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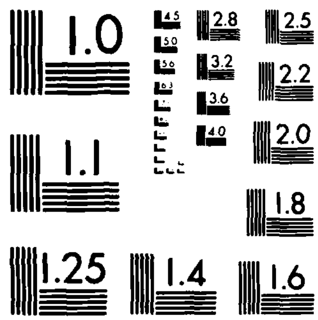

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REPORT

MRL-R-931

PULSED HYDROGEN-FLUORIDE LASER

R. McLeary

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PULSED HYDROGEN-FLUORIDE LASER

R. McLeary

ABSTRACT

This report describes a pulsed hydrogen-fluoride laser which has been constructed at MRL. The laser delivers an energy of 7 J in a 1- μs pulse from vibrational-rotational transitions in the wavelength region 2.6-3.1 μm. It simultaneously produces 1 mJ of energy in a 1- μs pulse from pure rotational transitions in the wavelength region 10-17 μm.

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This report describes a pulsed hydrogen-fluoride laser which has been constructed at MRL. The laser delivers an energy of 7 J in a 1 μs pulse from vibrational-rotational transitions in the wavelength region 2.6-3.1 μm. It simultaneously produces 1 mJ of energy in a 1 μs pulse from pure rotational transitions in the wavelength region 10-17 μm.

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CONTENTS

PULSED HYDROGEN-FLUORIDE LASER

1. INTRODUCTION

This report provides constructional and performance details of a pulsed hydrogen-fluoride (HF) laser constructed at MRL. The laser was required as a source of radiation at wavelengths around three microns for a program investigating fluorescence and optical gain in optically-pumped gas mixtures at high pressure [1].

The laser produces pulsed energies of up to 7 J at wavelengths between 2.6 μm and 3.1 μm from vibrational-rotational transitions of the HF molecule. It simultaneously produces 1 mJ of output at wavelengths between 10 μm and 17 μm from pure rotational transitions.

The laser design is similar to that reported by Pummer et al [2] but with geometry, power supply and operating conditions modified to provide laser pulse durations of approximately 1 μs as required for the gain-measurement experiments.

2. THE LASER

The device is a discharge-initiated, hydrogen-fluoride, chemical laser which uses gas mixtures of sulphur hexafluoride (SF_6) and hydrogen. Pulsed electrical power from a two-stage Marx generator is supplied to a discharge volume formed by a flat-plate anode and an array of pin cathodes which are decoupled by an electrolyte solution. Optical power is extracted by means of a stable resonator consisting of a curved metal mirror and a partially-transmitting flat output window.

In operation, the fast discharge in the gas mixture strips fluorine atoms from the SF_6 molecules and these atoms quickly react with hydrogen molecules to give vibrationally and rotationally-excited HF molecules. The optical power is extracted from the excited HF molecules at a number of wavelengths corresponding to the various allowed vibrational-rotational and purely rotational transitions.

2.1 Laser Construction

The laser body (Fig. 1) is constructed from a PVC tube 96-mm internal diameter and 9-mm wall thickness with aluminium end-flanges and mirror supports. Copper nails are used as pin cathodes arranged in three sections; each section contains 300 nails (six rows of fifty nails) arranged on a square (10 mm) spacing. The gap between sections is 30 mm. The anode is flat brass strip constructed in three sections each 50 mm x 510 mm. Electrode separation is 50 mm which gives a total discharge volume of approximately 3.8 litres. A dilute solution of copper sulphate in water is used as the electrolyte with a $Cu_2SO_4:H_2O$ ratio of approximately 1:380 by weight. The electrolyte bath is under the laser body which is suspended so that the block containing the lower ends of the pin electrodes is submerged in electrolyte. A slow flow of a mixture of SF_6 and H_2 enters the device at each end and is exhausted from a port half way along the laser.

