HIGH REPETITION RATE PULSED LASERS*

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For many applications, a pulsed laser operating at high repetition rates with reasonable power is needed. To further this objective, a low-threshold (1 joule) laser device using neodymium doped materials (glass and $CaWO_4$) has been evolved. A pulse repetition rate of 40 per second has been achieved. At 10 pps, peak power levels of the order of a kilowatt have been measured. Extension of the techniques developed to a class of lasers having higher powers and/or higher repetition rates will be examined.

Some of the important factors associated with this development, which have been investigated in some detail, will be presented. These are efficiency, pump source, power supply cooling, and component reliability. Finally, the characteristics of this laser will be compared to previous laser types with reference to potential application, in particular for a laser range finder.

I. INTRODUCTION

This paper is concerned with the design and development of a high repetition rate pulsed laser. In particular, a low threshold laser device using neodymium doped host materials will be described. This laser has been operated at a pulse repetition rate of 40 per second, using only forced air cooling. At 10 pps, peak power levels of the order of a kilowatt and an output beamwidth of about 10 milliradians have been measured. The total weight of the laser assembly and power supply is about 80 pounds.

This laser yields high power output as compared with continuously operating gaseous and solid state lasers and, at the same time, yields a high pulse rate as compared with previous high power pulsed lasers. Thus, it can be useful in a number of applications for which prior lasers were unsuited.

II. DESIGN CONSIDERATIONS

A. Materials Selection

The choice of the material is primarily based upon threshold and efficiency considerations. The three material candidates considered most promising were: ruby, neodymium glass, and neodymium doped crystalline materials.

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Table I shows the results of some threshold tests on these materials. The ruby rod was .160 inch diameter and was clad with a sapphire sheath .280 inch in diameter. All other materials were .250 inch diameter. All rods were 2 inches long, and had dielectric reflectors with 97% reflection on the transmissive end. On the basis of these tests and other considerations, the laser was designed around the borate-base glass and the calcium tungstate materials.

TABLE I: LASER MATERIAL THRESHOLD COMPARISON

Material	Coupling	Pump Pulse (microseconds)	Relaxation Time (reported) (microseconds)	Threshold (joules)
Ruby (.05%)	Elliptical No. 2	100	3000	50
Nd-Glass No. 1 (2%-Silicate)	Helical	about 200	500-600	900
	Elliptical No. 1	175		300
Nd-Glass No. 2 (1%-Borate)	Helical	100	70-100	250
	Elliptical No. 1	35		20
	Elliptical No. 2	40		4
Nd-CaWO$_4$ (0.5%)	Elliptical No. 2	40	500-600	1

B. Pumping Lamp Selection

Here again the criteria adopted were efficiency and achievement of longest possible lamp life within the geometrical limitations imposed by considerations of optical coupling efficiency.

With little previous experience on which to base lamp selection for high pulse rates, a careful search was made for a suitable lamp. The major problem encountered was sputtering or evaporation of the electrodes which rapidly darkened the lamp walls and lowered the efficiency. As a result of detailed tests of both commercial and experimental flash lamps, a standard lamp, the E.G. & G. FX 38A, was finally selected for the laser. The outstanding characteristic of this lamp is the elimination of any sharp corners on the front surfaces of the electrodes. Presumably this allows a more uniform current density and more uniform heating of the electrodes. Thus, higher average powers are permissible without localized high temperatures. The lamp also has an activated cathode and a tungsten anode. The FX38A was operated at various pulse energies below 30 joules for an estimated total of 40,000 flashes. Some evaporation was apparent at the end of this service, but only near the anode and the lamp efficiency had decreased only slightly, if at all.

C. Laser Configuration

An optical system is required to provide efficient coupling between the pump source and the laser material. Rugged mechanical construction was important. Another consideration is the ease with which lamp and laser rods can be changed.

The lamp and laser rod are placed quite close together, symmetrically displaced from the axis of a circular cylinder with 3/8" center-to-center spacing. The circular cylinder is a good approximation to an elliptical cylinder for coupling purposes[1] if close spacing between the lamp and laser rod are maintained. Figure 1 is a photograph of the finished laser showing inside detail. The housing has an inside diameter of 2". The two small tubes at the ends of the laser rod contain the external mirrors which form the optical resonant cavity. These mirrors can be aligned by three screws at each end. The spacing between the mirrors was adjusted so that the focal point of both mirrors was at the same location when the laser material was inserted. The use of an external mirror arrangement is imperative for high pulse rate operation. It is found that for laser rods with reflectors applied directly to the ends, the output ceases for a time because of uneven heating of the material and consequent warping or misaligning of the mirrors. The closed section at the left in Fig. 1 contains an auxiliary collimating lens to render the diverging laser beam more parallel. The closed section at the right contains the blower for cooling.

