IOPscience iopscience.iop.org

Home Search Collections Journals About Contact us My IOPscience

A pulsed Xe ion laser with a double-discharge excitation

This content has been downloaded from IOPscience. Please scroll down to see the full text.

1990 Meas. Sci. Technol. 1 605

(http://iopscience.iop.org/0957-0233/1/7/011)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 140.113.38.11
This content was downloaded on 28/04/2014 at 19:46

Please note that terms and conditions apply.

Meas. Sci. Technol. 1 (1990) 605–610. Printed in the UK

# A pulsed Xe ion laser with a double-discharge excitation

**Kaung-Hsiung Wu**
Department of Electrophysics, National Chiao Tung University, 30049 Hsinchu, Taiwan

Received 26 June 1989, in final form 22 February 1990, accepted for publication 13 March 1990

**Abstract.** A long-pulse (~30 μs) xenon-ion laser with a maximum output energy of 20 mJ has been developed by using a double-discharge technique. Design details of the laser tube and the discharge circuits are described. Laser performance for different discharge circuits and working parameters (gas pressure and excitation voltage) is also presented.

## 1. Introduction

Considerable interest exists in pulsed xenon-ion lasers, mainly because they have been successfully used as microsurgical tools in integrated-circuit manufacturing [1, 2] and as pumping sources for dye lasers [3–5]. Various commercially available lasers have been used for these applications. For instance, *Q*-switched Nd:YAG lasers and excimer lasers are suitable for laser microsurgery, while CW argon-ion lasers and copper-vapour lasers are used to pump dye lasers. Compared with these laser systems, a pulsed xenon-ion laser is inexpensive, has a simple structure, and can deliver a relatively high-peak-power emission in the blue–green region of the spectrum.

A pulsed xenon-ion laser with an output energy of 0.1–2.0 mJ, a pulse duration of 0.3–1.5 μs, and a repetition rate of 200 Hz is required for applications in semiconductor manufacturing, such as failure analysis, photomask repair, thin-film resistor trimming, cutting of redundant circuit link and laser-formed connections. On the other hand, a flat-topped laser pulse with a peak power of 0.1–1 kW, a long pulse duration of 10–50 μs, and a repetition rate of up to 10 Hz, is required to pump a colliding-pulse mode-locking (CPM) dye laser which can generate subpicosecond pulses [5] and is a useful tool to study ultrafast phenomena [6, 7]. Different electrical discharge circuits, such as a circuit with an energy-storage capacitor *C*, a single-mesh LC circuit, or a multiple-mesh LC circuit, should be chosen in order to obtain different output pulse characteristics. Several methods of auxiliary discharges, which consume less power, are used to preionise the gas and to improve the reliability and efficiency of the pulse discharge [5, 8, 9].

In the present paper, a pulsed xenon-ion laser operated with a gas-flow mode is described. A double-discharge circuit as well as a simple-discharge one is introduced to excite this laser tube. Laser performances for these circuits and different working parameters, such as gas pressure and excitation voltage, are reported.

## 2. Pulse discharge circuits

### 2.1. Simple-discharge circuits

The simplest capacitive-discharge circuit used to excite a laser tube is shown in figure 1(*a*). A spark gap is used as a switch in this circuit. Its discharge is controlled by an insulated plug which is concentrically placed on one of the electrodes. The capacitor *C* is charged through the resistors $R_1$ and $R_2$ to a voltage of 6–15 kV. When a positive pulse of 30 kV is applied to the spark plug, a negative high voltage (−6 to −15 kV) is provided to the cathode of the laser tube and causes a breakdown of the xenon gas immediately. The repetition rate is limited by the capabilities of the power supply available, the values of resistance and capacitance in the charging circuit, and the switching means. If a high repetition rate is required (>100 Hz), a thyratron tube and a suitable DC power supply with LC charging circuit should be used [10]. Under the same discharge conditions, such as the operating pressure, the charging voltage, and the diameter of the tube, the pulse duration is determined by the equivalent network for the discharge operation. The typical capacitance to obtain an output duration of 1 μs in this discharge circuit is about 0.2 μF. On the other hand, if a flat-topped long-pulse is required, a pulse forming network (PFN) with multiple-mesh LC network should be applied [11]. The PFN serves the dual purpose of storing exactly the amount of energy required for a single pulse, and discharging this energy into the load in the form of a pulse of specified shape. Suitable capacitors and inductors should be chosen in the PFN to match the impedance of the discharging plasma and thus to obtain a near rectangular current pulse waveform.

