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ABSTRACT

This report reviews recent laser work of the Optics Division, Naval Research Laboratory, which was sponsored by the Advanced Research Projects Agency (ARPA). The major topics covered include the effect of pumping on ruby quality, optical examination of lanthanum fluoride, testing of large ruby laser rods, dc operation of the AH6 mercury tube, hologram experiments, fast Q-switching, and magnetic Q-spoiling experiments.

PROBLEM STATUS

This is an interim progress report; work on this problem is continuing.

AUTHORIZATION

NRL Problem N01-09

ARPA Order 306-62

INTRODUCTION

This is a summary of the effort on this problem in the Optics Division, NRL, during the period 30 June 1964 to 1 Jan 1965. The project includes a number of different tasks and the effort in each is reported individually. Additional effort went into the preparation of reports and material for publication; for example the development of a flash lamp for operation at the temperature of liquid nitrogen was published in RSI. A bibliography of all reports and publications attributable to the ARPA project is appended for reference purposes; it includes material published during the present reporting period.

EFFECT OF PUMPING ON OPTICAL QUALITY

A ruby oscillator or amplifier functions only when pumped; hence it is important to know the extent to which pumping degrades the optical quality of a good laser rod. Some degree of change in refractive index may be directly associated with population inversion or with the localized lattice energy associated with the radiationless decay to the metastable state. These direct effects would, in each volume element, correspond in time to the local degree of pumping. In addition to these direct effects it is to be expected that the index of refraction would be modified by dimensional changes resulting from pumping. Dimensional changes would propagate through the ruby with the velocity of sound. These secondary effects would be delayed in time.

Preliminary experiments were performed to determine the degree of optical degradation associated with moderate pumping and to assess one technique for exploring this problem.

A beam of light from a 6328A gas laser was passed axially through a ruby rod mounted in a laser head. A streak camera was used to examine the far field pattern of this one millimeter diameter beam while the rod was pumped. Many pictures were made with the ruby alternately pumped and not pumped and there was no visible effect that could be correlated with pumping. Displacements or distortions of 2×10^{-4} radians would have been apparent. During these measurements amplitude modulation of the laser output was detected and traced to a relaxation oscillation in the helium-neon tube. By careful adjustment of the gas tube current it was possible to reduce this modulation to a degree satisfactory for this experiment. A more powerful laser probe source will be necessary if the sensitivity of this method is to be increased. With the slowest writing speed at which the streak camera can be operated, adequate exposure allowed an image not greater than one half millimeter.

A photomultiplier detector was placed in the streak camera and the light flux in the probe-beam image was examined during pumping. After various possible spurious effects had been eliminated or accounted for, such as those due to pump light, ruby fluorescence, electrical interaction, and mechanical motion, it was apparent that there was an observable decrease in the light flux incident on the photomultiplier during pumping, and that this might be a consequence of some change in the ruby rod. In order to see if enhanced absorption or enhanced wide angle scattering were contributing to the decrease, the ruby-to-photomultiplier path was arranged so that there could be no vignetting of any light within several degrees of the beam. The beam was incident on the center of the photocathode with the entire photocathode visible from the ruby rod. Pumping now had no effect on the output of the photomultiplier but when strips of tape were used to occlude areas of the photo surface, it was possible to arrange them in different positions so that pumping caused either a decrease or an increase in photomultiplier output. In Fig. 1(a), the response of the photomultiplier to the pump light is seen. The probe beam is off and the pump pulse is over within a few hundred microseconds. In Fig. 1(b) the upper trace is the zero reference with probe beam off, the lower trace is the output with probe beam on and the variable trace indicates a decrease in photomultiplier output with pumping of the ruby. The decrease is the result of the displacement of the partially occluded beam into the occluded region. It may be noted that the effect has the time characteristic of population inversion as indicated by the fluorescent output of ruby. In Fig. 1(c) the ruby is pumped with twice the pump light and a different portion of the beam is initially occluded. The pump pulse is seen to be followed by a decrease of beam flux, as before, but now a periodicity has been introduced. This is believed to be due to the mechanical ringing of the ruby rod following pumping.

TWYMAN-GREEN INTERFEROMETER

The Twyman-Green interferometer acquired for material evaluation was not in satisfactory operating condition when delivered and prolonged testing and adjustment were required to bring it to a satisfactory level of operation.

Step-by-step alignment of each optical component was necessary. Satisfactory alignment was accomplished, resolution was optimized and the instrument's characteristics were established.

OPTICAL EXAMINATION OF LANTHANUM FLUORIDE

Background

Four samples from each of two boules of lanthanum fluoride were furnished NRL Code 7310 for optical testing. Finishing problems due to the material's physical properties, and accentuated by the small size of the samples limited the experimental evaluation. Preliminary microscopic examination showed the material from one boule, #1301, to be clear and the material from the other boule, #1297, to contain a number of voids or inclusions. After x-ray examination by Mr. LaVerne Birks, Code 7320, the samples from the #1301 boule were sent to the A. D. Jones Optical Works, Cambridge, Massachusetts for optical finishing. The samples from #1297 boule were processed at NRL.

One of the samples processed at NRL was destroyed. The other three were given polished faces, flat and parallel to a few tenths of a fringe within a central region about 4 mm in diameter. The Jones Co. had difficulty meeting flatness specifications and their finished pieces were similar to the NRL samples in flatness and parallelism. For all of the samples only a small central region of the end faces was useful for interferometric and for field pattern tests. For this reason the sensitivity of these tests was limited. It is estimated that the interferometer would have showed an optical path gradient of one tenth fringe per millimeter. There was no detectable gradient.

Far field pattern tests are more sensitive indicators of optical path variation for small samples so these patterns were studied. The sample caused slight disturbances in the far field pattern but these could well have been caused by surface defects even though the beam was passed through only the central region of the faces.