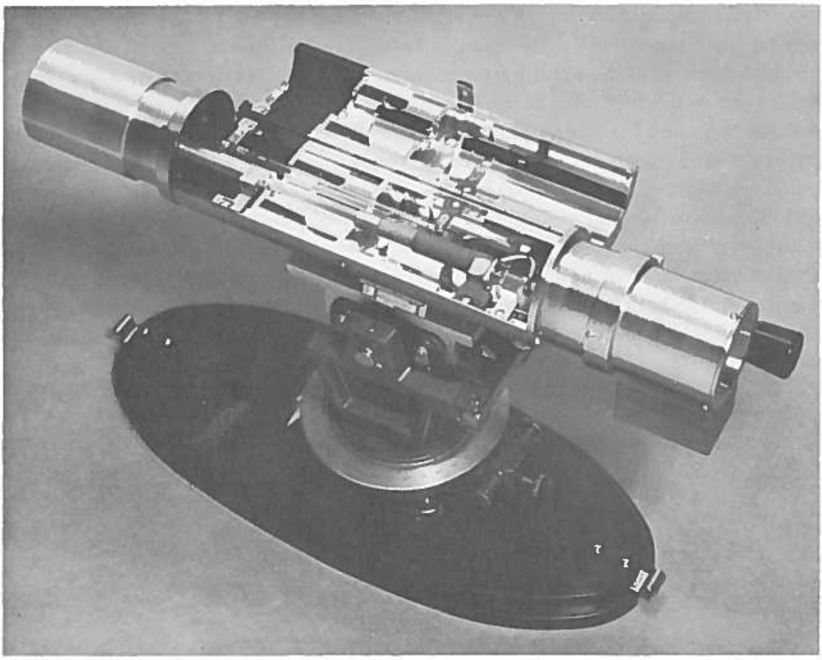

Fig. 1. Laser housing.

D. Cooling

Both the laser material and the pump source dictate the cooling requirements. In the beginning of the program, liquid cooling was regarded as a distinct possibility since the average power requirements might have run as high as 1500 watts if ruby had been used. After the choice of doped neodymium materials had been made, forced air cooling was found to be sufficient. This could also be predicted by appropriate calculations. Using a laser material with a four level energy configuration (especially with the glass hosts) the performance of the laser is relatively insensitive to changes of temperatures. Temperatures of as high as 130°C have been measured on the glass laser rod surface, but this did not seem to lower the laser efficiency. External wall temperatures of the lamp envelope of approximately 200°C were measured with a thermocouple at an input energy of 17 joules and a pulse rate of 10 pps. A Rotron vaneaxial blower running at 19,000 rpm was employed.

E. Power Supply

The design of a suitable power supply was based on efficiency, light weight and elimination of a triggering electrode on the flash lamp, so that liquid cooling could be used if necessary.

The choice of laser material determined the energy necessary for laser excitation. The maximum pulse energy was fixed at about 30 joules. This energy was delivered from a five-section pulse-forming network each having 2.5 μf with associated inductance to match the measured lamp impedance (about one ohm under the load conditions to be used). To ensure reliable triggering and prevent self-breakdown at high operating temperatures and high pulse rates, a high power switch tube in the form of a ceramic hydrogen thyratron was placed in series with the flash lamp and the energy storage network. Figure 2 is a diagram showing the essentials of the power supply. Also in series with the lamp is the secondary of a pulse transformer which is wound on a saturating core. This transformer allows the flash tube to be triggered with a short high voltage spike superimposed on the leading edge of the main discharge pulse. The pulse forming network is charged from a constant current network. Two SCR's shunted across the output of such a network provide both voltage protection and adjustment. The power supply consists of a single package, approximately 70 pounds in weight and includes the following sub-units:

a) 400 c/s constant current network.
b) Voltage regulation and protection unit using SCR's.
c) High voltage dc power supply.
d) Line type modulator for pulse forming.
e) Trigger generator operating from approximately 1 to 35 pps.
f) Trigger amplifier.

The weight mentioned above can certainly be reduced by optimizing circuitry and careful selection of components.

