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AR-006-434

RESEARCH NOTE
ERL-0508-RN

INVESTIGATION AT TWO WAVELENGTHS OF A MODULATED He-Xe RARE GAS LASER

Kenneth J. Grant, Shane A. Brunker and Robert J. Rossiter

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INVESTIGATION AT TWO WAVELENGTHS OF A MODULATED He-Xe RARE GAS LASER

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ABSTRACT (U)

A He-Xe rare gas laser has previously been reported to emit at several wavelengths in the 2 to 4 μm region, in continuous wave and modulated modes. This Research Note discusses the effect of variation of discharge parameters on the output power and pulse energy at two infrared wavelengths of 3.894 and 3.995 μm.

JULY 1990

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Postal Address: Director, Electronics Research Laboratory,
PO Box 1600, Salisbury, South Australia, 5108.

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1 INTRODUCTION

As part of an Air Force-sponsored task into applications of rare gas lasers (1), a He-Xe laser was investigated. This laser was operated in a modulated mode at selected wavelengths which lie in the atmospheric window around 4 µm. Irradiation by low level lasers requires accurate knowledge of the effect of laser discharge parameters on the output energy if full advantage is to be taken of the available laser power.

This Research Note discusses the effect of variation in discharge parameters (total pressure, He:Xe partial pressure ratio, current and duty cycle) upon the output power and pulse energy at wavelengths 3.894 and 3.995 µm.

2 EQUIPMENT

Figure 1 shows a schematic diagram of the equipment. It consists of a commercial He-Xe laser (Advance Kinetics, model XeHe-1) which produces laser radiation at a number of wavelengths in the 2 to 4 µm region, a 0.125 m monochromator (Oriel, model 7240) to disperse the infrared laser radiation, a PbSe sensor (Opto- Electronics, model OTC-12S-81T) to detect the radiation, and an XT-compatible microcomputer to digitize and store the data. The apparatus used in this work was described in detail in a previous Report (1).

The difference between this work and that described in Reference 1 is that the rear mirror in the laser cavity was replaced by a grating, to enable the laser to be selectively tuned. The grating is a 300 lines/mm master, ruled on a copper block with gold plating. At the blaze angle the reflectivity of the grating is more than 95%. The laser is tuned to different lines by adjusting the vertical micrometer. There is a total angular variation of 12° available about the horizontal axis. The grating and output coupler can be remotely operated by an AMM-4 Motor Controller.

3 RESULTS

The wavelengths and upper and lower states (Racah notation, (2)) of the observed laser transitions are listed in Table 1.

Table 1 Observed He-Xe Laser Lines

Wavelength [µm]	Upper State	Lower State
3.894	$5d[7/2]_3^{\circ}$	$6p[5/2]_3$
3.995	$5d[1/2]_0^{\circ}$	$6p[1/2]_1$

These transitions, and the non-lasing transitions which depopulate their lower levels, are shown in a schematic of the energy diagram of xenon (Figure 2). Shown for comparison are the previously-observed laser transitions obtained by using the rear mirror (1).

3.1 3.894 µm Line

3.1.1 Output as a Function of He:Xe Ratio at 100 mA

3.1.1.1 Temporal Profiles

Temporal profiles of output power were measured as functions of partial pressure ratio, under the following conditions: modulation frequency 125 Hz, 50% duty cycle, 100 mA peak current, He:Xe ranging from ≈60:1 to 320:1 at total pressures of 11 and 20 torr.

Figure 3a shows the temporal profiles versus He:Xe ratio at a total pressure of 11 torr. At high He:Xe ratios the 3.894 µm output power closely follows the square current pulse, except for initially overshooting the equilibrium value. As the mixture becomes richer in Xe, i.e. as He:Xe decreases, the initial peak becomes more prominent as the output in the later stages of the current pulse decays. At a He:Xe ratio of 70:1 there is no output after 0.3 ms. This phenomenon is probably a result of a change in the electron energy distribution (3). The mechanism of the dependence can only be determined after further investigation.

The results at a pressure of 20 torr exhibit similar features for He:Xe ratios up to 150:1 (Figure 3b). At higher ratios, however, the power tends to decrease, especially at later stages of the pulse. At the highest He:Xe ratio (325:1) there is no output after 0.3 ms.

3.1.1.2 Pulse Energy

Pulse energies were calculated by numerically integrating the area under each temporal profile. These values are in arbitrary, but internally consistent, units. The results are presented in Figure 4. The output is higher at 11 torr total pressure than at 20 torr for all partial pressure ratios. At both total pressures, however, the pulse energy peaks at a He:Xe ratio of 140:1. Note that, in the continuous wave (cw) case, the He:Xe ratio for maximum power is 180:1 (4).

3.1.2 Output as a Function of Discharge Current

3.1.2.1 Pulse Energy

Pulse energy was measured as a function of discharge current, under the following conditions: modulation frequency 125 Hz, 50% duty cycle, 11 torr total pressure, He:Xe = 140:1. For comparison, these measurements were repeated with He:Xe ratios of 100:1 (optimum for total cw output on all lines) and 180:1 (optimum for cw 3.894 μm).

At a He:Xe ratio of 100:1 the maximum pulse energy occurs at a peak current of 60 mA (Figure 5). At the other two ratios, however, the output increases monotonically with current. The output with a ratio of 140:1 is higher than that at 180:1 at all currents. For each total pressure there is a critical current, below which there is very little laser output. The value of this current increases with increasing He:Xe ratio.

3.1.2.2 Temporal Profiles

The temporal profiles at a He:Xe ratio of 140:1 are shown in Figure 6a. At a peak current of 20 mA there is only laser output during the first 0.3 ms of the current. At higher currents the output follows the current pulse, apart from initially overshooting the equilibrium value. The behaviour with a He:Xe ratio of 180:1 has similar trends. With He:Xe = 100:1, however, the temporal profiles behave differently. In that case (Figure 6b) there is significant output with 20 mA peak current. The profile at 60 mA (the optimum current) follows the current pulse shape. Increasing the current beyond this value results in the output in the later stages of the pulse decaying.

3.1.3 Output as a Function of Total Pressure

3.1.3.1 Pulse Energy

The effect of total gas pressure was investigated by measuring the pulse energy at a range of pressures from 11 to 30 torr, at constant He:Xe ratio of 140:1. The modulation frequency (125 Hz) and duty cycle (50%) were the same as in the previous measurements.

The output increases with decreasing pressure at all currents (Figure 7). At 11 torr the pulse energy increases monotonically with current, but at higher pressures there is an optimum current which decreases with increasing pressure. The minimum current required for laser output increases with increasing total pressure.

3.1.3.2 Temporal Profiles

Figure 8 shows the temporal profiles at peak currents of 80 mA for a range of total pressures. At 11 torr the output has a "square" profile, with the initial overshoot. As the pressure is increased the relative intensity at later stages of the pulse decreases until, at 30 torr, there is no laser output after 0.3 ms.

3.1.4 Output as a Function of Duty Cycle

The output was measured versus duty cycle under the following conditions: 125 Hz modulation frequency, 11 torr total pressure, He:Xe = 140:1, 100 mA peak current. The results are shown in Figure 9, which indicates that the output is linear with duty cycle. The line, however, does not pass through the origin (there is no output at ≈ 1% duty cycle).

The linearity of this plot is due to the fact that, under these operating conditions, the temporal profile of the laser output closely follows the (square) shape of the current pulse (Figure 10). We would therefore not expect linearity for richer Xe mixtures (Section 3.1.1.1).

3.2 3.995 μm Line

3.2.1 Output as a Function of He:Xe Ratio

The output at 3.995 μm was measured as a function of He:Xe ratio under the following conditions: modulation frequency 125 Hz, 100 mA peak current, duty cycle 3% (there is little output at duty cycles greater than 7% - see Section 3.2.2), He:Xe = 33:1 to 130:1, total pressure 11 torr.

