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XeCl LASER PUMPED IODINE LASER USING t-C$_4$F$_9$I

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In H. Hwang and Kwang S. Han
Department of Physics
Hampton University
Hampton, VA

ABSTRACT

An iodine photodissociation laser using t-C$_4$F$_9$I as the active material was pumped by an XeCl laser. An iodine laser output energy of 3 mJ with pulse duration of 25 ns was obtained when the pumping pulse energy was 80 mJ, the iodide pressure was 70 torr, and the reflectance of the output mirror was 85%. The high pumping efficiency and low threshold pump power achieved in this experiment are attributable to the high absorption cross section at the pump laser wavelength (308 nm) of the iodide used.

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I. Introduction

Since the atomic iodine photodissociation laser was discovered by Kasper and Pimentel in 1964 [1], numerous research efforts have been concentrated on this laser to increase the power level needed for laser fusion [2,3]. The fusion-experiment-oriented iodine laser is constructed in a master-oscillator-power-amplifier (MOPA) architecture [4].

The iodine laser is also being considered as a direct solar pumped laser for space applications such as the laser propulsion for an orbital transfer vehicle. The first solar simulator pumped iodine laser was reported in 1981 by Lee, et. al. [5]. This laser was operated in quasi-continuous-wave mode. After this report, various iodine compounds were tested and evaluated as candidates for direct solar pumped laser materials [6,7,8].

Although many space applications are best served by a continuous wave (CW) laser, a continuously pulsed laser also has good applicability in space, especially for laser propulsion. If weak pumping (such as solar radiation pumping) of laser materials exists, use of a MOPA system is essential for obtaining high peak power when the laser material has a long upper-state lifetime like an iodine atom. In previous research, the feasibility of the oscillator-amplifier scheme was proposed and tested for the solar pumped iodine laser [7,9].

In order to be incorporated in the MOPA system, the iodine laser oscillator must generate temporally smooth and short pulses. In the fusion-oriented-iodine-laser-experiment the short pulse is provided by mode-locking of the flashlamp-pumped oscillator. However, the repetition rate of the flashlamp-pumped oscillator is usually very low (<5Hz), and the mode-locking devices are generally complicated. An excimer laser pumped iodine laser oscillator was demonstrated by Fill et. al. [10]. In their experiment, a 500-mJ excimer laser was used for the pumping of the iodine laser, and a temporally smooth laser pulse with duration from 2.6 ns to 12 ns was obtained by using i-C_3F_7I as the laser material.

In this report, a XeCl laser pumped iodine laser using t-C_4F_9I is described. This laser oscillator has much a higher efficiency and a lower threshold pump power than the system using i-C_3F_7I. The laser output energy dependence on the gas-filled pressure and on the reflectance of the output mirrors are measured for both longitudinal and transverse pumping.

II. XeCl Excimer Laser

A laboratory built XeCl laser was used for the pumping of the iodine laser in this experiment. The electrical circuit of the XeCl laser is shown in Fig. 1. A pyrex tube with an I.D. of 0.1 m and a length of 0.66 m was used as the laser chamber. The two brass electrodes were rounded in order not to develop an arc discharge in the discharge volume. The width of the electrodes was 20 mm, and the length was about 0.45 m. The separation between the two electrodes was 20 mm. Seventeen pairs of arc arrays were located beside the electrodes so that the discharge volume could be preionized uniformly. The optimized gas composition was HCl: Xe: Ar: He = 0.2% : 5.9% : 19.5% : 74.4% at a total pressure of 2 atm. The addition of argon gas improved the discharge uniformity at the higher operating voltage.

When the XeCl laser was operated at the charging voltage of 25 kV, the output energy was 80 mJ per pulse. If the charging voltage was increased, the output energy also increased, but an arc discharge developed between the electrodes. Thus, operation above 25 kV was not pursued. A typical laser pulse is shown in Fig. 2. The half width (FWHM) of the XeCl laser pulse was about 25 nsec, and no significant variation of the laser pulse was found for prolonged operation.
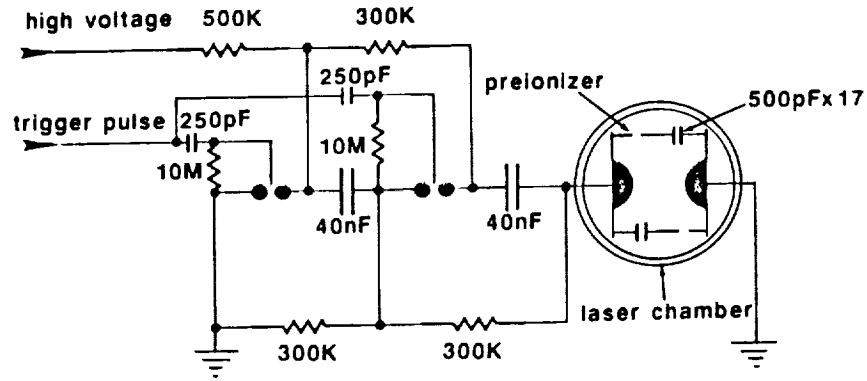

