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PE-TR-M7247

SECOND QUARTERLY REPORT

RUBY IMPROVEMENT FOR LASERS - TASK II

DATE OF THIS REPORT: 30 NOVEMBER 1962
PERIOD COVERED: AUGUST 1962 TO 31 OCTOBER 1962

U.S. Army Signal Research and Development Laboratories
U.S. Army Signal Supply Agency; Contract DA 36-039-SC-89091
DA Project No. 3A-99-21-001-05

THE PERKIN-ELMER CORPORATION
NORWALK, CONNECTICUT

[redacted]

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OBJECT

The objective of this contract is to evaluate and fabricate ruby material grown by the Linde Company Division of Union Carbide Corporation under Contract DA 36-039-SC-89089; and to develop improved geometries and test procedures for ruby lasers.

THE PERKIN-ELMER CORPORATION
NORWALK, CONNECTICUT

The following engineers and scientists participated in its preparation:
J. G. Atwood
G. W. Dueker

SUMMARY OF STATUS

This is the Second Quarterly Report on work conducted under Contract DA-36-039-SC-89091: "Ruby Improvement for Lasers - Task II". Boule lots 1, 2, and 3 were received, inspected, and fabricated into 1/4" x 2" rods with plane-parallel ends. The finished rods were anti-reflection coated, tested and delivered to USASRDL for further testing. A plane-parallel rod of the same dimensions was made from a boule not grown for the contract; for comparison.

Hours Expended: During the period covered by this report 771 man-hours were expended. Total man-hours since the beginning of the contract is 934.

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LIST OF ILLUSTRATIONS

SECTION I - INTRODUCTION

1.1 PURPOSE

This Second Quarterly Report covers the period from 1 August 1962 to 31 October 1962, reporting activity occurring under Contract DA-36-039-SC-89091, for USASRDL, Fort Monmouth, New Jersey. The purpose of the investigation is to evaluate and fabricate ruby material grown by the Linde Company, Division of Union Carbide Corporation, under Contract DA-36-039-SC-89089; to experiment with improved geometries for resonant structures, and to learn what test methods and fabrication techniques are necessary to ensure optimum performance of ruby lasers.

1.2 OUTLINE OF WORK

According to the terms of the contract, ruby and sapphire raw material is to be supplied by Fort Monmouth, for testing and fabrication by Perkin-Elmer. The optical evaluation procedure to be followed is outlined in the First Quarterly Report. In most instances, it is anticipated that maser power output, beam spread, and other important features will be measured at USASRDL. Fabrication is to be into geometries mutually agreed upon by the customer and contractor. The total number of pieces is to be 48.

Ten lots of ruby boules, comprising 33 boules in all,are to be grown under various conditions by the Linde Division. These boules are anticipated to provide a majority of the raw material to be fabricated during the investigation.

During the period covered by this report, the first three lots of rubies were received. Optical evaluation was made, and a total of 10 finished laser rods were made from them. Further evaluation of the finished pieces was made. A 1/4" x 2" rod Serial 01-D was made and tested, from disc boule 01.

1.3 ABSTRACT

A report is given on the optical evaluation of the first three lots of ruby crystals grown by the Linde Company under Contract DA-36-039-SC-89089.

SECTION II - PUBLICATIONS AND REPORTS

During the period covered by this report, no publications or other reports were issued.

SECTION III - DESCRIPTION OF NEW EQUIPMENT AND TECHNIQUES

3.1 INTERFEROMETER

As discussed in the First Quarterly Report, for material of very good optical quality, many of the less sensitive test procedures are ineffective. A test which is highly sensitive, and has the additional advantage of closely reproducing the operating conditions in a laser, is the interferometer. The equipment used to make the interferograms in this report is essentially that diagrammed in Figure 2, page 5, First Quarterly Report. The source used is a cadmium discharge lamp with a red filter to pass the 6440Å line.

The mirrors of the interferometer are adjusted to give a number of straight fringes across the field. Where the beam passes through the laser rod, variations in the optical path caused either by index gradients or irregularities in the surface cause deviation of the fringes. A fringe represents a region or contour of constant optical path length. The faces of the sample are worked to a flatness of better than 1/10 wavelength, so that practically all of the deviation is due to index gradients.

A pair of pictures is taken of each sample, with the sample rotated 90° between shots, so that an inhomogeneity lying parallel to a fringe in one orientation where it would cause only a change in the fringe spacing, is readily observed at 90°, where it causes a step across the fringes.

