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DISCLAIMER

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ABSTRACT

A technique is described for operating a mode-locked neodymium-glass laser in the TEM_{00} mode.

A successful technique is described for spatial control[1] of the transverse modes in a mode-locked Neodymium-glass laser.[2] The technique utilizes spatial aperturing (within the cavity) in conjunction with split-image near-field photography[3] through the 99% reflecting mirror.

The apparatus is shown in Fig. 1. Both Perkin-Elmer dielectric coated mirrors transmit in the visible. The 1.2 meter cavity has a round trip time of about 8 nanoseconds. The radius of curvature of the 99% mirror is 6 meters, and the 85% reflecting output mirror is flat. The cavity aperture is an adjustable iris, and is intentionally mounted at a slight angle to the beam on an adjustable x-y translation mount. The glass clad 3/8" diameter x 6" length American Optical laser rod is pumped laterally by two linear Xenon flashlamps in series with a 75 μh choke and 115 μf capacitor. The flashlamp duration is ≈200 μ sec, or about 1/3 of the Neodymium fluorescence lifetime. Operating voltages are ≈2400 volts (open aperture), ≈2700 volts TEM_{oo}, and ≈4000 volts TEM_{oo} mode-locked. The dye cell is well-protected from flashlamp light and roomlight, and dry nitrogen is bubbled through the cell every hour or so to reduce the oxygen concentration. These precautions seem to prolong the usefulness of the Kodak 9740 dye. The laser rod, aperture, and dye cell are placed as close as possible to the curved mirror (where the beam diameter will be the largest) in order to avoid optical damage. Since the curved laser mirror passes most visible light, initial alignment of the photography can be done by illuminating the far end of the laser rod. The phosphor[4] is activated by brief illumination with a Mercury vapor discharge, and the lens is chosen so that the resultant photograph will show views of two different cross-sections of the

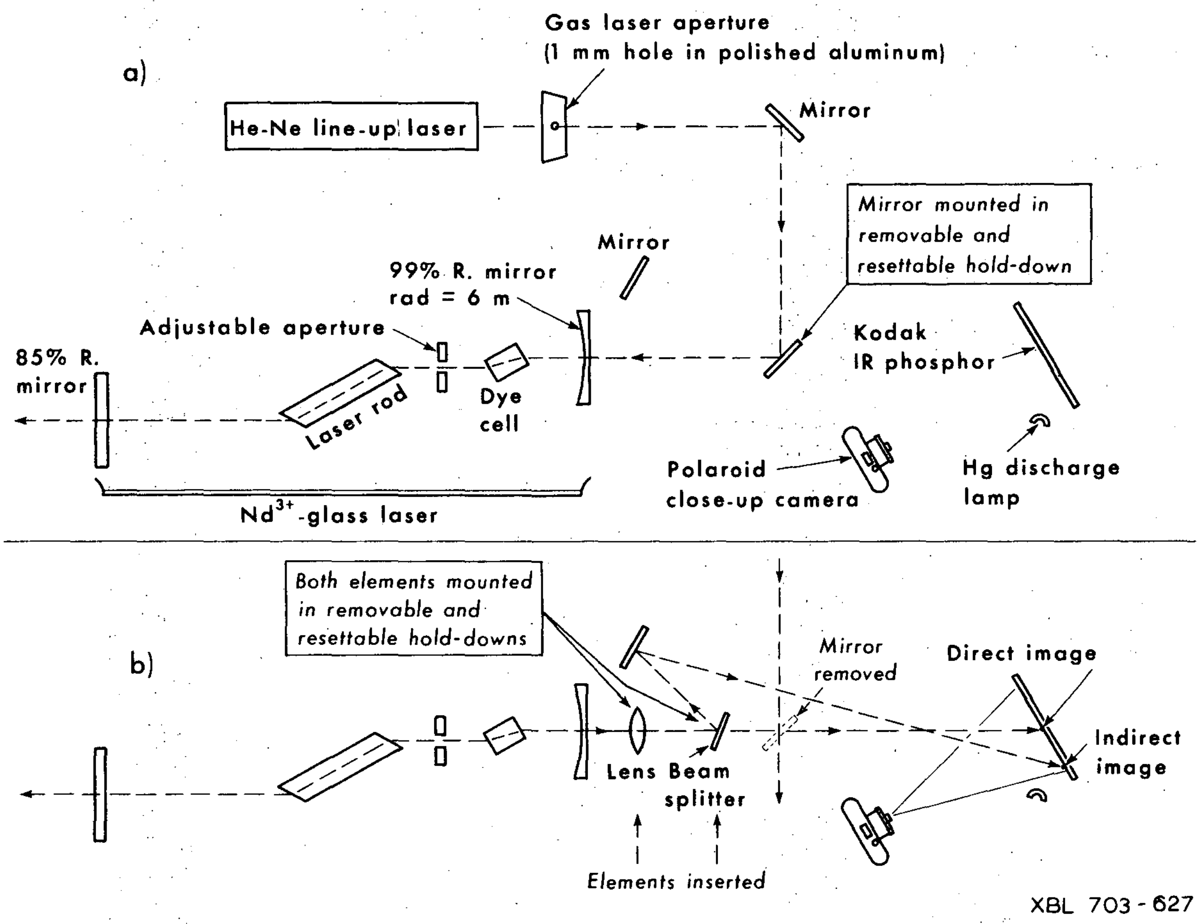

Fig. 1. Experimental setup
a) The gas laser lineup configuration.
b) The photographic configuration.

flashlamp-illuminated laser rod superimposed on the two views of the laser beam profile.[5] The apparatus is basically operated in two configurations: the gas laser lineup configuration (Fig. 1a) with the lens and the beamsplitter removed and the gas laser directing mirror in place, and the opposite (Fig. 1b) called the photographic configuration. One advantage of this setup is that one can direct the lineup laser through the mode-locked laser and into the experiment without interfering with the cavity or output optics.