The results are shown in Figure 11. There is a region in which the pulse energy is at a maximum, with the curve having a broad peak from He:Xe = 55:1 to 80:1.

3.2.2 Output as a Function of Duty Cycle

3.2.2.1 Pulse Energy

The effect of duty cycle on pulse energy was investigated by repeating the measurements of Section 3.2.1 at a range of duty cycles from 3% to 7%. (The laser power supply can, in fact, operate at a duty cycle of 2%, but the laser output is unstable at this value.)

The results (Figure 12) show that the optimum He:Xe ratio (i.e. the one at which maximum pulse energy occurs) increases for increasing duty cycle. The pulse energy, however, decreases with increasing duty cycle. The maximum pulse energy is achieved at 3% duty cycle. The output at 7% duty cycle is very low, and is independent of the He:Xe ratio.

Figure 13 shows the pulse energy as a function of duty cycle for He:Xe ratios of 79:1 and 103:1. In contrast to the behaviour of the 3.894 μm line (Figure 9) the relationship between pulse energy and duty cycle is non-linear. Moreover, the energy of the 3.995 μm line decreases with increasing duty cycle under these discharge conditions.

3.2.2.2 Temporal Profiles

Figure 14 shows the temporal profiles at 3% duty cycle for a range of He:Xe ratios. At He:Xe ratios less than 90:1 there is a small initial peak in power after 0.02 ms, with the maximum power occurring at 0.14 ms. The initial peak becomes less distinct as the He:Xe ratio increases. With Xe-lean mixtures (i.e. for high He:Xe ratios) the profile only has the main peak, and is 0.34 ms wide across the base. The main peak occurs at 0.14 ms at all He:Xe ratios.

The temporal profiles at a He:Xe ratio of 105:1 and duty cycles of 3 to 7% are shown in Figure 15. It is particularly interesting to note that the output laser pulse decreases in width as the current pulse increases. This may be due to the relaxation time of the lower laser level ($5d[1/2]_0^{\circ}$) being too long for it to clear between current pulses at higher duty cycles. Research is currently being undertaken to elucidate this phenomenon.

3.2.3 Output as a Function of Current

The effect on the 3.995 μm line of varying current at a constant duty cycle and He:Xe ratio was investigated. This was performed at a modulation frequency of 125 Hz and at a total pressure of 11 torr.

The results are shown in Figures 16a, b and c for He:Xe ratios of 80:1, 90:1 and 100:1, respectively. At each pressure the optimum current increases as the duty cycle decreases. The maximum output is achieved with 5% duty cycle, He:Xe = 90:1 and a peak current of 60 mA. These data are plotted in an alternative fashion in Figures 17a, b and c. The optimum current increases as the He:Xe ratio increases i.e. as the mixture becomes leaner in Xe.

Figure 18 shows the temporal profiles at He:Xe = 90:1, a peak current of 60 mA, and duty cycles of 3, 4 and 5%. In contrast to the results of Section 3.2.2.2, the laser pulse broadens with increasing duty cycle under these discharge conditions.

4 DISCUSSION

The spectrometer system described in this Research Note has been used to parametrically characterize a commercial He-Xe laser. This laser (Advance Kinetics, model XeHe-1) was described in detail in a previous Technical Report (1). In order to enhance output in the 4 μm region the rear mirror in the laser cavity was replaced by a grating. This enables the laser to be selectively tuned.

Lasing was observed at two wavelengths in this region using a modulated discharge (Table 1). One of these wavelengths (3.894 μm) is not observed using a rear mirror (1), and the other (3.995 μm) has its output significantly enhanced by using the grating.

The fact that the 3.894 μm line will not lase when a rear mirror is used can be explained in part by reference to the energy level diagram of Xe (Figure 2). This line shares a common upper level ($5d[7/2]_3^{\circ}$) with the 3.507 μm line. Due to the exceptionally high gain of this latter line (5) it is preferentially amplified. However, when a grating is used the feedback loop can be restricted to the 3.894 μm line. (In general, however, the power of individual lines drops when the rear mirror is replaced by a grating. This is probably due to the difference in reflectivities: 95% for the grating and ≈100% for the mirror.)

The optimum conditions for pulsed lasing were identified for each of these two lines. These are summarized in Table 2.

Table 2 Optimum Conditions for 3.894 and 3.995 μm Laser Lines.

	Wavelength [μm]	
	3.894	3.995
Pressure [torr]	11	11
He:Xe	140:1	90:1
Peak Current [mA]	100	60
Duty Cycle [%]	CW	5

REFERENCES

1 Grant, K.J. and Brunker, S.A."Modulated He-Xe Rare Gas Laser" ERL-0496-TR

2 Faust, W.L., McFarlane, R.A., Patel C.K.N. and Garrett, C.G.B. "Gas laser spectroscopy in the infrared" Appl. Phys. Lett. **1**, 85 (1962)

3 Targ, R. and Sasnett, M.W. "High repetition rate xenon laser with transverse excitation" IEEE J. Quantum Electron. QE-8[2], 166 (1972)

4 Brunker, S.A. and Grant K.J. "He-Xe neutral rare gas laser" In preparation

5 Bennett, W.R. Jnr "Inversion mechanisms in gas lasers" Appl. Opt. (Suppl. 2, Chemical Lasers), 3 (1965)

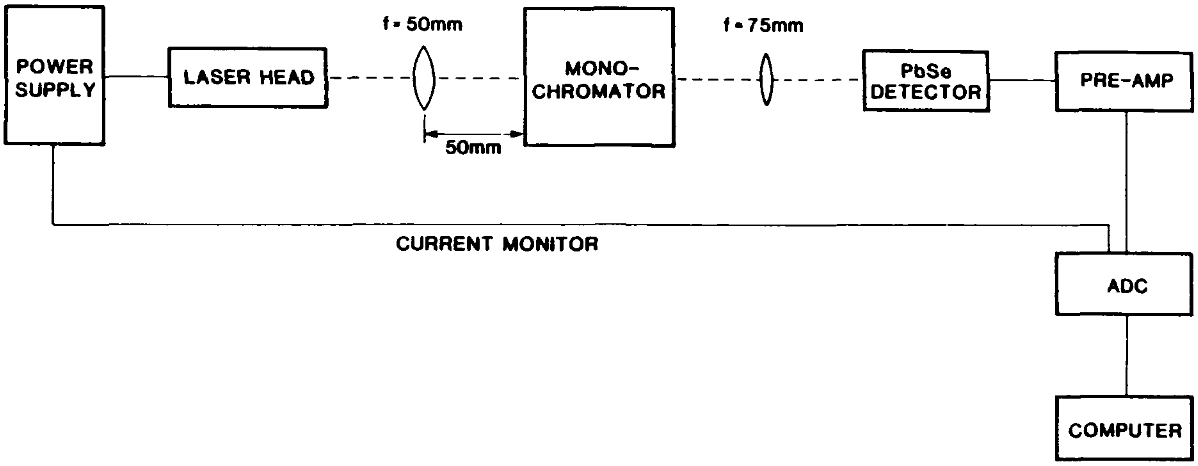


Figure 1 Schematic of experimental layout.