0957-0233/90/070605+06 $03.50 © 1990 IOP Publishing Ltd

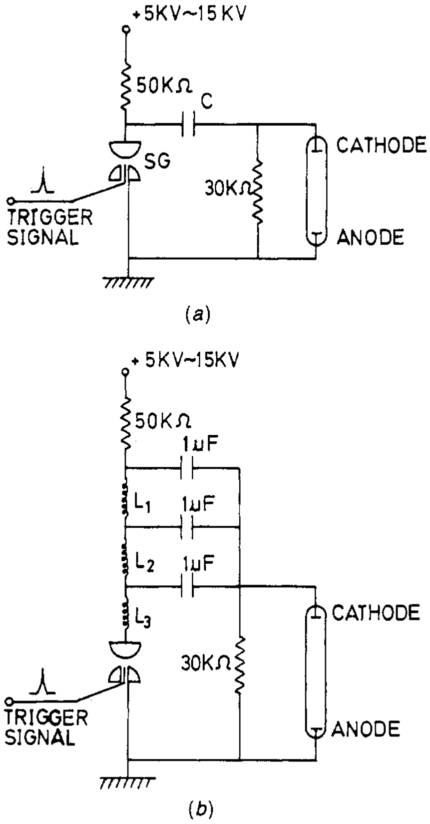


**Figure 1.** A simple discharge circuit, (*a*) with a capacitor, (*b*) with a PFN.

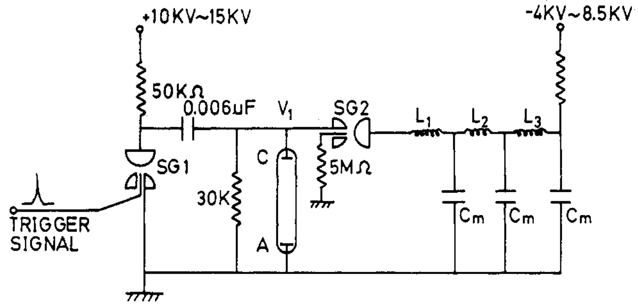


**Figure 2.** A double discharge circuit with a PFN in the main discharge circuit.

Most PFN employ the 'E' type circuit of a lumped constant transmission line [11]. In this configuration (figure 1(*b*)), capacitors are of equal value while the inductance values per mesh are different. Assuming a linear resistance $R$ of typically a few ohms through the plasma tube during the discharge, the equivalent circuit for the PFN can be simplified to a series RLC network with a switch S. The characteristic impedance of the network is

$$Z_n = \sqrt{\frac{L_t}{C_t}}$$

where $L_t$ and $C_t$ are the total inductance and capacitance respectively. The current through the plasma tube is [11]

$$i(t) = \frac{V_0}{R}\left(\frac{\alpha}{\beta}\right)\{\exp[-(\alpha-\beta)t] - \exp[-(\alpha+\beta)t]\}$$

where $\alpha = R/2L_t$, $\beta = (R/4L_t - 1/L_t C_t)^{1/2}$ and $V_0$ = the initial charging voltage on capacitors. The pulse width at the 70% point is $\tau_p = 2(L_t C_t)^{1/2}$.

In the present work, a three mesh LC network has been used. The capacitance for each mesh is 1 $\mu$F. The resistance of the plasma tube is estimated to be 6 Ω. Therefore, an inductance of 40 $\mu$H (per mesh) is chosen. In this case, the duration of the discharge current is about 35 $\mu$s.

There are some problems in a simple discharge circuit with a long-pulse duration; for example, the pulse repetition rate is erratic with many skipped pulses, and the voltage to initiate the discharge is higher than the optimum voltage for the lasing condition. Usually, these problems may be solved by adding a trigger electrode which is wrapped around the length of the plasma tube, and a trigger pulse circuit is connected to this electrode [8]. But this high frequency, high voltage circuit generates electrical noise which should be shielded from other instruments. Here a modification to the simple discharge circuit is introduced and described below.

