**Polishing Procedure and Surface Characterization
Lead Tungstate Crystal Scintillator Rod #723 and #754**

**Marcia Kellam
MMED Optics Group**

May 1, 1996

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ng

MASTER

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor the University of California nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or the University of California, and shall not be used for advertising or product endorsement purposes.

This report has been reproduced
directly from the best available copy.

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from the
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Rd.,
Springfield, VA 22161

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

Lead Tungstate Crystal Scintillator Rod #723
Pad Polished by Hand
96-022
May 1, 1996

The tapered four sided rod was hand ground to remove scratches and deep pits existing in the surfaces as received. There was also extensive chip damage that was too severe to grind out without removing more than 1mm of material per side. Some of this damage still remains.

Using a grooved 30cm diameter pyrex glass lap mounted on a Strasbaugh spindle polishing machine, the sides were hand ground using 9 micron aluminum oxide abrasive. Mixed in with the abrasive was water, a suspension agent and a few drops of Ivory soap. With rod in hand, grinding was done using hand strokes across the glass lap on one of the sides of the rod. After 25 strokes the rod was rotated end for end (180 degrees) and another 25 strokes were applied on this same side. Once these first 50 strokes were done, the lap was rotated 90 degrees to a fresh area and the two previous 25 stroke steps were repeated. Having applied 100 strokes to the first side of the rod, a visual eye loop inspection was done to see if the large scratches and pits were gone. The 100 stroke process was repeated if any damage remained on the surface. When the rod looked clear of damage it was rotated to another side to repeat the 100 stroke process. The surface looked gray at this point from grinding. It took 45 minutes to grind out each side of the rod.

The rod was then pad polished by hand using the same Strasbaugh machine as in the grinding. A 30cm diameter Buehler Tex Met 1000 pad with adhesive backing was bonded to a glass plate that was 6 to 7 waves convex. The polishing medium used was 2 micron opaline (cerium oxide). The pad polishing method used was identical to the previously mentioned 9 micron grind process. Pad polishing removed the gray surface left from grinding and most scratches or pits visible by eye. This rod was pad polished using same setup as crystal #754 to save time and materials. Pad polishing took approximately 45 minutes per side to finish.

Over the length of the rod, the central 8 to 10cm area was nominally flat and scratch free. However due to the large length to width aspect ratio the rod remained 8 to 10 fringes convex over the entire length with steep roll off at the edges. This was measured using a test plate. The metrology data taken before and after polishing this crystal is recorded in the traveler.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Lead Tungstate Crystal Scintillator Rod #754
Fine-Polished on Continuous Planetary Lap
96-020
May 1, 1996

The tapered four sided rod was hand ground to remove scratches and deep pits existing in the surfaces as received. There was also extensive chip damage that was too severe to grind out without removing more than 1mm of material per side. Some of this damage still remains.

Using a grooved 30cm diameter pyrex glass lap mounted on a Strasbaugh spindle polishing machine, the sides were hand ground using 9 micron aluminum oxide abrasive. Mixed in with the abrasive was water, a suspension agent and a few drops of Ivory soap. With rod in hand, grinding was done using hand strokes across the glass lap on one of the sides of the rod. After 25 strokes the rod was rotated end for end (180 degrees) and another 25 strokes were applied on this same side. Once these first 50 strokes were done, the lap was rotated 90 degrees to a fresh area and the two previous 25 stroke steps were repeated. Having applied 100 strokes to the first side of the rod, a visual eye loop inspection was done to see if the large scratches and pits were gone. The 100 stroke process was repeated if any damage remained on the surface. When the rod looked clear of damage it was rotated to another side to repeat the 100 stroke process. The surface looked gray at this point from grinding. It took 45 minutes to grind out each side of the rod.

The rod was then pad polished by hand using the same Strasbaugh machine as in the grinding. A 30cm diameter Buehler Tex Met 1000 pad with adhesive backing was bonded to a glass plate that was 6 to 7 waves convex. The polishing medium used was 2 micron opaline (cerium oxide). The pad polishing method used was identical to the previously mentioned 9 micron grind process. Pad polishing removed the gray surface left from grinding and most scratches or pits visible by eye. This rod was pad polished using same setup as crystal #723 to save time and materials. Pad polishing took approximately 45 minutes per side to finish.

In addition to pad polishing, hand polishing on a pitch lap was attempted on sides 1, 2 and 3 of this rod (#754). Pitch lap polishing uses a lap made of #55 gugolz pitch and 2 micron opaline as the polishing medium. The pitch lap was mounted on the same Strasbaugh machine rotating the lap at 30 revolutions per minute (rpm). The crystal rod was hand held applying enough pressure to establish good crystal surface to pitch lap contact, stopping regularly to re-grip the rod and add opaline. The surface scratches and pits decreased from the pad polishing method but the flatness figure remained 8 to 10 fringes convex over the entire length. This was measured using a test plate. After several hours of hand pitch polishing, it was concluded that this was an unsuccessful method to improve the crystal quality in a timely manner.

Final polishing was done on a 122cm diameter continuous planetary (CP) lap. Under normal circumstances the pad and pitch lap polishing step would be skipped and the CP final polishing would immediately follow the 9 micron grinding. The polishing table surface is a #82 gugolz pitch that rotates counter clockwise at 3 rpm. The 40cm diameter septum that rotates the crystal also runs counter clockwise at 3 rpm. The polishing medium is 1.3 micron Rhodes Hastilite Rare Earth Polish mixed with water. Weight used on the crystal during polishing was 4 kg. Run time for each side averaged 3.8 hours. Side #2 didn't polish-out on one of the corners of each end due to time constraints on the machine schedule. These areas are approximately 12.5mm in length and 4 mm wide. The metrology data taken before and after polishing this crystal is recorded in the traveler.