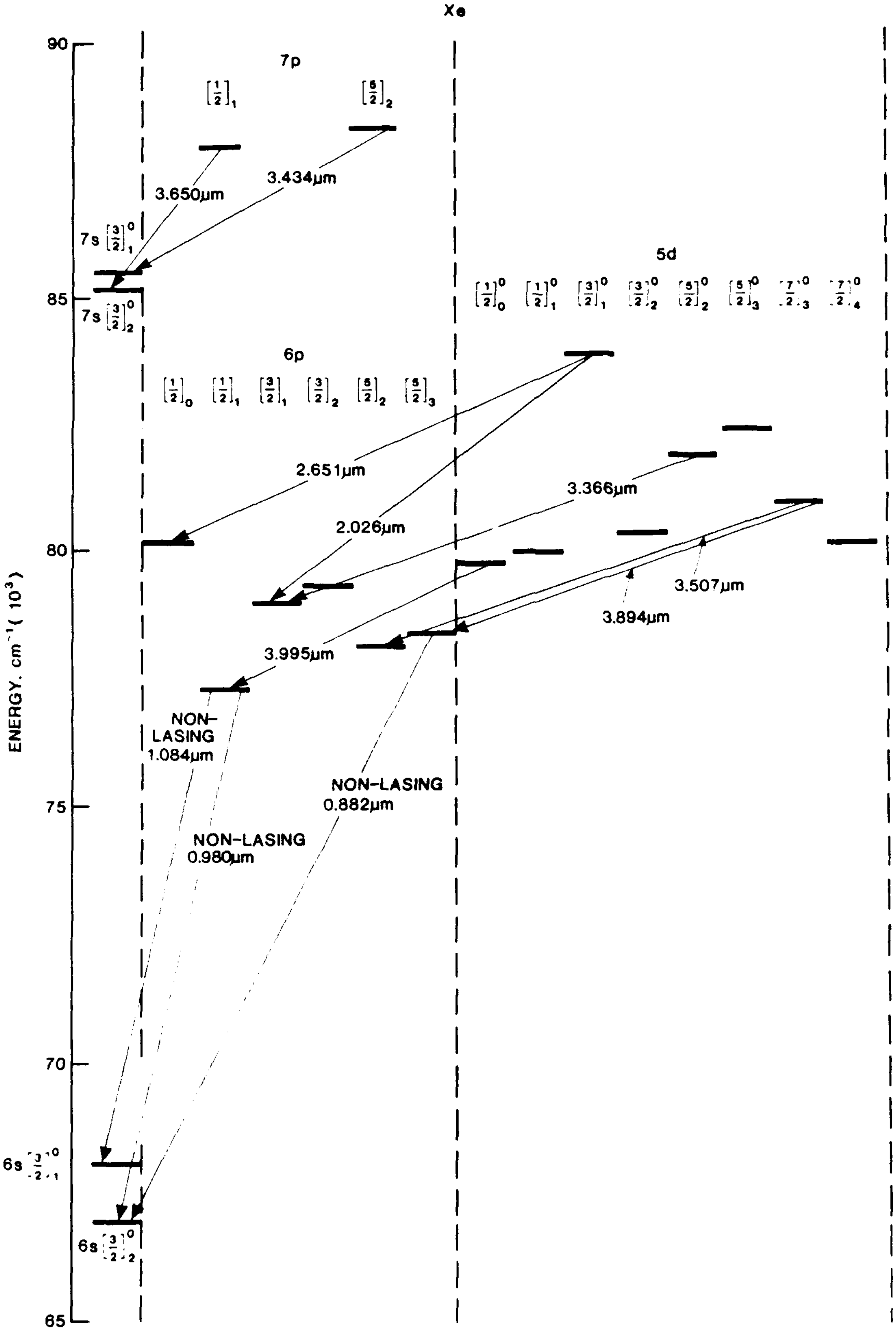


Figure 2 Schematic of the energy diagram of xenon showing observed lasing and three non-lasing transitions.

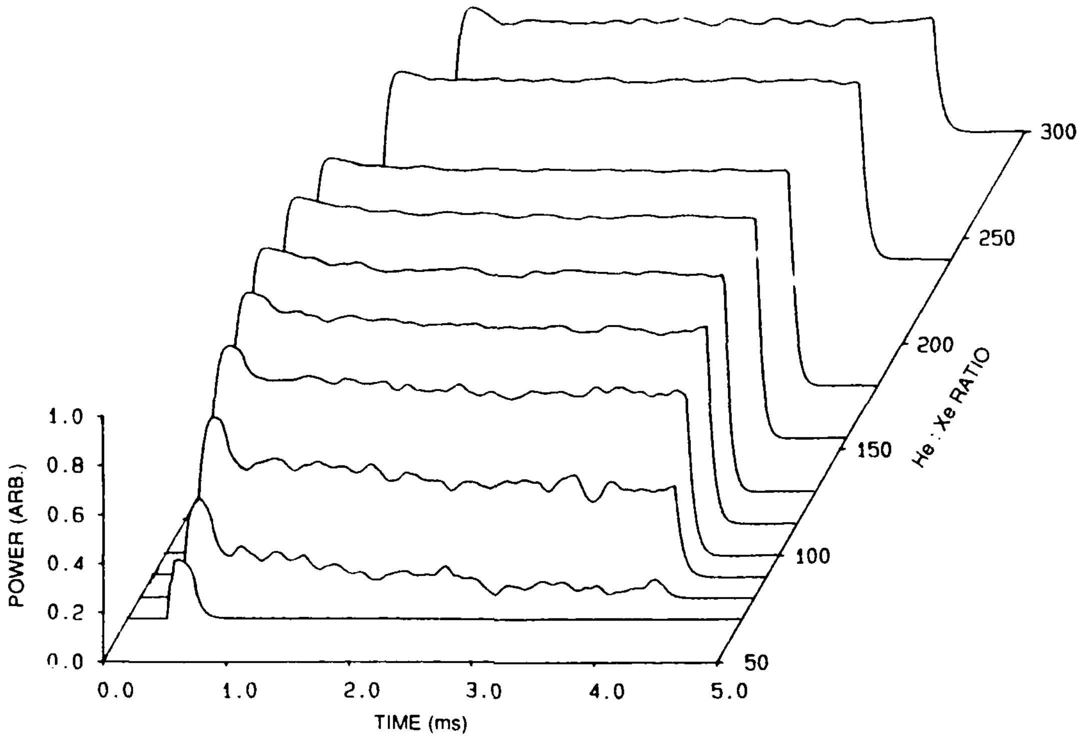


Figure 3(a) Temporal profiles of 3.894 μm line at 11 torr total pressure.

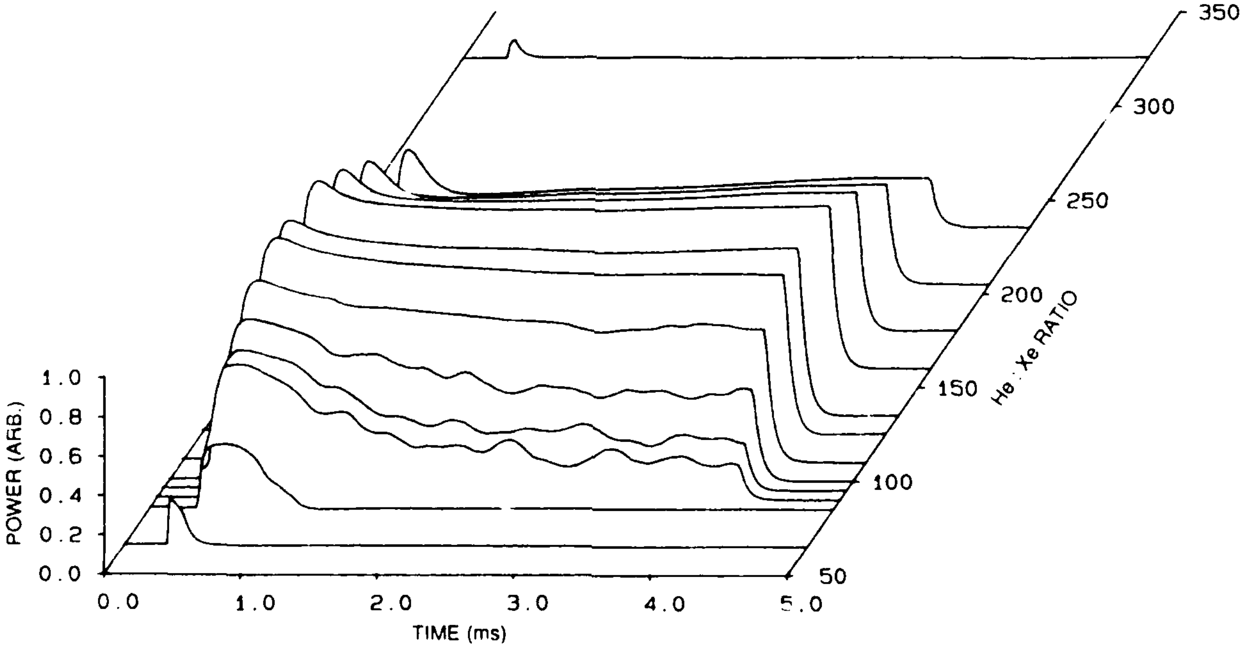


Figure 3(b) Temporal profiles of 3.894 μm line at 20 torr total pressure.