Measurement of the interferograms shows in most cases a variation of at least one fringe width from one side of the crystal to the other. This may be related to index variation as follows:

The condition for a bright fringe is:

$$2(n-1)d = m\lambda$$

where n is the index, d is the sample length, and m is an integer and the fringe spacing is then

$$2(n-1)\Delta d + 2d\Delta n = \lambda$$

for a plane parallel sample $\Delta d = 0$

$$\text{and } 2d\Delta n = \lambda$$
$$\text{or } \Delta n = \lambda/2d$$

for the photos, $d = 5$ cm and $\lambda = 6.4 \times 10^{-5}$ cm

$$\text{and } \Delta n = 6.4 \times 10^{-6}$$

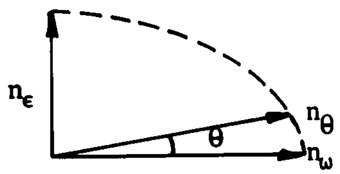
This may be related to concentration of chromium or to change in the orientation of the optic axis. Considering only the former:

	Chromium Concentration*	
	.05%	.5%
n_ϵ	1.7574	1.7633
n_ω	1.7656	1.7716

Δn_ω = .006 for Δ concentration of .45%

Δn_ω = of 6×10^{-6} for a 1-fringe deviation corresponds to a .00045% change in concentration

For variation of direction of the axis:



If n_θ is the index along the direction of viewing,

$$n_\theta^2 = \frac{n_\epsilon^2 \, n_\omega^2}{n_\epsilon^2 \cos^2\theta + n_\omega^2 \sin^2\theta}$$

and $$\frac{dn_\theta}{d\theta} = \frac{\sin 2\theta}{n_\theta^3 n_\epsilon^2 n_\omega^2} \left(n_\epsilon^2 - n_\omega^2\right)$$

take $n_\epsilon = 1.757$

$n_\omega = 1.765$

$n_\theta \cong 1.765$

and $\sin 2\theta = 2\theta$

then if $\frac{dn_\theta}{d\theta} = 6.4 \times 10^{-6}$

$\theta = 5 \times 10^{-3}$ or about 16 min of angle

---

*J. A. Mandarino, American Minerologist, 44, 961, (1959)

3.2 POLARISCOPE

A small hand-held polariscope consisting of two pieces of Polaroid sheet in a rotating holder is a useful device for preliminary inspection of crystals. The degree of twinning and amount of lineage of the crystal can be estimated, and the best section located with a minimum of preparation. All that is necessary is to have two surfaces of reasonable optical quality polished perpendicular to the optic axis.

Two different types of fringe patterns are observable in crossed polarizers. One arises when viewing the crystal in parallel light, and path differences are caused by inhomogeneities in the crystal. They may be observed at any direction to the optic axis. An example is shown in Figure 7, the polariscope shots of the rough boules.

The other type of pattern arises when the crystal is viewed in convergent light, and is caused by the differing velocities of propagation of the polarized light proceeding at different angles to the optic axis (see page 6, First Quarterly Report). When the crystal faces are perpendicular to the optic axis, this pattern is called the optic-axis figure, and in a uniaxial crystal such as ruby, for a perfect single crystal, appears as a set of concentric circles crossed by a black cross (Figure 1).

This perfect pattern appears only for a crystal in which there is only one direction of the optic axis within the field of view. If twinning is present, one may be looking at areas having two different directions for the axis, giving a result shown in Figure 2.

Figure 1. Optic Axis Figure of Single Crystal

All crystals inspected in this investigation have shown this twinning to about the same degree, as nearly as could be determined, by a visual inspection. Since the effect of twinning on a laser is not known, crystals have been cut so as to include both badly twinned sections, which in general lie on the central axis of the boule, and sections at the side of the boule, where twinning is less apparent.

