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ABSTRACT

A rotating mirror Q-switched CO_2 laser was designed and constructed for use as an excitation source in infrared fluorescence studies. Output power of 33 W was reached in the continuous wave (CW) mode. In the pulsed mode, peak powers of 3 kW and pulse widths of 200 ns FWHM have been measured. The repetition rate may be varied between 275 and 1000 Hz and single line operation is selectable with a diffraction grating. The design is compact and economical. The laser has shown freedom from electrical noise, and average power stability of the order of 1 per cent; it has operated reliably for more than 1000 hours with a minimum of maintenance.

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CARBON DIOXIDE LASERS; Q-SWITCHING; LASER MIRRORS; PULSE TECHNIQUES; PERFORMANCE

CONTENTS

1. INTRODUCTION

Since the early 1970s, pulsed CO_2 lasers have been used increasingly as convenient sources of intense optical radiation and for research into fast transient effects. As part of the AAEC research program on laser enrichment, a suitably pulsed CO_2 laser excitation source was required for time-resolved infrared emission studies of organic uranyl chelates [Hamilton et al. forthcoming]. Infrared emission from molecules as large as these had not been reported elsewhere, and was expected to give valuable information on the excited state of the molecule and its time evolution.

Ideally, the excitation source should provide short, monochromatic pulses at high repetition rates and at vibrational transition frequencies of the target molecule. Because the fluorescence signal was expected to be extremely weak, the ability to operate without the generation of electrical noise was also crucial.

This report describes the design, construction and operating characteristics of the Q-switched CO_2 laser developed for these infrared fluorescence studies.

2. DESIGN

When a lasing medium has upper level lifetimes sufficiently long to allow a large population inversion to be achieved by the injection of energy, Q-switching, caused by a sudden increase in the quality factor (Q) of the resonant laser cavity, releases the stored energy in a single large pulse. The continuous wave (CW) CO_2 laser is suitable for Q-switching, and techniques which have been applied include the use of rotating mirrors or prisms [Kovacs et al. 1966], mechanical shutters [Meyerhofer 1968], reactive switching [Bridges 1966], saturable absorbers [Wood and Schwarz 1967] and electro-optic crystals [Day et al. 1970]. A useful review of CW CO_2 lasers was provided by DeMaria [1973], comparisons of Q-switching techniques were made by Meyerhofer [1968] and McDuff [1972], and various theories of the Q-switching process were proposed by Arecchi et al. [1964], Midwinter [1965] and Kafri et al. [1971]. In the present work, the rotating mirror was chosen as the Q-switching method, since mechanical shutters produce double pulsing, even at high shutter speeds; reactive switching and saturable absorbers provide less flexible control of the laser and generally produce longer pulses; and suitable electro-optic crystals are scarce and expensive.

The following requirements were also considered when designing the laser:

(a) Minimum laser-generated electrical noise.

(b) High and variable repetition rates.

(c) Sub-microsecond pulse widths.

(d) High pulse energies and peak powers.

(e) Single frequency operation over the 9.4 and 10.6 μm CO_2 laser bands.

(f) Stable TEM_{00} mode operation.

(g) Long- and short-term stability of pulse characteristics and frequency.

(h) Long-term maintenance-free operation.

(i) Optical and electrical safety.

These requirements led to the choice of configuration described in detail in Section 3. In addition to rotating mirror Q-switching, the system incorporates intracavity Brewster window sealing of the active volume, line selection by a plane diffraction grating, water cooling and slow gas flow.

3. CONSTRUCTION

3.1 General

A schematic representation of the laser is shown in Figure 1 and a photograph of the laser with the protective cover raised is reproduced in Figure 2. The active volume is contained in a 1.25 m long x 10 mm i.d. quartz tube, sealed at each end by a Brewster angle window. The length chosen permits the laser and associated equipment to be accommodated on a conveniently available massive granite table which provides thermal and mechanical stability. The tube diameter was determined from conflicting requirements. Large diameter tubes have low diffraction losses and are easy to align, whereas small diameter tubes allow the use of cheaper and more readily available optical components, smaller backing pumps, favour good TEM_{00} mode stability and diffraction grating line selectivity, and are easier to cool. The end windows are incorporated in multi-functional window mount assemblies (see Figure 3) which serve as gas mixture inlet/outlet ports, supports for the coaxial platinum cathodes, and water jacket seals. The cooling-water jackets are fabricated from 25 mm i.d. Perspex tube.