Surface Characterization

Lead Tungstate Crystal Scintillator Rods #723 and #754

Methods

- Microphotography Phase interference contrast photographs were taken with a Leitz Aristomet microscope, using a Nomarski phase contrast attachment at magnifications of 200X and 500X. Interference contrast microscopes examine surface details that are difficult to see with an ordinary microscope. Since the surface has only small differences in height and reflectivity, high intensity light sources are required when photographing background texture and surface defects.
- Profilometry Surface profile measurements were made with the WYKO profilometer using an objective with 20X magnification. This profiler is a non-contact, phase measuring instrument with a Mirau interferometer built into the objective. It uses a 633 nm filtered light source to illuminate both the test surface and a .1 nm flatness reference mirror. The resulting interference pattern is displayed onto a 1024 element linear detector array where light intensity changes are digitized, allowing the computer to quantify surface height deviations.

Linear scans of 660 microns are analyzed by the computer and are used to produce a graphical display of the surface profile and to calculate the RMS roughness and peak-to-valley values. Several scans at random locations were used to characterize each part.
- Interferometry The ZYGO Mark IVxp Interferometer, a Fizeau design with a measuring wavelength of 633 nm, was used for surface figure measurements. A phase measuring technique with computer analysis is used to resolve complex fringe patterns. The fringe pattern is modulated and detected by a 100 x 100 diode array camera, using a dynamic phase measurement method. In this technique, the interference pattern produced by the recombination of the reference and test wave fronts is modulated by a transducer, producing varying light intensities. The phase difference between the two optical wave fronts is measured at each element of the detector and analyzed by the computer to give the RMS roughness, peak-to-valley statistics and a three dimensional graphic.
- Macrophotography Macrophotographs of the crystals were taken with the Polaroid MPA4 enlarger, while being illuminated by a high intensity lamp.

Surface characterization was done pre and post polishing at the LLNL Optics Shop.

PbW04 Crystal #723

Pre-polish at LLNL

- Microphotography Microphotography of the long side surfaces showed large and numerous scratches. These appear to be caused by the polishing method done prior to arrival at LLNL. Microphotography of the two end faces was not done due to the relatively short neck of the microscope.
- Profilometry Surface profiles taken at random locations on the long sides of the crystal revealed RMS values ranging from 3.0 nm to 6.1 nm. These variations in surface roughness were a result of the varying scratch sizes that were apparent in the microscopy photographs. Since the scan length size is only 660 microns, it is possible to measure an area of the surface that is between or clean of scratches as well as over a scratch. The average RMS value for all four sides was 4.0 nm with an average Peak to Valley (PV) of 20.0 nm.

The two end faces of the crystal showed RMS values of 3.0 nm to 4.6 nm and PV values of 13.0 nm to 20.0 nm.

- Interferometry Wavefront analysis was limited to a small area of each long side due to the extreme convexity of the surface. The area shown in the interferogram is approximately 37 mm to 50 mm of the entire surface, approximately 211 mm, located near the center of the part. The PV values stated, represent only the area that the interferometer could measure intensity changes, not the entire surface of the side. The end faces of the crystal showed surface figure errors of 6.7 waves on the smaller end and 3.9 waves on the larger end, both convex.
- Macrophotography Photographs were taken of each side of the crystal. Large surface scratches were apparent as well as chipped corners and edges.

Post-polish at LLNL

Ground and hand pad polished

- Microphotography Microscopy photographs revealed a very sleeked surface with large bumps and pits. The surface scratches that were visible before LLNL polishing have been removed. The curved shape of the bumps would explain the more rounded profile peaks that were analyzed post-polish, as compared to those of the highly scratched surfaces, with spiked peaks, measured prior to LLNL polishing.

- Profilometry Surface profile values averaged 4.0 nm RMS and 24.0 nm PV. This is only a slight change in the surface roughness compared to pre-polish measurements that were previously made. However, the shape of the profile peaks has become more rounded.
- Interferometry Wave front measurements taken on sides 1 and 3 revealed a still very convex surface. A larger area was visible than at pre-polish, but the entire surface could not be seen. These values represent only the area that the interferometer could read, not the entire surface figure. Interferometric measurements were not possible at all on sides 2 and 4, but video photos of the convex surface figures are included.
- Macrophotography The photographs show the removal of the large scratches and most of the chips that were previously found on the crystal surfaces and edges.

PbW04 Crystal #754

Pre-polish at LLNL

- Microphotography The long sides of the crystal showed large and numerous scratches. There were also some extremely large pits that were probably caused during polishing or handling. Overall, the surfaces appeared to have a better polish than crystal #723.
- Profilometry Surface profile RMS values averaged 3.5 nm, with an average PV reading of 17.0 nm. The end faces had RMS values ranging from 3.5 nm to 4.2 nm and PV roughness' of 13.5 nm to 20.0 nm. The surfaces of this crystal appeared to be smoother, with smaller and fewer scratches.
- Interferometry No interferometric data was attainable on the long sides of this crystal do to extreme surface figure irregularity of the 214 mm surfaces. Video photos are included to show the poor surface figure. The end faces were measurable, showing surface figures of 5.5 waves to 6.5 waves.
- Macrophotography Photographs show surfaces free from large scratches and only occasional chips on the edges.

