TEST FOR LASER DISCS

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March 17, 1975

This Paper Was Prepared for Presentation at the Workshop on Optical Fabrication and Testing, San Mateo, CA March 14-15, 1975
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Tests used by the Lawrence Livermore Laboratory and its vendors for laser discs will be discussed giving special emphasis to test aspects which are unique or more difficult for discs. The tests are divided into those for dimensional and optical properties. Some unusual aspects of laser disc testing include high precision of refractive index homogeneity and edge profile which can be measured using special gages or coordinate measuring machines. Analysis of data and the precision of the measurement will be discussed. Some alternate methods of test are included.

*This work was performed under the auspices of the Energy Resources & Development Association.
I would like to describe the tests for laser discs which are currently being used by Lawrence Livermore Laboratory and some of its vendors, with special emphasis on tests which are unique or more difficult for discs. Testing is important to the vendor so he knows when his product is completed and to the purchaser so he knows if he has obtained what he specified.

The tests one would like to do can be divided into two sections: tests for dimensional properties and tests for optical properties. The dimensional properties are length, width, diameter, thickness, edge profile, edge chamfer, edge chips, parallelism and flatness. The optical properties are: wavefront distortion, surface quality of faces, bubbles, inclusions, striae, refractive index, refractive index homogeneity, strain, absorption and doping concentration, edge coating quality and damage threshold.

A laser disc at first glance looks like an ordinary glass window or flat, although purple in color and should be easy to test for the mentioned properties. However, there are some unique characteristics of laser discs that can make testing them a non-trivial matter. It's not difficult to tell if a round disc has the right diameter or rectangular disc the right length and width but what about an elliptical disc? How do you tell if its edge profile is correct to determine if it will fit into its holder? It is straightforward to measure the transmission of a coating on a flat if the piece isn't too big for the spectrophotometer, but what if the coating is on the edge of an elliptical disc and what about its damage threshold to flashlamp illumination? The refractive index homogeneity of a finished flat can be judged as one of the contributing factors
in a final wavefront distortion, but what if the refractive index homogeneity of an unfinished disc must be measured to a high precision to determine the disc's suitability for finishing? These are the types of problems that confront the inspector of laser discs.

I would like to discuss some answers to these problems that have proved feasible for Lawrence Livermore Lab and some of our vendors.

The measurement of edge profile is appropriate for discs which are not rectangular, where measurements of length and width are straightforward, or circular, where the diameter can be measured. The edge profile can be measured for an elliptical disc, for instance, by using a gage specially designed for this purpose. (See Fig. 1.) The gage is rectangular with an elliptical aperture a known amount larger than the desired disc size. The gage is used in the following manner. First, a master disc is centered in the gage using four dial indicators, which are then zeroed. Then the master disc is replaced by the disc to be tested and centered with the dial indicators. To make the actual measurement, a hole gage is run between the disc and the gage aperture and then measured with a micrometer.

Another method which is more accurate is the use of a coordinate measuring machine. A stylus is moved around the part. The stylus readings go into a small computer which already has stored the coordinates of a perfect part. The machine then prints out the nominal dimensions, actual dimensions, difference and amount out of tolerance for a specified number of points around the disc.

A third possible method is the use of templates as go, no-go gages. This procedure will tell if a part is in tolerance but if it is not, can't determine the amount out of tolerance or its position.
The transmission of a disc edge coating normally cannot be measured on the disc itself. A small witness piece of the same glass with the coating on it is usually needed. This witness piece is required to have undergone the same coating application and annealing cycles as the edge coated disc.

The witness piece is placed in a spectrophotometer to measure its transmission at the wavelengths of interest. Often the coatings are quite rough and scattering from this surface can be a problem. To eliminate scattering effects, the sample is immersed in a small cell with oil of a refractive index that matches the rough coating as closely as possible. The transmission losses due to the glass of the cell and the interface between the uncoated surface of the witness piece and the immersion oil can be compensated for by a double cell method or taken into account through calculation. The use of an oil that is well matched to the coating is very important.