Figure 1
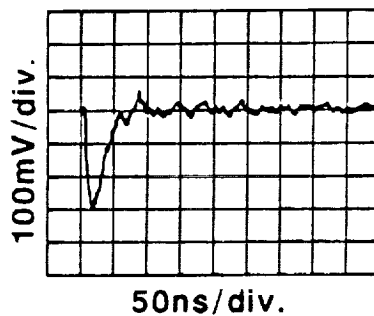Electrical circuit diagram of the XeCl excimer laser.

Figure 2
A typical pulse shape of the XeCl laser output.

III. Iodine Laser Experiment

The iodide used in this experiment was t-C_4F_9I (perfluoro-tertiary-butyl iodide). This material was chosen mainly due to the absorption cross section at the wavelength of XeCl laser light (308 nm). The published data show that the absorption cross section of t-C_4F_9I at 308 nm is about 3.6×10 -10 cm^2 [7]. Also, t-C_4F_9I has shown good chemical reversibility in a flashlamp-pumped system [6,7], and thus the iodine molecule buildup in the laser cell is minimized. The main disadvantage of this iodide is the low vapor pressure (≈ 85 torr) at room temperature. The other chemical kinetic properties are nearly the same or better than other commonly used perfluoroalkyl iodides in the flashlamp-pumped experiment [7]. The quantum yield of excited atomic iodine in the UV photodissociation is nearly unity [11].

A quartz cuvette with a square cross section of 1 cm^2 and length of 50 mm was used as the iodine laser cell. The windows of the laser cell were nearly perpendicular to the optic axis of the laser cell. Both longitudinal and transverse pumping of the iodine laser were employed.

When the iodine laser was pumped longitudinally, a dichroic mirror was used to introduce the XeCl laser light into the iodine laser cell. The dichroic mirror transmitted about 80% of the XeCl laser light and fully reflected the iodine laser light. The XeCl laser light was directed through the dichroic mirror and was focused into the center of the laser cell by a quartz spherical lens of focal length 0.2 m. When the iodine laser was pumped transversely, a quartz cylindrical lens of focal length 0.3 m was used to focus the XeCl laser light into the iodine laser cell.

The output energy dependence on the gas filled pressure at different output mirror reflectances is shown in Figs. 3 and 4. As shown in Fig. 3, there is an optimum iodide pressure for each output mirror reflectance for the longitudinal pumping. However, for the transverse pumping, the laser output energy increases monotonically with the t-C_4F_9I pressure as shown in Fig. 4 The results in Figs. 3 and 4 were taken when the laser was operated at 2-Hz repetition rate. When the pulse repetition rate was increased to 5 Hz, the laser output energy per pulse was reduced slightly ($\approx 10\%$) due to the reduction of the XeCl laser pumped energy.

A typical laser output is shown in Fig. 5. The half width (FWHM) of the pulse is about 25 nsec. The iodine laser onset is delayed from the XeCl pump laser and occurs at the end of the pump pulse. The pulse shape is nearly the same for both pumping geometries.

IV. Discussion

In this experiment, a XeCl laser pumped iodine laser was developed and tested by using t-C_4F_9I as the laser material. This lasant t-C_4F_9I has a larger absorption cross section at the XeCl laser line compared with other iodides used in the laser experiment, such as i-C_3F_7I. The larger absorption cross section allows the high utilization of pumping energy in short gain length and low pressure operation of the iodine laser. The low-pressure operation of the iodine laser is suitable for single longitudinal mode output because of the reduced pressure broadening of the gain profile. The single-longitudinal mode operation of the laser oscillator is necessary to obtain a temporally smooth pulse.