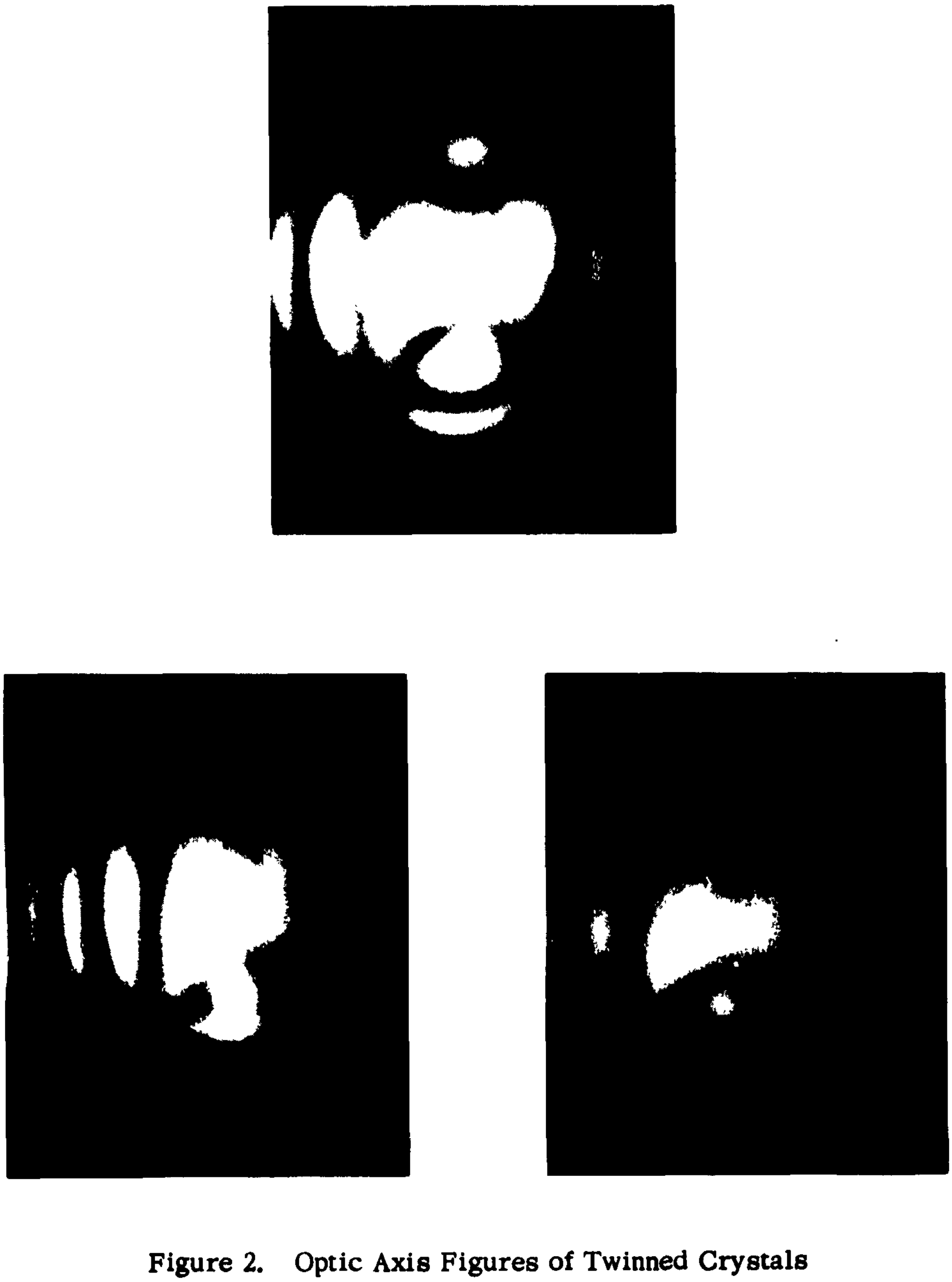


Figure 2. Optic Axis Figures of Twinned Crystals

3.3 EXTERNAL MIRRORS

In addition to threshold measurements to be made at Fort Monmouth, it is useful to have a standard setup for pumping crystals and observing the waveform of the output. An arrangement for measuring the threshold of the crystals is shown in Figure 3. It consists of a quartz tube, with an opening for insertion of the crystals, with quartz end mirrors coated for high reflectivity at 6943Å. The ends of the tube are polished to a flatness of 1/10 wavelength and parallelism of 5 sec, and the mirrors optically contacted to them. The entire assembly can be placed at the focus of an elliptical cavity, for pumping with a linear flash-tube. A schematic of the optical setup is shown in Figure 4. The flash-tube used is a PEK Xenon Lamp, Type X-E-1-3.

Figure 3. External Mirror Support

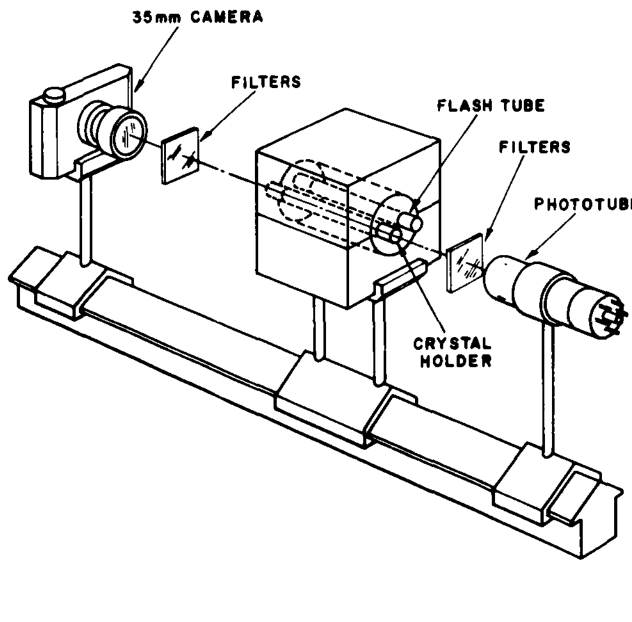


Figure 4. Arrangement of External Mirror Setup

A camera focussed on one mirror gives the near-field pattern, while a photocell at the other end records the time trace of the output. Examples of the output are shown in Figure 5.

Threshold for laser action may be observed by reducing the input energy until only one spike is seen on the time trace. There is a noticeable effect correlated with the orientation of the crystal axis in this arrangement. When the axis is perpendicular to the open side of the tube the threshold is as much as 18% lower than when it is parallel. Actual values of the threshold in joules input to the flash-tube are recorded in Table I.