The damage threshold of the edge coating to flashlamp illumination is also measured on a witness piece rather than on the disc itself. A testing apparatus has been developed which consists of a flashlamp bank fitted with a holder for several witness pieces. (See Fig. 2.) The pieces are placed in the holder such that light shines first on the uncoated surface, goes through the laser disc glass and finally into the edge coating material. The flashlamps are fired in a prescribed sequence at known voltages and the samples are checked periodically for damage. Failure due to single shots as well as cumulative failure due to many shots are investigated. The system is pulsed, not CW. Through calculation, knowing the geometry of the test setup and the characteristics of the damage tester, the system can be calibrated to relate voltage on the lamps to illumination on the sample in joules/cm². This calibration must be checked periodically as the lamps may change or deteriorate.
The finishing of laser discs is time consuming and costly, especially for large discs. Therefore, it is good practice to finish only those glass blanks which are of good quality. The refractive index homogeneity is usually the determining factor in the decision of whether or not to finish a given blank. Also, for the larger blanks, the refractive index homogeneity must be known to guide the optician in local hand correcting if this is necessary.

Therefore, it is necessary to have a method to test the refractive index homogeneity of a laser disc blank with as little surface polishing beforehand as possible. Several methods exist, the one chosen depending on the flatness of the discs, their size and the availability of equipment.

The first test is the oil-on-plate method. In this case, the effects of the non-flat surfaces of the disc are eliminated by oiling on good quality plates of known wavefront distortion onto the surfaces of the test disc with oil of refractive index matched to the test disc. The entire three piece sandwich is then optically approximately equivalent to one continuous piece of glass.

This sandwich is then tested in a Twyman-Green or Fizeau interferometer where only the internal defects in the test glass and the known good surfaces of the oil-on-plates participate. (See Fig. 3.) The accuracy of this method depends on the match of the refractive index of the oil and the disc and the flatness of the test disc. According to T. Izumitani and T. Yamashita of Hoya Glass Works, in order to keep the error introduced by the unpolished surfaces of the sample within a certain error, in this case, $0.3 \times 10^{-6}$ cm, the flatness and the index mismatch related in the following way must be less than this error:

$$4\Delta t \left| N_1 - N_g \right| \leq 0.3 \times 10^{-6} \text{ cm}$$
where Δt variation in oil thickness due to non-flatness of test block surface

\[ N_1 \] refractive index of oil

\[ N_2 \] refractive index of glass

This means, for a given error, if the refractive index match is improved, the requirement on the flatness of the disc faces can be relaxed. Of course, if a larger error for the test is allowable, fewer constraints need be placed on both the index match and the surface flatness. Therefore, polished surfaces are not needed for this test. However, oil-on-plates for large discs are difficult to acquire and awkward to use. The alternate solution of taking overlapping interferograms with small oil-on-plates covering only a part of the disc at a time can cause difficulties in interpretation. For large discs, other methods are better.

The conventional method for refractive index homogeneity has been the three interferogram method. The major attraction of this method is that no immersion tank or oil-on-plates are necessary. In this case, the effects of the surfaces of the disc must be eliminated mathematically by manipulating the results of three separate interferograms. First, an interferogram is taken of the disc in transmission; second, one is taken of the interference pattern formed between the front and back surfaces of the disc when the interferometer mirrors are covered. The third taken is an interferogram of the interferometer with the sample removed. This method is quite amenable to high speed computers, once the interferograms are digitized. This equipment is not mandatory, but the data reduction would be quite difficult without it. In the other methods, the single interferogram for each disc can be read directly in terms of the wavefront error, this is not true for the three interferogram method.
In the three interferogram method, the surfaces of the sample must be polished as no wringing-on-plate or immersion tank is used to eliminate the surface effects. The flatness of the surfaces does affect the precision to which the inhomogeneity within the glass of the disc can be measured. The distortions of interferogram fringes are caused by differences in path length due to inhomogeneity and to thickness variations. If the thickness variations are too large, they will completely mask the effects of the inhomogeneity.

Eric Roberts of Perkin Elmer has studied the effects of thickness variations and refractive index inhomogeneities and the interferograms themselves to determine the flatness necessary in the sample for a particular level of precision in the measurement of homogeneity. I will only summarize his results based on investigation of three cases: very flat surfaces, in-between surfaces and very poor surfaces. Using a signal to noise ratio of one and an interferogram error of \( \alpha \) of 0.05 to 1.0 times the peak to valley optical path difference:

\[
P_{\Delta t} \sim 10 t P_{\Delta n}
\]

where \( P_{\Delta t} \) is the error due to differences in thickness

\( P_{\Delta n} \) is the error due to differences in refractive index

\( t \) is the thickness of the disc

This means that the disc thickness variation must be no worse than ten times the OPD effect of inhomogeneity variation in order to detect the inhomogeneity.