3.2 Electrical

The laser excitation energy is provided from a relatively inexpensive Hipotronics Model 820-50 20 kV, 50 mA d.c. power supply (Figure 1). The two halves of the laser discharge are electrically in parallel to match the voltage and current characteristics of the discharge with those of the supply. A third cylindrical electrode, earthed through the spring contact made by a molybdenum-quartz seal, acts as a common anode for both halves of the discharge.

Since a glow discharge exhibits a negative impedance [Cobine 1941], it is inherently unstable and preferably should be fed from a constant current supply. An alternative approach is to include sufficient added series resistance to make the overall impedance positive. In Figure 1, this is provided by R1 and R2, each comprising four 100 kΩ, 75 W resistors in series. Although power is dissipated in these resistors, this system is cheaper than a more elaborate power supply, and the current regulation is sufficient for short- and long-term laser output stability. Since the window assemblies are at high voltage, gas connections are made through sufficient lengths of rigid polythene tubing to prevent establishment of a glow discharge in the low pressure gas lines.

The laser is housed under a hinged Perspex cover fitted with a microswitch safety interlock to switch off the high voltage and ground the window mounts if the cover is lifted. The cover also provides dust protection for optical surfaces and, although permitting visual inspection of laser operation, it is sufficiently opaque to contain scattered infrared radiation which may cause eye damage.

3.3 Optical

The laser tube assembly and cavity optics are supported in Oriel precision optical mounts. The resonator cavity is terminated at one end by a PTR Optics Corp. plane, aluminium diffraction grating of 70 lines/mm blazed for 10.6 μm, and at the other end by a II-VI Inc. ZnSe concave output coupler having 4 m radius of curvature and 80 per cent reflectivity. Originally, an Oriel 80 per cent reflective Ge output coupler was used, with Harshaw NaCl windows at the Brewster angle to seal the discharge volume. However, since an intracavity power of about 1 kW cm^{-2} in the CW mode resulted in thermal runaway, causing distortion of the laser optics and a reduction in output power, a ZnSe output coupler and ZnSe windows at the appropriate Brewster angle were installed. Unlike NaCl optics, these windows do not require heating to prevent fogging and hence eliminate the concomitant problem of high voltage insulation of the window heaters. Both types of window were sealed to the mounts with Vacseal silicone resin.

For CW operation, a fixed Spawr plane molybdenum mirror is placed at 45° to the beam tube axis. For Q-switched operation, this mirror is replaced by a Lincoln Laser model 6-60 beam scanner comprising a hexagonal polygon mirror integrally mounted on the shaft of a synchronous motor. The scanner is driven by a variable frequency power supply, thus allowing the laser pulse frequency to be conveniently adjusted in the range 275 to 1000 Hz.

3.4 Gas Handling

The gas mixture is supplied from a special gas handling rig. Each constituent gas is metered before mixing. Condensable impurities are removed by a cold trap, water vapour by a silica gel column, and oxygen by a heated MnO column with facilities for in situ regeneration. In addition, the gas mixture may be seeded with measured amounts of additives. The feedstock for the laser is a mixture of commercial grade CO_2, dry N_2 and He. The total pressure is measured by a 0-13 kPa capsule gauge before the gas enters the discharge tube through a Nupro 7 μm stainless steel filter.

4. PERFORMANCE

4.1 CW Mode

Table 1 lists performance details of the laser operating in a multi-line mode with a plane gold mirror replacing the diffraction grating. Power was measured with a Scientech Model 36-0001 disc calorimeter. After taking into consideration diffraction losses and active volume ultilisation, the maximum CW output power compares favourably with the expected upper limit of about 75 W per metre length for slow gas flow lasers [Rigden and Moeller 1966]. Significantly greater powers can be obtained with high gas flow rates to provide convective cooling and removal of gas decomposition products [Deutsch et al. 1969]. However, these require large throughput pumps, and either a high rate of gas consumption or the complexity of a recirculation and cooling system. The present laser is economical in gas consumption, using only about 0.1 L of gas mixture per minute, so only infrequent interruptions are required for gas bottle changes.

TABLE 1
CW OPERATING CONDITIONS

Gas mixture ratio (by volume)	$CO_2/N_2/He$ = 6/7/9
Pressure	700 Pa
Input power	10 kV, 2 x 25 mA
CW output power	33 W
Diffraction loss*	14 per cent
Active volume used*	36 per cent
Average power stability	within about 1 per cent

*Calculated values.