Twyman-Green Examination

Each sample was examined with a Twyman-Green interferometer. The sample faces had a central area about 4 mm in diameter with faces plane and parallel to a few tenths of a wavelength, the limit of resolution of the interferometer for an area of this size. No variation in optical path was evident in this region.

Small Angle Beam Deviation

A uniform beam of light was passed through each sample and the far field pattern of the beam was examined (Fig. 2). A beam diameter of 2.8 mm was used. Relative exposure and angular scale are indicated on each photograph. The slight anomalies in the far field pattern probabl resulted from the surface figure rather than from refractive index variations.

Visual Examination

Each sample was examined for visual evidence of anomalies. Samples from boule #1297 have what appear to be voids or inclusions of gas or amorphous material. These appear to be flat hexagonal prisms with their flat end faces at about 45^o to the sample axis (Fig. 3). Corresponding sides of the various occlusions are parallel; hence it is assumed that this crystalline shape is characteristic of the lanthanum fluoride crystal. The largest of these inclusions are about 0.1 mm across. The size density distribution is indicated in Fig. 4. Most of the inclusions seen in these photographs are blurred by being out of focus.

There is evidence of light stratified cloudiness in all of the samples. This cloudiness apparently consists of forward scattering centers and rear or side illumination is needed to make it visible. The samples from boule #1301 are free from defects which can be resolved microscopically but exhibit this stratified cloudiness (Fig. 5).

Index of Refraction

The index of refraction of these crystals was determined to be about 1.49 and in the case of boule #1297, there was a birefringence separation down the cylinder axis of 0.002. It is judged from the orientation of the hexagonal voids that the optical axis is about 45 degrees from the cylinder axis. It is assumed that the optic axis is normal to the flat end faces of the hexagons. Boule #1301 showed no birefringence down the cylinder axis and it is presumed that this is also the optic axis.

CZOCHRALSKI RUBY CUBE

A polished cube of Czochralski ruby from Linde was examined for optical quality. Visual observations were made of the far field pattern of a uniform light beam passing through the cube. The ruby had no observable influence on this far field pattern. Each direction through the cube was tried. The diffraction limited light beam was derived from the output of a helium-neon gas laser and was 6 mm in diameter. Since the diameter of the central disk of the far field pattern was about 10^{-4} radians, the absence of observable distortion means that any angular variation introduced by the ruby was less than about 10^{-5} radians.

Twyman-Green interferograms were made through the cube in each direction (Fig. 6). The variation in optical thickness was about one wavelength per cm and the deviation from optical flatness, the deviation of the phasefront from an imaginary best-fit plane, is much less than one wavelength. Beam deviation would then be expected to be about 6×10^{-5} radians and distortion less than about 10^{-5} radians. The phasefront distortion corresponds to the deviation from flatness observed when the cube faces were tested against a standard optical flat. It is probable that the variation in optical thickness is also geometrical.

TESTING OF LARGE RUBY LASER RODS

An order was placed by ONR for twenty-four large ruby laser rods to be supplied as manufactured over about a six month period. These rods are eight inches in length and five-eighths inch in diameter with Brewster-angle end faces. It was agreed that the rods selected by the manufacturer should meet certain prescribed specifications relative to the distortion of a collimated beam of light passed axially through the rod and that the chromium content should be within specified limits. The Optics Division was asked to test these rods as suppled to ensure that each rod meets its specifications. Basically the quality test involved measurements of the flux distribution in the far field pattern of a beam passed down the rod (Fig. 7).

Although measurements of chromium content were not initially contemplated, it was obvious from visual inspection of the rods and preliminary comparison tests that the variation was large and that this specification should also be monitored. Accordingly procedures were established for optically measuring the chromium content and plans were made to have the results checked by a wet chemical analysis.

Care had been taken to avoid sources of error in the optical quality tests, yet it was found that the NRL measurements showed significantly greater beam spread than did measurements made by the manufacturer. Thorough testing of the procedure and equipment showed no appreciable error. It was later found that the discrepancy resulted from the fact that the manufacturer's measurements had been made before the Brewster angle end faces were cut because their test equipment was not arranged to accommodate rods with inclined end faces. The Brewster angle end faces increase beam spread in one direction.

Preliminary tests were made on eight rods before the end of the year and the test results were communicated to ONR. Details of test procedures and test results will be reported at the end of the test program. Development of procedures and preliminary testing occupied most of the month of December and for this reason are mentioned here.

DC OPERATION OF THE AH6 MERCURY TUBE

The AH6 mercury tube is a high pressure 1000 watt, water cooled capillary source, and is normally operated from an ac power supply. It was operated this way to excite ruby fluorescence for the low temperature line width studies with the prism scanned spectrograph. The 120 cycle modulation of the source output is obviously undesirable and a direct current supply was designed. Tests were made to determine the static and the dynamic electrical characteristics of the AH6 tube. Breadboard experiments were used to ensure that the final system would start reliably and operate stably over the desired range of tube current. A rectifier, filter, and ballast were simply added to the ac supply for these first experiments. A special transformer and special chokes were designed and a power supply was built complete with all controls and accessories. Operation has been very satisfactory.

HOLOGRAMS

Photographic images of structure in three dimension are limited by being constrained to two dimensions. Depth of focus obviously restricts what can be clearly recorded when an attempt is made to photograph the interior of a sample of ruby. At the same time the confusion that would result from the superposition of sharp images is avoided by this restricted depth of focus. Holograms viewed in coherent light give the observer a true three dimensional effect in that the eye focus and convergence that are jointly required for visual inspection of an element of the picture enable the observer to disregard both intermediate detail and background structure while concentrating with acuity on the element of interest. The possibility was investigated that holograms might be useful for recording the interior structure of laser materials. Holograms were made by transmitted light of simple objects and it was concluded that the achievement of adequate resolution would require more time and care than could be justified by the application.