2.2 Resonator

The stable resonator consists of a curved (R = 10 m) gold-coated stainless-steel mirror and a flat partially-transmitting window, with a mirror-window spacing of 1.8 m. Several output-window reflectivities in the range 8% to 70% have been investigated. In this range the performance, in terms of output energy, is substantially unaffected by the mirror reflectivity, although the wavelength distribution tends toward longer wavelengths at higher reflectivities. A potassium-chloride flat with a single layer of arsenic-tri-sulphide on each face (total reflectivity = 60%) was used for the experimental results presented in this report. The arsenic-tri-sulphide coating protects the substrate from attack by the hydrogen fluoride created in the discharge. In addition, the flow of gas into the laser at the two resonator mirrors helps to prevent HF diffusing to these components. Resonator alignment is accomplished by a simple push-pull screw arrangement on each mirror mount.

2.3 Power Supply

The power supply, shown in Fig. 2, consists of a two-stage Marx bank [2] with spark gaps for electrical isolation. Each stage of the Marx bank incorporates a capacitor which may be charged to a maximum voltage of 45 kV. A capacitor value of 0.3 μF was found to produce the maximum laser-output energy. Halving the capacitor value to 0.15 μF decreases the laser energy by only 20%, with a consequent improvement in efficiency. All results in this report are for operation with 0.3-μF capacitors.

3. LASER PERFORMANCE

3.1 Laser Output from Vibrational-Rotational Transitions

The laser-output energy in the wavelength region around 2.8 μm is shown in Fig. 3 as a function of capacitor voltage for a gas mixture of 5 kPa of SF_6 and 0.3 kPa of H_2. This gas mixture gives the maximum output energy, although the dependence on total pressure over the range 4-8 kPa and the dependence on H_2 pressure over the range 0.1 - 0.8 kPa (Fig. 5) is relatively weak. A typical pulse shape is shown in Fig. 4. Higher total pressure or higher H_2 concentration results in shorter pulse durations although again the dependence is relatively weak. The tail of the pulse contains mainly shorter wavelengths and some pulse shortening can be achieved using a suitable filter.

When deuterium is substituted for hydrogen, output from deuterium-fluoride molecules at wavelengths around 3.8 μm is obtained, with energies reduced by approximately 20%. Pulse durations are similar to those obtained with hydrogen.

The multi-mode output beam shows little evidence of large-angle "wall-bounce" modes which are usually present in high-gain HF lasers. The curved walls and the multi-pin electrode structure in this device inhibit the formation of "wall-bounce" modes.

3.2 Laser Output from Pure Rotational Transitions

As well as the strong emission from vibrational-rotational transitions in the 2.6 μm to 3.1 μm region, weak emission from pure rotational transitions in the 10 μm to 17 μm region is also present in this device. The output pulse at these longer wavelengths is of a similar shape but slightly delayed (Fig. 4) with respect to the pulse at the shorter wavelengths. Output energy of approximately 1 mJ is achieved in a mixture of 5 kPa of SF_6 and 0.3 kPa of H_2 with a capacitor voltage of 30 kV. The output energy from these transitions is more sensitive to variations of mixture and pressure than is the output from the vibrational-rotational transitions. The variation of the output energies of both types of transition as a function of H_2 pressure for an SF_6 pressure of 5 kPa is shown in Fig. 5. The units of energy are arbitrary for both sets of results, and these show that the output from rotational transitions decreases rapidly with increasing H_2 concentration above the optimum value. Very similar results are obtained when the H_2 pressure is held constant at 0.3 kPa and the SF_6 pressure is increased above the optimum pressure of about 5 kPa.

4. CONCLUSION

The construction and performance of a multi-joule HF laser has been described. This device operated for a period of one year before maintenance (electrode cleaning) was required. The laser is capable of operating with a number of different gases and consequently can provide output at a range of wavelengths. Laser operation at wavelengths around 2.8 μm (HF), 3.8 μm (DF), 10-17 μm (HF) and 10.6 μm (CO_2) has been observed. In the case of CO_2 operation, output energies of approximately the same magnitude as those obtained from the vibrational-rotational transitions of HF are achieved. Other molecules such as CO (4.8 μm) and N_2O (10.6 μm) may also be suitable for laser action in this device although their operation has not been investigated.