4.2 Q-switched Mode

Figure 4 shows a Q-switched pulse captured by a Molectron P1-11H pyroelectric detector and recorded on a Tektronix 7623A storage oscilloscope with a 100 MHz bandwidth. The ringing following the pulse is typical of this type of detector. With the laser operating in a multi-line mode, a peak power of 3 kW can be attained. With the diffraction grating in place and tuned to the 10P (20) line, peak power is reduced to about 1 kW. In all cases, the beam can be focused to a spot size of less than 0.1 mm diameter, giving power densities in the megawatt per cm^2 range. The FWHM pulse width of about 200 ns is comparable to that produced by a CO_2 TEA laser. Although maximum peak power is achieved at a pulse frequency of about 500 Hz and maximum pulse energy at about 300 Hz, the pulse shape is largely insensitive to the rotational speed of the mirror; this indicates that the dynamics of the laser medium is more important than the rate of mirror alignment. The pulse peak height reproducibility is about 50 per cent due mainly to the tolerance spread of ± 30 seconds of arc (± 1 μrad) in the vertical alignment angle of the hexagonal mirror facets.

To establish the beam profile, the divergent beam was probed by a 0.05 mm diameter wire at a distance of 750 mm from the output coupler. As the cross section was traversed by the wire, energy scattered normal to the beam axis was measured by an InfraRed Associates HgCdTe detector. The resulting quasi-Gaussian profile (Figure 5) confirms that the laser operates in the desired TEM_{00} mode.

Calibration of the diffraction grating micrometer settings for frequency selection was carried out using an Optical Engineering CO_2 laser spectrum analyser. Laser line separation was found to be sufficient to allow accurate and reproducible selection, by using the micrometer setting alone, of the 00°1 - 10°0 transitions within the ranges 10P(8) to 10P(30) and 10R(12) to 10R(20).

To provide a source of trigger signals for associated instrumentation, an Optron OPB707 reflective sensor was mounted facing the rotating mirror. The resulting pulses, sharpened by a Schmitt trigger circuit, provide timing information that is synchronous with the laser pulses. The pulse jitter (about 30 μs) allows adequate triggering for the observation of processes on a millisecond time scale. Where more precise triggering is required, pulses derived from a pyroelectric detector which is directly monitoring the laser beam are used.

5. CONCLUSION

A laser which has given reliable, trouble-free service for more than a thousand hours of operation has been described. The only off-line maintenance period was due to a gradual build-up in the beam tube of metal sputtered from the cathodes, and to a smaller amount of contamination on the downstream ZnSe window which caused a slight reduction in output power. The disassembly, cleaning and reassembly of the laser can be effected simply and conveniently.

The use of this laser has been a key factor in the characterisation of previously unmeasured infrared emission from gaseous uranyl compounds. Lasers of this type could be used in related work, such as multiphoton dissociation, where sub-microsecond pulses are required. They offer an effective alternative to the chopped beam lasers, and the cumbersome and electrically noisy (although more powerful) CO_2 TEA lasers.