Post-polish at LLNL

Ground, hand pad polished, hand pitch polished (except side 4)

- Microphotography Microphotography showed that the majority of the larger scratches had been removed. Most of the large bumps and pits that were apparent after the hand pad polish had decreased in size and frequency. Side 4 was not hand pitch polished, however, and still showed the large bumps and pits from the previous polish.

No other tests were performed on the crystal at this time.

Ground, hand pad polished, hand pitch polished, continuous planetary lap polished(CP Lap)

- Microphotography Side 1 was inspected after 1.5 hours, 3 hours and 5 hours of polishing on the CP lap. After 1.5 hours, most large surface defects had been removed and the majority of the large scratches were eliminated. After 3 hours, small surface defects reappeared, but no new scratches were visible. Additional weight was added at this point for quicker material removal. After 5 hours, the small surface defects were removed, however, surface scratches remained.

Side 2 was viewed after 3 hours of CP lap polishing. Small surface defects were removed, but again, the surface showed many scratches.

Side 3 was photographed after 2.25 hours and 4.25 hours. At 2.25 hours, the surface still had some small defects and light scratching. After 4.25 hours, only an occasional defect was visible, but light scratching was apparent.

Side 4, after 3 hours of CP lap polishing, showed only occasional defects, but scratching over the entire surface, similar to the other 3 sides.

- Profilometry Profile scans done on the long sides showed average RMS values of .8 nm, with a PV average of 4.7 nm. Surface roughness improved by better than 70%. Side 3 had the smoothest surface, averaging .6 nm RMS and an average PV of 3.6 nm. This was due to a better polishing fit to the CP lap.

- Interferometry Wave front analysis showed tremendous figure improvement on all long sides. All surfaces were concave, with wave front figures of 2.5 waves to 5.0 waves. Full surface area was interferometrically measurable on sides 1, 3 and 4. Side 2 had a small under polished area at each end, approximately 12.5 mm in length and 4.0 mm wide. These areas are visible as gray or shaded spots on the interferogram provided in the data analysis folder. Due to time constraints, side 2 did not receive enough polishing time on the CP lap to obtain full surface interferometric analysis. However, the results stated are considered to be a valid representation of the surface figure.

- Macrophotography Photographs taken show surfaces free from large scratches. Some chips still remain on the ends and edges.

Conclusion

The grinding and hand pad polishing done on crystal #723 produced only minimal changes to the surface. The microscope photographs show sleeked surfaces with large pits and bumps. These defects were probably a

result of sub-surface damage caused by previous polishing methods or induced by the grinding process. As layers of material were removed, these defects were revealed. This is not an uncommon occurrence after a grinding or polishing process. The hand pad polishing process smoothed the sharp peaks and removed most of the scratches. The profilometry results show that the surface had only slight overall roughness changes compared to the pre-polishing results, but with wider, more rounded peaks than were seen in the pre-hand polished stage.

The surface figure on crystal #723 showed slight improvement after the hand pad polishing process. A larger convex area, but not the entire surface, was visible, but not measurable. At this point, all polishing processes were stopped on crystal #723.

Crystal #754 received an additional hand pitch polish, following the hand pad polish. This process removed most of the large pits that were remaining after the hand pad polish. When checked with an optical test plate, the surface figure showed only slight improvement. Side 4 of crystal #754, received no hand pitch polishing. Microscopy revealed a surface with large pits, similar to the surfaces of crystal #723 after hand pad polishing.

An additional polish on a continuous planetary lap (CP lap) was done on all 4 sides of crystal #754. The CP lap polishing removed any evidence of the large pits and bumps, and improved the surface figure on all sides. Side 4 showed the same surface improvement that was noted on sides 1, 2 and 3, without receiving the additional hand pitch polish process prior to CP lap polishing.

The length of time polished on the CP lap appears to have had the largest effect on the surface roughness and figure improvement. Characterization of side 3 of crystal #754 showed the smoothest surface, best surface figure, and few or no defects, after a polishing time of 4.25 hours on the CP lap. Sides 2 and 4, receiving only 3 hours of CP polishing, showed surface roughness and figures slightly worse than side 3. A few small defects were still present through microscopy. This would imply that additional polishing is necessary to improve the surface quality.

Side 1 of crystal #754 had surface characterizations similar to those of sides 2 and 4, after a total of 5 hours of CP lap polishing. However, side 1 is unique from the other sides in its CP polishing process. Weight was increased incrementally during the first 3 hours of CP polishing until 4 kg had been added. It was then polished for an additional 2 hours. The additional weight aided in the removal of material more efficiently. The amount of weight added was based on past polishing experience on the CP lap, in the polishing other optical glasses. It is not conclusive if this is the optimum weight for PbWO₄ crystals of this shape and size. This information should be considered when comparing polishing time for analysis.

Based upon the data analysis provided, one can conclude that the best surface figure and smoothest surface finish on crystals such as those measured in this report, can be achieved after polishing for approximately 4 hours on the CP lap. Additionally, the interim step of hand pitch polishing

was found to be of little value to the improvement of the crystal surfaces, if a CP lap polish is to follow.

Crystal Dimensions pre/post polishing at LLNL

Crystal dimensions were taken with a Mitutoyo Digital caliper. The measurement location was at each end, as close to the end face as possible. Please note that no grinding or polishing was done to the end faces of the crystals, so the overall length of each crystal was not altered.

