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ABSTRACT

Parametric and engineering studies of a high energy HBr laser are described. Use of benzene as a pre-ionization additive combined with optimised gas mixtures and output coupling has generated 320 mJ reliably at 1 Hz, and up to 550 mJ has been obtained. These energies are up to a factor of 4 greater than the maximum HBr laser outputs previously reported. The laser has been designed as a corrosion resistant, maintenance free system which generates dependable long term outputs.

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1. INTRODUCTION

The hydrogen bromide laser is the only powerful laser source in the 4-4.5 μm region, and is a useful pump for exciting CO_2 and N_2O directly or by collisional transfer. Optical pumping of these molecules has been used to produce continuously tunable outputs in the 9-11 μm region (T.Y. Chang and O.R. Wood, 1977) and line tunable outputs in the 16 μm region (R.M.Osgood, 1978, R.M. Osgood, 1976).

Despite the early discovery of the HBr laser in longitudinal discharges (T.F. Deutsch, 1967) and transverse discharges (O.R. Wood and T.Y. Chang, 1972, I. Burak et al, 1972) there are no published detailed studies of high energy transversely excited HBr lasers. With one exception (T.Y. Chang and O.R. Wood, 1973) the transverse discharge systems have all been of the resistively loaded pin-bar type, and typically produce total output energies of a few tens of millijoules. The highest output from a pin-bar laser is 100 mJ (R.M. Osgood, 1976) with rather poor beam quality, whilst 140 mJ has been obtained with a double-discharge HBr laser (T.Y. Chang and O.R. Wood, 1977).

We report a detailed parametric and engineering study of a transversely excited HBr laser. This has led to reliable long term outputs in excess of 300 mJ, with a maximum observed output of 550 mJ.

2. HBr LASER DESIGN

Bromine vapour and hydrogen bromide are exceptionally corrosive, especially in the presence of even very low levels of moisture (D.E. Lake and A.A. Gunkler, 1960) and hydrogen bromide lasers have become notorious for corrosion problems and damage to the associated vacuum system. We have therefore constructed the laser entirely from bromine resistant materials, in order to obtain long-term reliable operation.

Information on corrosion by bromine and hydrogen bromide is limited and in some cases contradictory, the major sources of information consulted being (D.E. Lake and A.A. Gunkler, 1960, H. Wiggin and Co.Ltd. Technical Bulletins, T. Lyman, 1961, C.A. Hampel, 1961, C.J. Smithells, 1961, N.A. Waterman, 1974).

In order to confirm and supplement the information from the references cited, some simple accelerated life tests were conducted on various constructional materials. Carefully weighed foil samples of metals and appropriate samples of non-metals were exposed to ~ 300 Torr of Br_2 vapour at room temperature in an evacuated glass apparatus for 14 days. The results of these tests are summarised in Table 1.

On the basis of these tests and the commercial availability of material in the size needed, Monel 400 was selected as the material for the main electrodes. A cross section of the tube is shown in Fig.1. All ancillary metal components are made of pure nickel, with the exception of the trigger wires which are tantalum. The main discharge tube is glass, and all vacuum seals are made with PTFE O-rings. The Brewster angle window mounts are machined from PTFE, and the electrode supports from Kel-F. Kel-F is chosen in preference to PTFE for these components despite its high cost and limited availability as it has much higher stiffness than PTFE and permitted accurate electrode spacing to be maintained. The electrode support rings also act as baffles to improve the gas flow distribution. The overall tube design maximises the ratio of pumped to unpumped gas volume, which reduces the pumping speed required. The active volume is 25 mm x 30 mm x 1500 mm.

Some difficulty was experienced in providing reliable seals to the 75mm x 6mm CaF_2 windows. Conventional PTFE O-rings require very high compression to achieve a seal and windows cleaved under the clamping forces. Specially machined PTFE 'knife-edge' seals (P. Shatford, 1977) require much lower clamping forces and proved satisfactory.