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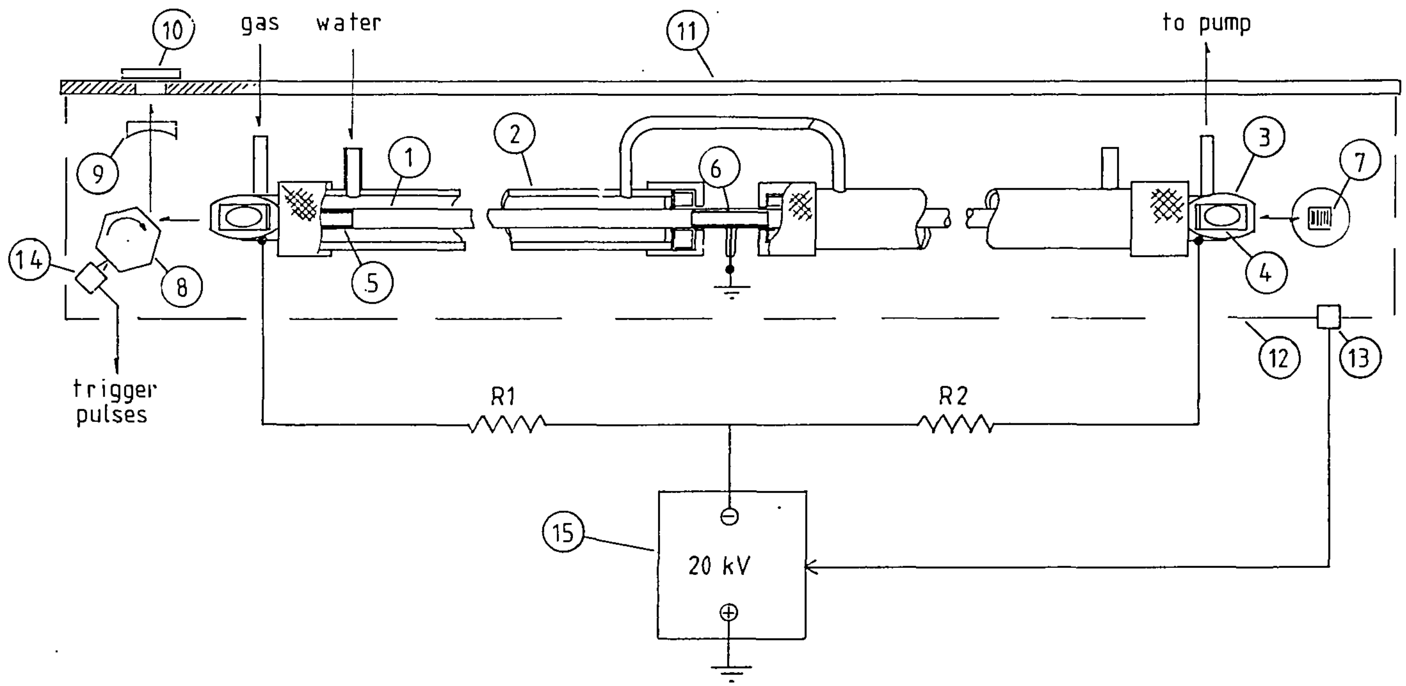


1. Quartz tube. 2. Water jacket. 3. Brewster window mount. 4. ZnSe window. 5. Cathode. 6. Anode.
7. Diffraction grating. 8. Rotating mirror. 9. Output coupler. 10. Beam stop. 11. Al backing plate.
12. Hinged cover. 13. Interlock switch. 14. Reflective sensor. 15. d.c. power supply.