LASER PHYSICS

Fast Q-Switching

As part of the effort to improve low temperature Q-switching, techniques for fast Q-switching were examined. A pulser used for repetitive actuation of a KDP cell was modified for single pulse operation. This line of experimentation was suspended when the KDP cell on hand became inoperative.

A gas turbine driven prism was bought for faster mechanical Q-switching. It can be rotated at 1500 RPS which is twenty-five times the speed of the electrically driven mirror previously used. The faster Q-switching improved performance at 110°K.

Low Temperature Q-Spoiling

The term Q-spoiling is used here to denote a reduction in single pass gain brought about to reduce loss from amplified stimulated emission and premature laser action. The gain of ruby is so high at 77°K that when the population inversion point is reached energy leaks out as fast as it is pumped in and so is not stored for Q-switching. This happens even though antireflection coatings are used to keep the cavity Q at a minimum in the pre-switching period.

Present Q-spoiling efforts involve Zeeman splitting of the ground levels and the ^2E levels by an inhomogeneous magnetic field. This amounts to a relative detuning between portions of the ruby rod subject to different magnetic fields. If advantage is to be taken of the narrowing of the fluorescent line at 77°K, with the attendant high gain and spectral purity, it will be necessary to switch off the magnetic field before Q-switching. For many other Q-switch applications however the magnetic field may remain during Q-switching.

The effectiveness of the magnetic field is being gauged at present by the delay the field introduces in the onset of laser action. The magnetic field is generated by the passage of the flash tube current through a rectangular coil. The ruby rod is parallel to and between the long sides of the coil. A Teflon retainer keeps the coil from being spread open by the mechanical impulse when the heavy flash tube current is passed (Fig. 8). An identical dummy coil is provided in another part of the dewar so that the electric circuit will be the same when non-Q-spoiled operation is desired. Two series connected argon-xenon flash tubes are used to pump the ruby rod. Two cylindrical glass rods serve as relay lenses for pumping. The ruby rod is 7.6 cms long, has one chisel end and one flat end with an antireflection coating. It is estimated that reflectivity of the flat end is less than one percent in liquid nitrogen.

With the present arrangement, onset of laser oscillation is delayed by roughly 100 μs when the magnetic field is present (Fig. 9). In each case feedback is from the antireflection coated output face and the onset of laser action implies a round trip gain greater than the reciprocal of this surface's reflectivity of less than one percent, that is a round trip gain greater than one hundred. The flash tube current rises to a peak of 1600 amps and has decayed to roughly 700 amps when the delayed laser action begins. The corresponding maximum magnetic fields are computed to be about 16,000 gauss and 7000 gauss. The present coil has twelve turns of No. 20 wire with a resistance of 0.5 milliohms and an inductance of 20 microhenries. Smaller wire sizes have been used but, under these conditions of operation, the conductors soon burn open.

For better control and to allow more intense magnetic fields to be established, it is planned to use a separate power source for the magnetic field, possibly a battery bank. Switching techniques for rapidly removing the field will then be investigated. Once proper controls are established it should be possible to investigate the effectiveness of Q-spoiling as a function of temperature. It appears possible that the sharpening of the components of the R_1 line at reduced temperatures might enhance the effectiveness of Q-spoiling.

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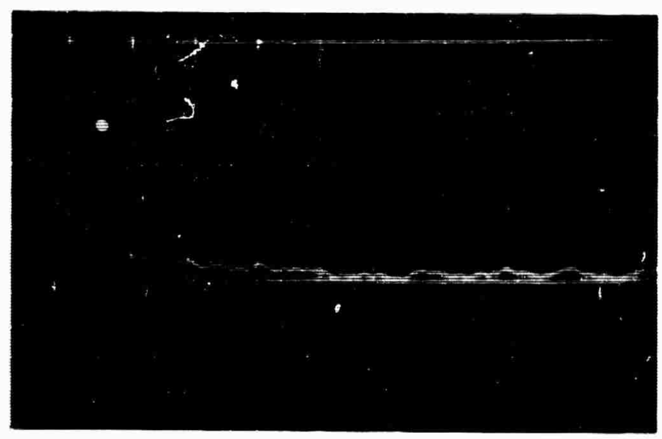
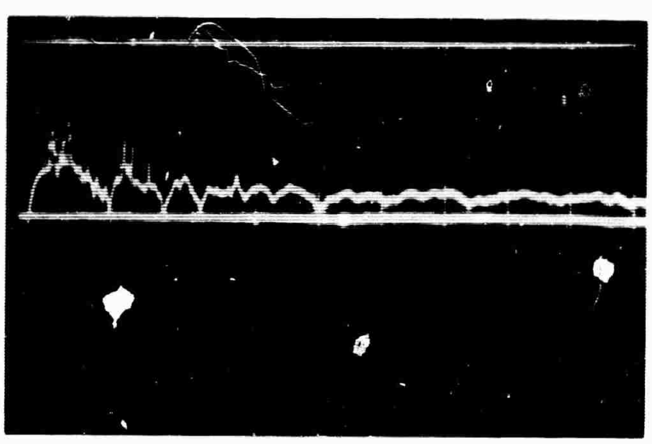
(a) Zero reference with probe beam off. Pump light pulse.



(b) Upper trace is zero reference. Lower trace is probe beam. Variable trace is probe beam with pumping.



(c) Upper trace is zero reference. Lower trace is probe beam. Variable trace is probe beam with pumping.