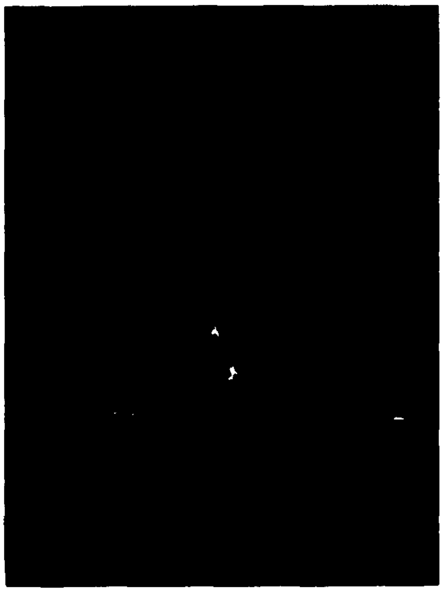


Figure 5A. Near Field Pattern Near Threshold

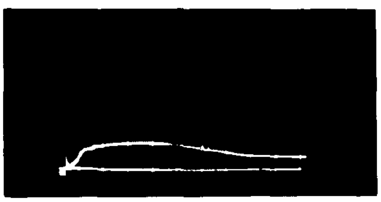


Figure 5B. Time Trace Near Threshold

Upper Trace: 20μ sec/cm
Lower Trace: 100μ sec/cm

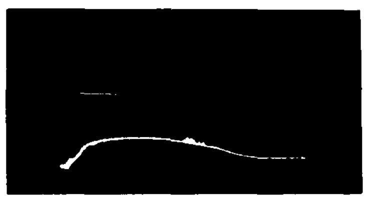


Figure 5C. Time Trace Above Threshold

Upper Trace: 20μ sec/cm
Lower Trace: 100μ sec/cm

SECTION IV - DATA

4.1 BOULE CUTTING DIAGRAM

In order to identify the section of the boule from which a rod was cut, the following letters were used. Rods are roughly centered within or between the sections indicated in Table I, column (5). "Bottom" and "Top" refer to the boule positions in the furnace.

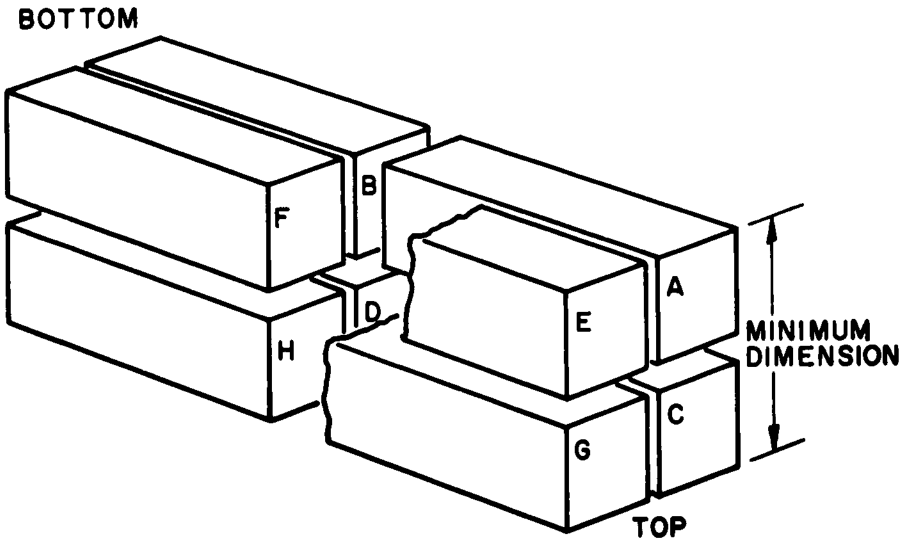


Figure 6. Boule Cutting Positions

Table I

Lot	Boule No.	Serial	Optical[1] Parallel	External[2] Parallel	Scatter[3] % per cm	Optical Density[4] (1 cm) 408 mμ	Optical Density[4] (1 cm) 553 mμ	Boule[5] Section	Threshold[6] Joules	Selection[7]
0		01-D	.5 Div		.15				148	
1	CP125-13	02	4.0	3"	.05	1.05	1.05	AE		Good
1	CP125-25	03	4.0	4"	.04	1.1	1.1	BFDH		Poor
1	CP125-33	04	6.0	2"	.03	1.17	1.07	BF		Good
2	CP126-15	05	1.5	4"	.03	.83	.83	AE		Good
2	CP126-42	06	0.5	3"	.04	.90	.90	CG		Good
2	CP126-46	07	1.0	2"	.04	.84	.84	A		Good
3	CP127-6	08-A	0.8	2"	.05	.62	.61	AEBF	$\frac{139}{161}$	Poor
3	CP127-6	08-B	0.5	3"	.05			CGDH	$\frac{143}{174}$	Good
3	CP127-30	09	0.6	2"	.04	.71	.71	DH	$\frac{139}{148}$	Good
3	CP127-26	10	0.4	2"	.04	.84	.83	AECG	$\frac{139}{161}$	Poor

(1) Calibration .71 minutes per division; deviation of a beam passed through the crystal.

(2) Measured externally with autocollimator

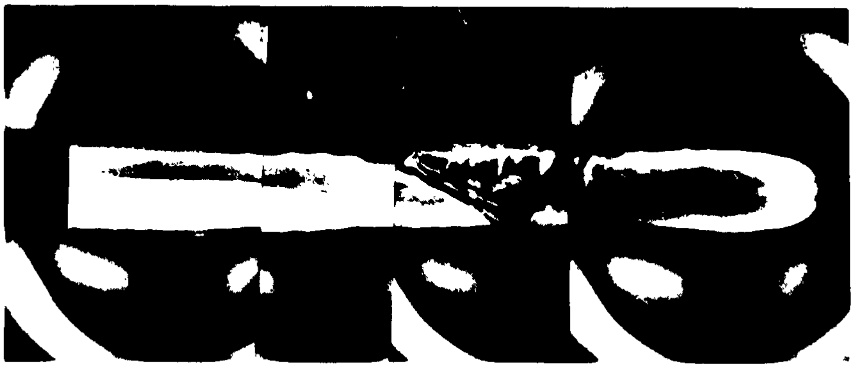
(3) In a wavelength band 300Å wide centered at 9000Å.

