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FINE FREQUENCY TUNING OF A HIGH POWER CO_2 LASER AND ITS APPLICATION TO OPTICALLY-PUMPED MOLECULAR LASERS

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ABSTRACT

We describe a novel technique for shifting the output frequency of a high power TEA CO_2 laser. The performance of a 16 μm laser is shown to be greatly improved when optically pumped by this tunable source.

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To date, intracavity solid etalons alone have been reported as a direct means of fine tuning the output from a TEA CO_2 laser.(1-5) However, this technique is limited to small devices only. In higher power CO_2 lasers there are problems of heating and optical damage which prevent the use of a high finesse etalon, while if a low finesse (ie uncoated, solid) etalon is used, its tuning range is severely restricted by the large gain per pass of the laser.

We describe here a new technique for fine tuning and frequency narrowing the output from a CO_2 TEA laser which is ideally suited to high power and/or high repetition rate applications. The technique involves the introduction to the laser cavity of a cell containing hot CO_2 gas at a low pressure. The effect of the hot cell is illustrated in Fig.1.

Fig.1a shows schematically the pressure-broadened gain lineshape of a CO_2 TEA laser transition. The effect of the hot cell is to produce a narrow band absorption at the centre of each gain line. In Fig.1a such absorption lines are shown for several hot cell pressures at 300°C, where we have chosen a value of 2 for a parameter α which we define as

$$\alpha = a_o \ell_a / g_o \ell_g \qquad \ldots(1)$$

where ℓ_a, ℓ_g are the lengths of the hot cell and gain medium respectively,

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a_o is the line centre absorption in the hot cell in the pressure broadened limit and g_o is the line centre gain in the laser medium. In Fig.1b the net loss and gain curves are plotted from the curves in Fig.1a. The absorption in the hot cell is seen to have produced two new gain maxima symmetrically shifted from the original line centre by an amount determined by the gas conditions in the hot cell. Narrow band, single wavelength operation can then be achieved by adding an etalon to the laser cavity. Since the etalon has only to discriminate between two gain maxima of equal magnitude (and not against the high gain at line centre) a low finesse solid etalon of high damage threshold (eg ZnSe) can be used effectively in this case.

The tuning range produced by this technique can readily be deduced. In the Doppler broadening (ie low pressure) regime of the hot cell, each of the gain maxima is shifted an amount $\Delta\nu$ from the line centre given by

$$\Delta\nu \simeq \pm [W_D/2(\ell n2)^{\frac{1}{2}}] \left\{ \ell n [\pi^{\frac{1}{2}}(\ell n2)^{3/2} W_L^2 \alpha W_p P/W_D^3] \right\}^{\frac{1}{2}} \qquad \ldots(2)$$

where W_L is the width (FWHM) of the CO_2 laser gain line, W_D is the Doppler width of the absorption line, P is the hot cell pressure and W_p is the pressure broadening coefficient.

Similarly in the Lorentz broadening (high pressure) regime of the hot cell, we have

$$\Delta\nu = \pm \tfrac{1}{2} \left[(W_L^2 W_p P - W_L W_p^2 P^2 \alpha^{-\frac{1}{2}}) / (W_L \alpha^{-\frac{1}{2}} - W_p P) \right]^{\frac{1}{2}} \qquad \ldots(3)$$

In Fig.2, $\Delta\nu$ is plotted as a function of pressure for CO_2 gas at 300°C for several values of α. In the region of ~ 15 Torr where the Doppler and Lorentzian contributions to the absorption linewidth are comparable, the value of $\Delta\nu$ has only been estimated in a semi-quantitative manner. The inset in this figure gives more detail on the behaviour of $\Delta\nu$ at low pressures. The figure also includes a dashed curve showing the behaviour of the output of a CO_2 laser with hot cell pressure under the experimental conditions discussed below. At low hot cell pressures the exponential fall away from line centre of the Doppler broadened absorption line is seen to give rise to an almost constant value of $\Delta\nu$ (except at very low pressures) while the relatively strong 'wings' of the Lorentzian broadened absorption line give rise to a uniform increase in $\Delta\nu$ with pressure at higher pressures.