The alignment procedure is as follows. With the system in the gas laser lineup configuration, the cavity iris wide open, and the dye cell filled only with solvent, one adjusts the cavity mirrors and the gas laser directing mirror until the appropriate reflections are centered on the shiny surface of the gas laser aperture. The laser is then fired with small adjustments of the cavity mirrors until lasing is detected. The laser is then converted to the photographic configuration. If the lens is not too heavy, it can rest on the rear crosspiece of the 99% mirror angular orientation mount. One briefly illuminates the phosphor and then fires the laser with the camera open, and, in the photograph, the lasing should appear in the same region of both cross-sections (otherwise the line of lasing is not parallel to the long axis of the laser rod). (Adjustment of the flat output mirror orientation controls this <u>parallelness</u> as well as the <u>location</u> of the beam, while adjustment of the 99% curved mirror controls only the <u>location</u>.) The parallelness (output mirror) adjustment should be done in small steps (with appropriate 99% mirror adjustments to keep the lasing near the center of the rod) until the lasing is parallel to the long axis of the laser rod. If the laser is operated too far above threshold, the mode structure will saturate the rather restricted dynamic response of the phosphor, and little information can be extracted. After the lasing is centered and parallel to the long axis of the laser rod, one should check to see that the power supply voltage is near threshold, and one should produce a burn spot on an unexposed portion of developed Polaroid film mounted outside the output mirror. The apparatus is then returned to the gas laser lineup configuration. The orientation and location of the gas laser directing mirror should be adjusted until the beam is centered on the burn spot and, simultaneously, that the reflections from the laser mirrors are centered on the shiny gas laser aperture, so that the gas laser beam is nearly duplicating the path of the 1.06μ light. The cavity aperture should then be centered on the gas laser beam, and the laser should be returned to the photographic configuration.

The next step is to accurately center the laser cavity aperture on the center of the lasing. This is done by carefully adjusting the position of the iris until the location of the center of the lasing pattern (in the photograph) is independent of the iris opening. The photographs then can readily indicate the mode structure of the beam, and one should simply close down the aperture until only the TEM_{00} mode remains.[6] In this experiment, TEM_{00} operation (not mode-locked) was achieved with an aperture of ≈3 mm. Examination of the photographs can be facilitated if the beamsplitter reflectivity is much different than 50%. The two images will then be of two different laser intensity profiles (which effectively increases the dynamic range of the phosphor).

The mode-locking dye should then be added to the solvent (and the input power should be correspondingly increased) until mode-locking is observed. Then the transverse mode control of the adjustable aperture should be rechecked because the dye can influence the mode patterns. It also is convenient every few shots to closely examine the cavity iris for burn spots, and to touch any spots with a drop of India ink. This helps to prevent the buildup of multiple pulses[7] within the cavity. It is also beneficial every few shots to dust off all optical surfaces in the cavity. Either a clean dry camel's hair paint brush or a dust-free air brush is suitable.

In operation in this laboratory, a rather thick dye cell (3/8" optical path) was chosen so that the problems of multiple pulsing could be reduced.[8] Although the optimum dye cell thickness has not yet been determined, there may be disadvantages to having too thick a cell because the solvent (an optical Kerr liquid) may in part be responsible[9] for the inherent frequency modulation detected by E. B. Treacy.[10] The orientational Kerr effect in the solvent could be reduced[11] by a factor of four (by changing the cavity configuration so that the light is linearly polarized in the laser rod, and is circularly polarized in the dye cell), and such experiments to determine the possible improvement of the mode-locked laser are now being undertaken. It has also been suggested[12] that the TEM_{00} operation could simplify the phase modulation function of an individual mode-locked pulse.

If one must operate the laser near the threshold of glass damage, this technique will permit a nondestructive alignment procedure. This technique could also increase the effective life of a laser rod by allowing one to keep track of the laser rod regions which have been damaged in previous shots.

The results of this mode-control technique have been encouraging. We report no visible damage to the laser rod (and no increase in threshold) and only two tiny burn spots on one of the mirrors after thousands of firings. The absence of optical damage could well be due to the uniform spatial distribution of the beam and the resultant reduction of focusing instabilities.

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2. For a review of the mode-locking technique, see A. J. DeMaria, W. H. Glenn, Jr., M. J. Brienza, and M. E. Mack, Proc. IEEE 57, 2 (1967).
3. For a discussion of near-field photography, see H. G. Heard, Laser Technology Section, Microwaves Magazine, Hayden Publishers 7, 71 (1968).
4. A prepumped Kodak IR Phosphor (Eastman Kodak Company) emits in the visible if excited by the 1.06μ light.
5. The 1% laser light leakage through the 99% mirror is sufficient to stimulate the phosphor.
6. The study of the mode structure via Polaroid film burn spots is confused by the fact that a mild burn is white while a strong burn turns brown. Thus the center of the TEM_{oo} burn spot might appear darker than its surroundings, and one might be tempted to identify it as the TEM_{10*} mode.
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8. When a thin dye cell "opens" for a strong pulse passing through it, an unwanted weak pulse could pass in the other direction, but this may be partially prevented in a thicker dye cell if the entire thickness is not simultaneously bleached. It has been suggested by H. P. Weber [J. Appl. Phys. 39, 6041 (1968)] that placing the dye cell adjacent to the cavity mirror can also help to reduce multiple pulsing.

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