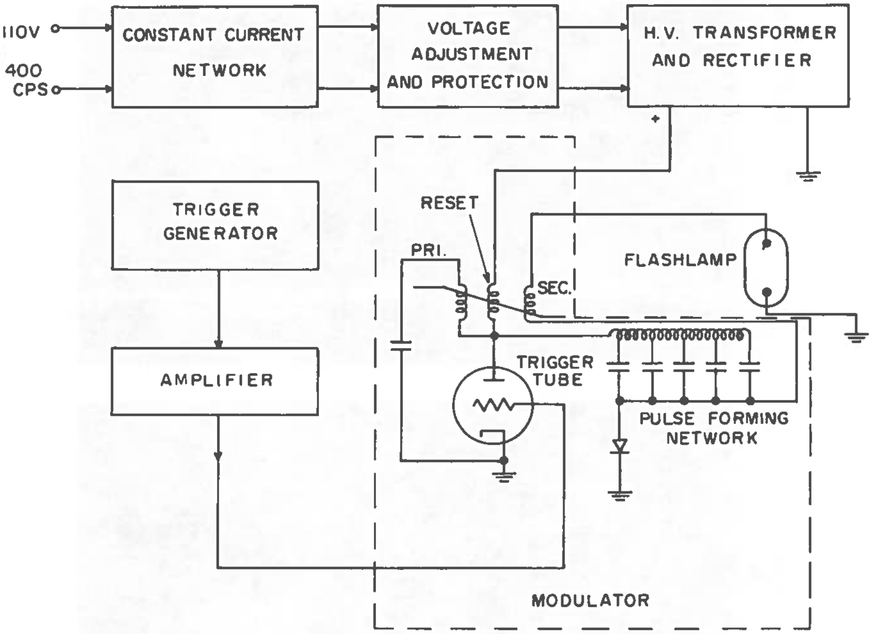

Fig. 2. Power supply.

III. LASER PERFORMANCE AND LIMITATIONS

A. Characteristics

Peak output powers greater than 1 kw have been measured using the glass rod with output energies of about .03 joule and a pulse length of about 35 μsec. These figures are for the laser operating continuously at 10 pps, so 300 mw average power have been attained. The maximum efficiency attained is about 0.1%. Beam collimation to about 10 milliradians has been obtained. With better end reflectors, energies of 0.1 joule are probable with the present design. Higher pulse repetition rates (up to 40 pps) have been achieved with the calcium tungstate rod. Figure 3 shows a series of photographs taken to show output pulse shape and repeatability.

B. Limiting Factors

1. Cooling

The method of cooling used in the laser, while adequate for the present power levels, would need modification if the power input capability per unit length were to be increased. This is one way of extending the output power and energy. The best method of improving the cooling would be to enclose the laser rod and lamp in separate tubes and force air or a liquid coolant through them. Either the air or liquid could be refrigerated if the input power were made high enough. Some