### 2.2. Double-discharge circuits

A double-discharge (or cascade-discharge) technique with spark gaps has been used in $CO_2$ lasers [12]. It consists of two consecutive discharges. The first one is a higher voltage, less energetic preionised discharge, and the second one is a lower voltage, more energetic main discharge. The discharge circuit is shown in figure 2. The sequence of events is described as follows. Once the spark gap SG1 is triggered by an external trigger source, the capacitor $C_1$ provides a lower power pulse of 12–20 kV to the laser tube to preionise the xenon gas. Meanwhile the voltage at $V_1$ becomes a high negative voltage and the spark gap SG2 fires immediately. The main power is then delivered to the laser gas through the PFN. This main discharge has a relatively lower discharge field strength and a higher current density than the preionised discharge. As a consequence intense laser light with long pulse duration is obtained.

The advantages of this double-discharge circuit are obvious. First, a reliable, high repetition rate can be obtained under PFN with large storage capacitors (>1 $\mu$F).

**Table 1.** Summary of some work on pulsed Xe ion lasers

| Workers | Active length (mm) | Bore diameter (mm) | Pulse width ($\mu$s) | Output energy (mJ) |
|---|---|---|---|---|
| Gundersen and Harper [8] | 3000 | 17 | 0.11–0.2 | 9 |
| Ansari, Dienes and Whinnery [5] | 800 | 4 | 100 | 5 |
| Bergamasco, Cecchetti and Polloni [3] | 1000 | 4 | 15 | 10.5 |
| Wu (this work) | 1350 | 6 | 30 | 21 |
| Wu (intracavity type) | 1450 | 8 | 30 | 30–45 |

Second, since the ratio of field strength to pressure ($E/P$ value) approaches the optimum value for population inversion [13], a greater laser output with a higher efficiency is obtained. In fact, the output energy in the present system is the highest reported so far (see table 1).

## 3. Xe-ion laser description

The schematic diagram of the pulsed xenon-ion laser in the present work is shown in figure 3. The water-cooled laser tube is made of Pyrex glass. The discharge tube has an active length of 1350 mm with a bore inner diameter of 4.8 mm. A helical return path, as usual in ion lasers, is attached in parallel to the plasma tube, to reduce the gas pumping effect [8]. The electrodes are made of 99.99% purity indium and are formed by melting the indium metal around tungsten pins [14]. The system can be operated either in a sealed-off or a glas-flow mode. Since the absorption of xenon gas on the indium electrodes and the walls of the plasma tube is serious, the xenon gas would reduce gradually. Accordingly, the discharge conditions as well as the power output characteristics would change with time. Besides, it is bothersome for the treatments of the sealed-off operation, such as re-evacuation, baking and refilling. Therefore, a gas-flow type is recommended for a laboratory-built device.

The laser windows are set at the Brewster angle and sealed with Torr-seal (Varian) at a distance of 150 mm from the electrodes. The optical cavity consists of a pair of mirrors normally used in an argon-ion laser. The reflectivity of the flat output mirror is either 80% or 90%.

A diffusion pump is used to evacuate the laser tube to $7 \times 10^{-5}$ Pa. Then the xenon gas is added through a leak valve. The operating pressure, which is measured by a precision pressure gauge (MKS model 127AA-00001D), is controlled by a leak valve and the right-angle valve of the vacuum system. All the connectors and valves in this system are of ultrahigh vacuum-type quality. Two sections of metal meshes with length 120 mm each are inserted in the return path and the gas outlet of the leak valve to avoid the discharge running through them.

Two kinds of discharge circuits described in section 2 are applied to this laser tube. The pulse current is monitored either by means of a small resistor (0.01 Ω) in series with the discharge tube or by a Rogoswki coil. The laser output energy is monitored by an energy meter (Laser Precision model 7610) and its pulse shape is monitored by an accessory of the energy meter (option RQ). All these signals are fed into a storage oscilloscope.