5. ACKNOWLEDGEMENT

The author is grateful for the technical assistance of A. Hutchins, D. Juchnevicius and J. Ferrett.

6. REFERENCES

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2. Pummer, H. et al. (1973). "Parameter Study of a 10-J Hydrogen Fluoride Laser". Applied Physics Letters, 22, (7), 319-320.

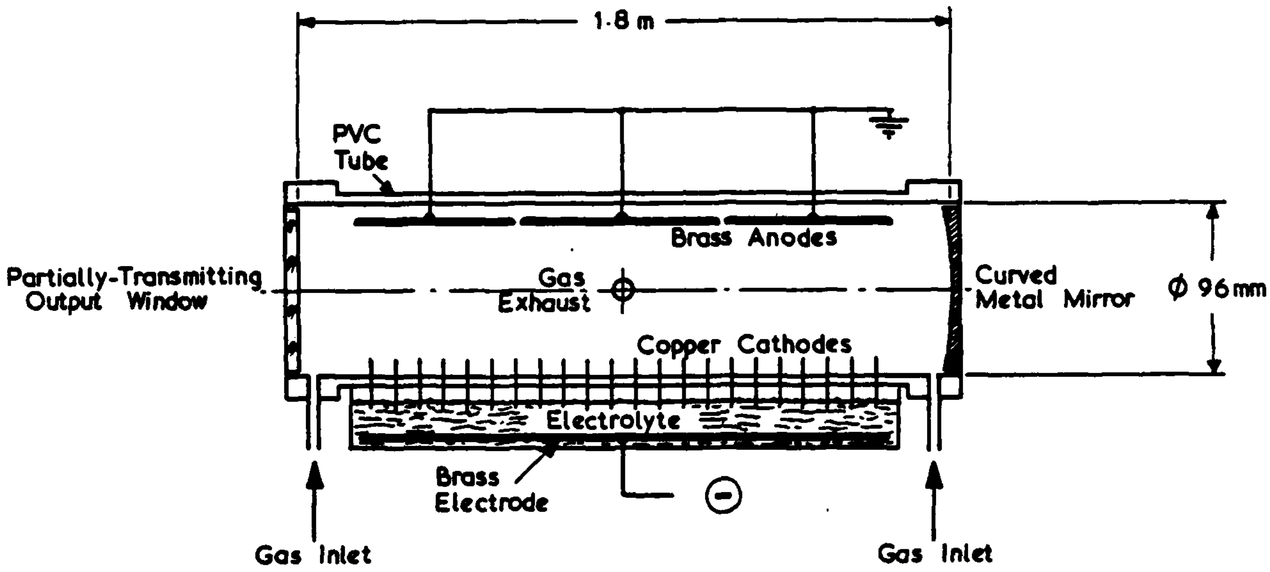

Figure 1. Schematic Diagram of Laser.