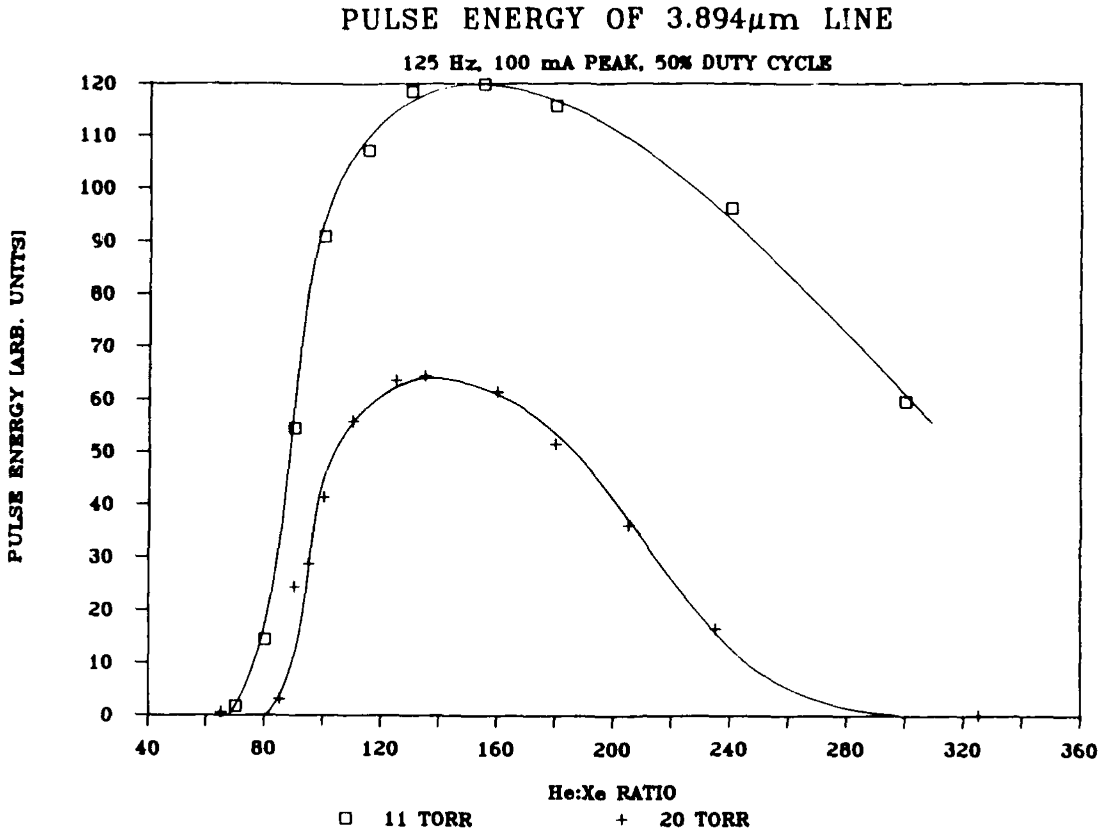


Figure 4 Pulse energy versus He:Xe ratio at 11 and 20 torr total pressure.

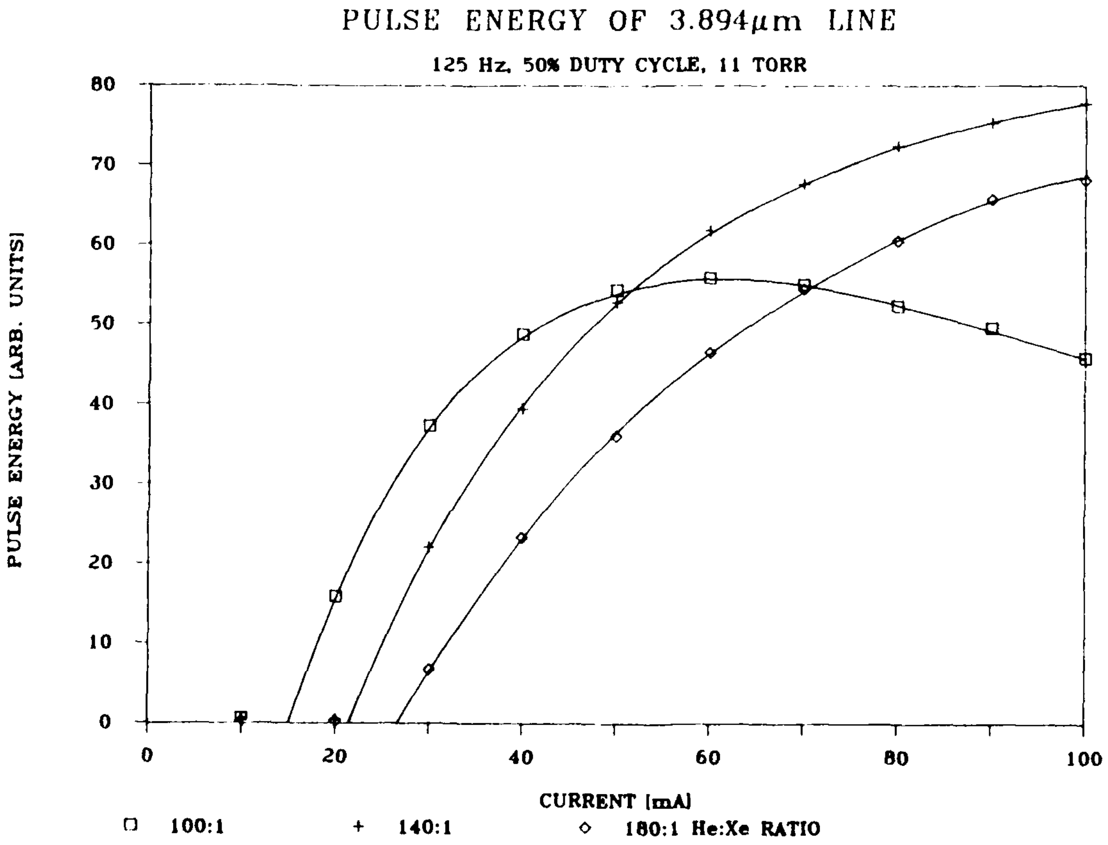


Figure 5 Pulse energy of 3.894 μm line versus current at three He:Xe ratios.