## 4. Experimental results and discussion

The laser output consisted of eight lines in the visible region: 430.6, 495.6, 500.8, 515.9, 526.0, 535.3, 539.5 and 595.6 nm. The intensity of these lines depends on the various laser parameters, such as gas pressure, discharge voltage and energy storage capacitor. The output energy was distributed mainly over the lines at 526.0, 535.2 and 539.2 nm. The line at 595.6 nm (orange) appeared only when the laser operated with a smaller capacitor ($<0.5\ \mu$F) and at a relatively higher pressure.

Figure 4 shows the total output energy as a function of discharge voltage for different storage capacitors when a simple discharge circuit (figure 1(*a*)) was applied to the laser tube. All data in this figure and throughout the present work was taken from an average value of 100 pulses and under a repetition rate of 5 Hz. The pulse duration was varied from 0.2 to 6 $\mu$s when the capacitor was changed from 0.1 to 3 $\mu$F. When an inductor of 100 $\mu$H was in series with the storage capacitor, both the pulse duration and the energy of output pulse could further increase to 20 $\mu$s and 10 mJ respectively (figure 5). For all these simple discharge cases, stable discharges could be obtained only when the repetition rate and the capacitor were less than 10 Hz and 0.5 $\mu$F respectively. When the capacitor was larger than 1 $\mu$F, both the pulse discharge and the output energy became unstable even at a low repetition rate (< 5 Hz).

As shown in figures 4 and 5, there exists an optimum voltage for each capacitor to obtain a maximum output energy. This optimum voltage decreased when the value of the capacitor was increased. It is well known that the saturation and quenching effects of laser output powers

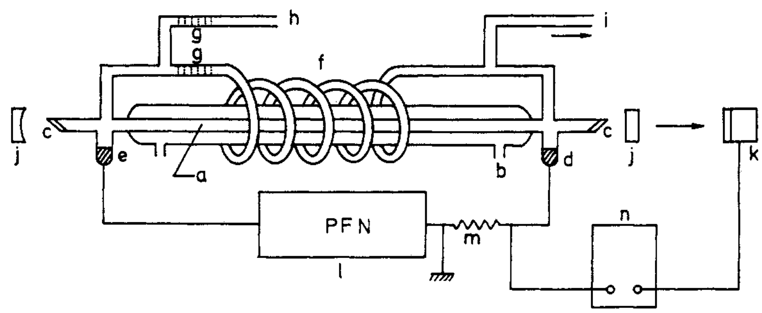


**Figure 3.** Schematic diagram of a flow-type pulsed Xe laser. a, laser tube; b, water jacket; c, Brewster windows; d, anode; e, cathode; f, gas return path; g, metal mesh; h, gas inlet; i, vacuum system; j, mirrors; k, energy meter; l, pulse discharge circuit; m, current monitor; n, storage oscilloscope.