The tuning range obtainable for a given value of α is, however, not as large as might be supposed from Fig.2 because of the absorption losses which the hot cell introduces at the new gain maxima. This effect is illustrated in Fig.3 where the ratio at the (shifted) gain maxima of hot cell absorption ($a\ell_a$) to laser gain ($g\ell_g$)is plotted against $\Delta\nu$ for a variety of α values. This figure illustrates the point that for $\alpha \leq 1$, the tuning range available by this technique is strictly limited to the $\Delta\nu$ values for which the appropriate curve intercepts the horizontal broken line in the figure. For $\alpha > 1$ the tuning range is limited only by other losses in the laser cavity. These losses become increasingly important with increasing $\Delta\nu$ giving rise in practice to the eventual extinction of laser action. However, for any value of $\Delta\nu$ the losses in the hot cell are minimised by maximising the value of α.

In order to prove the fine tuning technique described above, we modified a high power CO_2 TEA laser to include an intracavity hot cell, and used the fine-tuned laser output to optically pump a 16 μm CF_4 laser. The CO_2 laser was a Lumonics 203 grating tuned device having a gain length of ~ 120 cm. With the cavity length increased from 2.5m to 6m to include the hot cell, the output from the laser decreased by a factor of two to a value of 4J on the strongest lines. This decrease we largely attribute to the use of a non-optimised output coupling mirror, which in this case had a 25m radius of curvature and 70% reflectivity.

The hot cell comprised a thermally insulated 2m long quartz tube, heated electrically by a Nichrome wire spiral wound internally along its length. The tube was sealed at each end by Brewster-angle sodium chloride windows. The temperature of the cavity was set to be ~ 300°C which maximised the value of the line centre absorption of the 9 μm R(12) line (the line which gives rise to the strongest laser action in CF_4) at 1.4% cm^{-1} in the pressure broadened regime. This absorption coefficient compares with a value ~ 1.3 cm^{-1} for the R(12) gain in the laser, and so we estimate a value of ~ 2 for the parameter α. If lower laser level populations in the CO_2 laser could be neglected, then it should be possible to choose a hot cell temperature such that the value of α remains approximately independent of laser line, but in practice this is not the case.

On Fig.2 the dashed curve shows the 9 μm R(12) laser output as a function of hot cell gas pressure. From this figure we estimate that a tuning range of ± 2500 MHz was achieved in this case. From Fig.3 it is clear that this tuning range could have been increased significantly by using a higher reflectivity output coupling mirror. At all pressures we checked that laser action was indeed confined to the R(12) line, and that laser action on the CO_2 hot bands did not occur. When an uncoated solid germanium etalon (both 5 mm and 10 mm etalons were tried) was added to the laser cavity to force oscillation on to only one of two new shifted frequencies (as described previously) the output from the laser was observed to decrease by ~ 70%, presumably due to 'walk-off' losses in the etalon and optical damage to the etalon surfaces. The use of a lower finesse etalon with a higher damage threshold has yet to be tried. The optical pumping experiments described below were therefore taken without any etalon, ie with the CO_2 laser presumably operating at both shifted frequencies simultaneously.

Using an optically pumped laser cavity previously described(6), the performance of the various CO_2 laser pumped CF_4 laser lines(7,8) was measured as a function of pressure in the CO_2 hot cell. The CF_4 laser operated on ten lines in the 16 μm region, each pumped by a different CO_2 laser line. In Fig.4 these various CO_2 pump lines are used to label the curves for the CF_4 laser lines. The dashed curves correspond to the weaker Q-branch lines which were obtained under different CF_4 gas conditions as indicated in the figure caption.

Following the results presented in Fig.2, we can interpret the curves in Fig.4 in terms of the amount, δ, by which the line centres of the various CO_2 laser lines are shifted from the line centres of the corresponding CF_4 absorption lines which they pump. We can distinguish three cases:

(a) <u>$|\delta| \leq 100$ MHz - the R(12) and R(20) Pumped Lines</u>

Consistent with a considerable enhancement in the performance of the CF_4 laser when pumped by a 'hybrid' CO_2 laser(9) (and also with diode laser measurements for the case of the R(12) pump line(10)) the CF_4 output on these lines was observed to decrease sharply with the addition of even a trace quantity of CO_2 gas to the hot cell. This behaviour is brought about by the large shift in $\Delta\nu$ which is produced even at very low hot cell pressures, as indicated in Fig.2. The fact that the R(12) pumped laser transition (the strongest in CF_4 and one which exhibited ASE in a cell of only 2.5m length) can be extinguished by the addition of less than 1 Torr to the hot cell is indicative of the effectiveness of this tuning technique.

(b) <u>100 MHz $\leq |\delta| \leq 200$ MHz - the R(18) and R(22) Pumped Lines</u>

In the low pressure region in which Doppler broadening is dominant, the curves in Fig.2 show that only a small amount of frequency tuning can be achieved by changing the hot cell pressure. We equate this fact with the observed insensitivity of CF_4 laser output to hot cell pressure at low pressures for these lines.