If \( \alpha \), the interferogram error could be reduced, the surface flatness requirement could be reduced in direct proportion. Some reduction in \( \alpha \) is possible if more interferograms are taken and averaged. Especially for large discs, it is
more economical to take additional interferograms than to attempt to rework the disc to get it flatter.

This discussion suggests the following course of action to minimize the polishing costs for conventional homogeneity analysis.

1. Decide how bad the material is likely to be, and the window's thickness, and from that, the value of thickness times peak inhomogeneity \( tP_{\Delta n} \), in waves which must be detectable.

2. Polish the window until either:
   (a) the Fizeau picture is obviously no longer following the pattern of the transmission picture by the factor \( n/(n-1) \) ( = about 3).
   (b) the combined surface flatness \( P_{\Delta t} \) is less than about 6 \( (tP_{\Delta n})/(n(n-1)) \) ( = about 10. \( tP_{\Delta n} \)).

   This is equivalent to requiring the Fizeau picture to be less than 5 . \( tP_{\Delta n} \).

By stopping when either (a) or (b) occurs, that value of inhomogeneity \( tP_{\Delta n} \) should be just detectable. Once detected, to go further and obtain a meaningful mean of \( \Delta n \) over the window's area, further polishing must be done until (a) occurs, or until one of the interferograms is as good as one can afford.

The third method for measuring the refractive index homogeneity uses an immersion tank to eliminate the effects of the unpolished surfaces of a laser disc blank. A modified Fizeau interferometer is constructed with an immersion tank incorporated into it. The reference flat becomes the bottom of the immersion tank and the surface of the liquid is the other surface of the Fizeau cavity. The disc is suspended in the tank which is filled with an index matching oil. (See Fig. 4.)
Discs with fine ground surfaces can now be measured, the oil serving to eliminate effects of the surfaces. The interferograms can be read directly to determine the wavefront distortion due to the internal glass quality. (See Fig. 5.)

As in the other methods, the flatness required on the disc surfaces is dependent on the precision of the match of the index oil and the glass and the accuracy required in the measurement. Unlike the three interferogram method, ground surfaces can be used. According to Al Brodbeck of Fecker Systems, surface flatness and index mismatch can be related to the optical path length difference or error allowed; for an OPD of $\lambda/20$.

$$2\Delta\alpha n \leq \text{OPD}$$
$$2\Delta\alpha n \leq \lambda/70$$
$$2\Delta\alpha n \leq 0.03 \times 10^{-6} \text{m}$$

The three methods for refractive index homogeneity all require interpretation of interferograms either manually or by computer. It is important to keep in mind the type of interferometer used as it directly determines the interferogram's relation to the item being tested. The terms double pass and single pass wavefront distortion must be clearly understood in specifying the disc's performance and in evaluating it. If the vendor and the purchaser use the same terms to mean different things or one uses one term and the other another, problems can result. Interferogram analysis should be carefully done and not taken for granted. Efforts should be made also to take clear interferograms of sufficient size to allow easy, accurate reading. The interferogram may be the only record of a test; if it is illegible, the information content is lost.
I have described briefly a few of the tests that are being used at the Lawrence Livermore Laboratory and by its vendors to evaluate laser discs. There are probably other methods for solving some of these problems. Perhaps they can be discussed during the panel. The tests we use will soon be issued as a laboratory standard test specification. Testing according to this specification will be required by our vendors to show compliance with our disc specifications. The document does contain alternate methods of test for some properties and includes tests for finished and unfinished discs. There is less confusion and misunderstanding on the part of the vendor and the purchaser if the test methods are written down formally and approved by both sides at the time of initial letting of the contract.

Distribution:

TID, L-9 (15)
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References


Edge profile measurement (Gauge method)

Figure 1
Gloss sample

Reflector shield with cutouts for sample

Lucite lamp holder

Flashlamps

Aluminum base

Edge coating damage tester

Figure 2
Figure 3

REFRACTIVE INDEX HOMOGENEITY INTERFEROGRAM - B DISC
Figure 4