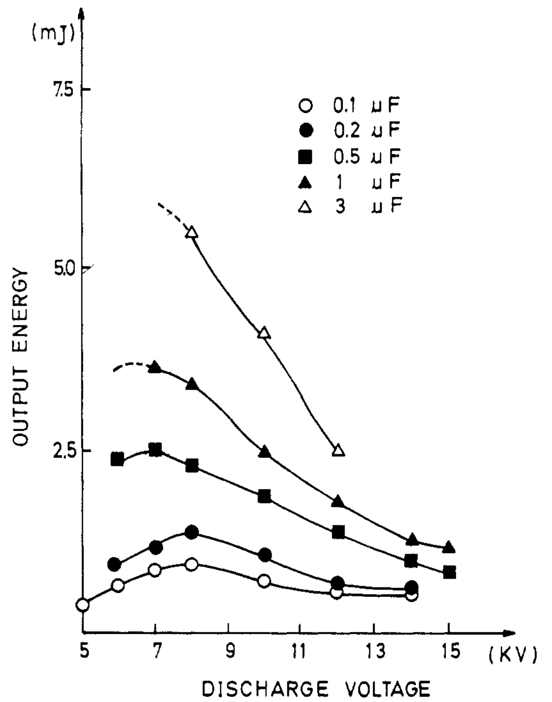


**Figure 4.** Output energy against discharge voltage for a simple discharge circuit with a capacitor.

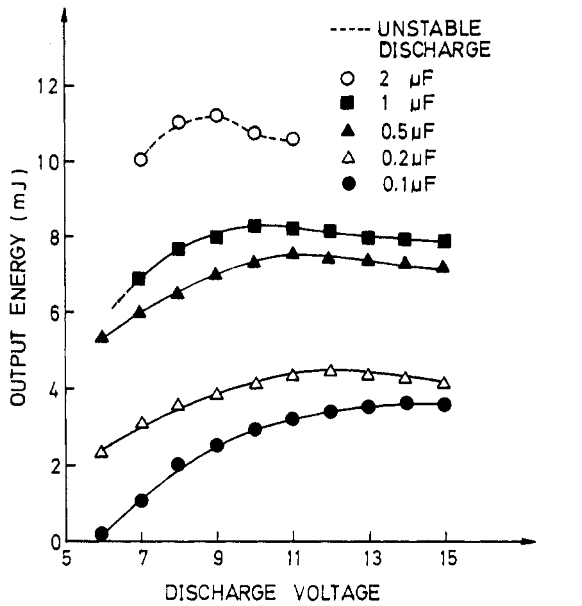


**Figure 5.** Output energy against discharge voltage for a simple discharge circuit with an inductor and a capacitor.

limit discharge current for CW, quasi-CW, and short-pulsed operations of ion lasers [17]. In the latter two cases, when a pulsed charged voltage is applied to a laser tube of low-pressure gas, the gas is rapidly ionised to the point where it can be described as a good conductor. Then a very high peak discharge current (600–2000 A in our case) occurs and the discharge is contracted under the self-magnetic force of the discharge current. This is a so-called pinch discharge [18]. The laser action in this case has been found to saturate with increasing bank energy and hence charging voltage, and this effect limits the power output from this type of laser [19]. Therefore, for a larger capacitor, the maximum voltage (current) to saturate the laser output power was lower.

When a double discharge circuit is applied to the laser system, a suitable $C_p$ should be chosen to reduce the erratic discharge and give a smaller variation in the laser output energy each time. A capacitance of 0.006 μF was chosen for the present experiment. Several main discharge circuits, including a simple storage capacitor, a single-mesh LC network and a multiple-mesh LC network, were tested.

Some results are shown in figures 6 to 10. A stable discharge could be obtained even when a three-mesh LC network (figure 2) was used in the main discharge circuit and the repetition rate was up to 20 Hz. The output energy and its waveform changed tremendously with

