01 Jan 1975

A High-Power Pulsed Xenon Ion Laser As A Pump Source For A Tunable Dye Laser

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Abstract—**An inexpensive pulsed xenon ion laser with peak power outputs up to 4 kW has been constructed and used as a pump source for a tunable rhodamine 6G dye laser with a 0.25-Å bandpass in the yellow–red range of the spectrum. The dye laser is tunable from 5465 to 6300 Å. Over 50 W are obtained at the peak of the tuning range.**

I. Introduction

There has been considerable recent interest in the pulsed xenon ion laser [1]-[4]. The interest stems primarily from the simplicity of a high-gain laser system which is capable of relatively high peak power emission in the blue-green region of the spectrum accompanied by relatively long pulsewidths. We have investigated the properties of a high-power pulsed xenon ion laser and its use as a pump source for a tunable dye laser. Peak pulse powers of 4 kW and pulse durations up to 1 μs have been obtained in a 120-cm × 4-mm xenon discharge at pressures between 5 and 30 m · torr. The high peak power available in the xenon laser has enabled us to use it as a pump source for a rhodamine 6G dye laser which is tunable from 5465 to 6300 Å with a 0.25-Å bandwidth. At the peak of the dye laser output, ~ 5750 Å, we obtain over 50 W of peak power with 500-ns pulsewidths.

In the sections following we describe the operating characteristics of our pulsed xenon laser and its use as a pump source in the design and construction of the tunable dye laser system.

II. Xenon Ion Laser

Data obtained in earlier work on this type laser system are summarized in Table I along with the results of our work. It is important to note that, based on the volume of the excited gas, the work reported here represents a substantial improvement in both the peak pulse power and pulse duration obtained. In particular, we compare the results of our work with that of Hänsch *et al.* [3]. It was the report of their work on the xenon laser and dye laser that provided the initial motivation for the work we report here. The particular aspect of the Hänsch *et al.* work which attracted our attention was the low construction cost and simplicity of design of the xenon laser and the dye laser system.

The only work which reports a higher peak power than that reported here is that of Gundersen and Harper [4] who obtained approximately 80-kW peak pulse power. Their laser tube, however, was over 10 ft in length with a bore area approximately 20 times greater than the one we used.

TABLE I
Summary of Recent Work on Pulsed Xenon Ion Lasers

Workers	Active length (cm)	Bore diameter (mm)	Total Peak Power (W)	Pulse width μs
Hoffmann and Toschek [1]	175	5.0	380	0.6 - 1.5
Simmons and Witte [2]	150 300 30	2.3 3.0 1.5	900 1,300 100	0.5 - 5
Hansch, Schawlow and Toschek [3]	120	4.0	300	0.3
Gundersen and Harper [4]	300	17.0	80,000	0.11 - 0.2
This work	120	4.0	4,000	0.1 - 1.5

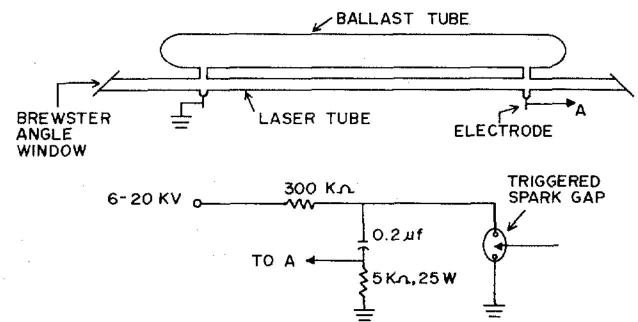

Fig. 1. Pulsed xenon ion laser and electrical discharge circuit.

The active length of the discharge tube was 120 cm with a bore diameter of 4 mm. The laser tube length was supplemented by an additional 25 cm at each end between the internal electrodes and the windows which terminated the laser tube. The electrodes are high-current indium cathodes constructed by melting pure indium metal around the tungsten electrodes [5]. The additional spacing between the electrodes and Brewster windows was provided to reduce the possibility of window contamination by sputtering of the metal at the electrodes. The laser tube also included a ballast tube as shown in Fig. 1.

We utilized a number of electrical circuits for the pulsed excitation of the laser discharge tube. The first method and probably the simplest we utilized was that described by Hänsch *et al.* in their report on the xenon laser [3]. The power supply consisted of a 15-kV 60-mA high-voltage transformer of the type used to excite neon signs and a bank of twenty-two 500-pF capacitors connected across the transformer terminals and laser electrodes. In this condition the laser tube discharged at a 120-Hz rate, i.e., on each half-cycle.

