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ADDENDUM TO FINAL TECHNICAL REPORT

LASER PUMPING SOURCES

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1. Summary

Following completion of the final report[1] on this contract, a clerical error was found which when corrected allowed for additional studies. At the time of writing the final report, the investigations of pyrotechnics and shock tubes for laser pumping sources indicated an upper limit of about 5000°K for the brightness temperature of the former whereas peak brightness temperatures of 10,000°K to 12,000°K were observed in linear shock tubes, using only 1 gram of combustible material as the energy source.[1] During the latter study, considerable difficulty was encountered in obtaining sufficient time duration; sharp quenching of the radiation emission was observed after about 50 μsec. By removing particulate matter from the driver system and by decreasing the length of the driven portion of the shock tube, the quenching was eliminated and a radiation pulse of 400 to 500 μsec duration was produced.

It was decided to direct the additional study effort toward further exploration of the use of this shock tube radiation source as a laser pumping source. Previously a 2" long 1/4" diameter Nd doped calcium tungstate rod having an electrical threshold of 23 joules had been pumped above threshold by the shock tube radiation source, using a coaxial geometry. During the additional study reported here two side pumping configurations were fabricated and were used in attempts to pump a Nd doped glass rod and ruby rods, 2" long by 1/4" diameter. The glass rod, having an electrical threshold of 80 joules produced strong laser oscillation when pumped by the shock tube source. However no laser output was produced from the ruby rods.

Since the spectral studies indicated that the shock tube radiation source provides sufficient intensity and duration to pump ruby above threshold, several suspected difficulties were explored. The UV transmission of the thermal setting plastic used to encapsulate the rubies was measured and found to cut off at a wavelength of 3300A thus ruling out removal of the upper laser levels by UV pumping below 3000A as a possible explanation. On the other hand a marked increase in the threshold of ruby was observed when it was pumped only from one side. This is currently thought to be the cause of the difficulty found in using the linear shock tube to pump ruby crystals.

2. Laser Pumping Configurations and Instrumentation

The shock tube used for these studies is the same as that used in the earlier phase of the work to study spectral output, but modified to accept a laser crystal at the end wall. The shock tube and the first pumping configuration used are shown in Figure 1. The driver gas is separated from the driven gas by a milar diaphragm, .005 inches thick. The two driver gas mixtures listed below were used.

Partial Pressures of Combustion Driver Gas Mixtures

	1	2
Helium	150 psi	185 psi
Oxygen	35 psi	55 psi
Hydrogen	55 psi	120 psi
Total	240 psi	360 psi

A 1 mil thick tungsten wire running the length of the driver section was exploded using a 7 kilovolt 15 uf capacitor to produce uniform ignition of the combustion mixture.

The driven section of the shock tube used in these studies was 49-5/8" long. The incident shock speed was determined by timing signals from three solid state photodiodes viewing the incident shocked gas luminosity through three ports spaced 4-1/2" apart near the end wall of the tube. The driven gas used was xenon at an initial pressure of 300 mm Hg and ambient initial temperature, 294°K. Shock speeds are quoted here as shock Mach numbers by using the initial sound speed of the driven gas as a normalizing factor. Incident shock Mach numbers of 8 to 9 were generally produced at the end wall using combustion driver gas mixture 1, whereas values of 10 to 11 were recorded for mixture 2.

The pumping configuration shown in Figure 1 was designed, built and used in 1963 to pump a neodymium doped calcium tungstate crystal. However subsequent analysis and experimental investigation of the axial extent of the radiating gas slug showed that it extended only about 1 inch from the end plate, roughly one third the value computed from idealized shock tube analysis. Thus a portion of a 2" long laser crystal mounted as shown in Figure 1 would not be surrounded by shock heated radiating gas, resulting in a poor optical pumping configuration.

It became evident that the plane radiating surface at the end of the shock tube is well suited to laser pumping. A natural approach to exploiting this pumping source geometry is to utilize a trumpet shaped laser designed for pumping from one end. A second approach is to utilize the plane radiating surface at the end of the shock tube to pump the laser crystal from one side. The latter approach was chosen here for further study.