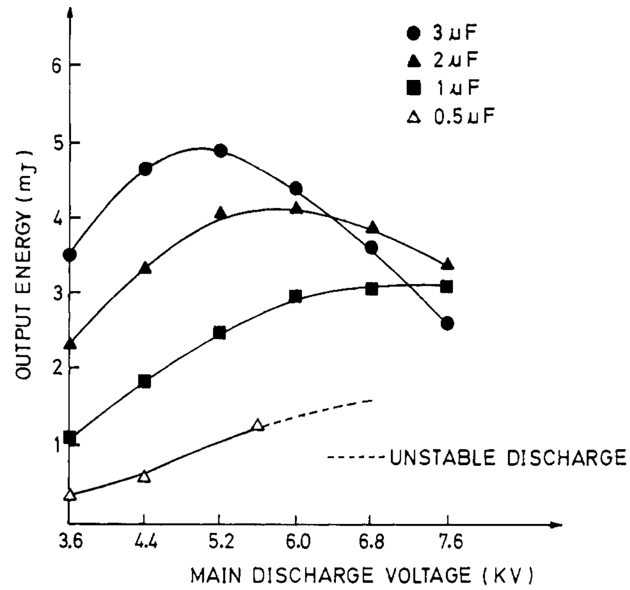


**Figure 6.** Output energy against main discharge voltage for a double discharge circuit with a capacitor only.

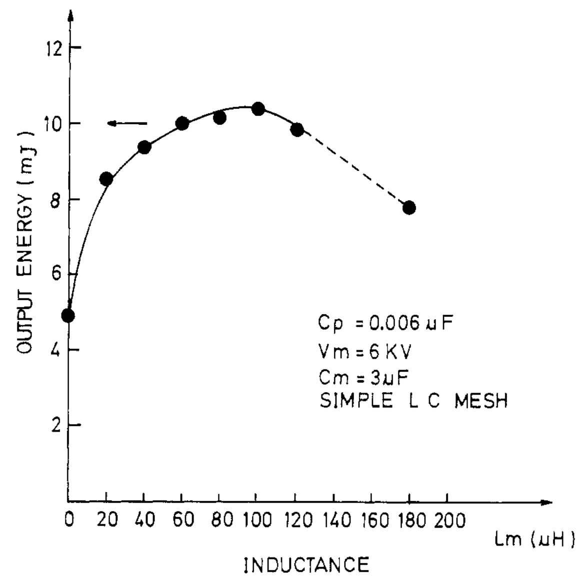


**Figure 7.** Output energy against inductance for a double discharge circuit with one section of LC combination.

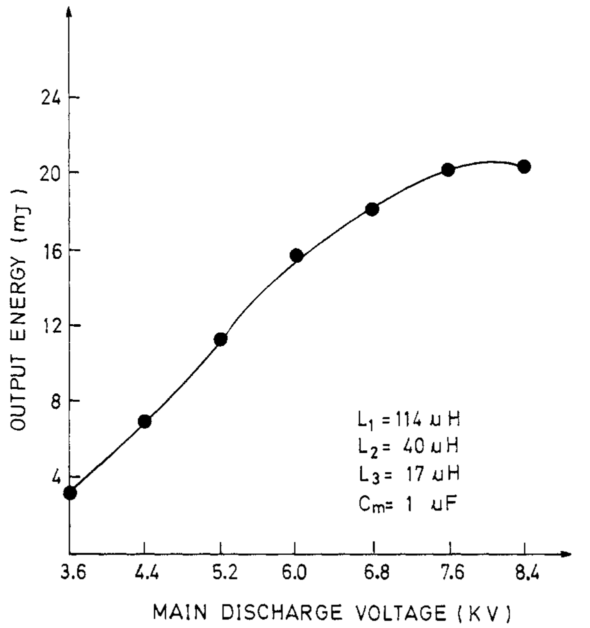


**Figure 8.** Output energy against main discharge voltage for a double discharge circuit with three sections of LC combination.

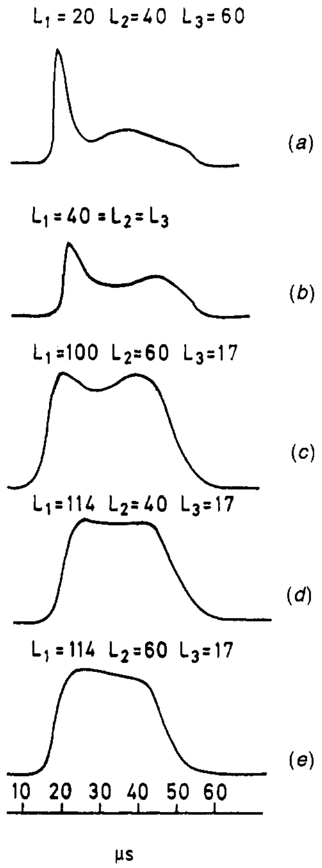


**Figure 9.** Laser pulse shapes obtained for different values of inductance (units, $\mu$H).

different inductances. As shown in figure 9(*b*), the output waveform was not the desired one when all the inductors were set to an equal value [11]. In order to suppress the first peak in the waveform, a larger inductor $L_1$ should be used.