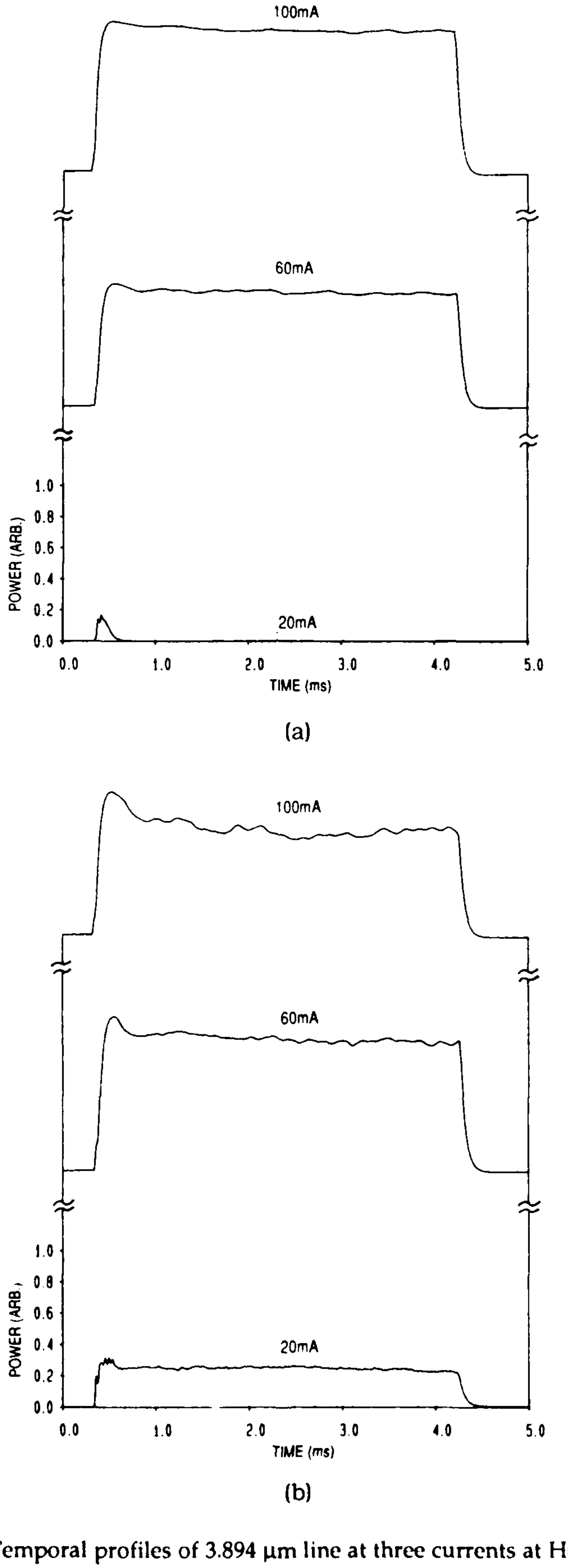


Figure 6 Temporal profiles of 3.894 μm line at three currents at He:Xe ratios of (a) 140:1 and (b) 100:1.

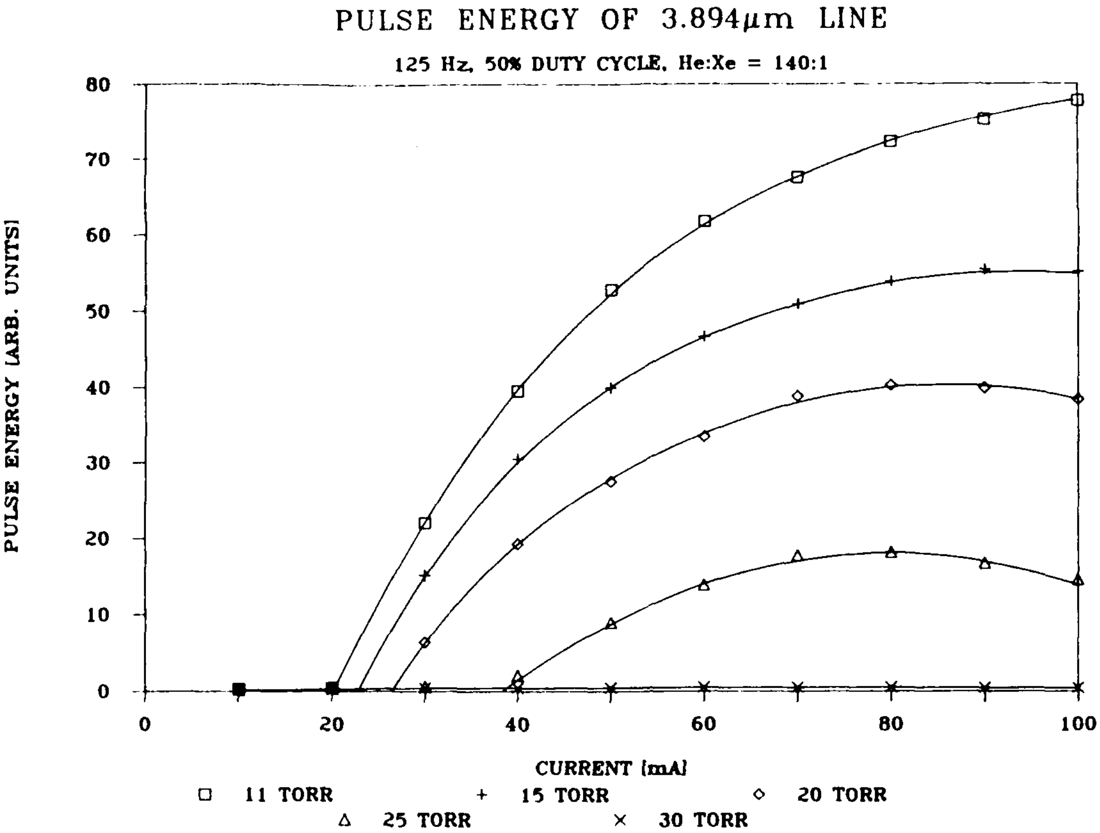


Figure 7 Pulse energy of 3.894 µm line versus current at five total pressures.

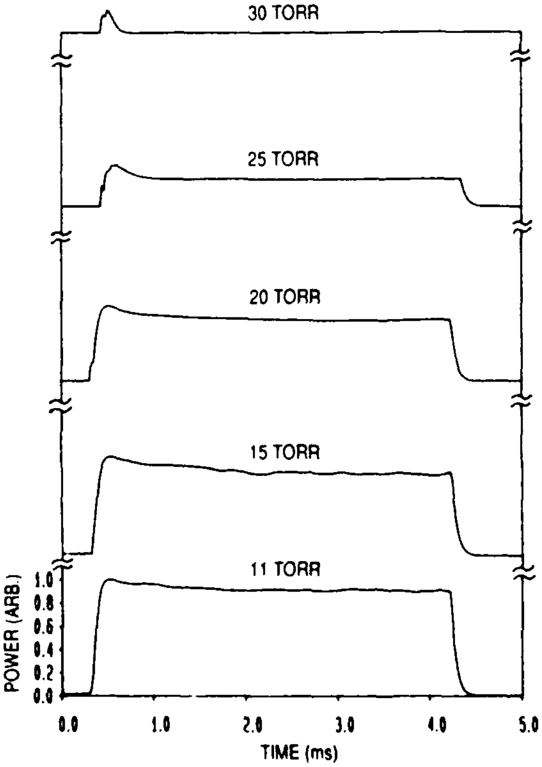


Figure 8 Temporal profiles of 3.894 µm line at 80 mA peak current at five total pressures.