Two side pumping configurations were tested in sequence. The first configuration, shown in Figure 2, consists of a 3 in long transition section and a parabolic laser pumping cavity having a projected cross-section 1 in by 2 in. For some studies the parabolic surface was constructed of polished stainless steel, silver plated to produce high specular reflectivity. In other cases, the parabolic surface was coated by pressed MgO or $MgCO_3$ powder to produce a high diffuse reflectivity. The radiating surface area, 2 in^2, is slightly larger than the circumferential area of a 2 in by 1/4 in laser crystal. Thus if all of the radiation entering the parabolic cavity were to reach the surface of the crystal, the radiation intensity at the crystal surface would approach that in the pump source gas. However, rough ray tracing for this geometry indicates that only about forty percent of the radiation entering the parabolic cavity actually intercepts the laser crystal before being reflected back out. Thus if a blackbody radiating source at 10,000°K were used in this geometry, the average brightness temperature seen by the laser crystal would be roughly 7500°K (assuming the crystal has a high absorption coefficient in the pumping bands). Since the observed shock tube radiation source brightness temperature is above 10,000°K for about 150 μsec, falling to 6000°K after a total of 450 μsec, there is a good possibility that a ruby laser crystal can be pumped above threshold using this geometry.

The shock tube transition section used with this laser pumping cavity (Figure 2 produces a change in internal tube cross-section from 1 in diameter circular to 1 in by 2 in rectangular over an axial distance of only 3 in. This produces a rapid increase in tube area, weakening the shock, and reducing the radiation intensity and duration. To avoid this possibility a gradual, nearly constant area transition section and associated laser pumping cavity were constructed as shown in Figure 3. The cross-sectional area ratio of transition section 3 is 1.6 over a 10 in length whereas that of section 2 is 2.6 over a 3 in length.

The radiation surface area for the laser pumping cavity of Figure 3 is one half that of 2. However a larger fraction of the radiation entering the cavity reaches the crystal, roughly 70%. Thus the two cavities appear to have roughly equal pumping efficiency.

Laser crystals chosen for use in these shock pumping experiments were first evaluated using an electrical flash lamp pumping system to establish a relative measure of threshold pumping energy and to verify repeatability of laser crystal performance. The crystal was then imbedded in a thermal setting plastic, Maraglas #655, contained in the laser pumping configuration under study, and cured at 140°F for 12 to 24 hours. Following the shock tube experiment, the surface of the Maraset was cleaned (a slight carbon deposit was formed on the surface in each experiment) and the threshold pumping energy of the potted crystal in the shock tube laser pumping configuration was determined using an electrical flash lamp pumping device.

The instrumentation used to determine the intensity of laser output consisted of a solid state photodiode array, a vacuum photodiode, and a polaroid film (with ruby) to record the laser spot. Prior to carrying out shock tube experiments, verification that the instrumentation was in operating condition was obtained using an auxiliary laser crystal and the electrical flash lamp pumping system. No absolute energy or intensity calibration of the photodiodes was carried out to measure laser energy or power output because of the difficulties encountered in achieving threshold pumping of ruby.

3. Experimental Results

Shock tube laser pumping studies were conducted using four combinations of laser crystals and pumping configurations. In all experiments the 49-5/8 in long driven section, the gaseous combustion driver, and a 5 mil thick milar diaphragm were used. The laser crystal was imbedded in a clear thermal setting plastic, Maraglas 655, having properties similar to lucite.

The first combination studied was a 2 in by 1/4 in diameter ruby laser crystal imbedded in the configuration of Figure 2. The parabolic surface of the pumping cavity was lined with a polished stainless steel sheet onto which a silver coating was vacuum deposited. This ruby crystal lased in a conventional spiral flash lamp electrical pumping cavity with a threshold of 280 joules before being encapsulated. A modified electrical pumping system was adapted to the side pumping configuration of the encapsulated ruby and was found to require 1200 joules to reach threshold. At this energy the flash lamp pump light decayed to half intensity in 800 μsec. Laser oscillation began 400 μsec after peak flash lamp luminosity, terminating after an additional 400 μsec. This verified that laser output can be stimulated in the pumping cavity being used with the shock tube, but that the threshold requirement is considerably greater than the arguments given in Section 2 would suggest.

Several shock pumping experiments were carried out with the laser and pumping cavity described above using both combustion gas mixtures, but none showed evidence of laser output. The photodiode records showed a 200 μsec plateau of pumping radiation indicating that the performance of the pumping source was unchanged from that observed spectrally.[1] Based on the electrical threshold information a duration of 400 μsec or more would have been required. No damage to the ruby crystal occurred as a result of these experiments.