FIGURE 1. CONSTRUCTION OF LASER ASSEMBLY

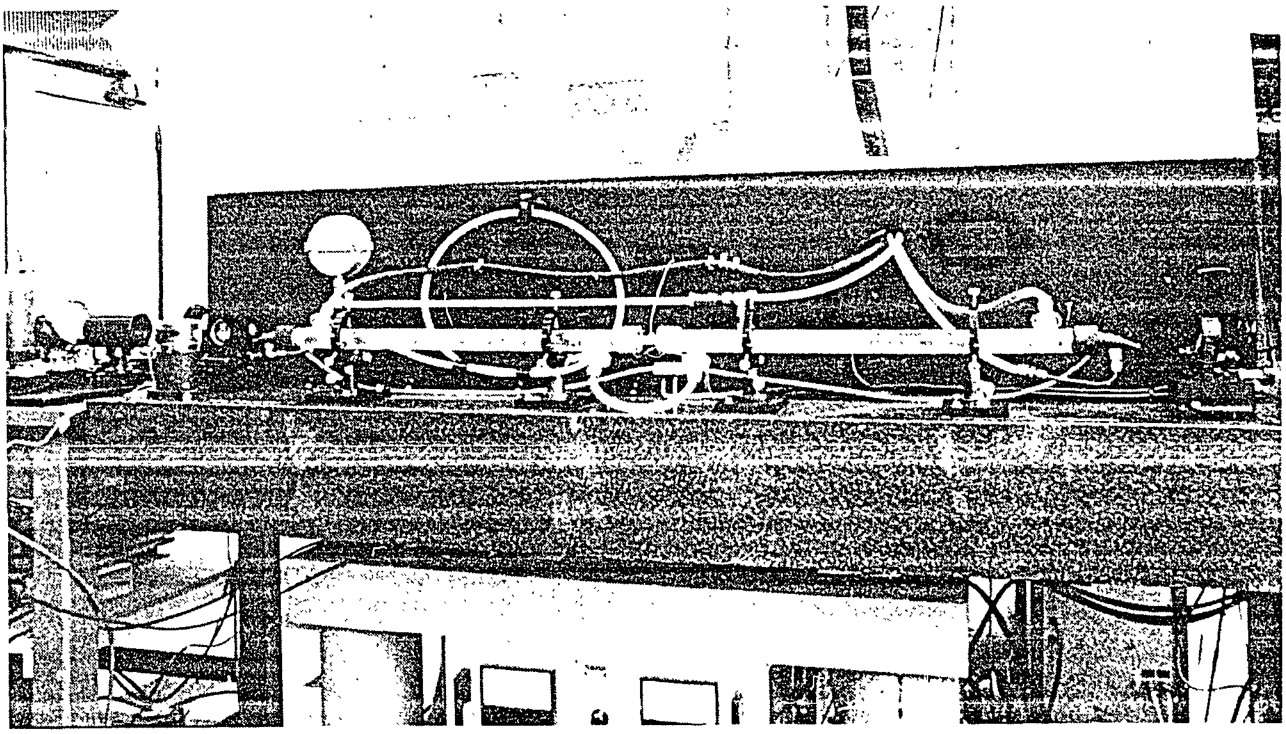


FIGURE 2. PHOTOGRAPH OF THE LASER

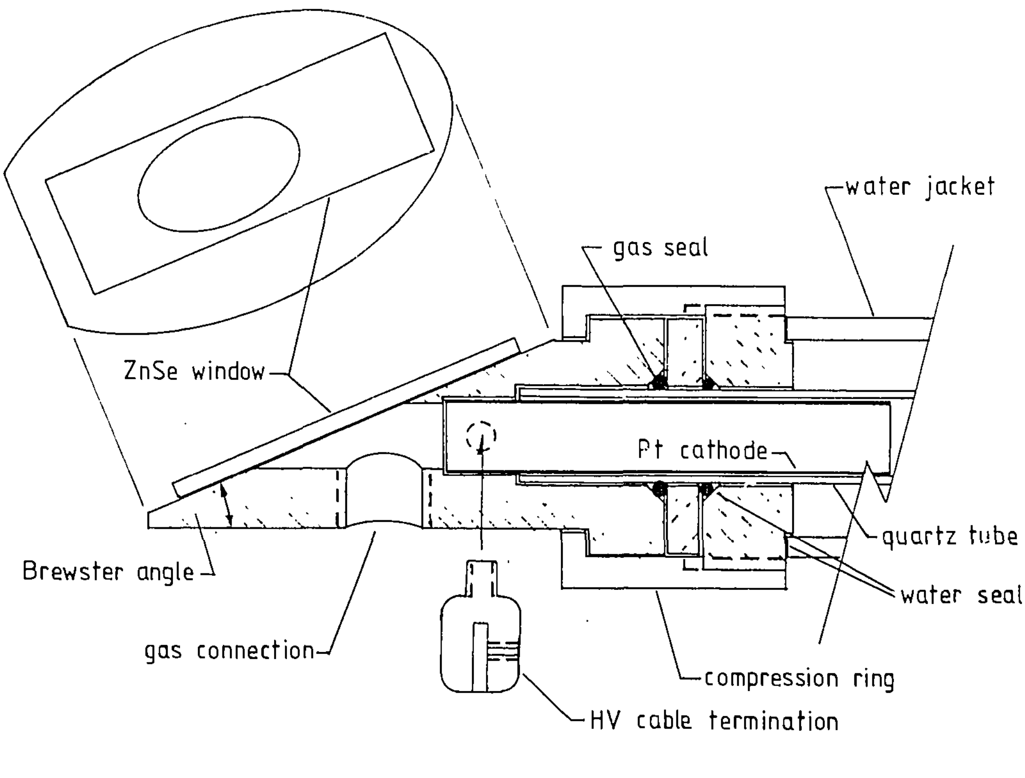
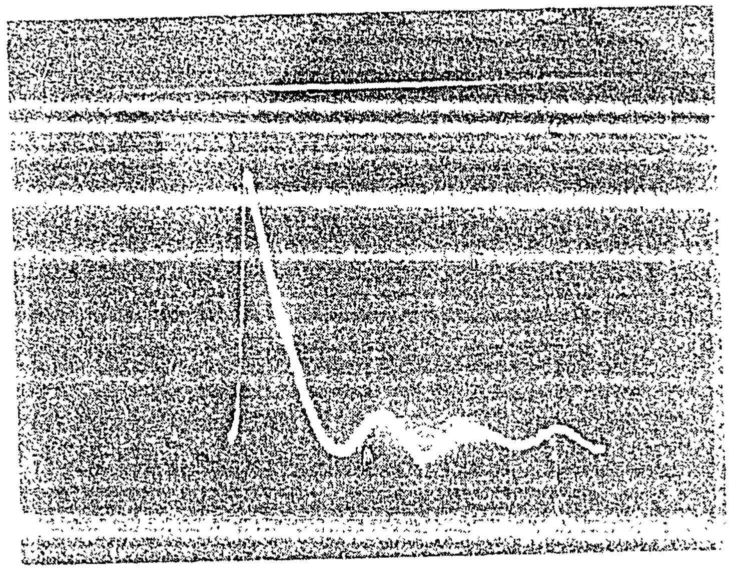