Crystal #723

03/07/96

Pre-polish by LLNL

Sides 1-3 17.70 mm 20.54 mm

Sides 2-4 17.17 mm 20.04 mm

04/04/96

Post-polish by LLNL

Sides 1-3 17.67 mm 20.33 mm

Sides 2-4 17.13 mm 19.81 mm

Length 211.60 mm

Crystal #754

03/07/96

Pre-polish by LLNL

Sides 1-3 18.08 mm 20.74 mm

Sides 2-4 17.86 mm 20.98 mm

04/16/96

Post-polish by LLNL

Sides 1-3 17.99 mm 20.53 mm

Sides 2-4 17.67 mm 20.71 mm

Length 214.73 mm

Comments and recommendations

- Cleaning Deionized water was used to rinse off the polishing compound between each of the polishing steps. No water staining was visible to the eye.

Final cleaning prior to surface characterization was done with several different products. We found that both Acetone and Iso-propyl alcohol left a reddish-brown residue on the surface, that was visible under the microscope. The surfaces were wiped with either lintless lens cleaning paper or Kaydry EX-L, Extra Low-Lint Wipers, saturated with one of these solutions. This is a commonly used practice in optical cleaning. The Acetone left a slightly heavier residue than the alcohol. When the surface was "fogged" with mouth vapor and wiped with one of the above tissues, this residue was removed. The third solution used for cleaning was Micro, a product manufactured by Cole-Parmer Instrument Company for cleaning optical surfaces. This also left a slight residue that was removable by fogging and wiping the surface with a tissue.

We were unable to deduct why this residue remained on the surface after cleaning or why it was reddish-brown in color. More testing will be required to make conclusions regarding this finding.

- Edges We recommend that radiused, polished edges are used instead of bevels on the crystals. Since the crystal material is so soft, it chips and scratches easily. A bevel leaves angled, sharp edges on the part, consequently allowing a greater potential for chipping and scratching. Small fragments of crystal were found in the packaging tissue during handling, which caused the large scratches that are now present on the surfaces. This probably occurred with only a minimal bump to the edge of the crystal. Radiused edges would reduce damage potential tremendously.

- Crystal clarity Transmission through the crystal, end to end, was poor. Poor end face surface quality from under polishing was evident on both crystals. This was visible by eye, as well as interferometrically. The end faces of both crystals were convex and unparallel, which will heavily influence the quality of transmission.

When viewing an object several feet away through the crystal, the image appeared blurry. This could be due to poor end face surface quality, crystalline structure quality, or the combination of both. A cloudiness was also noted in both crystals, more in crystal #723. This is probably related to the crystal structure itself, not surface finish quality.

- CP Lap There are still many sleeks or scratches left on the surfaces of crystal #754 after CP lap polishing. They are small in size, but large in number. We believe these were caused by the hardness of the pitch used on the lap and the width of the groove pattern. Pitch and groove selection should be further investigated to find the optimum pitch hardness and pattern to compliment the crystal shape and structure.

PbWO₄ Crystal #754

- **Polishing Process and Procedures**
- **Surface Characterization Analysis**

MMED - OPTICS
INSPECTION TRAVELER

Part Number PW025 PW004 (#754)

Surface Characterization

Equipment:

Profilers:

WYKO Profiler
OHP Profiler
Federal Surf analyzer

Documentation Req'd

Date Completed

☒

3/12/96 mk

Wavefront/transmission:

ZYGO Interferometer
TG Interferometer

☒

3/19/96 mk

Microscopy:

Reichert:
Mag. 90 179 500 840
Leitz
Mag. 50..100. 200 500.1000
Enlargements
Mag. ✓

☒
☒

3/18/96 mk
3/14/96 mk

Stress/structure:

Polariscope

COMMENTS: POOR TRANSMISSION THROUGH PART

Pre-Polish Surface Characterization

Microphotography

2E-POLISH 754

PRE-POLISH 754

7551

200x

3/15/76

PW07551

500x

3/15/76

SSI 500x 3/15/96

PWOSI 3/15/96 500x

PWC75S2 200x 3/15/96

PWC75S2 200x 3/15/96

E POLISH #754

PRE-POLISH #754

PWC75S3 50x 3/15/96

PWC75S3 200x 3/15/96

DW075S3 500x 3/15/96

DW075S3 500x 3/15/96

DW075S3 500x 3/15/96

Polatoid F8E37A55592A

PWC 75 S4 200x 3/18/96

PWC 75 S4 200x 3/18/96

26-PC-15M -# 754

00-75S4 200x 3/18/96

PRE-PC-15M -# 754

PWC 75 S4 200x 3/18/96

W0075S4 200x 3/15/96

PW075S4 500x 3/18/96

ISH # 754

W0075S4 200x 3/15/96

PRE-POLISH # 754

PW075S4 500x 3/15/96

Profilometry

754
Ph

PWOS1
75

Time: 21:11

Date: 3/12/96

RMS: 3.83nm

PROFILE

PV: 17.6nm

RA: 3.14nm

RC: 6417 mm

Distance on Surface in Microns (20.0X)

PWQ51

Time: 21:10

Date: 3/12/96

RMS: 2.36nm

PV: 13.3nm

RA: 1.93nm

RC: 16.5 m

PROFILE

Distance on Surface in Microns (20.0X)

#1111 P0

PWOS1₇₅

Time: 21:12

Date: 3/12/96

RMS: 3.34nm

PV: 16.4nm

RA: 2.70nm

RC: -199 m

PROFILE

Distance on Surface in Microns (20.0X)