Fig. 1 - Effect on Probe Beam of Pumping Ruby Rod

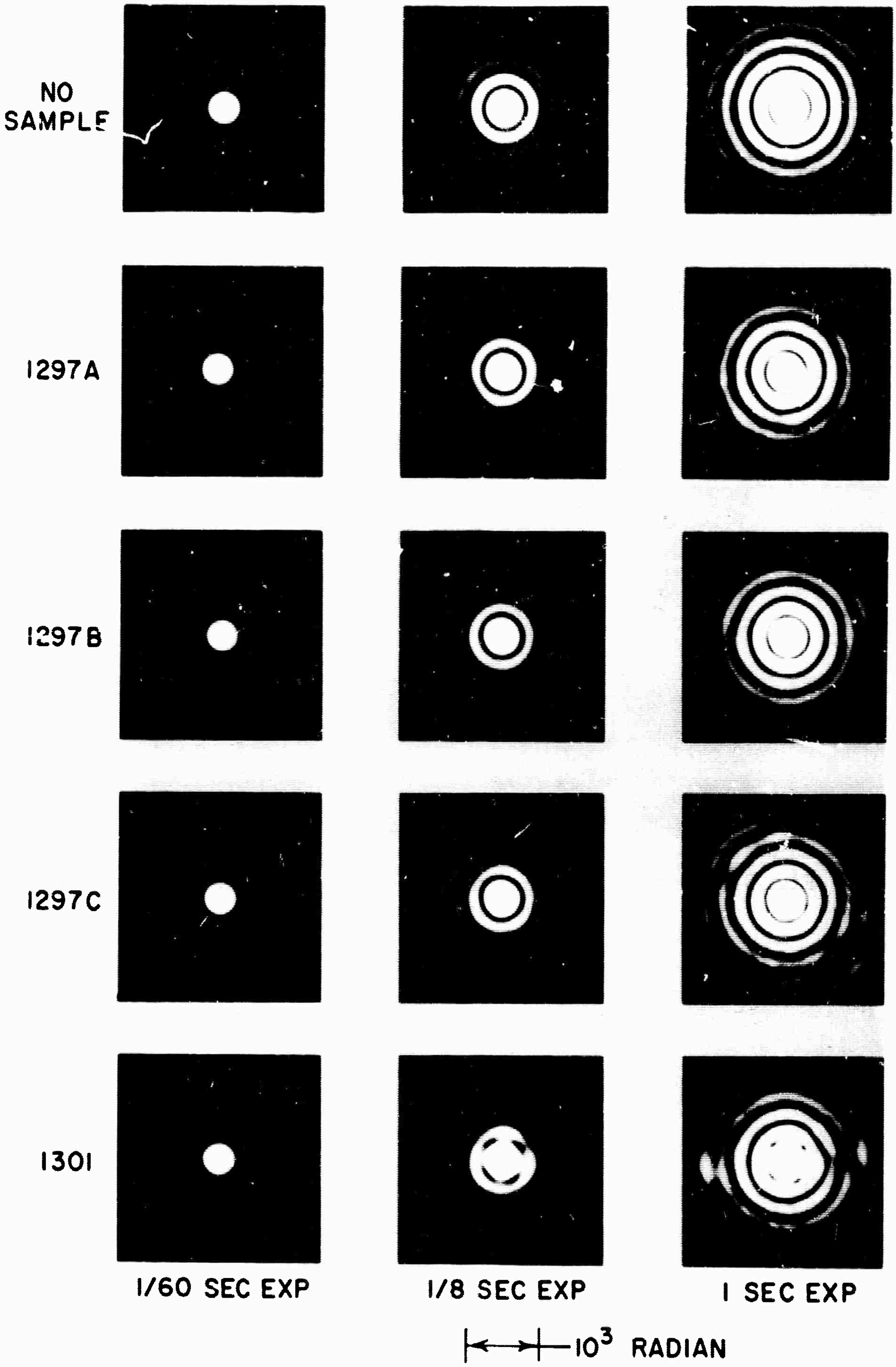


Fig. 2 - Lanthanum Fluoride Samples - Far Field Patterns

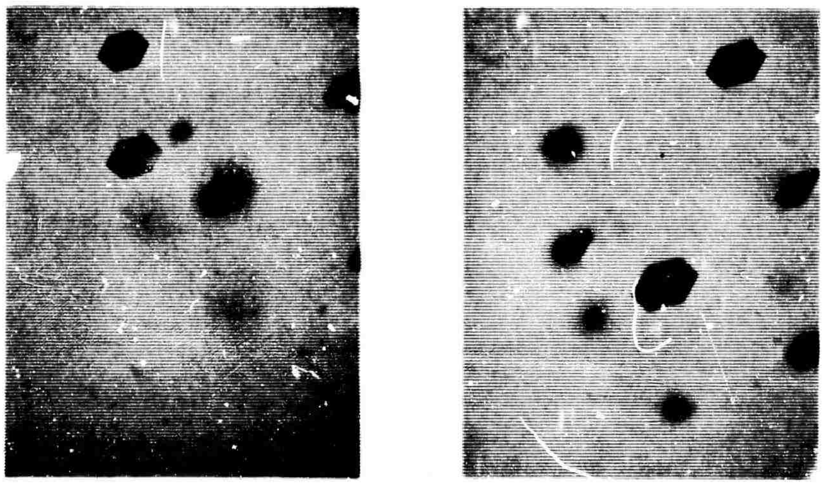


Fig. 3 - Lanthanum Fluoride Samples - Inclusions Seen at Slightly Different Depths