3. PUMPING SYSTEM AND GAS SUPPLY

The tube volume (~ 7 litres) combined with 1 Hz operation define a pumping speed of ~ 450 ℓ min^{-1}. The gas leaving the laser contains both HBr and Br_2, and is highly corrosive. Conventional vacuum pumps and vacuum pump oil are rapidly destroyed by this mixture.

In order to avoid the use of sophisticated corrosion resistant high speed pumps and oils we have chosen to trap out the corrosive products prior to the pump. The system used is shown in Fig.2. It is constructed from 1" 'QVF' components with PTFE valves and seals. The traps are specially made. The majority of the Br_2 is collected in the first trap, but significant amounts collect in the second and third liquid nitrogen traps. Activated charcoal traps are provided as a back-up, and all liquid nitrogen filling and vacuum valve operations are under automatic, interlocked control.

During the course of an experimental run, 1-2 litres of solid bromine collect in the liquid nitrogen traps. On warming up a large over-pressure of HBr is generated, and blows off via the relief valve. Liquid bromine is then drained from the system and disposed of.

The noncorrosive gases are supplied to the laser pre-mixed in the conventional manner. Bromine vapour is supplied from a reservoir heated to 40°C via a heated flowmeter and PTFE needle valve, in order to obtain adequate bromine vapour pressure. The Br_2 vapour is mixed with the other gas components in a jet mixer which avoids back streaming of Br_2 vapour to the non-corrosion-proof part of the system. The large quantity of bromine and hydrogen used requires adequate safety precautions to be taken.

4. DISCHARGE CIRCUITRY

The discharge circuitry is of a conventional TEA laser type, using low inductance discharge capacitors and a field distortion spark gap. A wide range of main discharge capacitors (0.02 μF - 0.2 μF) trigger wire coupling capacitors (250 pF - 16,000 pF) and discharge voltages (10 kV - 45 kV) have been investigated. Optimum outputs were obtained with the 0.2 μF main capacitors, discharge voltages of 20-25 kV, and 5000 pF coupling capacitors for each trigger wire. This optimum value for the coupling capacitor is very much larger than is typically employed in CO_2 TEA lasers.

5. GAS MIXTURES

Gas mixtures reported for the HBr laser have varied from stoichiometric H_2:Br_2 (G. Wolga, 1972) to 3% Br_2 in H_2 (H. Oodate et al, 1975). The addition of He and SF_6 has been reported to improve HBr laser performance (H. Oodate et al, 1975, H. Oodate et al, 1975, G. Inove et al, 1974) whilst (G. Wolger, 1972) reports enhanced outputs on addition of air, He, A, N_2 and O_2.

Initial experiments showed that dilute $Br_2:H_2$ mixtures produced much better discharge quality and laser output than stoichiometric mixtures, and the addition of argon provided strongly increased output and wider operating range. Fig.3 shows the variation of the laser output as a function of H_2, A and Br_2 flow rates for a total pressure of 180 Torr and 22 kV charging voltage. The output was ~ 320 mJ maximum.

Additions of He and N_2 were tried over a wide range of operating conditions. Although for non-optimum mixtures some enhancement could be obtained on adding He, no conditions were found under which a helium containing mixture provided greater output than the standard mix given in Fig.3. Additions of N_2, air, and small amounts of O_2 reduced the output under all operating conditions. Additions of SF_6 and NF_3 produced arcing at flow rates in excess of 2.5 cm^3s^{-1}. At this flow rate the laser output was unaffected.

6. PREIONIZATION ADDITIVES

The addition of low ionization potential organic compounds to TEA CO_2 lasers is now a well established technique for improving the laser output and discharge quality.

A wide range of possible pre-ionization additives were screened for ionization potential, absorption at the HBr laser wavelength, and reaction with Br_2 vapour. The results of these tests are summarised in Table 2. A large number of the additives used for CO_2 lasers are unsuitable due to their reaction with Br_2 vapour. Some fluorinated derivatives of these compounds do not react with bromine, but were not good preionization additives.

