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# FREQUENCY MEASUREMENTS OF FAR INFRARED cw LASING LINES IN OPTICALLY PUMPED $CHCl_2F$

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The wavelengths, frequencies, and relative polarizations of 15 FIR cw lasing lines obtained by optically pumping $CHC\ell_2F$ with a cw $CO_2$ laser have been measured. The lines are in the wavelength range from 340.3 to 905.4 μm and were pumped by P- and R-branch laser lines in the 9 μm band of $CO_2$.

Key Words: $CHC\ell_2F$, laser frequency measurement, FIR laser, new laser lines, $CO_2$ laser, wavelengths, relative polarization.

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## Introduction

Most far infrared lasers are now formed with molecules which are optically pumped with 9 and 10 µm $CO_2$ laser radiation. Searches for new molecules have been made because of the interest in filling the spectral gaps between the known FIR lines and also in finding new efficient laser candidates. In this work, the molecule $CHCl_2F$ (Dichlorofluoromethane, fluorocarbon 21) was selected as the FIR laser medium on the basis of its infrared absorption spectrum. Photoacoustic spectroscopy has been used to check the suitability of various gases as FIR laser media, especially when they are weak absorbers of the $CO_2$ laser radiation (1). A recent photoacoustic spectroscopic study of $CHCl_2F$ revealed promising coincidences between its vibration-rotation transitions and $CO_2$ laser lines; however, no laser action was reported (2). We have succeeded in obtaining lasing action by optically pumping $CHCl_2F$ in a FIR laser cavity with a cw $CO_2$ laser and report here the wavelengths, frequencies, and relative polarizations of 15 of these lines.

## Experiment

The FIR cavity consisted of an open structure (non-waveguide) resonator 1-m-long with 2 m radius-of-curvature concave mirrors at each end. One mirror was mounted on a micrometer to tune the resonant frequency of the cavity. The laser tube consisted of a 1-m-long, gold plated, copper cylinder 51 mm in diameter. Nearly transverse pumping was achieved by focusing the $CO_2$ radiation through a side window into the tube at an angle of 75° with respect to the laser axis. After about 20 reflections from wall to wall in the copper tube, the $CO_2$ power level dropped to 50% because of absorptions on the wall and in the laser gas. The FIR radiation was reflected out of the cavity by a variable coupler which consisted of a a 45° mirror 6 mm in diameter whose distance from the laser axis was adjustable. The FIR radiation then exited through a polyethylene window located at the side of the cavity and was detected with a pyroelectric detector or metal-insulator-metal (MIM) point contact diode. The wavelengths were determined to ± 0.1 µm by counting the number of half wavelengths in a measured scan of the laser end mirror over approximately 5 mm.

The $CO_2$ pump laser used a grating as one reflector and a piezoelectric tuned mirror as the other. The laser delivered cw powers up to 35 W on the strongest lines.

The frequencies were measured by synthesizing each FIR frequency from the difference between two $CO_2$ lasers as already reported (3).

## Experimental Results

The data are presented in Tables I and II. Pump lines are in the P- and R-branches of the 9 μm band of the $CO_2$ laser. We measured the wavelengths of 15 FIR lines in the wavelength range from 340.3 to 905.4 μm with an uncertainty of ± 0.1 μm, and subsequently measured their frequencies to a fractional uncertainty of $\pm 1.5 \times 10^{-7}$.

Polarization of the laser output with respect to the pump laser was determined by use of a homemade, polyethylene, four layer Brewster angle window with each layer 43 μm thick. The optimum operating pressures were measured with a thermocouple gauge calibrated with a capacitance manometer. The $CO_2$ power was measured at the frequency which produced the maximum FIR output intensity.

Lasing action was detected over a narrow range of pressures from 5 to 24 Pa, possibly explaining the absence of oscillation as reported in the previous work (2). In that experiment, the gas pressure was always kept at 22.7 Pa, and the $CO_2$ pumping power levels were one-half of those used here. Intensities varied from weak to medium; the strongest line at 492.0 μm was about a factor of 30 weaker than the 118.8 μm line in $CH_3OH$ pumped by $P_{II}(36)$.

## Conclusion

Continuous wave lasing action on these relatively weak lines are quite pressure and pump frequency sensitive, indicating that lasing conditions are near threshold. These measurements tend to indicate that almost any vibrationally absorbing molecule with a reasonable dipole moment can be made to lase if all parameters are carefully optimized.