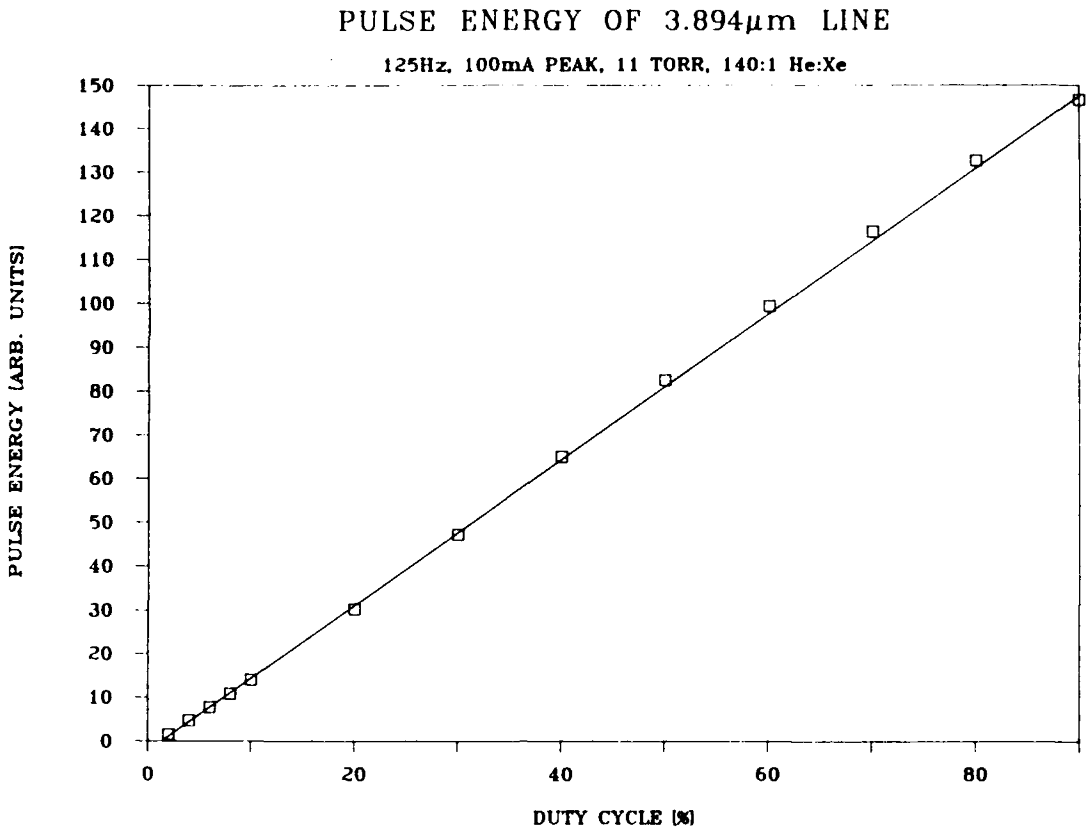


Figure 9 Pulse energy of 3.894 µm line versus duty cycle.

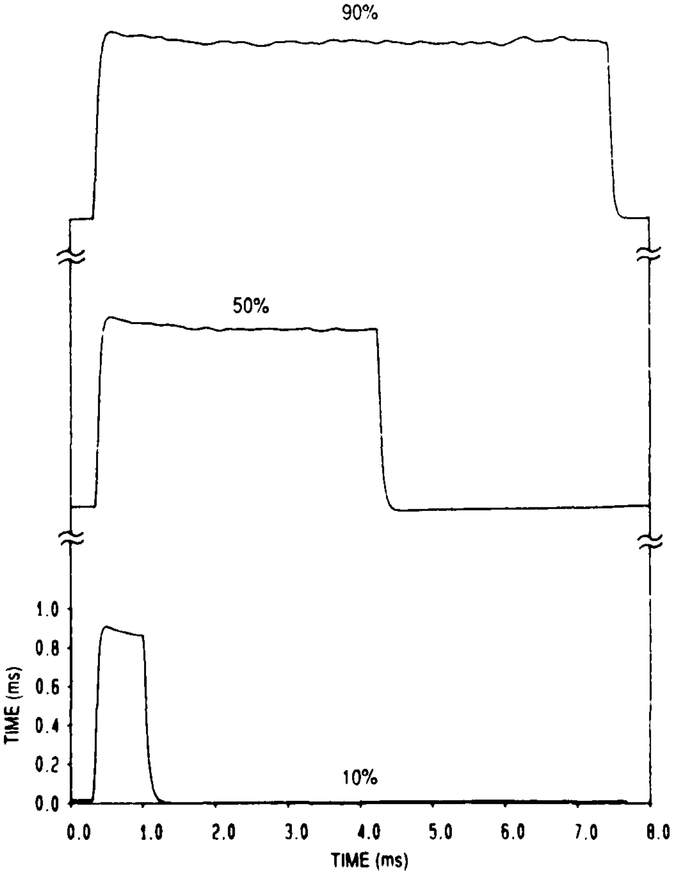


Figure 10 Temporal profiles of 3.894 µm line at three duty cycles.

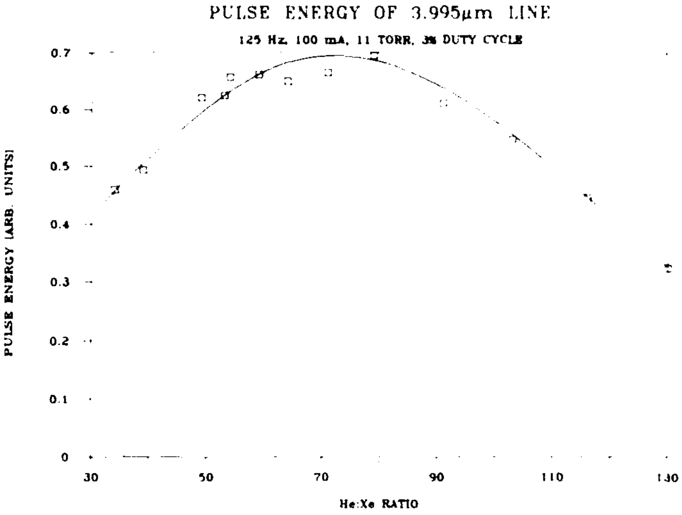


Figure 11 Pulse energy of 3.995 μm line versus He:Xe ratio at 3% duty cycle.

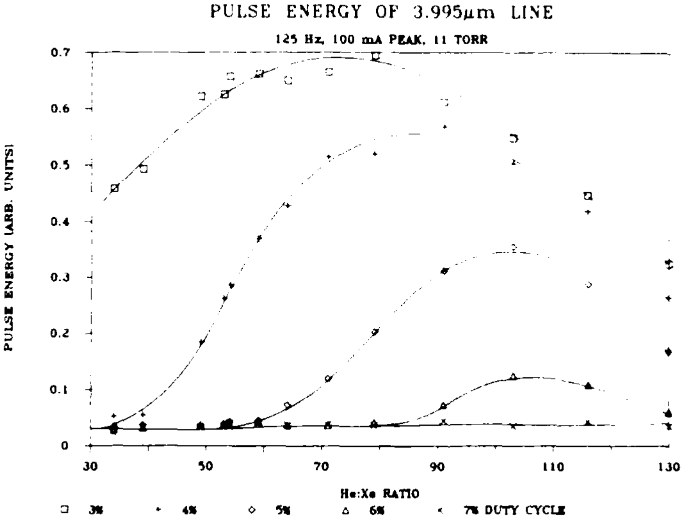


Figure 12 Pulse energy of 3.995 μm line versus He:Xe ratio at five duty cycles.

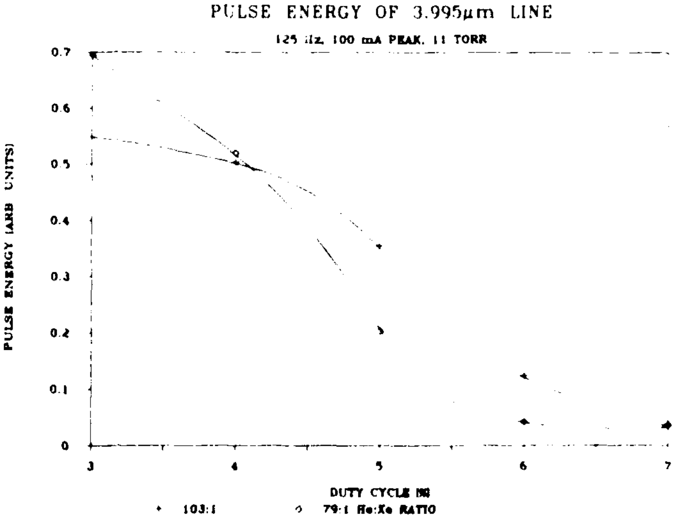


Figure 13 Pulse energy of 3.995 μm line versus duty cycle at He:Xe ratios of 103:1 and 79:1.