Benzene proved by far the best additive, and use of benzene vapour doping of the H_2 supply has more than doubled the laser output. Benzene flows are ~ 25 cm^3 liquid C_6H_6 per hour. Use of benzene doping causes complex brominated hydrocarbon mixtures to be deposited in the laser tube, but these do not affect the laser output. Fouling of the windows by these deposits initially required the windows to be cleaned every two hours. However, heating the windows to ~ 40°C with infrared lamps reduces deposition on the windows, which under these conditions require only occasional cleaning.

7. LASER PERFORMANCE

The optical cavity comprised a flat multi-layer dielectric coated CaF_2 output coupler and a gold coated glass total reflector of 5m or 10m radius. The output energy was independent of the mirror radius, but was noticeably sensitive to the optical quality of the mirrors and windows.

The total laser output was determined as a function of output mirror reflectivity, Fig.4, and the optimum output coupling found to be 10%. The fraction of the total output energy which is contained in the 1-0 band emission increases with decreasing output coupling. For 10% coupling approximately 45% of the total energy is in the 1-0 band. Using this coupling, benzene doping, and 25 kV charging voltage maximum outputs of 550 mJ have been observed. Long term reliable outputs of 320 mJ have been obtained, with only one arc occurring in 1,000 shots and an energy fluctuation of ± 3% in the same period, with a repetition rate of 1 Hz. The system has been operated continuously at this output level for periods of several hours.

The spectrum of the laser output is shown in Fig.5, and is fairly typical of HBr lasers. A considerable number of other weak output lines have been observed, including all those previously reported from HBr lasers (R. Beck et al, 1978) and some new weak lines which have not been investigated in detail.

The laser output occurs in two pulses, as shown in Fig.6, the first delayed by 500 ns from the peak of the current pulse. The first pulse contains the 3-2 and 2-1 emission lines, the second being the 1-0 lines. This is easily demonstrated by passing the laser output through a cell containing HBr (10 cm, 100 Torr) which totally absorbs the 1-0 band. The output pulse shape is dependent on the output coupling, high couplings producing longer delays between the two pulses, whilst for very low couplings (2.5%) the pulses partially overlap.

Laser output as a function of repetition rate is shown in Fig.7. The available pumping speed (450 ℓ min^{-1}) is clearly barely sufficient for full power operation at 1 Hz. A 25% enhancement of output power occurs on reducing the repetition rate to 0.5 Hz. However the system can be run with ~ 40% output and increased arcing rate at up to 1.5 Hz.

The beam divergence was measured to be ~ 4 milliradians by observing the diameter of the beam pattern in the focus of a 50 cm KBr lens.

8. CONCLUSIONS

The HBr laser system described has produced long-term reliable outputs of 320 mJ, in excess of a factor of two greater than those previously reported, with maximum observed outputs of 550 mJ.

The system requires no routine servicing other than draining the liquid bromine from the trapping system and occasional window cleaning, in contrast to systems previously described. It is completely resistant to Br_2 and HBr corrosion.

The enhanced outputs and reliability of this system greatly facilitate experiments using HBr lasers.

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TABLE 1

CONSTRUCTIONAL MATERIALS FOR HBr LASERS

	Metals	Non-metals
No attack	Nickel Tantalum Pure lead Zirconium Tungsten	PTFE (Teflon) PCTFE (Kel-F) Ceramics Glass Carbon
Useable, some attack	Monel 400 Molybdenum Platinum (Silver)*** (Inconel 750)***	Perspex (Slight swelling) PVC (" ") HD Polythene (" ")
Heavily attacked	Copper 316 stainless steel Immac 5 stainless steel Titanium ** Aluminium *	Nitrile rubber (Embrittles) Viton A (") Silicone rubber (") Epoxies

* Protected by heavy anodization.