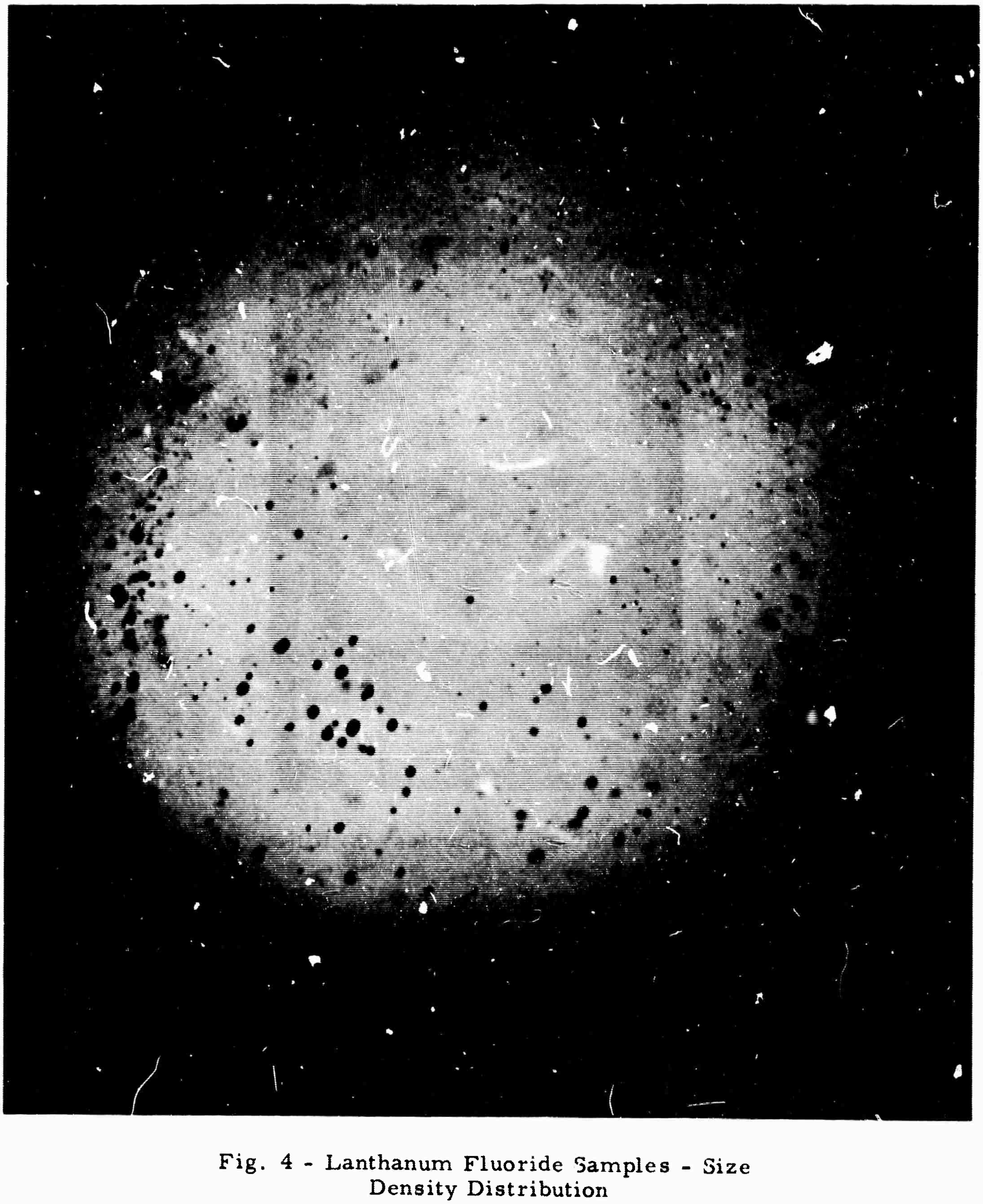


Fig. 4 - Lanthanum Fluoride Samples - Size
Density Distribution

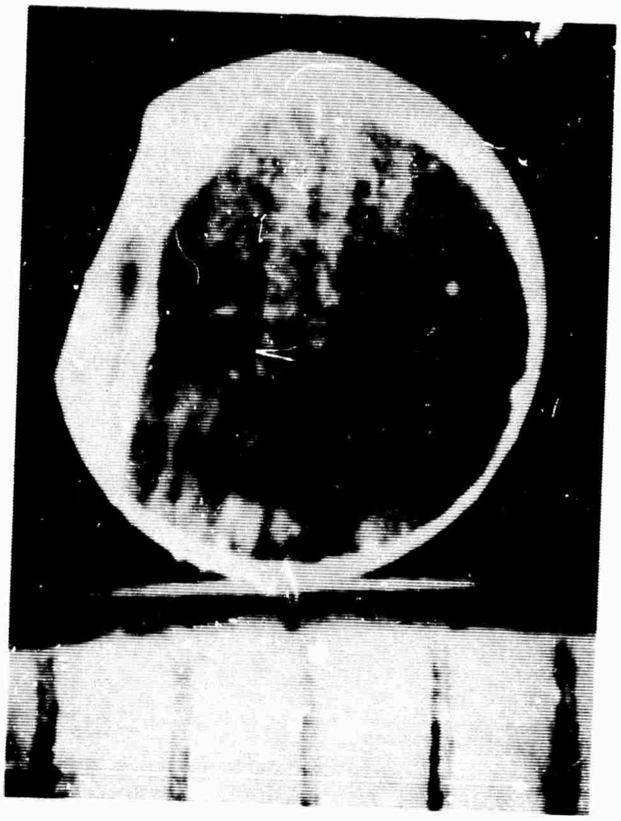