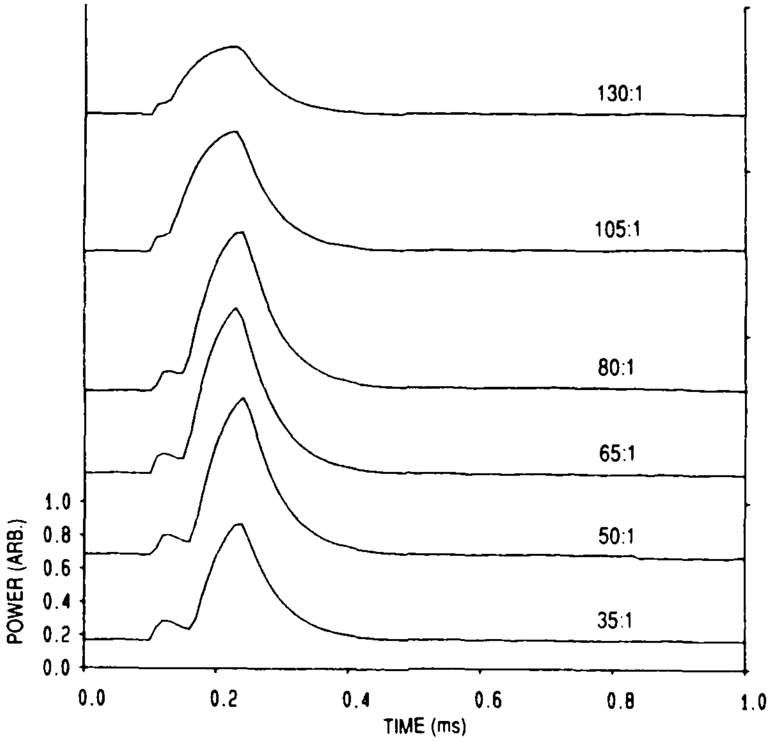


Figure 14 Temporal profiles of 3.995 μm line at 3% duty cycle for six He:Xe ratios. (For clarity, each profile has a dc offset).

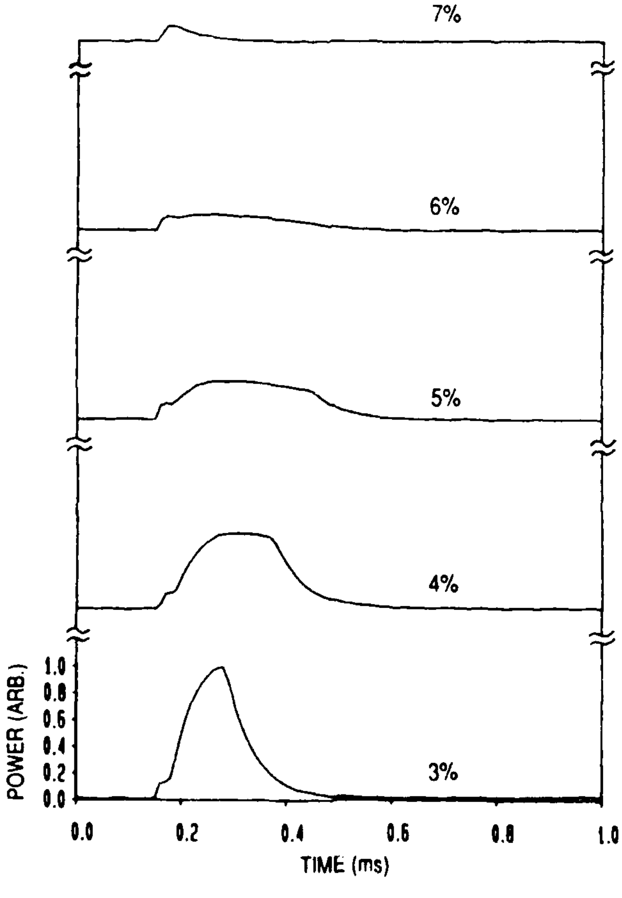
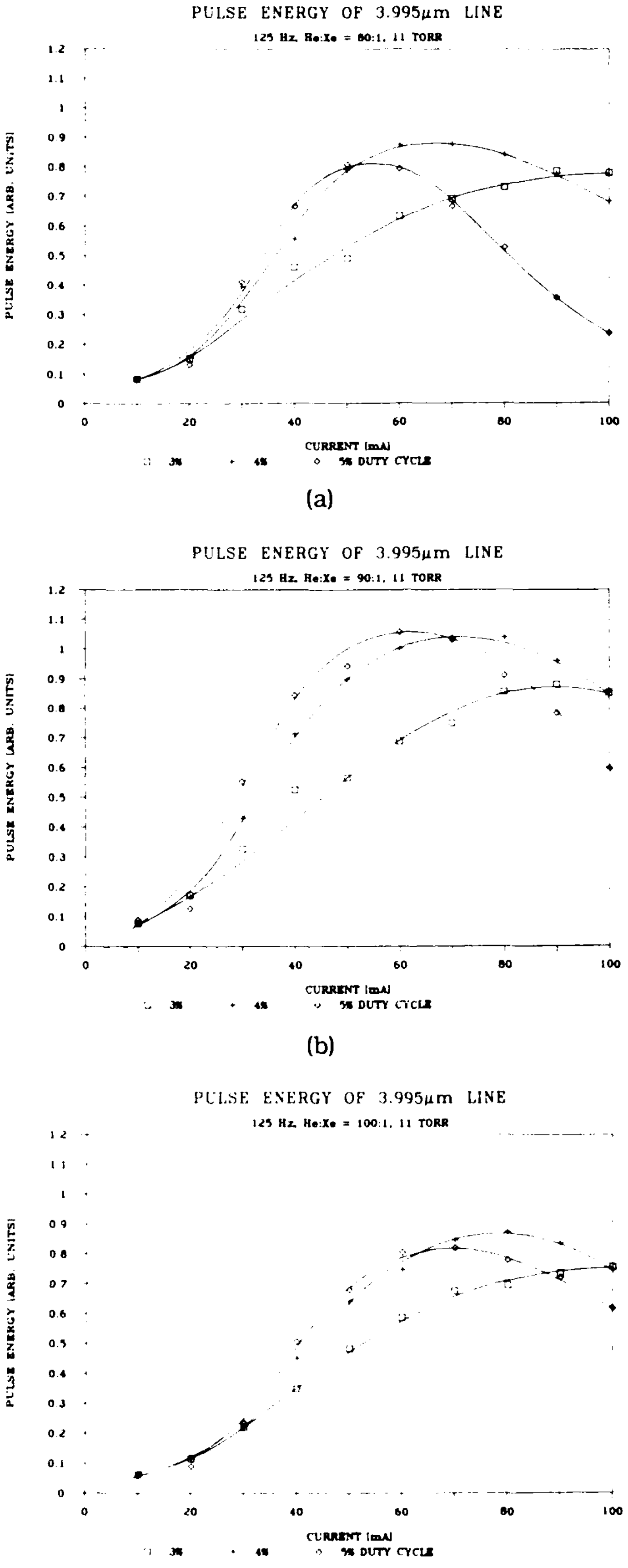


Figure 15 Temporal profiles of 3.995 μm line at He:Xe ratio of 105:1 and five duty cycles.



PULSE ENERGY OF 3.995μm LINE

125 Hz, He:Xe = 80:1, 11 TORR

(a)

PULSE ENERGY OF 3.995μm LINE

125 Hz, He:Xe = 90:1, 11 TORR

(b)

PULSE ENERGY OF 3.995μm LINE

125 Hz, He:Xe = 100:1, 11 TORR

(c)

Figure 16 Pulse energy of 3.995 μm line versus current at He:Xe ratios of (a) 80:1, (b) 90:1 and (c) 100:1.