** Reported to be resistant to wet Br_2, but very rapidly attacked by dry vapour.

*** Very heavily tarnished but no progressive attack. Use not advisable.

TABLE 2

PREIONIZATION ADDITIVES SCREENED FOR USE IN THE HBr LASER

Compound	ABS at 4.3μm	I.P.eV	Br_2 Reaction	Discharge Quality	Laser Output	Notes
Benzene	W	9.25	A	+++	+++	
Hexafluorobenzene	VW	9.97	A	--	--	
Toluene	-	8.82	A	+	+	
Xylene	VW	8.4	A	+	+	Mixed isomers
Aniline	-	8.04	N			
2,4,6 Trifluoroaniline	?	?	N			Solid, low VP
Pentafluoroaniline	VW	8.9	A	(+)	(+)	Solid, low VP
M-Toluidine	VW	7.50	N			
N,N Dimethyaniline	VW	7.51	N			
Tetrachloroethylene	-	9.58	A	--	--	
Trichloroethylene	VW	9.48	A	-	-	
1,1 Dichloroethylene	-	9.74	A	(+)	-	
N-Methylaniline	VW	7.73	N			
Tri-N-Propylamine	VW	7.23	N			
Triethylamine	VW	7.84	N			
Nitrous oxide	-	9.23	A	(+)	(+)	Partial reaction to NOBr
Pyridine	VW	9.3	N			
Pentafluoropyridine	-	10.1	A	-	-	

A = Acceptable
N = Not acceptable. Rapid reaction to low vapour pressure products.
Ionization potentials are taken from J.W. Robinson, 1974.
Infrared absorption from C.J. Pouchert, 1975, and measurements where necessary.

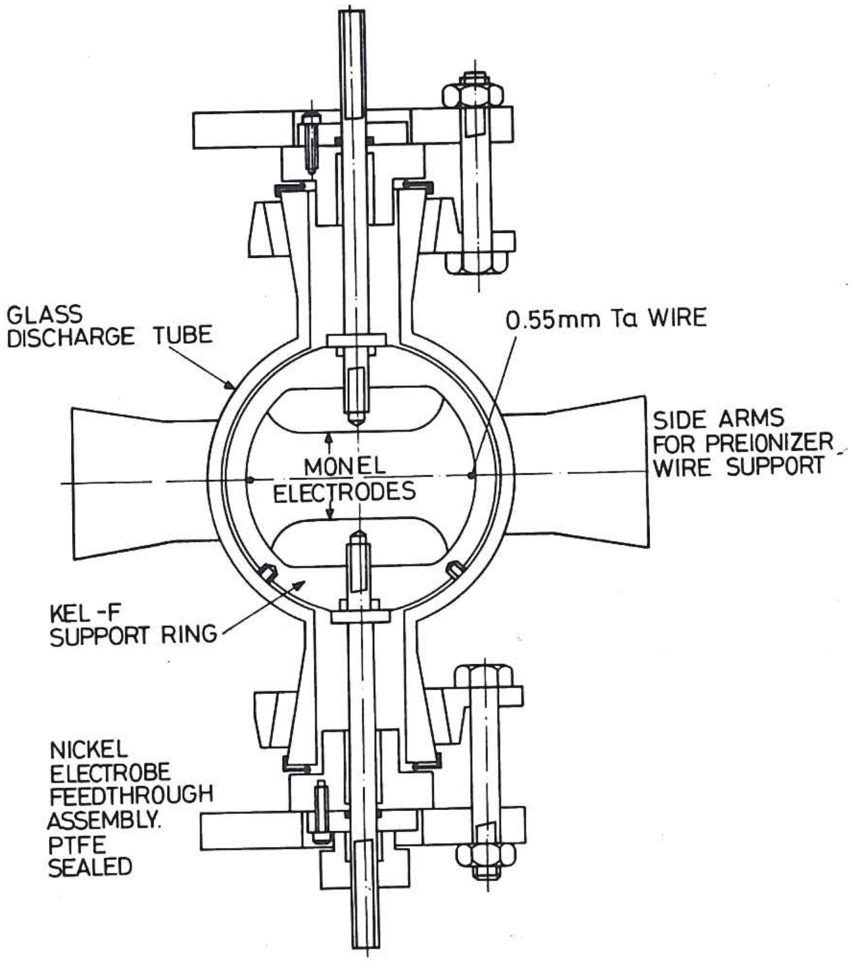

Fig.1 Discharge tube assembly.