With an 80-percent output reflector in place we obtained

Manuscript received June 16, 1975. This work was supported in part by the Air Force Office of Scientific Research under Contract 2672, and in part by the Office of Naval Research under Contract N00014-75C-0477.

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results identical with those reported by Hänsch *et al.* [3]. There were eight visible lines observed in laser emission ranging from the violet at 4306 Å to the orange at 5956 Å. The maximum peak power output obtained was 300 W with laser pulsewidths up to 350 ns.

With the circuit described previously the pulse repetition rate was erratic with many skipped pulses. We had additional difficulty with periodic failure of the doorknob capacitors. As a result of these difficulties we abandoned this excitation method and constructed a spark-gap-triggered discharge. The important features of the spark gap are its exceptionally low inductance, its capacity for holding off high voltages, and when it does break down, its capacity of transferring large quantities of electrical charge. Our triggered spark gap has properties similar to those of commercial manufacture.

The capacitive discharge circuit is shown as part of Fig. 1. When the properties of the laser system were evaluated with this circuit we obtained a substantial increase in both peak power and laser pulse duration.

The peak pulse power obtained and the pulsewidth as a function of the charging voltage on a 0.2-μF capacitor are shown in Fig. 2. These data were obtained when the laser pressure was optimized for maximum power. Table II summarizes typical peak powers obtained for seven of the eight observed transitions.

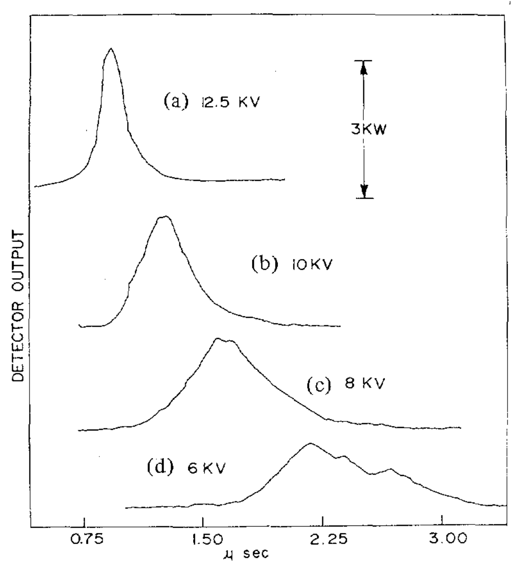

Fig. 2. Laser pulse shapes obtained at various charging voltages for a 0.2-μF capacitor. The curves were obtained with a high-speed silicon photodiode and a PAR boxcar integrator. The scale shown on the horizontal axes represents time delays after a trigger pulse is applied to the spark gap.

TABLE II
PEAK POWER ON OBSERVED LASER LINES

Wavelength(Å)	Peak power(watts)
5956	110
5395	480
5353	800
5260	680
5190	250
4954	800
4306	50

This laser system was capable of repetition rates from single shot up to 30 Hz. The upper limit is determined by the present capacity of our power supply. From the energy-per-pulse measurement and the repetition rate one can obtain the *average* laser power output. The highest average power we obtained was approximately 20 mW.

The data shown were obtained with an 80-percent broadband reflecting output mirror. In an effort to determine the optimum output coupling we repeated the power measurements for output mirror reflectivities of 98, 50, and 20 percent. At 98 percent, the power output was reduced by a factor of 2. At 20 percent the output power was down an order of magnitude, while with the 50-percent mirror similar results were obtained. We thus conclude that the mirror reflectivity required for optimum power output lies between 50 and 80 percent.

The availability of substantial laser output power even with mirrors which transmit 80 percent of the incident optical energy is an indication of the relatively large gain of several of the laser transitions. This in turn suggests that relatively lossy elements can be inserted in the optical cavity while still maintaining laser action. As a next step in this work the addition of a nonlinear crystal in the optical cavity is planned to attempt intracavity frequency doubling of the Xe ion laser emission.

III. THE TUNABLE DYE LASER CAVITY

Several dye laser cavitites have been developed in the past for use in CW dye laser applications. In these systems one needs a cavity design which provides an intracavity focus to meet the pumping requirements. In CW systems pump power is at a premium and the pump beam is generally focused to a small spot to provide a high energy density within the dye. One also desires a long cavity length as well, for tuning purposes.

Cavity configurations which satisfy these requirements are resonators with an internal lens or the equivalent three-mirror cavity [6].

Hänsch *et al.* constructed a three-mirror resonator and pumped the dye with the output of their pulsed xenon ion laser. With rhodamine 6G dye they obtained 12 W of peak power at 5700 Å. The resolution of the dye laser emission they reported as <100 Å. However, they did not include a frequency-selective element inside the dye laser cavity. Consequently, the dye laser output was not tunable and their laser output had poor resolution.