The iodine laser described in this report was operated up to 5 Hz, which was limited by the power supply of the XeCl laser. Further increase of the repetition rate can be made by scaling up the pump laser system. The iodine laser was operated in a sealed-off mode. There was no significant reduction of the laser output energy after a few hundred pumpings with a single fill t-C_4F_9I in the laser cell. There

was also no noticeable change in the t-C_4F_9I gas after a few hundred pumpings and no deposits on the wall of the laser cell (contrary to the report of Ref. 10 where t-C_3F_7I was used). This may be attributable to the superior chemical reversibility of the iodide used.
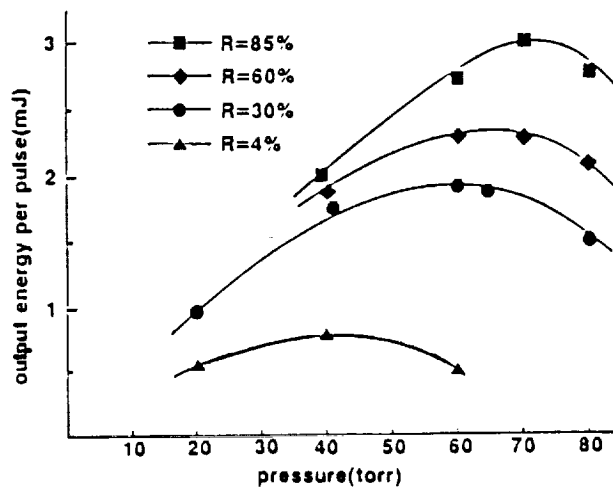

Figure 3 - Iodine output energy dependence on the gas fill pressure in the laser cell at each output mirror reflectance. The iodine laser was pumped longitudinally with the XeCl laser of pulse energy 80 mJ.
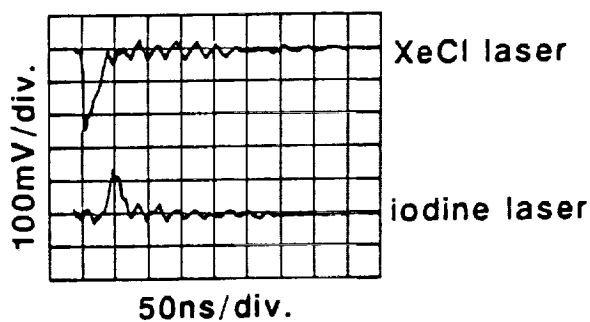

Figure 4 - Iodine laser output energy dependence on the gas fill pressure when the iodine laser was pumped transversely. The pumping energy from the XeCl laser was fixed to 80 mJ.
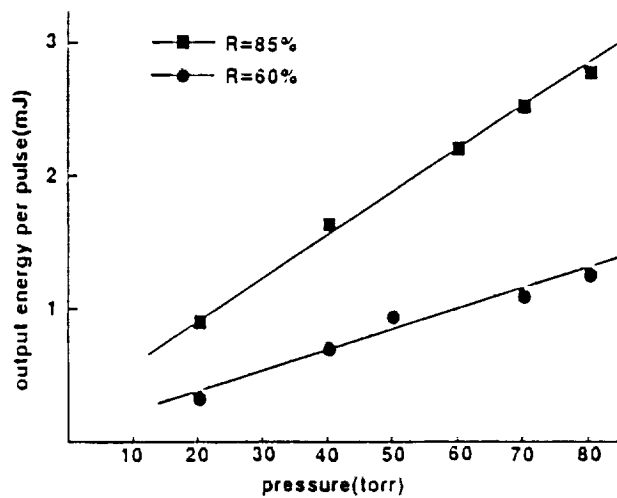
Figure 5 - A typical iodine laser pulse shape which is compared with the pumping pulse. (a) XeCl pump laser pulse. (b) Iodine laser output pulse.

V. Conclusion

An iodine laser oscillator pumped by an XeCl laser was developed using t-C_4F_9I as the laser material, and a 3 mJ laser output energy was obtained with only 80 mJ pumping energy. Compared with previous results, the pumping energy was dramatically reduced in this experiment, The pumping efficiency (i.e., the ratio of the iodine laser energy and the XeCl laser energy) was 3.75%. This experiment also demonstrated a repetitive operation of the iodine laser oscillator with a stable output. Since the threshold pumping energy (20 mJ) is low for t-C_4F_9I, a moderate size XeCl laser may suffice for the pumping of the high-repetition-rate laser oscillator required for solar pumped master-oscillator power-amplifier systems.

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