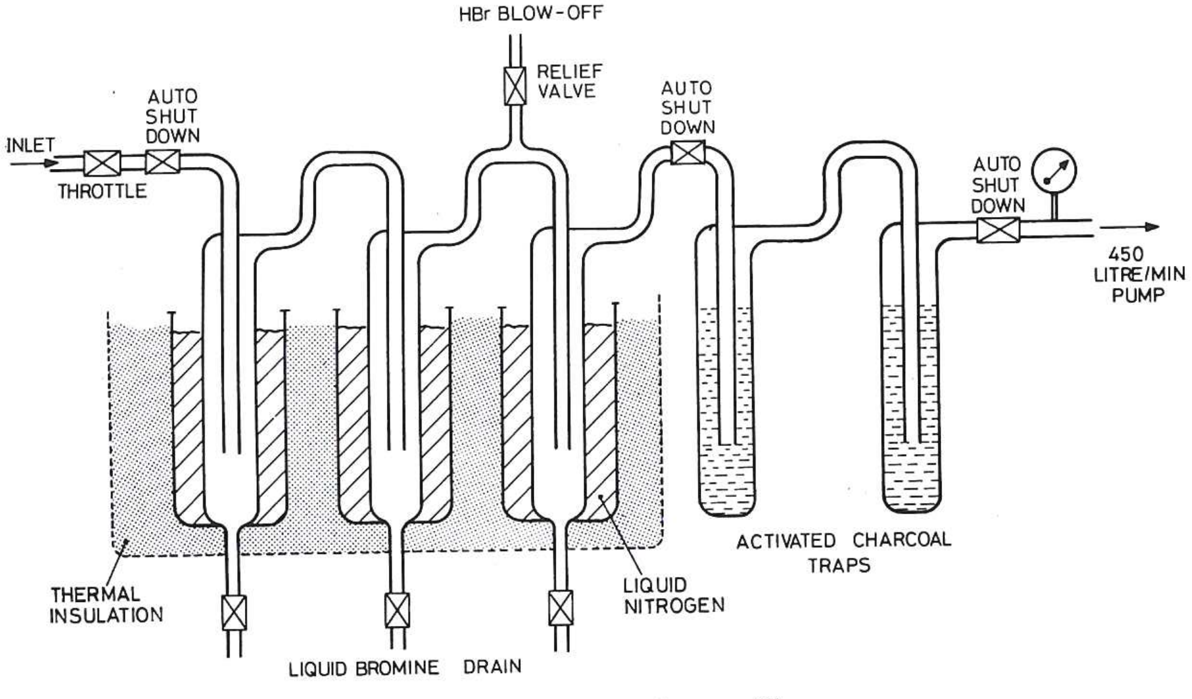

Fig.2 Bromine pumping assembly.