(c) <u>$|\delta| > 200$ MHz - the R(10), R(14), R(16), P(8), P(10), P(12) Pumped Lines</u>

This, the largest group of lines in the CF_4, benefits considerably from fine tuning of the CO_2 laser. Among the most spectacular improvements shown in Fig.4 is that of the R(10) pumped line, which improved in output by over two orders of magnitude to give an output pulse energy comparable with that achieved on the strongest (R(12) pumped) CF_4 line. The optimisation of the R(10) pumped output also adds support to the validity of the simple theory presented here; published diode laser measurements(10) have shown a strong CF_4 absorption line lying $\sim$ 380 MHz from the CO_2 9 μm R(10) line, a result entirely consistent with the calculated value of $\Delta\nu$ at the pressure of 15 Torr for which the output from R(10) pumped line is maximised, using the previously estimated value for α of 2 (see Fig.2).

In conclusion, we have described and demonstrated a technique which allows for the first time the direct fine tuning of a high power CO_2 laser. By appropriate choice of the length and temperature of the hot cell, losses can be minimised and a wide tuning range can be achieved. Further, since this technique provides attenuation of all CO_2 lines simultaneously, there are not the problems of 'line switching' which can occur in etalon tuning. We have also demonstrated that this technique can be used to considerable advantage in CO_2 laser pumped lasers, in particular more than a hundred-fold enhancement of laser output from some lines in CF_4 has been achieved.

In the future we plan to use this technique to extend the range of CO_2 laser pumped laser transitions, make direct linewidth measurements of such a tuned CO_2 laser and apply the technique to multi-atmospheric pressure CO_2 lasers.

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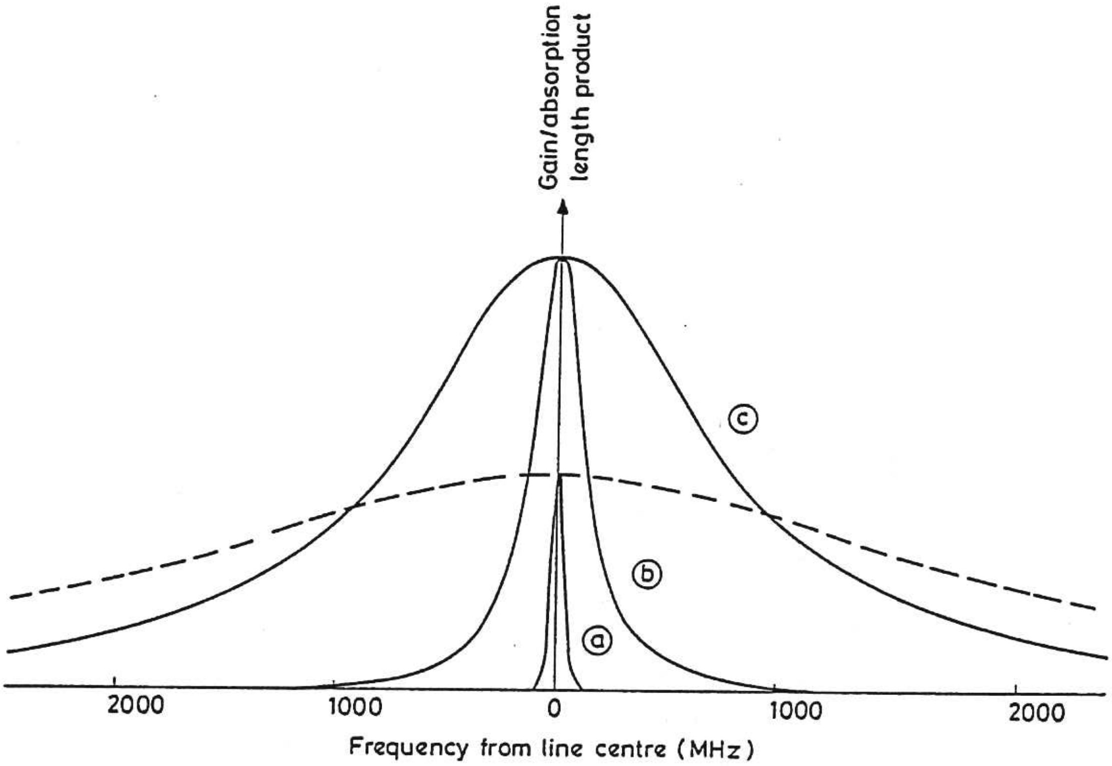

Fig.1(a) Gain and absorption curves for laser and hot cell media. Dashed line shows gain in laser medium, solid lines show absorption in hot cell for $\alpha = 2$ and 300°C temperature with gas pressures of (a) 5 Torr, (b) 30 Torr, (c) 200 Torr.