Fig. 5 - Lanthanum Fluoride Samples - Stratified Cloudiness

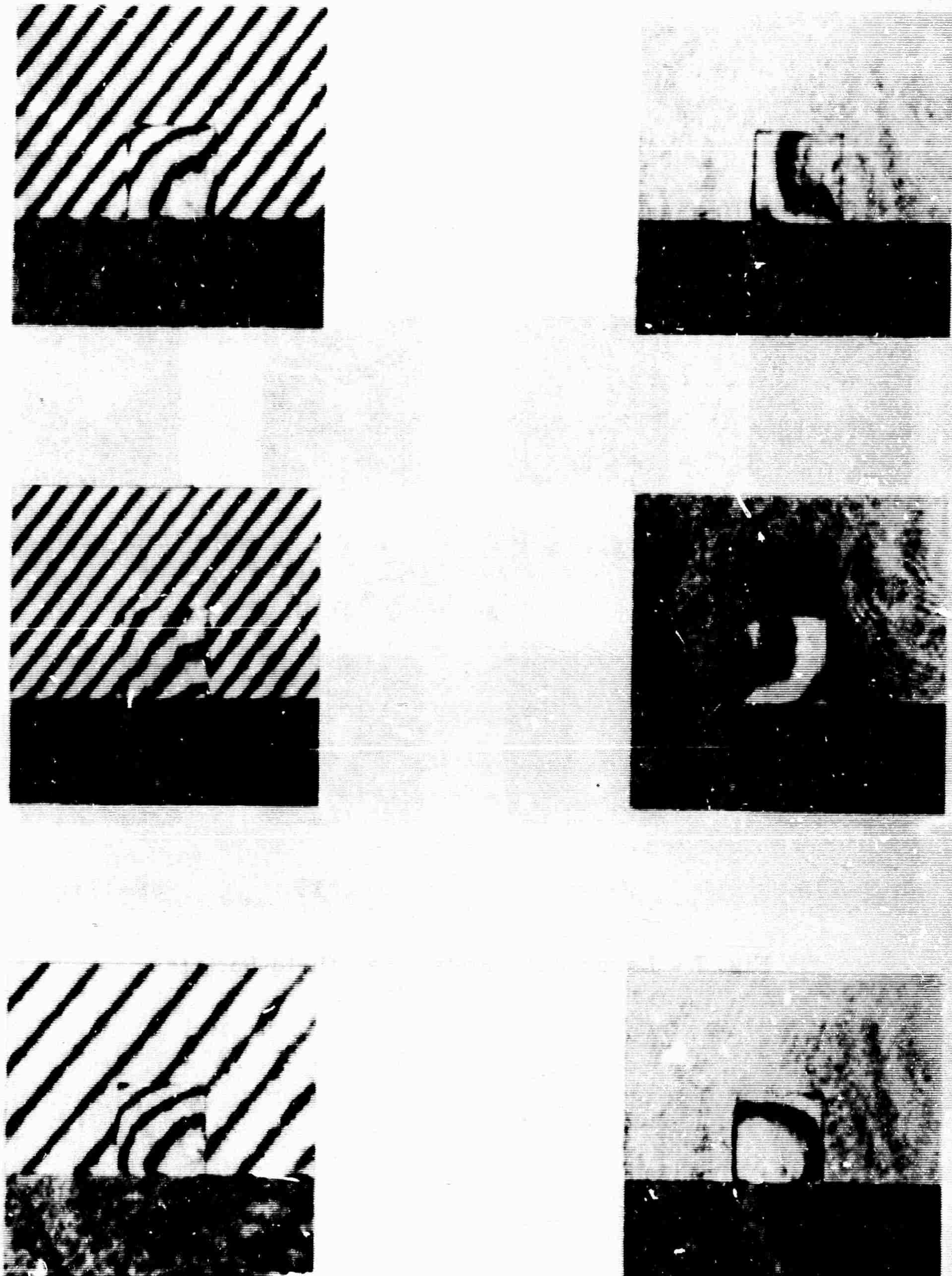


Fig. 6 - Czorchralski Ruby Cube - Twyman-Green