FIGURE 3. WINDOW MOUNT ASSEMBLY



Horizontal scale 200 ns cm^{-1}; pulse frequency 300 Hz; pulse energy 0.7 mJ; average power 210 mW; peak power 3.1 kW; lasing on the 10P(20) line.

FIGURE 4. Q-SWITCHED LASER PULSE

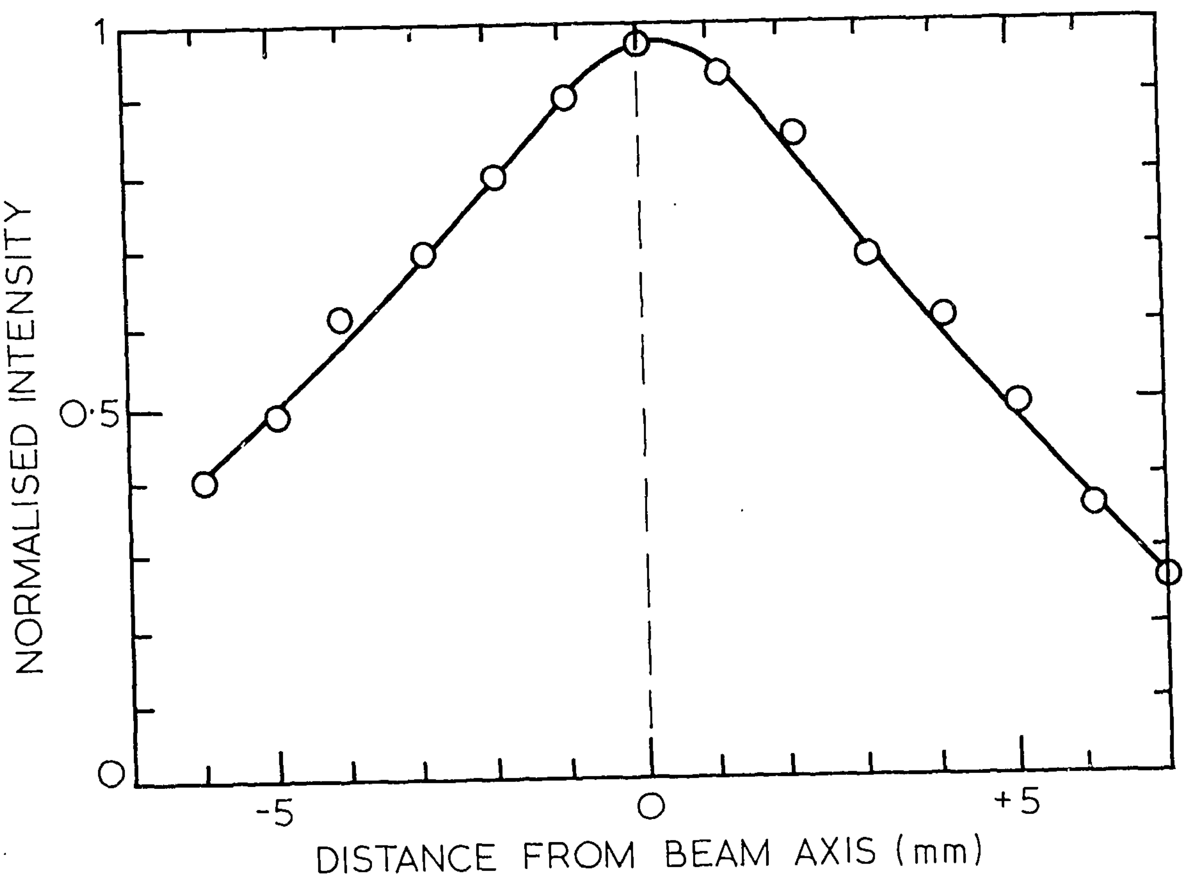


FIGURE 5. LASER BEAM PROFILE