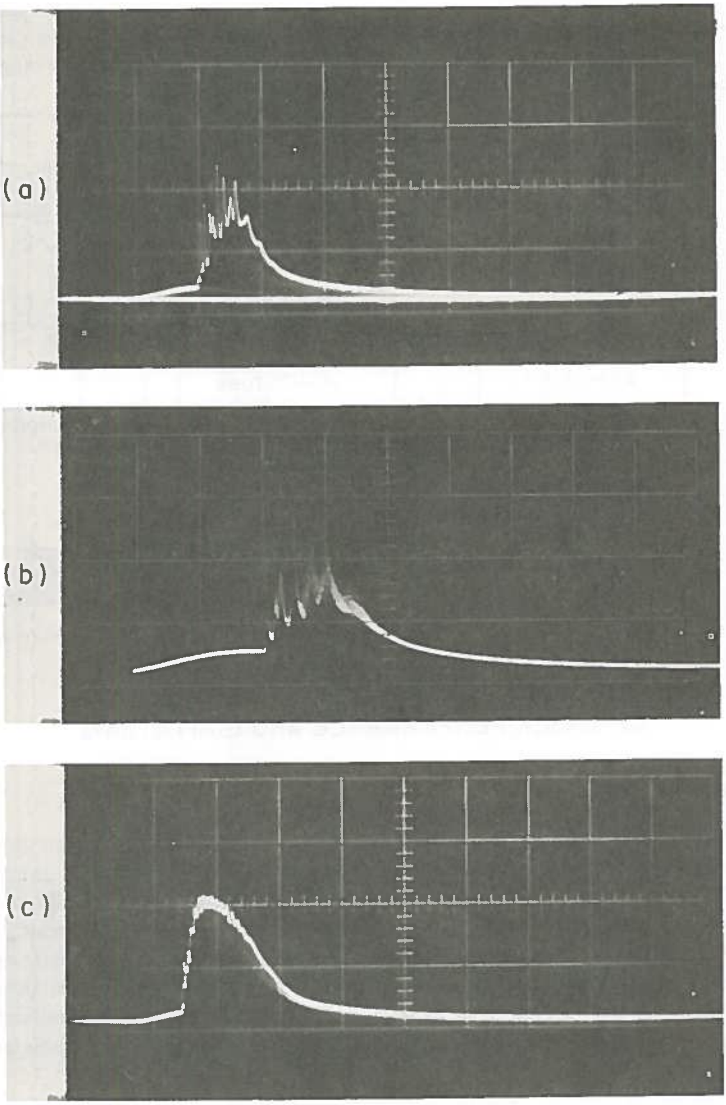

Fig. 3. High pulse rate laser output. (a) 20% above threshold, 20 μsec/cm; single pulse exposure of operation at 5 pps. (b) 50% above threshold, 10 μsec/cm; 10-second exposure of operation at 10 pps. (c) 5 times threshold, 20 μsec/cm; single pulse exposure of operation at 5 pps.

pumping losses would be associated with these tubes from reflective losses at the extra surfaces. Tubes around both the lamp and laser rod might result in an efficiency loss of about 30% to 40%. However, the gain in allowable average power density could conceivably be many times this loss.

2. Resonant Cavity Reflecting and Anti-Reflecting Layers

Life of the mirrors and anti-reflecting coatings is probably limited to about an hour at the present peak powers and energies. Most of the optical companies who make these coatings have development programs under way to improve the quality and durability of optical coatings, but unless and until improvements are made, any work done toward increasing the output power and energy above the present levels should include an exploration of the possibility of eliminating all coatings in the resonant cavity. For example, the reflectors might be replaced by totally reflecting prisms with output coupling provided by reflection from a prism located in the resonant cavity at a suitable point. Reflective losses could be reduced, at some cost in complexity of the geometry, by the use of surfaces on the optical elements oriented at the Brewster angle.

3. Pump Lamp Capability

The degree to which further average power density can be attained from the present type of pumping lamps without improved cooling is uncertain. For extensions of the present work toward higher powers, this factor would have to be investigated. Greater peak powers desirable for greater efficiency by more intense pumping of the present short-spontaneous-lifetime materials (such as the borate glasses) might be a more severe problem than greater pulse rates because of peak heating of the inside lamp wall.

4. Laser Material Characteristics

New laser materials and better quality of doped glasses and calcium tungstate can always improve laser performance. In particular, good optical quality will reduce scattering losses. Furthermore, long spontaneous lifetime is desirable, as this would make it possible to lengthen the pumping pulse and thus increase the energy per pulse. Finally, the laser system should have a good quantum efficiency and be insensitive to moderate temperature changes.

5. Size Limitation

A rather large gain in output energy per pulse can probably be obtained merely by increasing the length of the laser rod and the pumping lamp. Lamps of the type used have been made as long as six inches, and longer ones can probably be made.

IV. APPLICATIONS AND PROSPECTS

Numerous applications for the laser have been proposed which utilize its characteristic properties of coherence, spectral radiance, and monochromaticity. Therefore, the output and performance parameters of the laser just described should assist in the evaluation of possible optical ranging and surveillance systems. Especially in an application placing stringent weight limitations and oriented to relatively short working distances, this type of laser can be employed effectively.

Also in other areas one can find distinct advantages if use is made of the prime feature of this laser (i.e., a high repetition rate). For instance, tests have been made with the prototype model to explore the feasibility of optical maser micromachining. The results indicate that cutting speeds of about one to two inches per minute are possible in 2-mil thick stock with the present design.

It is believed that a laser can be built to deliver a pulse energy output of one joule at a pulse rate of 10 per second utilizing present techniques. If higher pulse repetition rates are more desirable at about the present power levels, a pulse rate of 30 can probably be attained with pulse energy outputs of about 0.1 joule. For many applications a much shorter pulse length (of the order of 10 to 50 nanoseconds) is desirable. This can be obtained with the use of so-called Q-switching techniques, which could be incorporated without difficulty in the laser design described in this paper.

ACKNOWLEDGMENTS

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REFERENCE

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