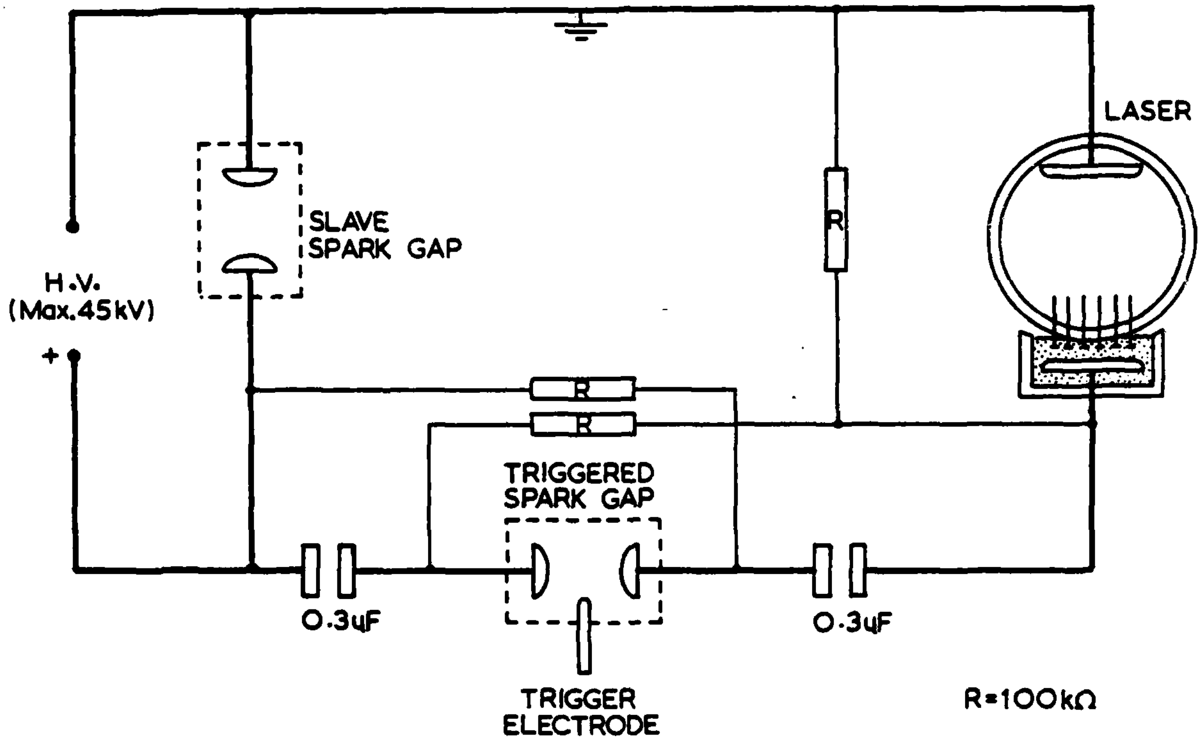

Figure 2. Discharge Circuit.

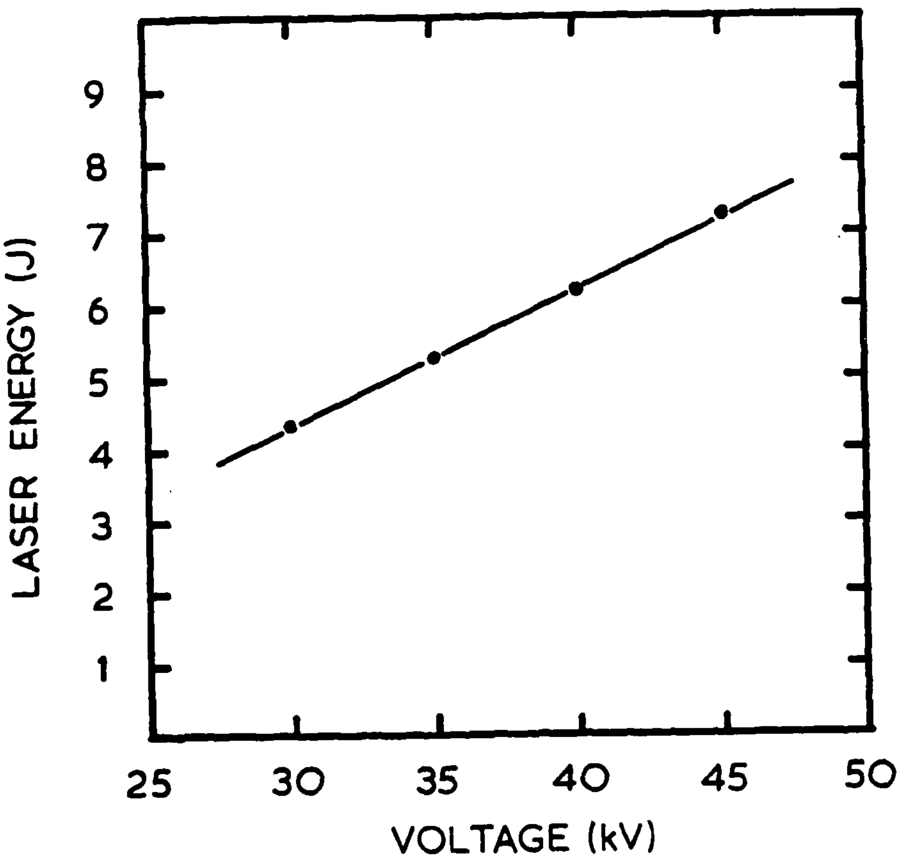

Figure 3. Laser Energy Vs. Capacitor Voltage (C = 0.3 μF)