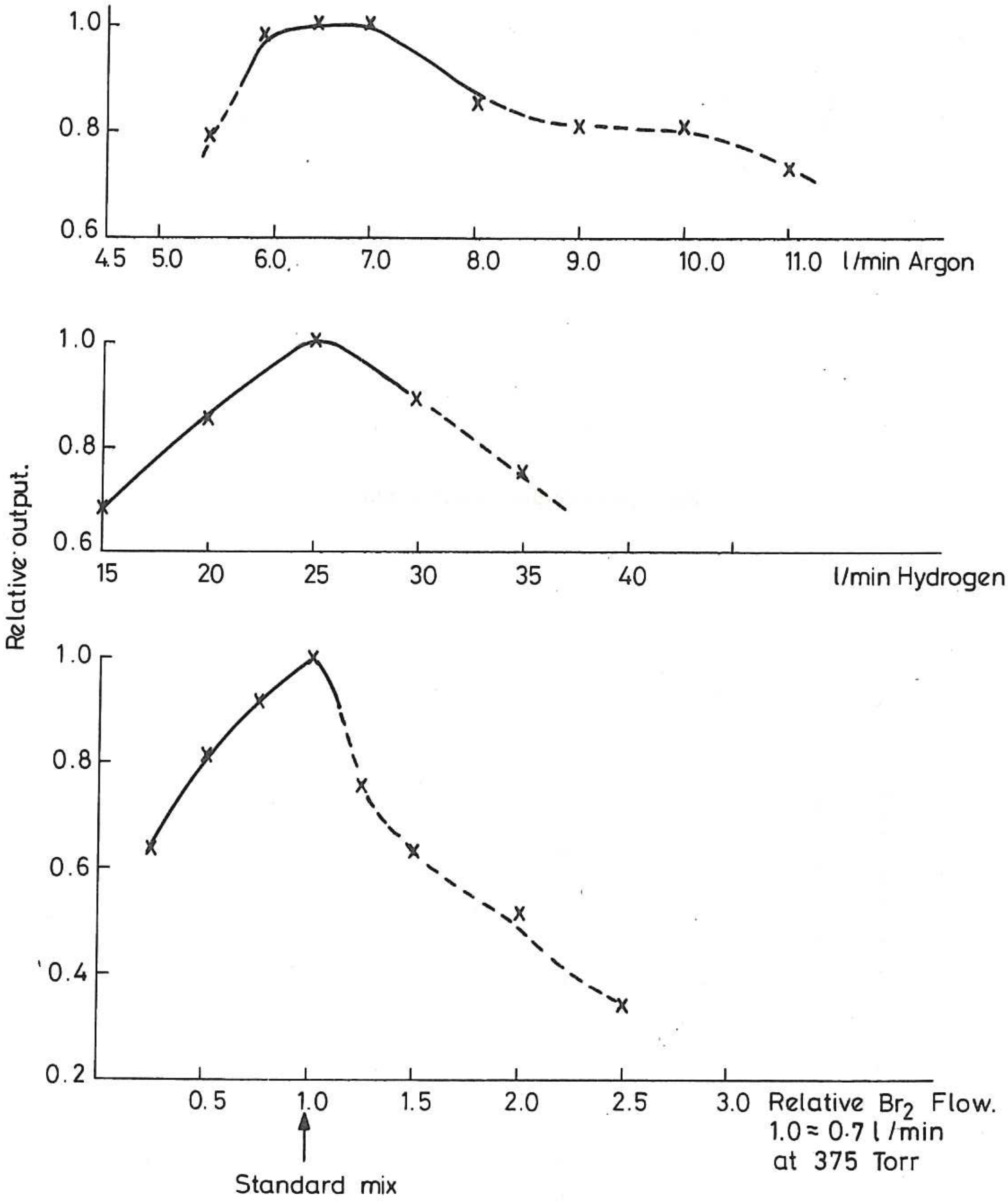

Fig.3 Laser output against gas flow rates. (Solid line stable glow discharge. Dotted line some arcing.)