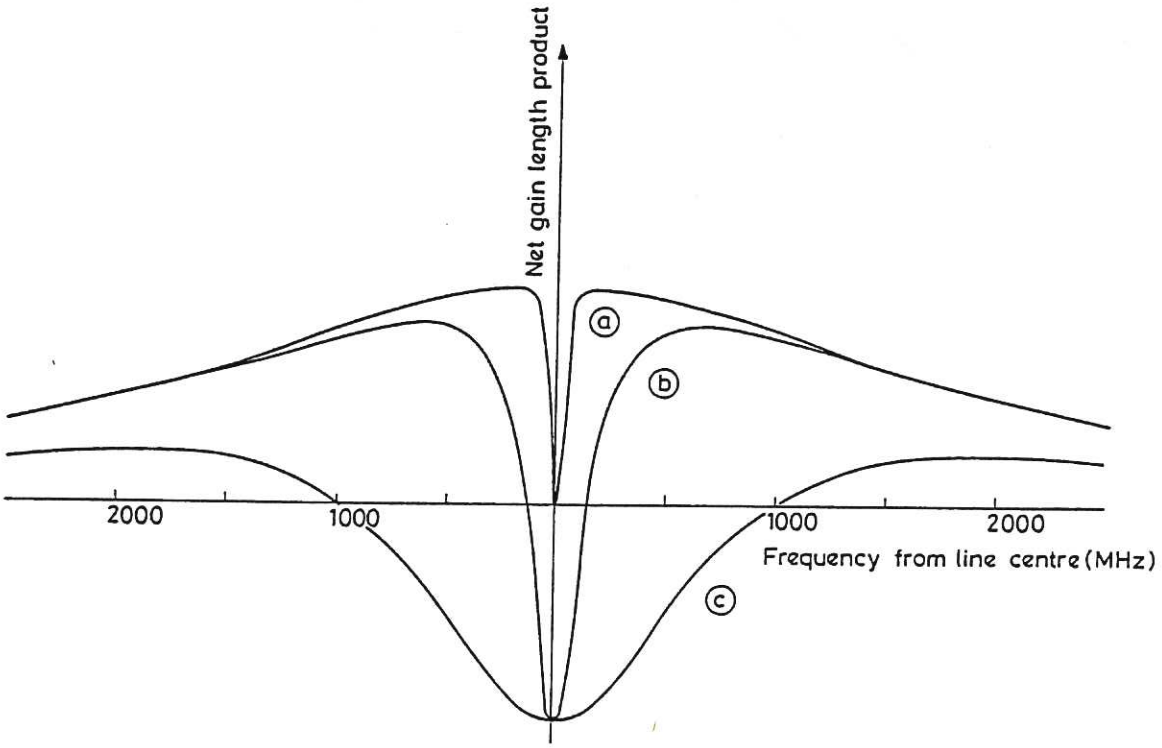

Fig.1(b) Net gain or absorption per pass of laser and hot cell. Conditions as for (a) above, with same labelling of curves.