(4) For a 1 cm thickness.

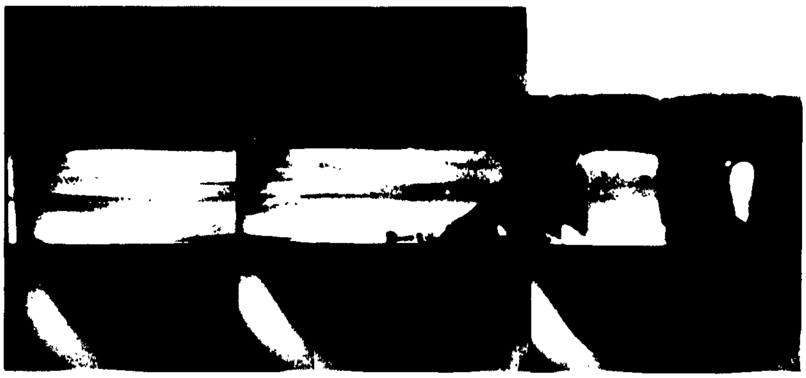
(5) See Page 14, Section 4.1, Boule Cutting Diagram

(6) See Reference to Table I, Page 10, Section 3.3, External Mirrors.

(7) Polariscope evaluation



Serial No. 02



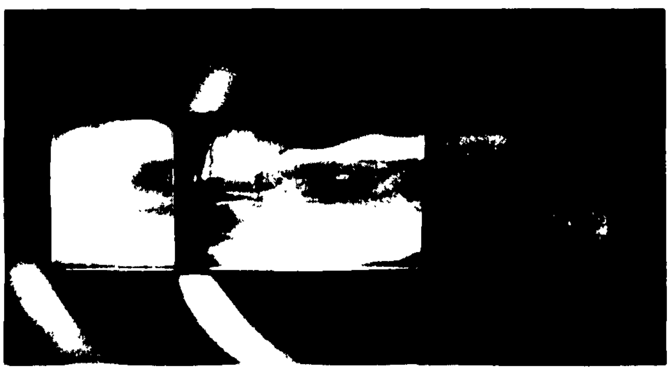
Serial No. 03

Serial No. 04

Figure 7. Polariscope Photographs

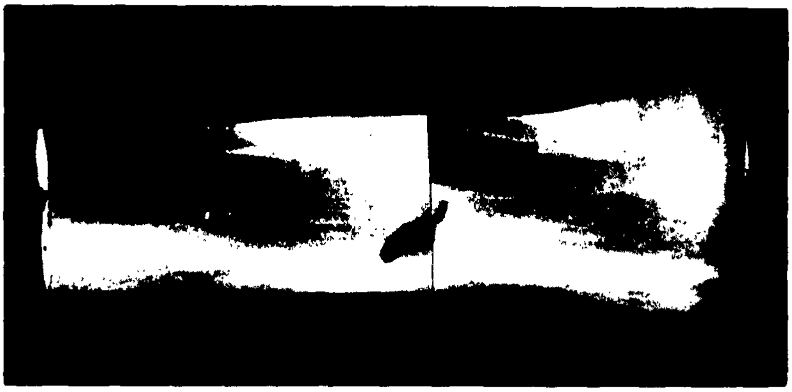
Serial No. 05

Serial No. 06



Serial No. 07

Figure 7. Polariscope Photographs (Continued)



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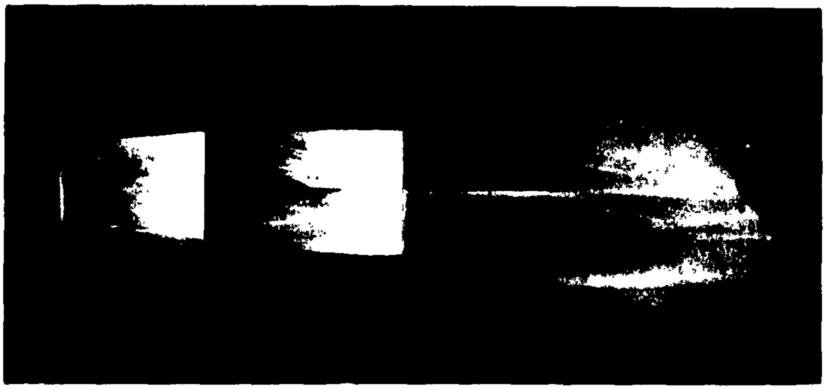