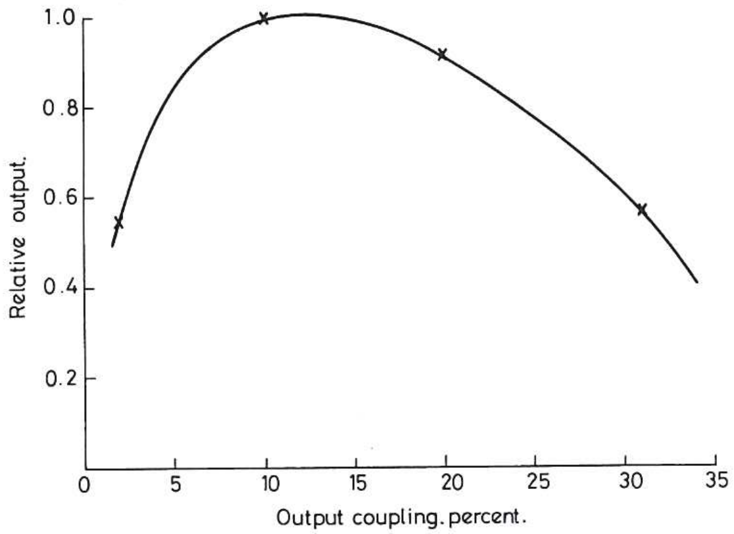

Fig.4 Laser output against output coupling.

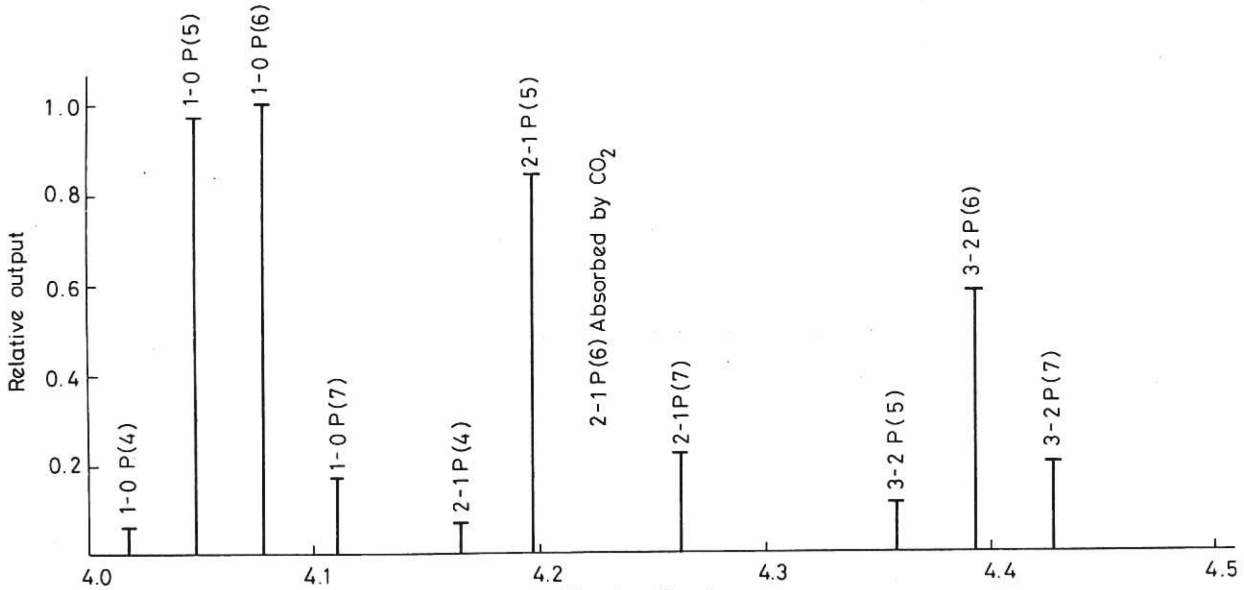

Fig.5 Intensity of the major output lines 0·5 Hz. 20% coupling.