The second combination studied was a 2 in by 1/4 in diameter glass laser rod containing 2% Nd doping, encapsulated in the parabolic cavity of Figure 2. The parabolic surface was coated with a pressed MgO diffuse reflecting layer. The electrical threshold of this rod prior to being encapsulated was 80 joules. The electrical threshold after being encapsulated was not determined. Using combustion mixture number 1, this crystal produced strong laser oscillation when pumped by the shock tube source as shown in Figure 4. The output produced here is qualitatively the same as that produced by the same rod in a 150 to 200 joule conventional electrical flash lamp pump. The duration of the plateau in pumping intensity is seen to be about 300 μsec. The glass laser rod cracked across the diameter in one place as a result of the mechanical shock and could not be used in subsequent experiments.

The third combination studied was a ruby half cylinder, cut from a 2 in by 1/4 in crystal, encapsulated in the parabolic cavity of Figure 2. The flat face of the cylinder was oriented parallel to the plane radiating surface of the shock tube pumping source. The cut was made such that the direction normal to the cut surface corresponded to the maximum absorption coefficient in the green pumping band. The ruby threshold was 300 joules prior to being cut, and 280 joules after being cut. In potting this crystal, the space between the flat surface of the half cylinder and the shock tube gas was occupied by a 1/16 in lucite sheet rather than the Maraglas 655 used in other tests.

It was anticipated that the half cylinder ruby would have a considerably lower threshold for side pumping than did the cylindrical ruby. However, no laser output was recorded with the shock tube pumping source, using combustion gas mixture number 2. Furthermore the impact shattered the crystal and no further studies with it were possible. The photodiode record of pump luminosity decayed to a negligible value within 150 μsec, indicating inferior performance of the shock tube pumping source than had been experienced in the past. This may have been due to the ruby fracture since the pump light viewed by the photodiodes was only that transmitted through one end of the ruby. On the other hand it may have been due to the combination of the short shock tube transition section and the higher speed shock produced in this experiment.

The fourth and final combination studied was a 2 in by 1/4 in cylindrical ruby imbedded in the configuration of Figure 3, and the 10 in long shock tube transition section. Before being encapsulated the ruby used in this experiment had a threshold of 200 joules. The electrical threshold of the encapsulated crystal was determined only after the shock tube experiment, which caused a crack down the center of the Maraglas. Under these conditions no laser output was produced using electrical energies up to 1280 joules. Following this the ruby was removed and the threshold in a conventional electrical pump was again determined to be 200 joules. Thus the crystal was not damaged in the experiment.

As before no laser ouput was produced in the shock pumping experiment using the components described above and combustion mixture number 2. However the more gradual transition section did somewhat improve the duration of the pumping source to a value of 300 μsec.

The difficulty in pumping ruby using the shock tube radiation source evidenced by the preceding results may be caused by a number of factors. Among these is the possibility that UV pumping below 3000A may be sufficiently strong to remove atoms from the upper laser level so rapidly that inversion is never achieved. To check this possibility a spectral absorption curve of Maraglas 655 was run from 2000A to 4000A. It was found that a sample 1/16 in thick, the minimum thickness between the shock heated gas and the ruby crystal, transmits only about 1/8th of the incident intensity for wavelengths from 3000A to 2000A, whereas at 4000A it is virtually transparent. Thus UV de-pumping is probably not an important contributing factor in making ruby so difficult to pump in the shock tube.

4. Conclusions and Recommendations

From the studies of sh ·k tube laser pumping described above, a number of conclusions can be drawn. First, successful pumping of a Nd-doped glass laser rod indicates that laser action can be produced using this pump even under conditions of mechanical stress on the crystal caused by the high pressure gas in contact with the plastic potting material. Second, the electrical energy equivalent inferred from the shock pumped laser output of the Nd-doped glass laser rod indicates an equivalent chemical to electrical energy conversion efficiency of about 2%. Further improvement can be expected by more thorough engineering and design studies, making this source competitive with other stored chemical energy laser pumping systems. Third, the majority of experiments caused no damage to the laser crystal, allowing the possibility of developing repetitively pulsed chemically powered laser devices based on this concept. Fourth, considerably more difficulty was encountered in pumping ruby than was anticipated. This may be due to (a) the side pumping geometry chosen for study, (b) the low spectral intensity of the shock heated xenon source at 4100A compared to that at 5600A,[1] (c) mechanical stress, or other factors not yet recognized. Because the side pumping configuration caused an unexpectedly large increase in the electrical threshold (a factor of 4 to 6 or more) it is believed that this is the major cause of the difficulty.