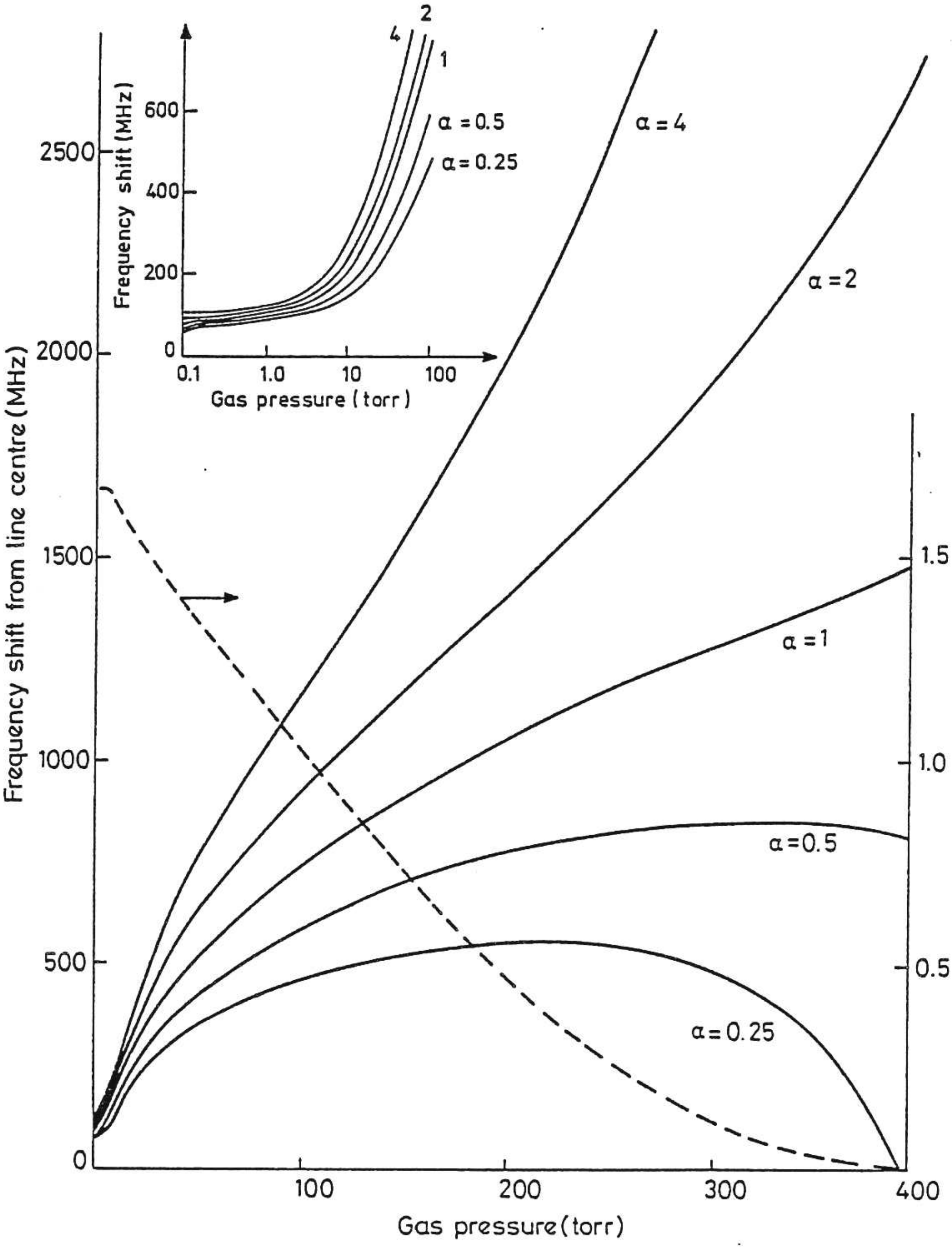

Fig.2 Δυ vs CO_2 gas pressure in hot cell for various values of α. Dashed line shows experimentally measured CO_2 laser output vs hot cell pressure.