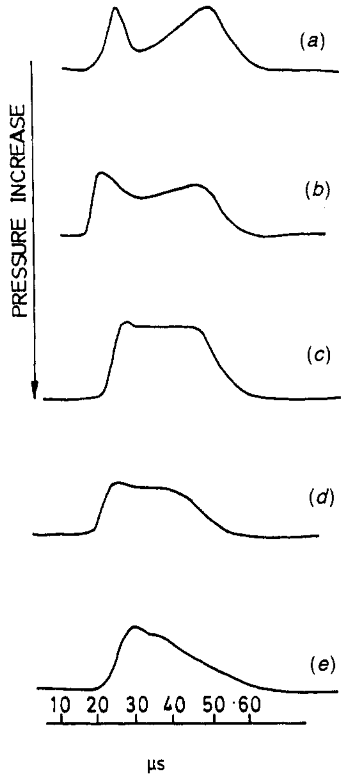


**Figure 10.** Laser pulse shape changes with increased pressure.

It was also noted that the operating pressure strongly affected both the output energy and shape of the laser pulse (figure 10). At higher pressures, the pulse became peaked and the output energy decreased simultaneously. On the other hand, at lower pressures, the pulse tended to split into two pulses and the output energy also decreased.

The most nearly perfect waveform we observed is shown in figure 9(*d*). It was obtained when $L_1 = 114$ $\mu$H, $L_2 = 40$ $\mu$H; and $L_3 = 17$ $\mu$H. The output energy was about 20 mJ and the pulse duration was about 30 $\mu$s. The peak power was about 700 W. Some results reported in other papers and the present work are listed in table 1. The improvement of the total output energy by the double discharge technique is obvious.

## 5. Conclusions

An inexpensive pulsed xenon-ion laser, which was excited by different discharge circuits, was built for laboratory experiments. The operational characteristics for these circuits was reported. By using a double-discharge technique, a reliable, high repetition rate and a long pulse duration with a high energy output was obtained. This pulsed xenon-ion laser will be used as a pumping source and an amplifier for a CPM dye laser. This work has been in progress and will be reported elsewhere. Besides, since it has the potential to obtain a high output energy per pulse, either in the blue–green or near UV spectrum, an intracavity-type pulsed xenon laser with output energy up to 45 mJ has been built for application to thin-film formation of high $T_c$ superconductors which requires an energy density of 5–10 J $cm^{-2}$ [15, 16].

### Acknowledgment

This work was supported by the National Science Council of the Republic of China project no NSC77-0608-E0009-06. The author wishes to thank Dr C L Pan for his valuable suggestions.

### References

[1] Modlin D N and Ravich G 1986 *SPIE Manufacturing Applications of Lasers* **621** 76
[2] Gregor E, Guio P and Segundo E 1976 *SPIE Industrial Applications of High Power Laser Technology* **86** 105
[3] Bergamasco G, Cecchetti W and Polloni R 1983 *Opt. Laser Technol.* **15** 191
[4] Schearer L D 1975 *IEEE J. Quantum Electron.* **QE-11** 935
[5] Ansari H, Dienes A and Whinnery J R 1985 *Opt. Lett.* **10** 19
[6] Iscoff R 1988 *L&A* **7** 46
[7] Chan C K 1978 *Spectra-Physics, Inc. Laser Tech. Bull. No. 8*
[8] Harper C D and Gundersen M 1974 *Rev. Sci. Instrum.* **45** 400
[9] Lomnes R K and Taylor J C W 1971 *Rev. Sci. Instrum.* **42** 766
[10] Merchant V E, Seguin H J J and Dow J 1978 *Rev. Sci. Instrum.* **49** 1631
[11] Glasoe G N and Lebacqz J V 1948 *Pulse Generators* (New York: McGraw–Hill) Ch 6
[12] Huang K C and Hsu K Y 1976 *Proc. 1st Int. Symp. Electron Devices and Materials, IEEE ROC* **1** 141
[13] Chari R and Chakrapani G 1986 *Appl. Opt.* **25** 1854
[14] Simmons W W and Witte R S 1970 *IEEE J. Quantum Electron.* **QE-6** 648
[15] Witanachchi S, Kwok H S, Wang X W and Shaw D T 1988 *Appl. Phys. Lett.* **53** 234
[16] Lengfellner H, Renk K F, Fickenscher P and Schindler W 1989 *J. Phys. D: Appl. Phys.* **22** 323
[17] Hattori S and Goto T 1968 *J. Appl. Phys.* **39** 5998
[18] Papayoanou A, Buser R G and Gumeiner I M 1973 *IEEE J. Quantum Electron.* **QE-9** 580
[19] Katzenstein J and Lovberg R H 1975 *Appl. Phys. Lett.* **26** 113