Recommendations for future work include (a) exploration of symmetrical ruby pumping geometries such as end pumping or complete immersion of the protected ruby in the shock heated gas, (b) further spectral studies aimed at increasing emission in the violet ruby pumping band, and (c) development of concepts on which repetitive pumping systems using this technique can be based and evaluated.

References

1. S. Byron, et.al., "Laser Pumping Sources," Aeronutronic Report U-2771, 15 July 1964.

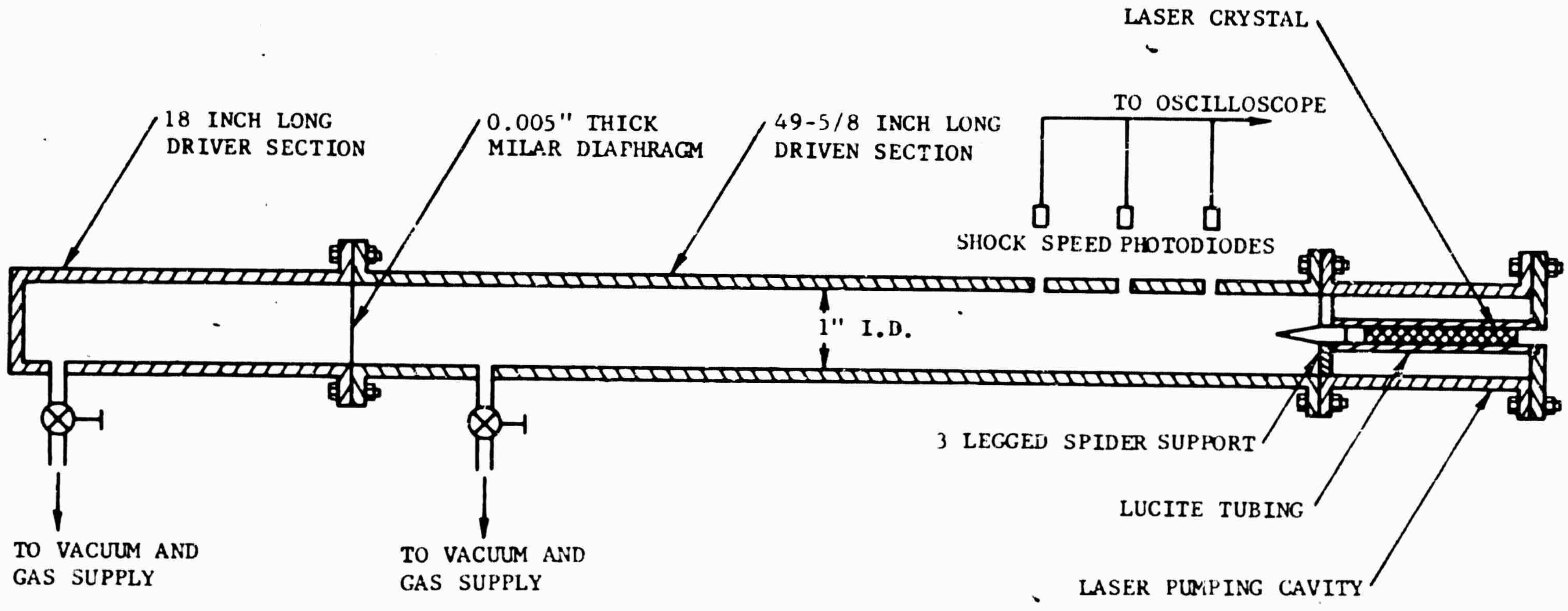

FIGURE 1. CHEMICALLY DRIVEN SHOCK TUBE AND THE FIRST LASER PUMPING CAVITY USED IN STUDIES OF SHOCK PUMPING LASER CRYSTALS