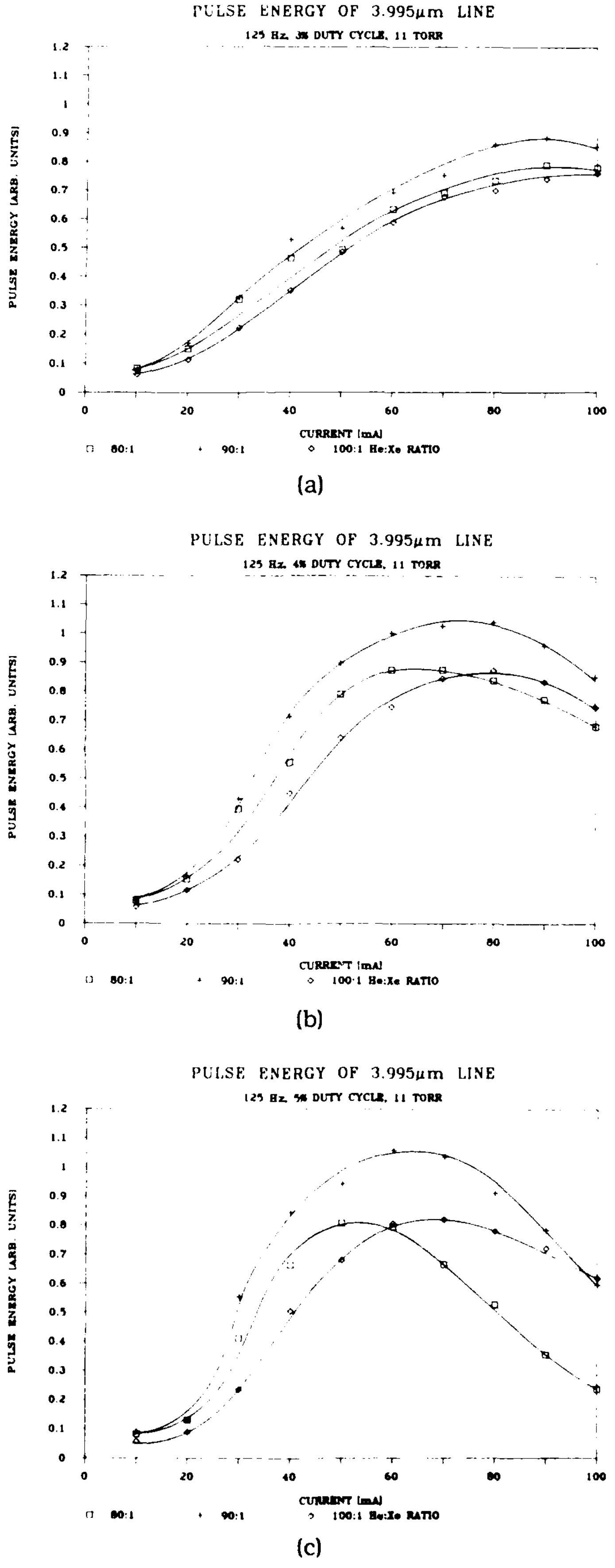


Figure 17 Pulse energy of 3.995 µm line versus current at duty cycles of (a) 3%, (b) 4% and (c) 5%.

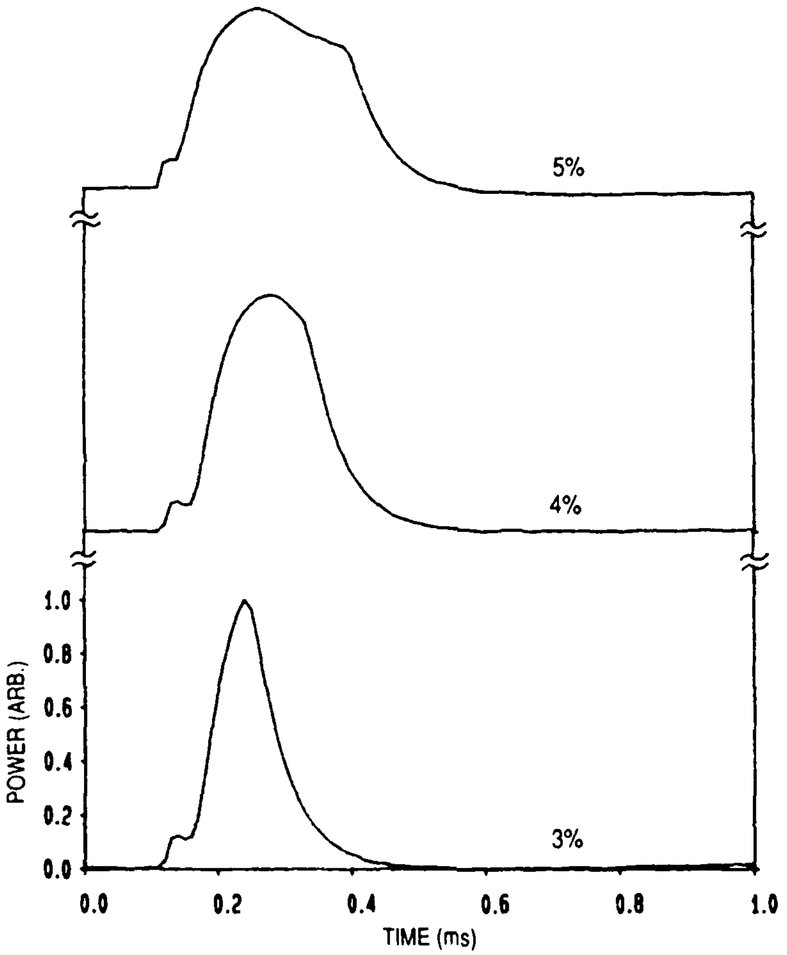


Figure 18 Temporal profiles of 3.995 μm line with He:Xe ratio of 90:1 and a peak current of 60 mA.

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Security classification of this page : UNCLASSIFIED

1 DOCUMENT NUMBERS		**2 SECURITY CLASSIFICATION**	
AR Number:	AR-006-434	a. Complete Document:	Unclassified
Series Number:	ERL-0508-RN	b. Title in Isolation	Unclassified
Other Numbers:		c. Summary in Isolation	Unclassified
		3 DOWNGRADING / DELIMITING INSTRUCTIONS	

4 TITLE

"INVESTIGATION AT TWO WAVELENGTHS OF A MODULATED He-Xe RARE GAS LASER".

5 PERSONAL AUTHOR (S)

Kenneth J. Grant

Shane A. Brunker and

Robert J. Rossiter

6 DOCUMENT DATE

July 1990

7 7.1 TOTAL NUMBER OF PAGES

18

7.2 NUMBER OF REFERENCES

5

8 8.1 CORPORATE AUTHOR (S)

Electronics Research Laboratory

9 REFERENCE NUMBERS

a. Task: DST 89/098

b. Sponsoring Agency:

8.2 DOCUMENT SERIES and NUMBER

Research Note
0508

10 COST CODE

233

11 IMPRINT (Publishing organisation)

Defence Science and Technology Organisation Salisbury

12 COMPUTER PROGRAM (S) (Title (s) and language (s))

13 RELEASE LIMITATIONS (of the document)

Approved for Public Release.

Security classification of this page : UNCLASSIFIED

Security classification of this page : UNCLASSIFIED

14 ANNOUNCEMENT LIMITATIONS *(of the information on these pages)*

No limitation

15 DESCRIPTORS

a. EJC Thesaurus Terms	Gas lasers Helium xenon lasers	
b. Non - Thesaurus Terms		

16 COSATI CODES

0903

17 SUMMARY OR ABSTRACT
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