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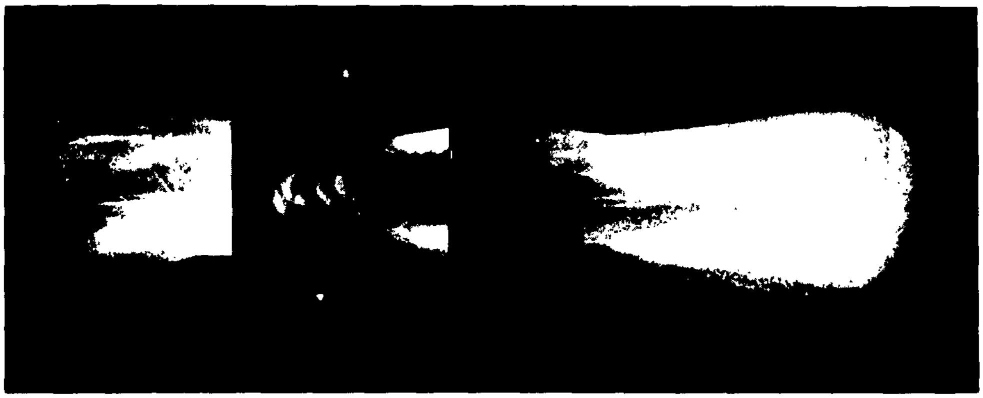
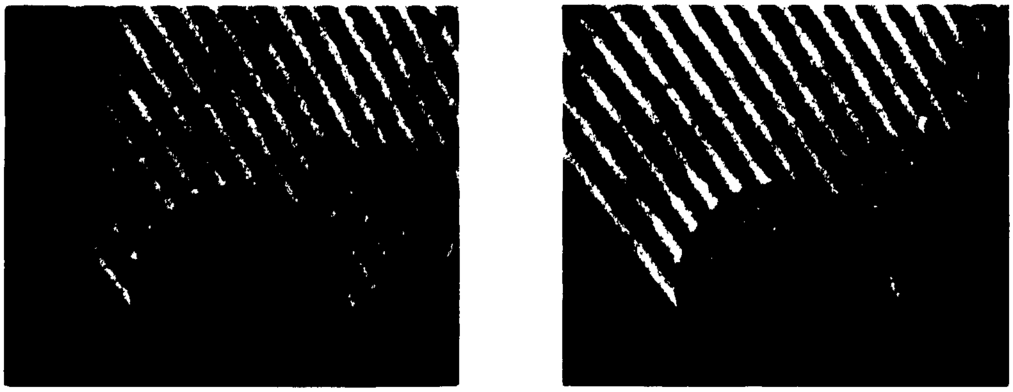
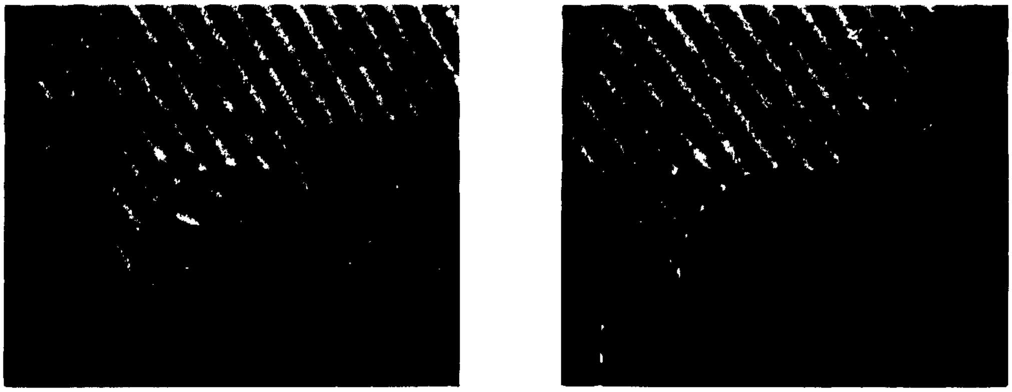


Serial No. 10

Figure 7. Polariscope Photographs (Continued)



