reference 7. The specimens to be machined were disks cut from an LIP fiber optic preform (about 20 mm in diameter) using a diamond saw. A flat surface was roughed-in using a carbide tool. A parameter study was then performed with the following diamond tool rake angles and feed rates.

Table 1 Parameter Study

<u>Rake Angle (degrees)</u>	<u>Feed Rates (mm/min)</u>
0	0.5
-22.5	1
-30	2.5
-40	5
	10

Figure 1. Effect of feed rate.

The best results were obtained at -40° , a feed rate of 2.5 mm and 1200 rpm, the highest speed used. The lubricant was Cutwell 50. The best surfaces appeared glossy when viewed at a glancing angle. Examination of electron micrographs revealed voids (or pits). The density was greater near the center as opposed to the edge of the samples. Thus it appears that tangential cutting speed plays a role. Fewer voids are created at the higher speeds. Higher rotational speeds and moving the part so as to machine it off center may improve the process. An example machined piece is shown in Figure 1. In this example, the five different tool feed rates produced the different rings seen in the photo. The rake angle was -30° . The rms surface roughness generally increased from the rim (where it was about 200 nm) to center. At 2 mm from the center it was approximately 300 nm, in the central zone it rose to 800 nm. Figure 2 shows the best overall sample. It was cut twice with the diamond tool. For the final pass, the feed rate was constant, 2 mm per minute, the depth of cut was 5 microns, and the rake angle was -40° . The rms surface roughness ranged from 90 nm near the rim to 300 nm near the center (filter 200 microns). All measurements were made with a Dektak 8000. There was no ring structure that was observed as with Figure 1 owing to the constant feed rate.

In a final test, a concave surface was applied to a larger diameter specimen. A 180 mm radius-of-curvature was cut across a 54 mm diameter sample, yielding an F# of about 3.3. Visually the surface appears comparable to other samples. It may be noted that there was some tool wear. However, it was not catastrophic as might be the case if a more conventional glass material were used.

5.0 CONCLUSION

Figure 2. Best overall sample.

It appears that a surface of useful quality can be machined from the lead-indium phosphate glass. The overall conclusion then is that this material lends itself to netshaping and figuring. A buffing or post-polishing step would need to be added in order to produce an optical quality finish. Further study and development may improve on these results. As suggested by Brehm and Haisma¹, machining at higher temperatures and use of a chemically active lubricant could lead to improvement. We will be evaluating how this new capability may be useful for producing precision optical components.

6.0 ACKNOWLEDGEMENT

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