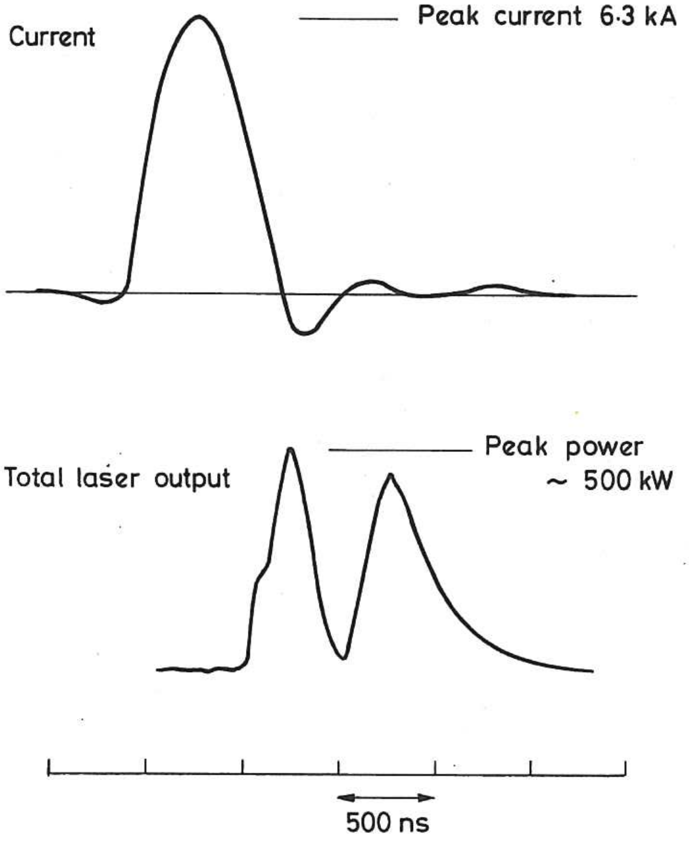

Fig.6 Laser current pulse and power output.

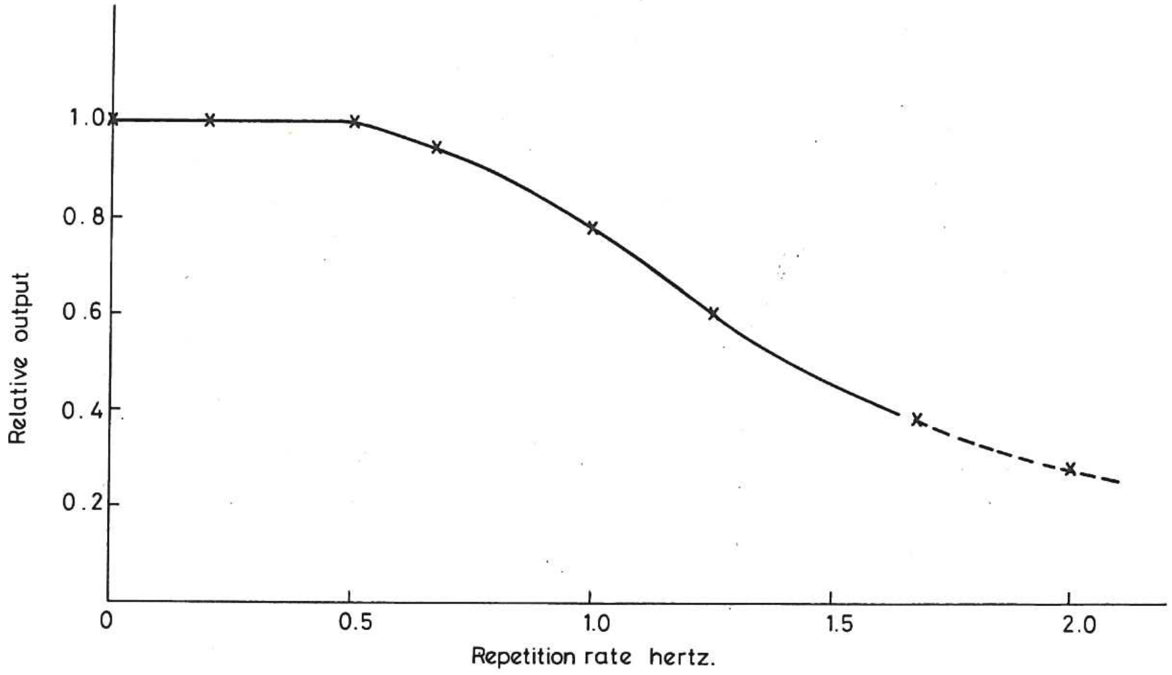

Fig.7 Laser output against repetition rate.