LIGO-T880059-00-R

Test of Optical Homogeneity of Thick SiO_2

§1 Introduction

This note describes a project to measure the magnitude and spatial distribution of optical inhomogeneity and the residual birefreingence in two specimens of fused silica. This information will be of use in the design of the LIGO cavities, and will help us to predict the extent to which interferometer contrast and recycling may be limited by the quality of the material available.

Our present knowledge of the optical homogeneity of thick fused silica is somewhat fuzzy. The glass manufacturers quote maximum index inhomogeneities of $\Delta n = 1 \times 10^{-6}$, but they give no information regarding the spatial distribution of the inhomogeneity. Discussion with experts in the field gives conflicting answers, with some maintaining that low spatial frequency inhomogeneity predominates and others stating that all spatial frequencies appear. Further, few people have extensive experience with thick glass blanks.

The two pieces of fused silica will be polished on their end faces. A Fizeau interferometer will be used to measure the refractive index inhomogeneity. If possible, a static measurement of the birefringence of the pieces will be made. If it is deemed necessary, it may be possible to measure the birefringence in the Fizeau interferometer.

§2 Index inhomogeneity and birefringence

Residual stress and compositional non-uniformity are the dominant sources of index inhomogeneity in glass. Fused silica is essentially pure SiO_2, so residual stress is the primary source of inhomogeneity. The stress develops during the annealing process.[1] At high temperatures, the glass blank is stress free. As it cools, temperature variations develop, and these temperature variations persist as the blank cools past the strain point. When the temperature eventually equalizes a strain pattern is formed which mirrors the temperature gradient pattern in the cooling blank. To the extent that the residual strain is non-isotropic, it also results in the residual birefringence of the glass. Glass which is annealed slowly will thus show less residual birefringence and index inhomogeneity.

The index inhomogeneity, Δn, is a measure of the average index fluctuation over the

---

[1] See M. Burka, *On the LIGO Receiver Mirrors,* 28 January 1988, unpublished.

thickness of the blank. If an optical wavefront traveling in the z-direction traverses a glass blank, then two points on the wavefront $P_1(x_1, y_1)$ and $P_2(x_2, y_2)$ traverse optical path lengths which differ by an amount $\Delta n(x_1, x_2, y_1, y_2) \times t$ where t is the thickness of the blank and $\Delta n(x_1, x_2, y_1, y_2)$ is the index difference between those two points, averaged over the thickness of the blank.

§3 The fused silica specimens

Two pieces of Corning Code 7940 Grade 0A fused silica have been obtained. They have been slowly annealed to reduce the intrinsic birefringence to a level of 1 nm/cm. This is the highest quality, most homogeneous glass available. One piece is 4.5 inches in diameter by 1.5 inch thick, and the other is 4.0 inches in diameter by 3.5 inches thick. The latter piece has a one inch hole through its center.

These pieces will be polished on their end faces to a surface quality of $\lambda/50$ (λ=6328 angstroms), with a 5-10 arc minute wedge and a scratch/dig specification of 80/50. The polishing is being done by Zygo Corporation, and the cost is $2400 per piece. The polishing order is currently making its way through the MIT purchasing office, and it is anticipated that the polishing will begin in early September, and that it will take eight to ten weeks.

§4 The Fizeau interferometer test

The fused silica specimens will be measured with a Zygo Mark IV Interferometer. The Zygo is a Fizeau interferometer. The position of the reference piece in the Mark IV is varied piezoelectrically, producing a modulated interference pattern which is imaged onto a CCD pixel array.[2] The useable area of the CCD array is 210 × 210 pixels, and the clear aperture which is mapped onto this array is variable from 1.7 cm to 10 cm square.

The purpose of the interferometer test is to measure the index inhomogeneity of the material by measuring the distortion of a plane wavefront as it traverses the material. This is done by placing the test piece between the Fizeau reference plate and a high quality reflector. To reduce systematic error, a calibration measurement is done without the test piece in place. Also, reflection measurements are done for each surface of the test piece so that figure error can be subtracted out.

---

[2] Moshe Schaham, *Precision optical wavefront measurement,* SPIE Vol. 306, 1981.

The specifics of the test setup remain to be decided. The conventional test utilizes two passes of the optical beam through the full aperture of the test piece, and this test will certainly be carried out. Also, some test will be done with the interferometer "zoomed in" on one or more small segments of the test piece in order to get information about the high spatial frequency inhomogeneities. Zygo has suggested that we may wish to do this measurement with the test piece in a high finesse cavity. The advantage is that the fringes are narrower, leading to increased accuracy. The disadvantage is that there are more reflections from the reference surfaces, leading to increased systematic error. These points will be studied more thoroughly in the coming weeks while the pieces are being polished.

§5 Anticipated resolution

§5.1 *Accuracy*

The overall accuracy claimed by Zygo for their interferometer is "better than $\lambda/50$." This includes all systematic errors from the calibration and surface subtraction measurements. The raw computational resolution is $\lambda/1024$. If we take the figure of $\lambda/50$ as a lower limit to the accuracy, then we can compute the index inhomogeneity resolution as

$$\Delta n = \frac{\lambda}{50} \times \frac{1}{2t}$$

where t is the thickness of the blank and the factor of 2 results from the double passage of the wavefront through the blank. Thus,

$$\begin{aligned}\Delta n &= \frac{6.3 \times 10^{-7}\ \mathrm{cm}}{t} \\ &= 7.1 \times 10^{-8}\end{aligned}$$

for the 3.5 inch thick blank. For the thinner blank, the resolution is $\Delta n = 1.7 \times 10^{-7}$.

§5.2 *Spatial resolution*

The Zygo Fizeau interferometer maps a four inch clear aperture onto an array of 210 by 210 pixels. Thus, there is about one pixel for each half-millimeter of clear aperture. At maximum zoom, the clear aperture is $\frac{2}{3}$ inch, and the pixel spacing is 8.1×10^{-2} millimeters.

§6 Birefringence

The normal way to test qualitatively for birefringence is to put the test blank between crossed polarizers. Any light that gets through is a result of birefringence in the material. This will probably be tried with our test blanks. However, it remains to be seen how well one can do with pieces this large, since a high quality polarizing sheet with a four inch clear aperture may be difficult to obtain.

If we decide that it is necessary, we can have Zygo modify one of their interferometers to measure the birefringence of our test blanks. Since it is a modification which they are reluctant to make, it has been decided to have just the index inhomogeneity measured first, and to decide whether to do the birefringence measurement on the basis of those results.

Since index inhomogeneity and residual birefringence are both related to residual thermal stresses, one expects them to show similar spatial distribution through the material.

Michael Burka
6 September 1988