PW075S2

Time: 21:04

Date: 3/12/96

RMS: 3.71nm

PROFILE

PV: 16.6nm

RA: 3.01nm

RC: 6709 nm

#7

PW075S2SMEND

Time: 21:05

Date: 3/12/96

RMS: 3.31nm

PROFILE

PV: 15.7nm

RA: 2.75nm

RC: 11.6 m

PW07552

Time: 21:08

Date: 3/12/96

RMS: 2.90nm

PV: 13.6nm

RA: 2.44nm

RC: -13.2 m

PROFILE

8.0

Nanometers

Distance on Surface in Microns (20.0X)

PW053
75

Time: 21:15

Date: 3/12/96

RMS: 2.23nm

PROFILE

PV: 10.2nm

RA: 1.82nm

RC: 22.3 m

PWOS3
75

Time: 21:15

Date: 3/12/96

RMS: 3.69nm

PV: 20.6nm

RA: 2.94nm

RC: -21.8 m

13.2

Nanometers

6.6

0.0

-6.6

-13.2

Distance on Surface in Microns (20.0X)

PW053
75

Time: 21:13

Date: 3/12/96

RMS: 3.57nm

PROFILE

PV: 17.8nm

RA: 2.84nm

RC: 54.1 m

Distance on Surface in Microns (20.0X)

PW054

Time: 21:19

Date: 3/12/96

RMS: 4.15nm

PROFILE

PV: 22.6nm

RA: 3.32nm

RC: 409 m

PWOS4
75

Time: 21:20

Date: 3/12/96

RMS: 5.12nm

PROFILE

PV: 26.7nm

RA: 4.06nm

RC: -2175 mm

#7.

PWQ54
15

Time: 21:17

Date: 3/12/96

RMS: 3.44nm

PV: 16.0nm

RA: 2.63nm

RC: 13.6 m

PROFILE

9.3

Nanometers

Distance on Surface in Microns (20.0X)

#1

PW054
15

Time: 21:17

Date: 3/12/96

RMS: 3.44nm

PROFILE

PV: 16.0nm

RA: 2.63nm

RC: 13.6 m

PW075LGEND

Time: 22:46

Date: 3/12/96

RMS: 3.58nm

PROFILE

PV: 15.6nm

RA: 2.79nm

RC: -8891 mm

8.8

Nanometers

PW075LGEND

Time: 22:44

Date: 3/12/96

RMS: 2.94nm

PV: 13.4nm

RA: 2.28nm

RC: 65.7 m

PROFILE

Distance on Surface in Microns (20.0X)

PW075SNEND

Time: 22:41

Date: 3/12/96

RMS: 3.80nm

PROFILE

PV: 20.1nm

RA: 2.92nm

RC: 10.6 m

10.7

Distance on Surface in Microns (20.0X)

788
FA

PW075SNEND

Time: 22:43

Date: 3/12/96

RMS: 4.17nm

PROFILE

PV: 22.8nm

RA: 3.35nm

RC: 6451 mm

12.3

Nanometers

6.1

0.0

-6.1

-12.3

0

132

264

396

528

660

Distance on Surface in Microns (20.0X)

Interferometry

#7.
P.
A.

zygo

Sm Aperture

Measure Ctrl

Analyze Ctrl

Analyze Attr

Process

Profile

Reprocess

Mask Data

Save Data

Load Data

Calibrate

Reset

zygo

Phase Map

Filled Plot

Oblique Plot

PV 6.346 wave

RMS 1.190 wave

Filter: Off

Filter Type:

Trimmed: 2

Removed: PST TLT

Save Data

Input

RMS 1.190 wave

0.8mm 0.1996

Clear

zygo

Intensity

PV 6.346 wave

RMS 1.190 wave

0.8mm 0.1996

Clear

zygo

Intensity

Time: Tue Mar 19 09:08:50 1996

0632.8mm

F40751gend

F40751 sm end

LOG ENDS

Macrophotography

PW075 S1

3/14/96

PW075 S2

3/15/96

POLISH # 754

0075 S3

3/14/96

PDE-POLISH # 754

PW075 S4

3/15/96

PW0 75

3/14/96

PW0 75

3/14/96

Post-Polish Surface Characterization

MMED - OPTICS
INSPECTION TRAVELER

754

Part Number 66075 4/10/96

Surface Characterization

Equipment:

Profilers:

WYKO Profiler
OHP Profiler
Federal Surf analyzer

Documentation Req'd

Date Completed

✓

4/16/96

Wavefront/transmission:

ZYGO Interferometer
TG Interferometer

✓

4/11/96 nik

Microscopy:

Reichert:

Mag. 90 179 500 840

Leitz

Mag. 50..100..200..500..1000

Enlargements

Mag. ✓-----

✓

4/3/96, 4/11/96 nik.

✓

4/16/96 nik.

Stress/structure:

Polariscope

COMMENTS:

PO. 1 - POLISH DATA

**Ground/Hand Pad Polish/
Hand Pitch Polish**

Microphotography

754 S1 200x Pol. 4/3/96

HAND DITCH POLISH

754 S1 500x Pol. 4/3/96

754 S1 200x Pol. 4/3/96

HAND DITCH POLISH

754 S1 200x Pol. 4/3

75452 200X R1 4/3/95

75452 200X R1 4/3/95

Polaroid 85555030

75452 200X R1 4/3/95

75452 200X R1 4/3/95

754S3

4/3/96

200x

H.R.T. Pol

754S3

Pol 200x

4/3/96

HAND PITCH POLISH

HAND PITCH POLISH

754S3

500x Pol

4/3/96

754S3

500x Pol

4/3/96

73454 200x
NO Pitch - 4/1/96
HAWSPAS FOR.