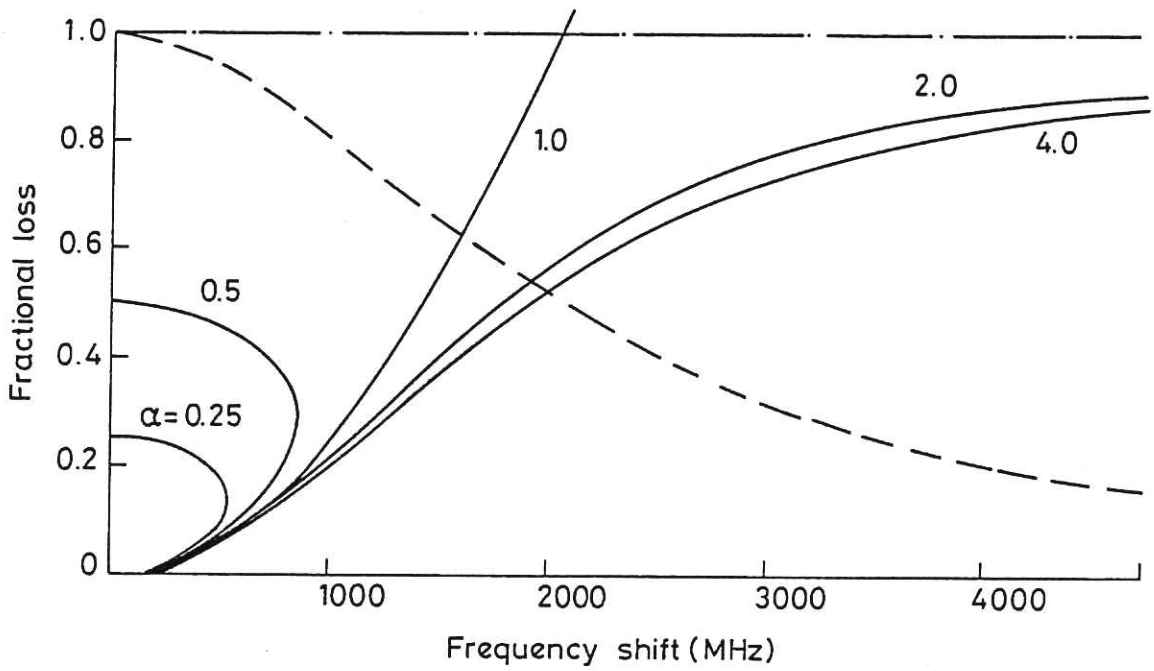

Fig.3 Absorption loss in hot cell at shifted gain maxima as a fraction of laser gain for various values of α.

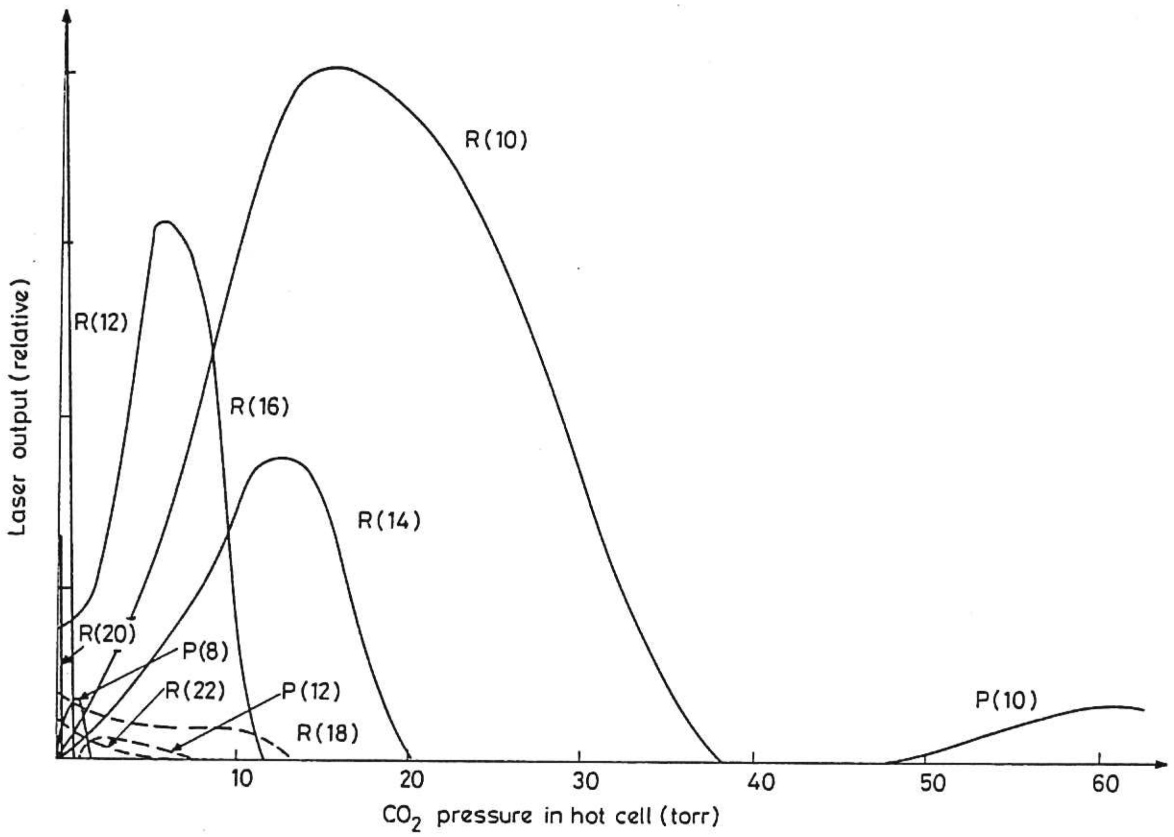

Fig.4 CF_4 16μm output vs hot cell pressure for various CO_2 pump lines in the 9μm P and R branches. Solid lines correspond to a CF_4 pressure of 1·9 Torr and -130°C; dashed lines correspond to a CF_4 pressure of 0·5 Torr and -140°C.