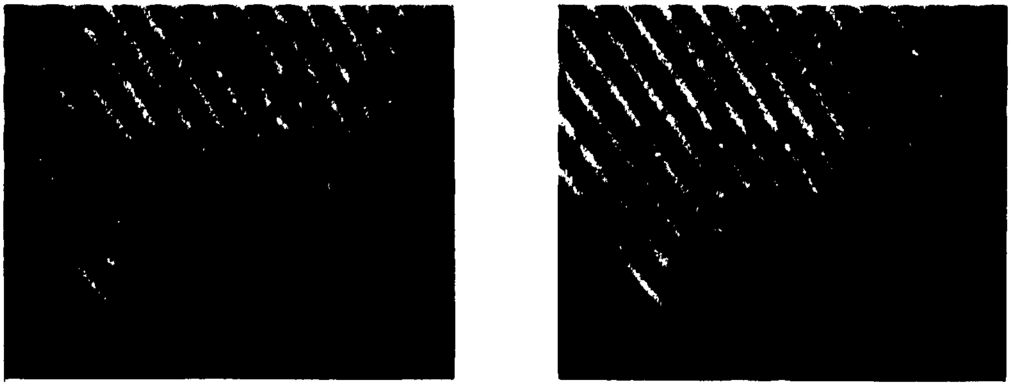
Serial No. 01-D



Serial No. 02

Serial No. 03

Figure 8. Interferograms



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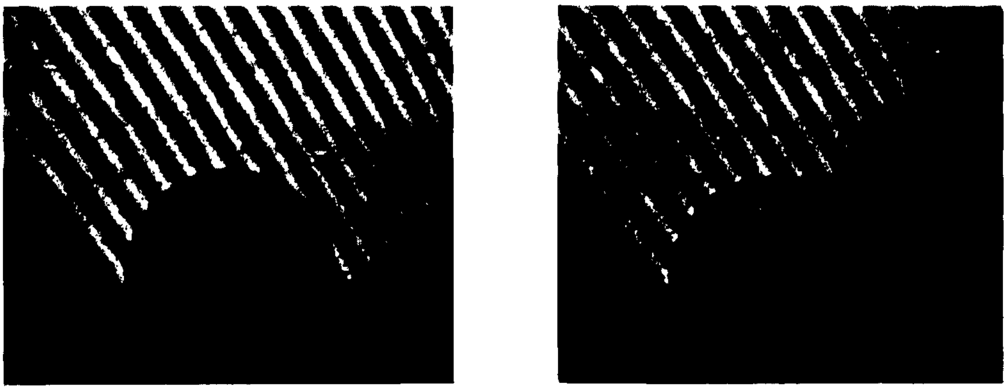

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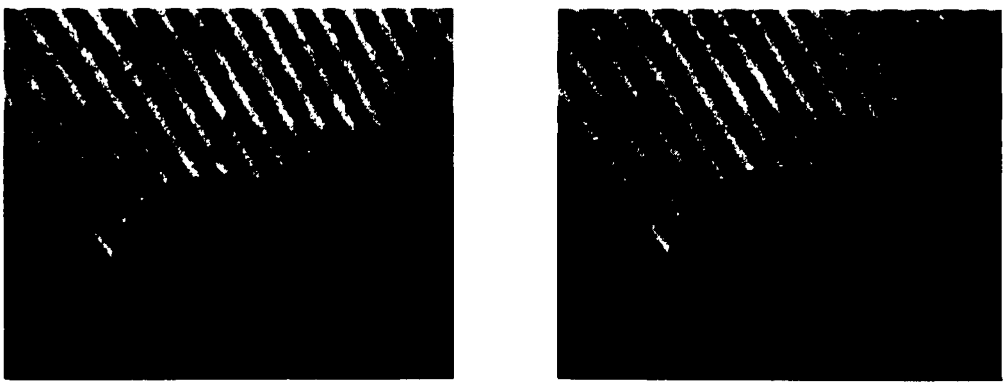
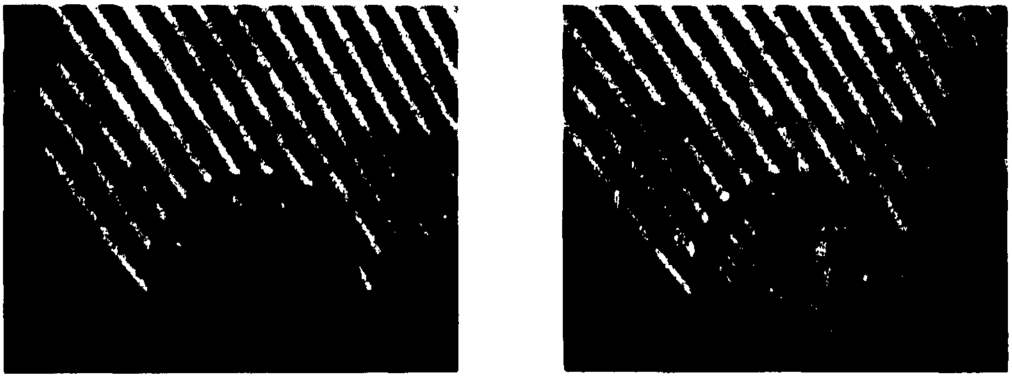


Serial No. 06

Figure 8. Interferograms (Continued)



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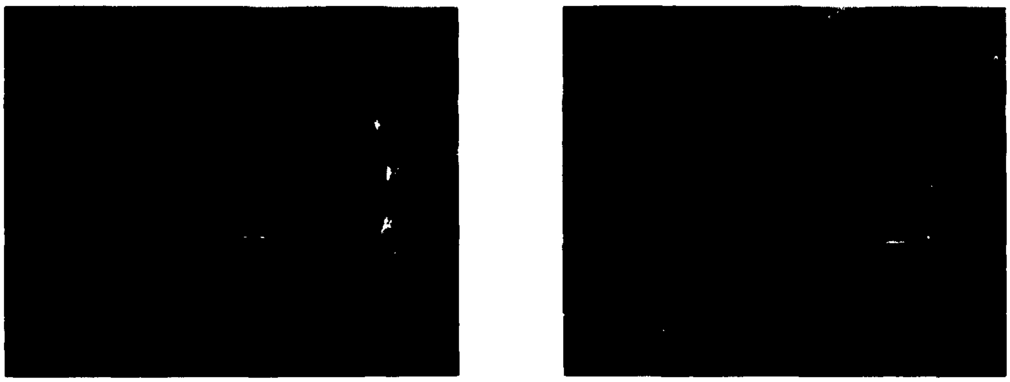
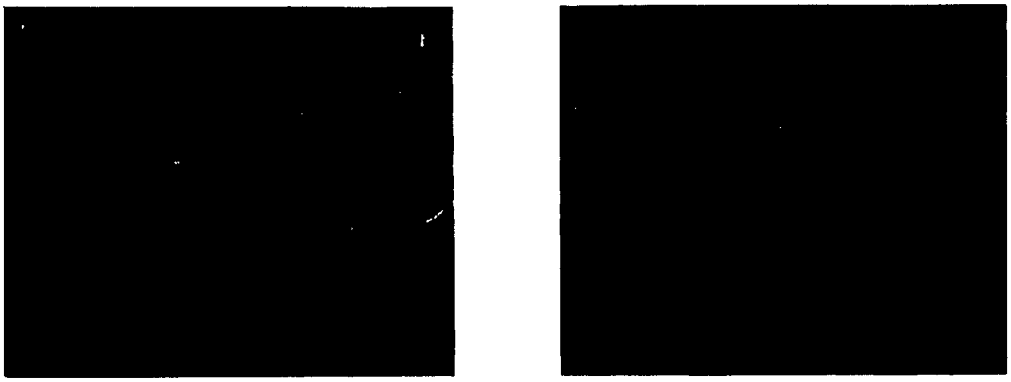