Profilometry

754S3

4/3/96

200x

H.A.T. Pol

754S3

Pol 200x

4/3/96

HAND PITCH POLISH

HAND PITCH POLISH

754S3

500x Pol

4/3/96

754S3

500x Pol

4/3/96

754 S4 200x
 NO Pitch - 4/3/96
 HANDS PAZ.

754 S4 200x Pol 4/3/96

Polaroid E50637A55503C

NO PITCH
 S4
 LAP

NO HAND PITCH POLISH

754 S4 500x Pol. 4/3/96

**Ground/Hand Pad Polish/
Hand Pitch Polish/CP Polish**

Profilometry

754S1

Time: 10:27

Date: 4/16/96

RMS: 0.697nm

PV: 4.37nm

RA: 0.555nm

RC: 23.4 m

PROFILE

Distance on Surface in Microns (20.0X)

47

75451

Time: 10:29

Date: 4/16/96

RMS: 0.755nm

PV: 4.41nm

RA: 0.592nm

RC: 6837 mm

PROFILE

Distance on Surface in Microns (20.0X)

C
A

15.151

Time: 10:26

Date: 4/16/96

RMS: 0.890nm

PROFILE

PV: 4.92nm

RA: 0.702nm

RC: 34.6 m

2.6

Distance on Surface in Microns (20.0X)

754S1

Time: 10:27

Date: 4/16/96

RMS: 0.697nm

PROFILE

PV: 4.37nm

RA: 0.555nm

RC: 23.4 m

C1 R

25451

Time: 10:26

Date: 4/16/96

RMS: 0.890nm

PV: 4.92nm

RA: 0.702nm

RC: 34.6 m

2.6

Nanometers

1.3

0.0

-1.3

-2.6

Distance on Surface in Microns (20.0X)

754S1

Time: 10:24

Date: 4/16/96

RMS: 1.07nm

PV: 5.77nm

RA: 0.880nm

RC: 73.9 m

3.1

Nanometers

Distance on Surface in Microns (20.0X)

CP
Pb

754S2

Time: 10:37

Date: 4/16/96

RMS: 0.943nm

PV: 5.65nm

RA: 0.738nm

RC: -47.1 m

PROFILE

75452

Time: 10:35

Date: 4/16/96

RMS: 0.811nm

PV: 3.88nm

RA: 0.643nm

RC: 33.3 m

2.2

PROFILE

Distance on Surface in Microns (20.0X)

CP
Hh

754S2

Time: 10:33

Date: 4/16/96

RMS: 0.901nm

PV: 5.29nm

RA: 0.714nm

RC: -45.6 m

PROFILE

Distance on Surface in Microns (20.0X)

75452

Time: 10:32

Date: 4/16/96

RMS: 0.766nm

PROFILE

PV: 4.86nm

RA: 0.587nm

RC: 31.7 m

2.4

Nanometers

1.2

0.0

-1.2

-2.4

Distance on Surface in Microns (20.0X)

754S3

Time: 10:42

Date: 4/16/96

RMS: 0.795nm

PV: 4.66nm

RA: 0.620nm

RC: 16.2 m

PROFILE

Distance on Surface in Microns (20.0X)

754S3

Time: 10:41

Date: 4/16/96

RMS: 0.667nm

PROFILE

PV: 4.02nm

RA: 0.530nm

RC: 33.0 m

2.0

Nanometers

1.0

0.0

-1.0

-2.0

Distance on Surface in Microns (20.0X)

C.F.
P.O.

754S3

Time: 10:40

Date: 4/16/96

RMS: 0.589nm

PV: 3.03nm

RA: 0.475nm

RC: -570 m

1.7

Distance on Surface in Microns (20.0X)

754S3

Time: 10:38

Date: 4/16/96

RMS: 0.518nm

PV: 3.11nm

RA: 0.412nm

RC: 28.8 m

PROFILE

Distance on Surface in Microns (20.0X)

C:
R/

75434

Time: 10:52

Date: 4/16/96

RMS: 0.851nm

PV: 7.21nm

RA: 0.570nm

RC: -73.9 m

3.8

Nanometers

Distance on Surface in Microns (20.0X)

75434

Time: 10:49

Date: 4/16/96

RMS: 0.739nm

PV: 3.56nm

RA: 0.638nm

RC: 50.0 m

PROFILE

Distance on Surface in Microns (20.0X)

75434

Time: 10:48

Date: 4/16/96

RMS: 1.06nm

PV: 5.62nm

RA: 0.840nm

RC: -26.3 m

PROFILE

Distance on Surface in Microns (20.0X)

P0

75434

Time: 10:46

Date: 4/16/96

RMS: 1.00nm

PV: 5.04nm

RA: 0.821nm

RC: -23.8 m

PROFILE

Distance on Surface in Microns (20.0X)

Interferometry

öffn

Fig Aperture

MI ASURE
Analyze
Most Data
Save Data
Load Data
Calibrate
Reset

Measure Ctrl
Analyze Ctrl
Analyze Attr
Process
Profile
Report

1014 Fall 11:3

Filter:	Off
Filter Type:	

PM5	PM2.5	PM10
1.101	1.097	1.097

Trimmed: ?
Removed: PST T

Filter Type:

Oblique Plot

Save Data

11 MS .40

Intensity

956
956

Wave	4.974	1.401	RMS
Wave			

S/N: 75452 C632.8mm
Time: Thu Apr 11 11:57:13 1996

The screenshot displays the Mark IVxp Application software interface, which is used for surface metrology measurements. The interface is divided into several sections:

- Top Bar:** Shows the application name "Mark IVxp Application" and the current measurement mode "Phase Map".
- Left Panel:** Contains a menu with options: "File", "Aperture", "Measure Ctrl", "Analyze Ctrl", "Analyze Attr", "Print", "Print File", and "Report". Below this is a "Measure Ctrl" section with buttons for "Measure", "Analyze", "Load Data", "Save Data", "Calibrate", and "Reset".
- Main Display Area:**
 - Top Left:** A "Filled Plot" showing a dark, rectangular feature on a light background.
 - Top Right:** An "Oblique Plot" showing a 3D surface profile. The vertical axis is labeled "wave" with values +1.5380 and -0.9905. The horizontal axis is labeled "mm" with values 9 and 226. A "Save Data" button is located to the right of the plot.
 - Bottom Left:** A table of measurement data:

Parameter	Value	Unit
PV	2.528	wave
PM5	0.766	wave
 - Bottom Right:** A table of filter settings:

Filter Type	Filter
Filter Type	Off
Filter Type	?
- Right Panel:**
 - Top:** A "Zygo" logo and a "Zygo" button.
 - Middle:** A "Zygo" logo and a "Zygo" button.
 - Bottom:** A "Zygo" logo and a "Zygo" button.

Macrophotography

754S1 POST-CP POLISH 4/16/96

754S2 POST-CP POLISH 4/16/96

754S3 POST-POLISH - CT 4/16/96

754S4 POST-CP POLISH 4/16/96

Polishing Procedures and Surface Characterization

Lead Tungstate Crystal Scintillator Rod #723

Prepared by the
MMED Optics Group
May 1, 1996

Lawrence Livermore National Laboratory

MMED - OPTICS
INSPECTION TRAVELER
Part Number 723 PbW04

Surface Characterization

Equipment:

Profilers:

WYKO Profiler
OHP Profiler
Federal Surf analyzer

Documentation Req'd

Date Completed

✓ 3/7/96 mk

Wavefront/transmission:

ZYGO Interferometer
TG Interferometer

✓ 3/11/96 mk.

Microscopy:

Reichert:

Mag. 90 179 500 840

Leitz

Mag. 50..100. (200) 500..1000

Enlargements

Mag. _____

✓ 3/8/96 mk.

✓ 3/11/96 mk.

Stress/structure:

Polariscope

* ✓ 3/11/96 mk.

COMMENTS: * Couldn't see through part - NO DATA

PbWO₄ Crystal #723

- **Polishing Process and Procedures**
- **Surface Characterization Analysis**

Pre-Polish Surface Characterization

Microphotography

Profilometry

723S1 -CENTER

Time: 2:25

Date: 3/7/96

RMS: 4.96nm

PV: 20.2nm

RA: 4.06nm

RC: 4586 mm

PROFILE

Distance on Surface in Microns (20.0X)

723S1(SMEND)^{CLOSER TO SMALL END}

Time: 3:11 Date: 3/7/96

RMS: 4.40nm

PV: 19.7nm

RA: 3.74nm

RC: -15.9 m

PROFILE

Distance on Surface in Microns (20.0X)

72352

Time: 2:27

Date: 3/7/96

RMS: 6.19nm

PROFILE

PV: 23.1nm

RA: 5.27nm

RC: 4799 mm

center

723S2SMEND

Time: 3:17

Date: 3/7/96

RMS: 3.57nm

PROFILE

PV: 19.6nm

RA: 2.99nm

RC: -2861 mm

12.3

Distance on Surface in Microns (20.0X)

723S2LGEND

Time: 3:16

Date: 3/7/96

RMS: 4.55nm

PROFILE

PV: 20.1nm

RA: 3.79nm

RC: -20.6 m

72353

Time: 2:30

Date: 3/7/96

RMS: 4.06nm

PROFILE

PV: 18.0nm

RA: 3.39nm

RC: -5603 mm

Distance on Surface in Microns (20.0X)

crater

723S3SMEND

Time: 3:18

Date: 3/7/96

RMS: 6.77nm

PV: 29.9nm

RA: 5.52nm

RC: -5081 nm

17.5

Nanometers

Distance on Surface in Microns (20.0X)

72353LGEND

Time: 3:20

Date: 3/7/96

RMS: 5.25nm

PROFILE

PV: 19.3nm

RA: 4.47nm

RC: 11.7 m

Distance on Surface in Microns (20.0X)

CLOSER TO LARGE
723S1(LGEND) END

Time: 3:09

Date: 3/7/96

RMS: 3.61nm

PROFILE

PV: 20.0nm

RA: 2.90nm

RC: -3453 mm

Distance on Surface in Microns (20.0X)

72354

Time: 2:32

Date: 3/7/96

RMS: 2.85nm

PV: 12.7nm

RA: 2.32nm

RC: 50.8 m

PROFILE

Distance on Surface in Microns (20.0X)

723S4SNEND

Time: 3:07

Date: 3/7/96

RMS: 5.92nm

PROFILE

PV: 28.2nm

RA: 4.70nm

RC: 24.9 nm

Distance on Surface in Microns (20.0X)