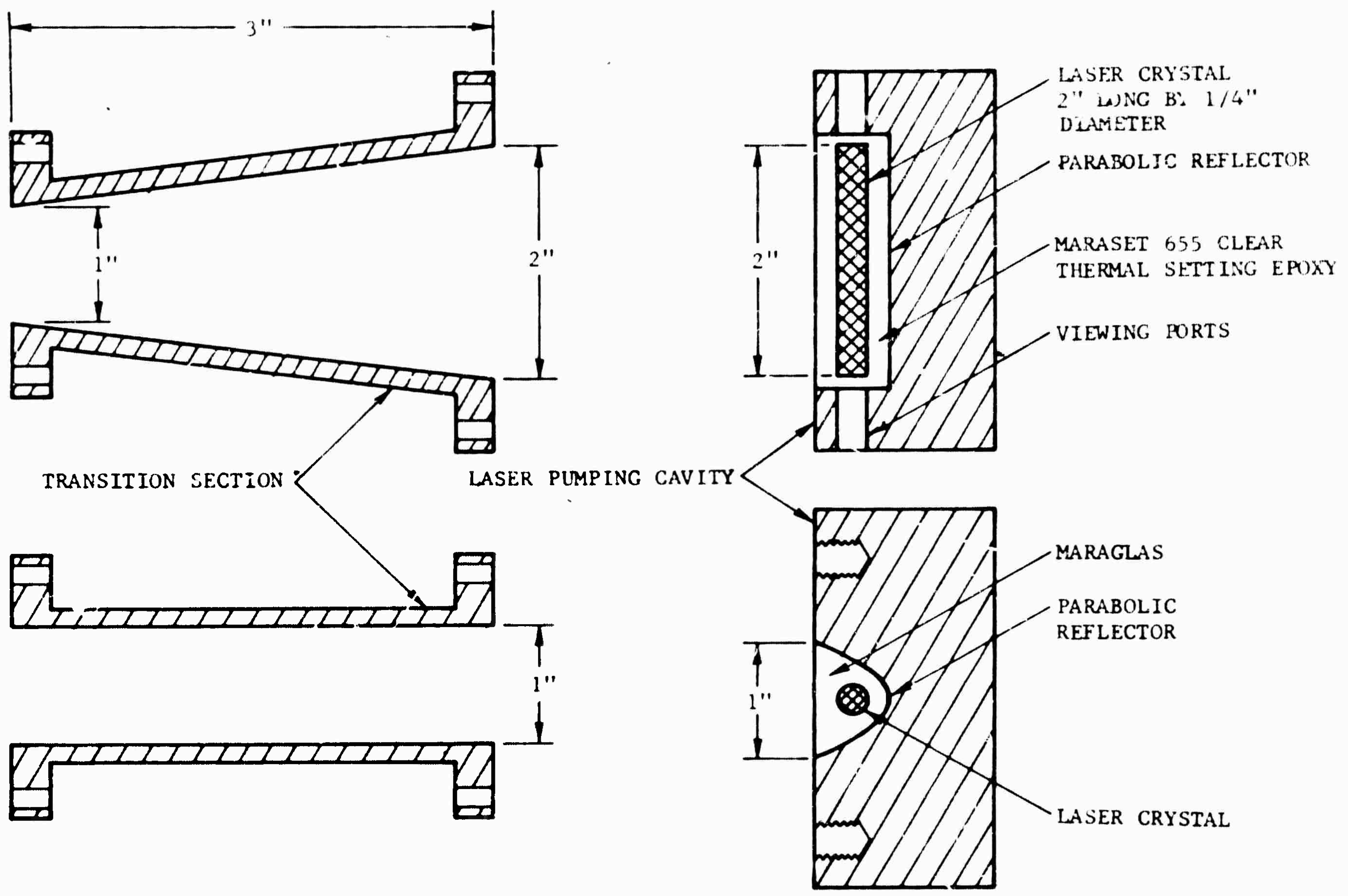

FIGURE 2. 3" LONG SHOCK TUBE TRANSITION SECTION AND PARABOLIC LASER PUMPING CAVITY

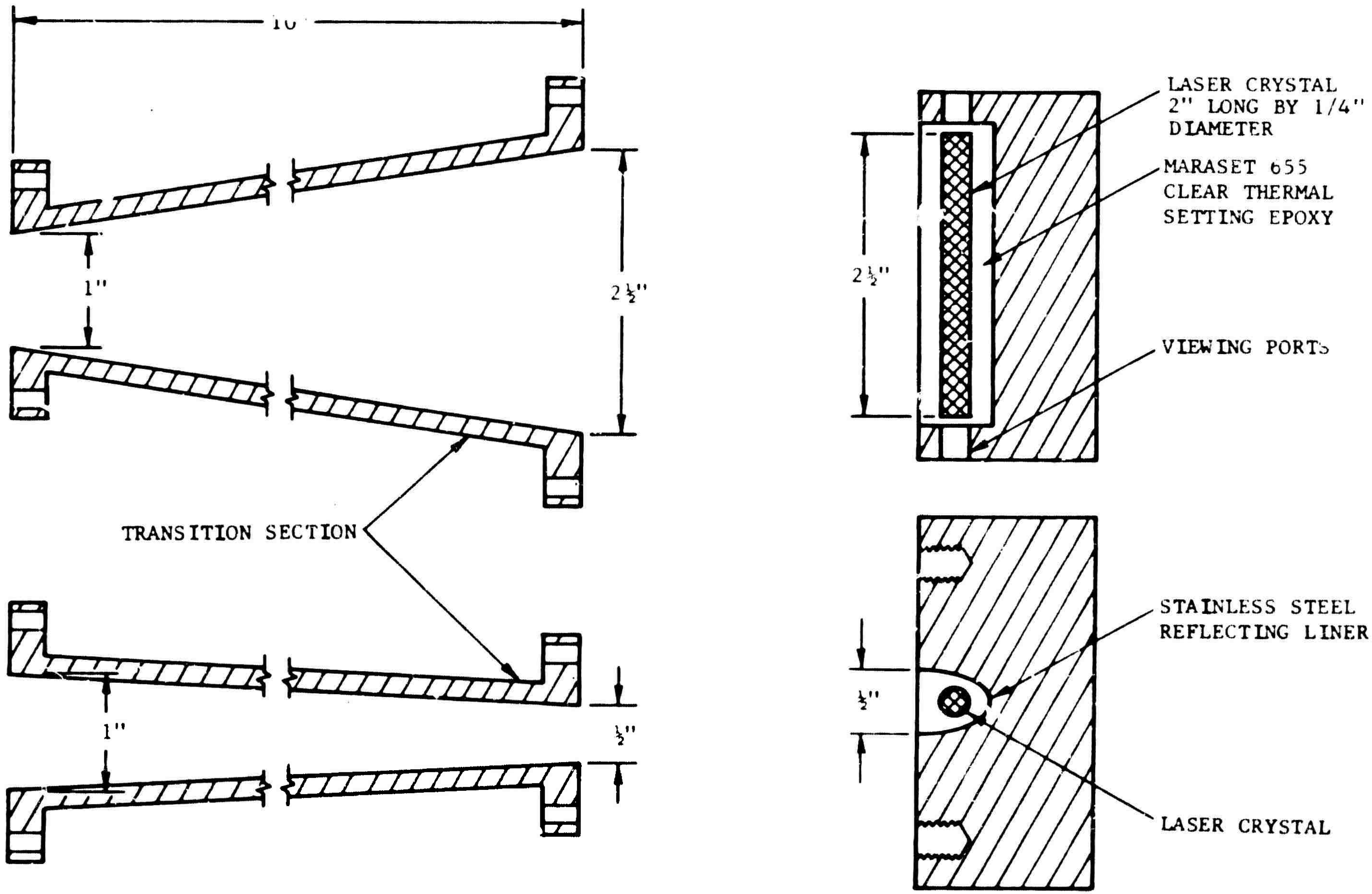

FIGURE 3. TEN INCH LONG SHOCK TUBE TRANSITION SECTION AND LASER PUMPING CAVITY