Interferogram

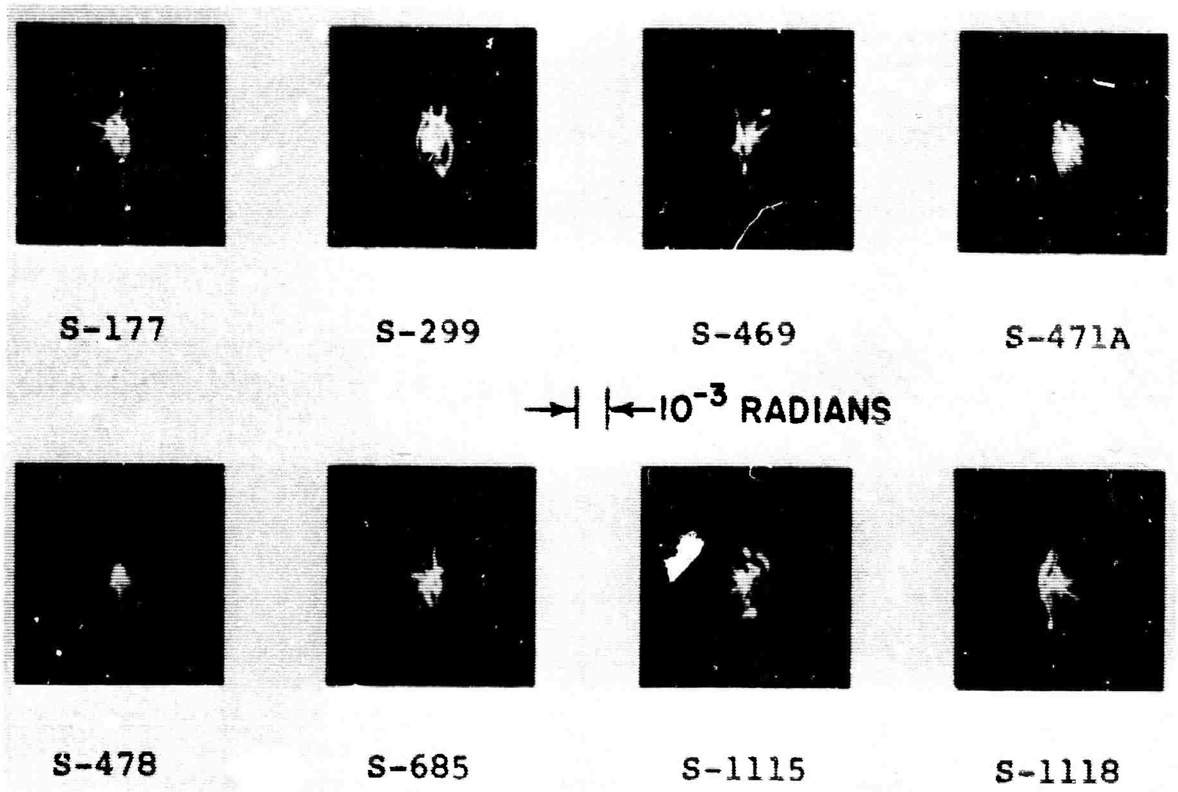
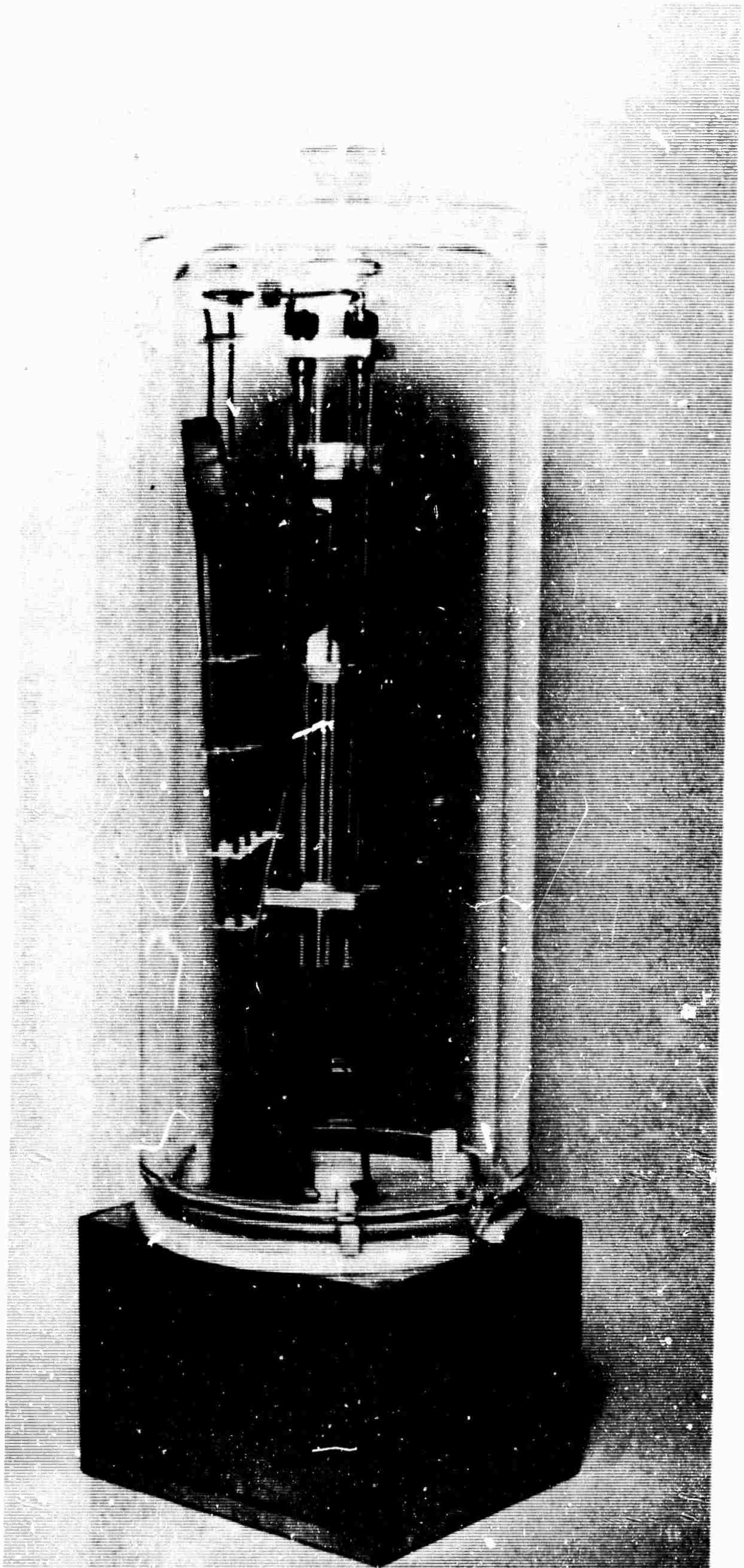
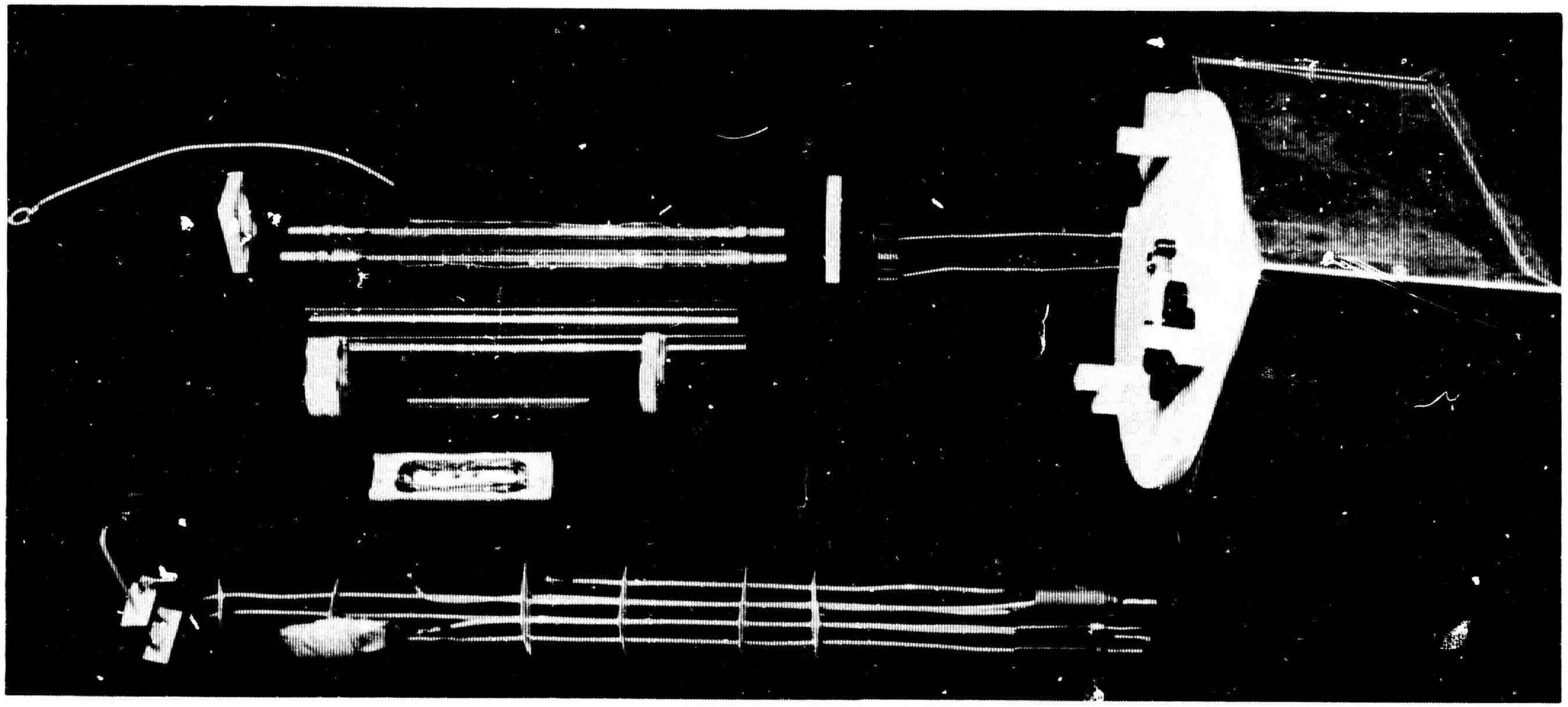