Serial No. 08-A

Serial No. 08-B

Figure 8. Interferograms (Continued)



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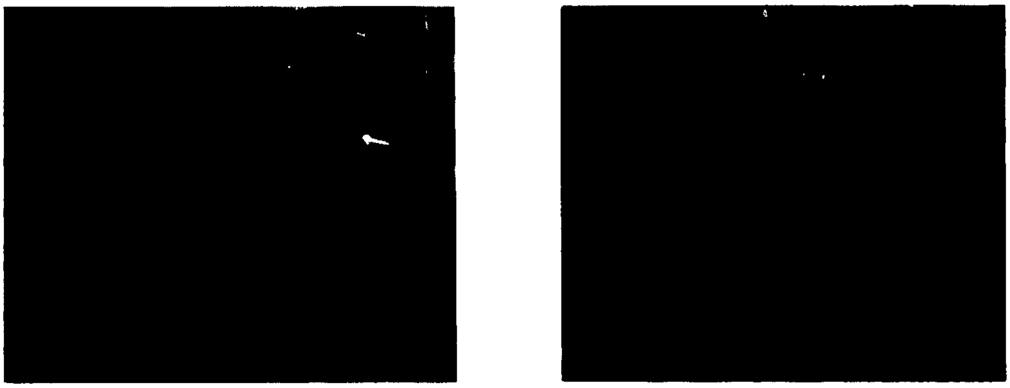

Serial No. 10

Figure 8. Interferograms (Continued)

SECTION V - DISCUSSION OF DATA

A visual inspection of the three lots of rubies shows a number of differences among them. However, it is not readily apparent how important these differences are to performance of the finished laser. For example, lineage in lot 2 appears to be less than in lot 1, but localized areas in individual boules show a wide variation from the average. By selecting from these areas, good and bad samples can be made from either lot. The selection in each case is noted in Table I, Column (7).

Layering: A visual feature which is difficult to assess quantitatively is layering of the chromium density. This appears as dark and light layers in the crystal, and is frequently accompanied by ridges or lumps on the surface of the boule. The volumes involved are too small to be distinguished spectrographically without special optics. These layers have been avoided as much as possible in selecting the samples.

In boule 08, a visible veil or light colored cloudy plane parallel to the boule axis was present on one side of the boule. Two rods were fabricated from this boule; 08-A including the veil, and 08-B from a part not having the veil.

In boule 09, the best section of the crystal was selected; in boule 10, the worst part was chosen, on the basis of the polariscope observations.

It becomes apparent when examining the interferograms that the polariscope is not entirely reliable for choosing the best section of the crystal. On future lots the ends of the boules will be given a polish of sufficient quality to enable an interferogram to be made of the entire end, then the best section chosen on this basis. As suggested by Hercher*, it would be possible to correct for local inhomogeneities in the crystal by polishing, provided the figure required is not too complicated.

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*Applied Optics, Vol. 1, No. 5, p. 665, September 1962

SECTION VI - CONCLUSIONS

The boules being supplied for inspection are of sufficient quality that only interferometry is able to provide a reliable evaluation. On subsequent boules the entire piece will be inspected in the interferometer before cutting.

SECTION VII - SUMMARY OF WORK PERFORMED THIS QUARTER

Lots 1, 2, and 3, and a reference boule were inspected, fabricated, and tested, and data outlined for inclusion in this report.

SECTION VIII - PROGRAM FOR NEXT QUARTER

Inspection and fabrication will be completed for boule lots 4, 5, and 6, scheduled to be received during the next quarter. Figuring of a selected piece of good quality to compensate for index variations will be attempted.

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Mr. C. Kellington, Project Engineer, Telephone 53-52831

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Perkin-Elmer Corp., Norwalk, Conn.
RUBY IMPROVEMENT FOR LASERS
G. W. Dueker
Report No. M7247, 30 Nov. 62, 22pp 8 illus.
Prime Contract DA36-039-SC-89091

1. Ruby Improvement
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