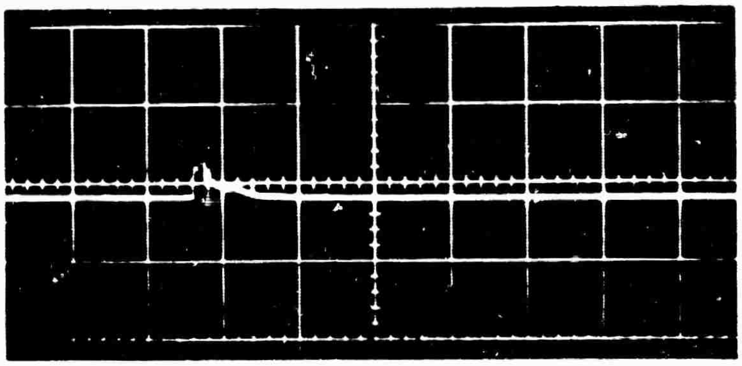

FIGURE 4. VACUUM PHOTODIODE RESPONSE TO CHEMICALLY DRIVEN SHOCK TUBE LUMINOSITY PLUS Nd-DOPED GLASS ROD LASER OSILLATIONS. SWEEP SPEED, 500 μSec/div. SENSITIVITY, 1 Volt/div. SWEEP TRIGGERED BY IGNITION OF COMBUSTION DRIVER GAS.