Fig. 7 - Large Ruby Rods - Far Field Patterns



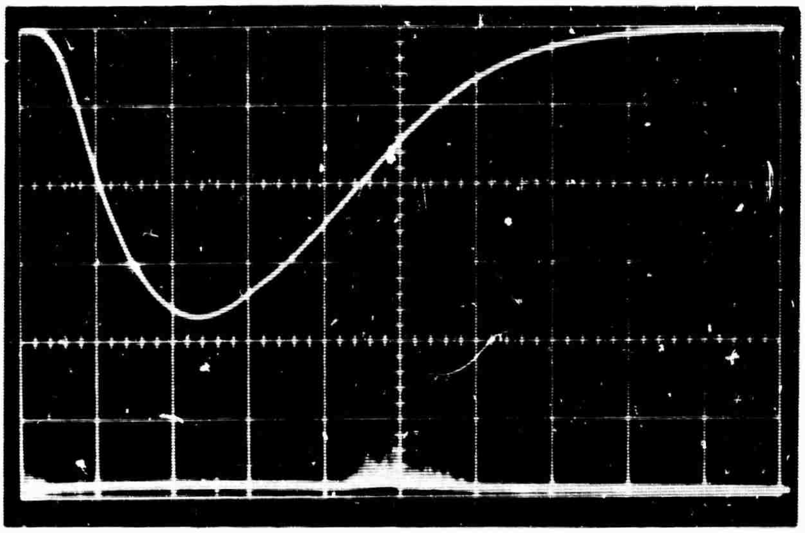
(a) Assembly in Special Glass Dewar

Fig. 8 - Laser for Low Temperature Q-Spoiling

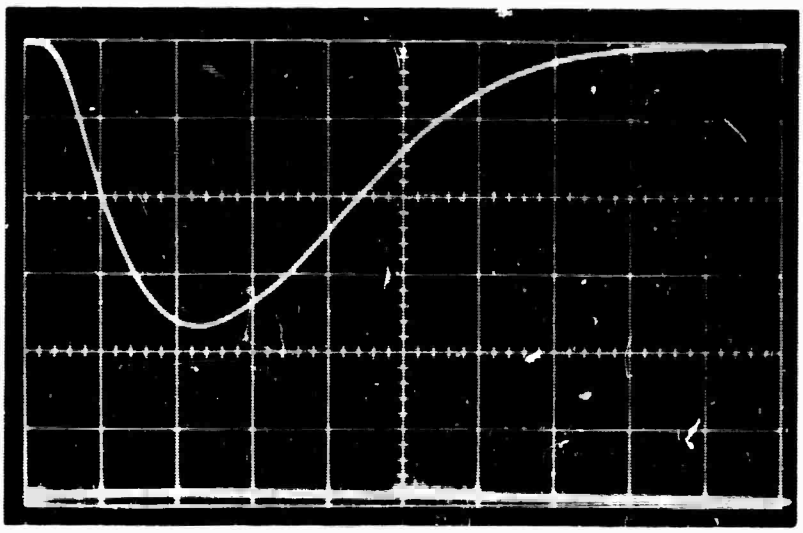


(b) Components of Assembly

Fig. 8 (cont'd) - Laser for Low Temperature Q-Spoiling



(a) No magnetic field. 200 μs/div



(b) With magnetic field. 200 μs/div

Fig. 9 - Q-Spoiling - Delay in Start of Laser Action - Top traces are of the pump light. Bottom traces show the laser output which begins 4.2 divisions after the start of the sweep in (a) and 4.8 divisions after the start in (b).