TABLE I. Summary of observed submillimeter laser lines obtained from $CHC\ell_2F$ pumped by a cw $CO_2$ laser.

| $CO_2$ Pump Line 9.4 μm Band | $CHC\ell_2F$ Laser Line λ(μm) | Relative Polarization | Pressure for Maximum Power Pa(mTorr) | $CO_2$ Power (W) | FIR Output Power (μW) |
|---|---|---|---|---|---|
| R(40) | 561.0 | ∥ | 9(70) | 5 | 26 |
| R(36) | 492.0 | ∥ | 11(80) | 17 | 77 |
| R(34) | 470.4 | ⊥ | 10(75) | 15 | 39 |
| R(30) | 661.2 | ∥ | 9(65) | 19 | 26 |
| R(12) | 580.9 | ∥ | 10(75) | 19 | 15 |
| R(10) | 547.5 | ⊥ | 10(75) | 17 | 9 |
| R( 8) | 549.3 | ∥ | 9(70) | 9 | 40 |
| R( 6) | 530.9 | ⊥ | 8(60) | 14 | 8 |
| | 467.5 | ∥ | 9(65) | 18 | 6 |
| R( 4) | 905.4 | ∥ | 7(50) | 12 | 5 |
| | 832.8 | ∥ | 5(40) | 12 | |
| P( 8) | 496.0 | ⊥ | 17(125) | 13 | 39 |
| P(16) | 376.0 | ∥ | 13(100) | 23 | 3 |
| P(18) | 365.7 | ∥ | 23(170) | 23 | 36 |
| P(20) | 340.3 | ∥ | 24(180) | 23 | 4 |

Table II. Summary of the $CHCl_2F$ frequency measurements.

| $CHCl_2F$ Laser Line $\lambda(\mu m)$ | Measured Frequency (MHz) (Uncertainty: $\frac{\Delta\nu}{\nu} = \pm1.5\times10^{-7}$)[a] | Vacuum Wavenumber $(cm^{-1})$[b] | $CO_2$ Pump Line 9.4 μm Band | Pump Offset Frequency (MHz)[c] |
|---|---|---|---|---|
| 340.3 | 880 965.6 | 29.385 849 | P(20) | + 1.5 |
| 365.7 | 819 720.5 | 27.342 932 | P(18) | + 13.0 |
| 376.0 | 797 362.5 | 26.597 151 | P(16) | + 27.7 |
| 467.5 | 641 246.9 | 21.389 695 | R( 6) | - 4.9 |
| 470.4 | 637 332.6 | 21.259 127 | R(34) | + 9.8 |
| 492.0 | 609 284.6 | 20.323 546 | R(36) | - 3.4 |
| 496.0 | 604 465.0 | 20.162 782 | P( 8) | - 18.1 |
| 530.9 | 564 736.1 | 18.837 569 | R( 6) | + 24.8 |
| 547.5 | 547 537.6 | 18.263 890 | R(10) | - 3.7 |
| 549.3 | 545 813.2 | 18.206 368 | R( 8) | - 42.1[d] |
| 561.0 | 534 362.8 | 17.824 424 | R(40) | + 5.0 |
| 580.9 | 516 110.2 | 17.215 584 | R(12) | - 8.3 |
| 661.2 | 453 438.9 | 15.125 094 | R(30) | + 2.4 |
| 832.8 | 359 999.9 | 12.008 304 | R( 4) | + 12.2 |
| 905.4 | 331 105.8 | 11.044 499 | R( 4) | + 12.2 |

a. Estimated uncertainty in the reproducibility of the FIR laser frequency. Other measurement uncertainties are negligible in comparison.

b. Calculated from the measured frequency with c = 299 792 458 m/s.

c. Heterodyne frequency measurement between the $CO_2$ pump laser and a Doppler free stabilized $CO_2$ reference laser operated on the pump line.

D. Near end of pump laser frequency tuning range.

## References


1. G. Busse and R. Thurmaier, Appl. Phys. Lett. 31, 194 (1977).

2. C. P. Li and J. Davis, Appl. Opt. 18, 3541 (1979).

3. F.R. Petersen, K.M. Evenson, D.A. Jennings, J.S. Wells, K. Goto, and J.J. Jimenez, IEEE J. Quantum Electron. QE-11, 838 (1975).