723S3LGEND

Time: 3:20

Date: 3/7/96

RMS: 5.25nm

PV: 19.3nm

RA: 4.47nm

RC: 11.7 m

PROFILE

11.0

Nanometers

5.5

0.0

-5.5

-11.0

Distance on Surface in Microns (20.0X)

723S3SMEND

Time: 3:18

Date: 3/7/96

RMS: 6.77nm

PROFILE

PV: 29.9nm

RA: 5.52nm

RC: -5081 mm

72353

Time: 2:30

Date: 3/7/96

RMS: 4.06nm

PV: 18.0nm

RA: 3.39nm

RC: -5603 mm

PROFILE

Distance on Surface in Microns (20.0X)

crude

Profilometry

SC 50X 4/3/96

GRIND - HAND PAD POLISH

72354 50X POL 4/3/96

72354 50X POL 4/3/96

060555VZ03031 D:01K6

76353 200x Pol 4/3/96

76353 200x Pol 4/3/96

GROUND-HAND PAD POLISH

76353 200x Pol 4/3/96

FOOTED E66637A5E803C

GROUND - HAND PND FOLISH

-352 200x POL 4/13/92

GROUND - HAND PND FOLISH

72352 200x POL 4/13/92

72352 200x POL 4/13/92

-352 200x POL 4/13/92

A723 -3

#723 S.

#123 01

zygo

Log Aperture

Measure

Analyze

Mask Data

Save Data

Load Data

Calibrate

Reset

Measure Ctrl

Analyze Ctrl

Analyze Attr

Process

Profile

Report

zygo

Mark IVxp Application

Phase Map

Filled Plot

PV 2.764 wave

PMS 0.368 wave

Filter: Off

Filter Type:

Trimmed: 2

Removed: PST TLT

Save Data

Oblique Plot

+0.5201 wave

-2.2434 100 pix

59

166

66

Save Data

Video Monitor Output

RMS 0.368 wave

0632.8mm 1:29:09 1996

Clear

On

zygo

Intensity

Reflection

Interferometry

L
F1

723SMEND-FACE

Time: 22:53

Date: 3/12/96

RMS: 4.67nm

PROFILE

PV: 19.8nm

RA: 3.79nm

RC: -4402 mm

723SMEND - Face

Time: 23:01

Date: 3/12/96

RMS: 2.95nm

PROFILE

PV: 13.2nm

RA: 2.45nm

RC: -15.5 m

8.0

Nanometers

Distance on Surface in Microns (20.0X)

723LGEND-FACE

Time: 22:58

Date: 3/12/96

RMS: 2.89nm

PROFILE

PV: 13.8nm

RA: 2.31nm

RC: -5758 mm

CA
FA

723LGEND-FACE

Time: 22:55

Date: 3/12/96

RMS: 4.64nm

PROFILE

PV: 18.5nm

RA: 3.88nm

RC: -3736 mm

723S4LGEND

Time: 3:08

Date: 3/7/96

RMS: 3.22nm

PROFILE

PV: 13.5nm

RA: 2.76nm

RC: 13.3 m

Crystal 754: Side 4, Hand pad polished, 200X

Crystal 754: Side 3, Hand pitch polished, 200X

Crystal 754: Side 2, Hand pitch polished, 200X

Crystal 754: Side 1, CP polished for 5 hours, 200X

Crystal 754: Side 1, CP polished for 3 hours, 200X

POST - PLISH

4/10/96

75322

Post - Plush

POST - PLISH

4/10/96

75324

Post - Plush

PPL

P05:
POL

zygo

Lg Aperture

Measure Ctrl

Analyze Ctrl

Analyze Attr

Process

Profile

Report

Slope X

zygo

Application

Phase Map

Filled Plot

PV 8.213 wave

RMS 1.385 wave

Filter: Off

Filter Type:

Trimmed: ?

Removed: PST TLT

Oblique Plot

+1.3845 wave

-6.8280

44 mm 204

Save Data

zygo

Intensity

Output

RMS 1.385 wave

632.8nm

52 1996

Clear

PV 8.213 wave

RMS 1.385 wave

632.8nm

52 1996

Clear

PV 8.213 wave

RMS 1.385 wave

632.8nm

52 1996

Clear

S/N: 72351

Time: Thu Apr 11 12:06:52 1996

Interferometry

723SMEND-FACE

Time: 22:53

Date: 3/12/96

RMS: 4.67nm

PV: 19.8nm

RA: 3.79nm

RC: -4402 mm

PROFILE

Distance on Surface in Microns (20.0X)

EN
F1

723LGEND-FACE

Time: 22:58

Date: 3/12/96

RMS: 2.89nm

PROFILE

PV: 13.8nm

RA: 2.31nm

RC: -5758 mm

8.1

Distance on Surface in Microns (20.0X)

EN
A

723SMEND - FAcE

Time: 23:01

Date: 3/12/96

RMS: 2.95nm

PROFILE

PV: 13.2nm

RA: 2.45nm

RC: -15.5 m

Distance on Surface in Microns (20.0X)

723S4LGEND

Time: 3:08

Date: 3/7/96

RMS: 3.22nm

PROFILE

PV: 13.5nm

RA: 2.76nm

RC: 13.3 m

2.7

Distance on Surface in Microns (20.0X)

EA
FA

723LGEND-FACE

Time: 22:55

Date: 3/12/96

RMS: 4.64nm

PROFILE

PV: 18.5nm

RA: 3.88nm

RC: -3736 mm

Distance on Surface in Microns (20.0X)