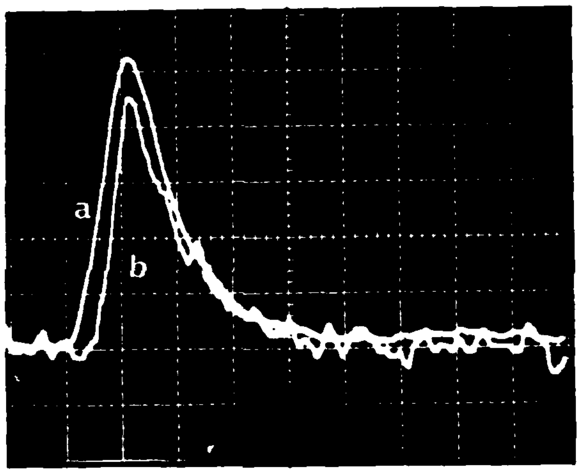

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Figure 4. Output Pulse Waveforms
(a) Vibrational-Rotational Transitions
(b) Pure Rotational Transitions

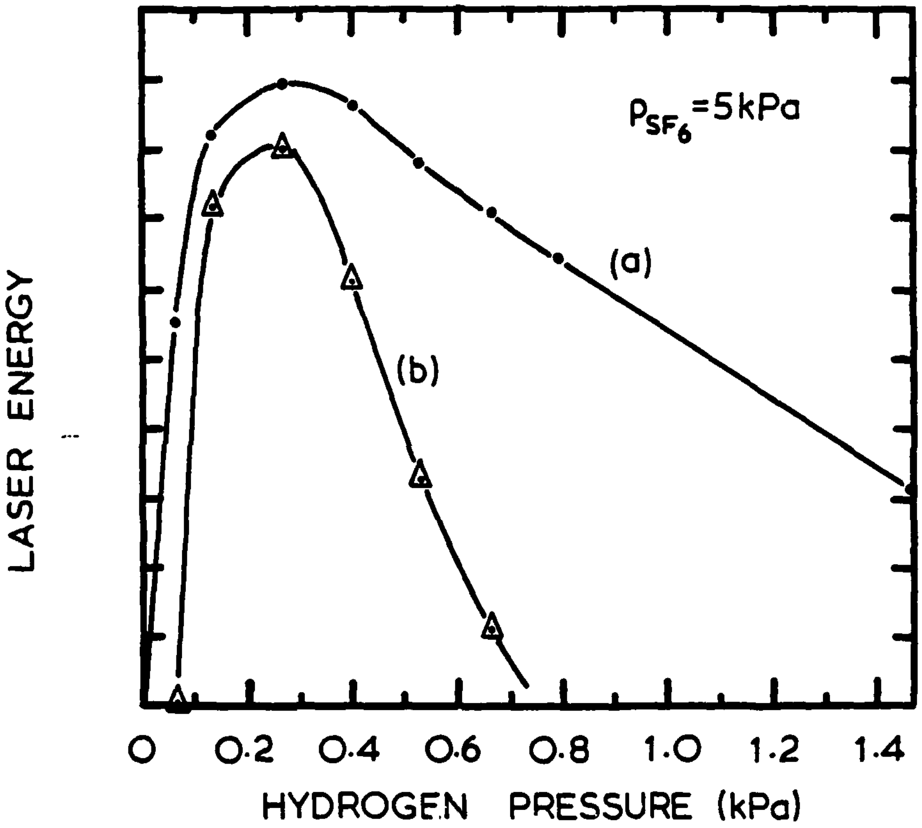

Figure 5. Output Energy Vs. Hydrogen Pressure
(a) Vibrational-Rotational Transitions
(b) Pure Rotational Transitions

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