The three-mirror resonator of [6] was modified slightly by replacing the flat mirror (1) by a 1200-l/mm grating in Littrow mount as shown in Fig. 3. Mirrors 1 and 2 are highly reflective over a broad band and have radii of curvature of 5 and 10 cm, respectively. When the mirrors are separated by 10 cm there is a tightly focused spot at the center of the 2 mirrors. At this point a cell of thickness 1 mm containing a 10^{-3} M solution of rhodamine 6G dye in ethanol is inserted at Brewster's angle. The dye is contained in a sealed cell. It

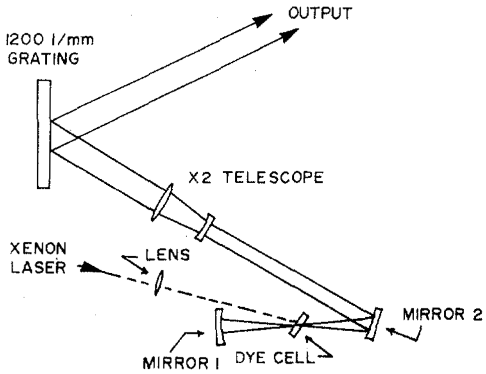

Fig. 3. The astigmatic dye cavity. A 1200-l/mm grating is used as the output reflector.

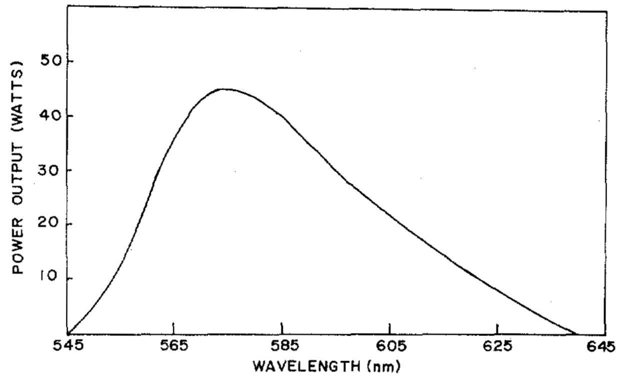

Fig. 4. Power tuning curve for rhodamine 6G. Bandwidth is less than 0.25 Å over entire range. Pulsewidth is 350 ns. Pump power is approximately 1.6 kW.

was found unnecessary to flow the dye. The grating is located 25 cm from mirror 2. A two-power telescope is used inside the cavity as shown to expand the beam on the grating.

The xenon ion laser light is focused on the dye cell by a 20-cm fL spherical lens as shown. When properly adjusted the dye system lases with no difficulty. The dye output is taken from the zero-order diffraction from the grating which was blazed for 5000 Å. No system degradation over many days was observed by using a sealed dye cell containing 0.1 ml at repetition rates to 30 Hz.

With the dye laser system described in the preceding section pumped by our xenon ion laser we were able to obtain substantially higher peak power outputs from the dye laser than that reported by Hänsch *et al.* In addition, the presence of the grating permits tuning of the dye laser output and results in a much higher resolution of the laser emission.

Our tuning width with rhodamine 6G ranged from approximately 5465 to 6300 Å, with a bandwidth of less than 0.25 Å. The peak output power at the center of the tuning range was 50 W. The dye laser pulsewidth was slightly shorter (~20 percent) than the xenon pump pulse. The power tuning range we obtained for rhodamine 6G is shown in Fig. 4. The dye laser gain pumped by the xenon laser is sufficiently great that the system lases even when a clear quartz plate is used as the output reflector.

This is the first reported instance of a tunable dye pumped by a repetitively pulsed xenon ion laser. Without the telescope, the dye laser bandwidth was about 2 Å with a peak power output of 100 W at the center of the tuning range.

Rhodamine B dye was used also; contrary to expectations it did not provide operation further into the red than rhodamine 6G. This may be more a property of the dye mirrors and grating used which were standard commercial reflectors for rhodamine 6G than any inherent difficulties with the pumping source.

The attractive features of this xenon pumped dye laser are the relatively high repetition rates and the relatively long pulsewidths available in a simple, inexpensive system. The 0.25-Å bandpass obtainable with the grating telescope combination should make this a valuable tool in atomic spectroscopy. We also note that a considerable improvement in the efficiency of the system and the bandwidth should be possible by using coated optics in the telescope and, in general, by upgrading the quality of the components.

Acknowledgment

The author wishes to thank W. Hoffman and S. Price for assistance in the design and construction of the lasers.

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