International Journal of Infrared and Millimeter Waves, Vol. 2, No. 4, 1981

FREQUENCIES AND WAVELENGTHS FROM A NEW, EFFICIENT FIR LASING GAS: CD_2F_2

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We report for the first time wavelength, relative polarization, and frequency measurements for 47 new cw FIR laser lines in the wavelength region from 120 to 1714 μm, all obtained by optically pumping CD_2F_2 with a CO_2 laser. Relative output powers were also measured. For comparison, the 189.8 μm line pumped by $R_I(34)$ is nearly five times as efficient as the 118.8 μm methyl alcohol line.

Key words: CD_2F_2, laser frequency measurement, FIR laser, new laser lines, CO_2 laser, wavelengths, relative polarization, relative power.

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0195-9271/81/0700-0705$03.00/0

Efficient FIR lasing has recently been obtained from the CH_2F_2 molecule pumped by a CO_2 laser (1-4). The deuterated form, CD_2F_2, also has strong infrared absorption in the 10 μm region (5) and is for that reason an interesting molecule worth studying as a possible laser medium. In this work, we report for the first time laser action from CD_2F_2 when pumped by lines in the P and R branches of the 9 and 10 μm bands of a cw CO_2 laser. The 47 FIR lines found are in the wavelength region from 120.5 to 1714.1 μm, and this laser gas is one of the most efficient yet discovered in this spectral region.

The experimental setup was the same one described in previous work on CH_2F_2 (2), except that a transverse pumping scheme was used instead of a longitudinal one. Transverse pumping minimizes instabilities in the CO_2 laser caused by the feedback of pump radiation from the FIR cavity. Briefly, the FIR laser consisted of a Fabry-Perot resonator pumped by a grating and PZT tuned cw CO_2 laser delivering average powers up to 35 W on the strongest lines. The FIR cavity consisted of a 1 m long hollow copper tube 5 cm in diameter, with concave mirrors at each end, each with a 2 m radius of curvature. One of the mirrors was moved with a micrometer in order to change the length of the cavity. The pumping radiation entered the cavity near one end at an angle of 75° with respect to the laser axis. The FIR radiation was coupled out through a polyethylene lens located at the side of the cavity. Optimum coupling was achieved by transversely moving a small copper mirror, oriented at an angle of 45° with respect to the laser axis, in and out of the cavity mode. The FIR output power was measured with a pyroelectric detector provided with an X-cut crystal quartz filter (0.24 mm thick) to block the CO_2 pump radiation. Calibrated attenuators were used to prevent saturation of the detector. Results were corrected for the wavelength response of the detector. The polarization of the FIR line relative to that of the CO_2 pump laser was measured with a stacked plate polarizer in front of the pyroelectric detector. Pressures were measured with a thermocouple guage calibrated with a capacitance manometer. The wavelength of each FIR line was determined by counting modes in a calibrated 5 mm scan of the laser end mirror. Wavelength measurements were made on all 47 lines with an accuracy of ± 0.05 μm. They are listed in Table I along with the corresponding CO_2 pump line, relative polarization, pressure for maximum power, FIR output power, and CO_2 pump power.

Frequency measurements relative to stabilized CO_2 lasers (6) were made on most of the CD_2F_2 laser lines and are shown in Table II. Here, the vacuum wave numbers have been calculated from the frequency measurements, and the CD_2F_2 pressure at which each frequency measurement was made is also given.

The 189.8 μm line pumped with the $R_I(34)$ CO_2 laser line has a conversion efficiency of about one-half that of the 184.3 μm line of CH_2F_2 pumped with $R_{II}(32)$ and five times that of the 118.8 μm line of CH_3OH pumped with $P_{II}(36)$; therefore, CD_2F_2 is one of the most efficient of the cw FIR lasing gases. We conclude that CD_2F_2 is one of the best FIR cw lasing gases reported to date, limited only by the difficulty in finding a supplier of the gas and in its cost.

The authors acknowledge with appreciation the assistance of Darien G. O'Brien who discovered nine additional new lines in the later stages of this work and who verified all the wavelength measurements and pump line assignments.

References

1. E. J. Danielewicz and C. O. Weiss, IEEE J. Quantum Electron. QE-14, 705 (1978).

2. A. Scalabrin and K. M. Evenson, Opt. Lett. 4, 277 (1979).

3. E. J. Danielewicz, T. A. Galantowicz, F. B. Foote, R. D. Reel, and D. T. Hodges, Opt. Lett. 4, 280 (1979).

4. F. R. Petersen, A. Scalabrin, and K. M. Evenson, Int. Journ. IR and Mm Waves 1, 111 (1980).

5. I. Suzuki and T. Shimanouchi, J. Mol. Spectrosc. 46, 130 (1973).

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

Table I. Summary of CD_2F_2 Laser Lines

CO_2 Pump Line	CD_2F_2 Laser Line λ(μm)	Relative Polarization	Pressure for Maximum Power Pa(mTorr)	FIR Output Power (mW)	CO_2 Power (W)
$R_{II}(34)$	236.1	∥	40(300)	0.07	15
	365.9		27(200)	0.02	15
$R_{II}(10)$	166.9	⊥	27(200)	0.03	19
	314.6	∥	20(150)	0.02	19
$P_{II}(8)'$	192.8	∥	33(250)	0.02	19
$P_{II}(8)''$	286.4	∥	20(150)	0.01	16
$P_{II}(10)$	233.7	∥	27(200)	0.005	21
$P_{II}(18)$	267.8	⊥	27(200)	0.03	25
$P_{II}(20)$	417.2	∥	20(150)	0.05	26
$P_{II}(28)'$	497.7	∥	27(200)	0.004	24
$P_{II}(28)''$	203.3[c]	∥	14(100)	0.03	21
	219.6[c]	⊥	14(100)	0.1	21
	465.5[c]	∥	20(150)	0.05	21
$P_{II}(30)'$	280.5	⊥	16(120)	0.1	24
$P_{II}(30)''$	593.3		27(200)	0.006	24
	1 714.1		27(200)	0.005	24
$P_{II}(34)$	331.0	∥	17(130)	0.006	23
$P_{II}(40)$	317.1	∥	20(150)	0.5	18
	323.2	∥	24(180)	0.4	18
$P_{II}(42)$	249.8[c]	⊥	20(150)	0.03	14
	488.3	⊥	20(150)	0.1	14
$P_{II}(44)$	342.1	∥	27(200)	0.02	11
R_I (48)	303.8[c]	∥	20(150)	0.07	12
R_I (44)	320.6	∥	27(200)	0.3	4.5
R_I (42)'	192[c]	∥	27(200)	0.07	12
R_I (42)"	456.2[c]		27(200)	0.4	12
R_I (38)	207.8	∥	40(300)	1.5	22
	218.3	∥	20(150)	0.3	22
R_I (36)'	120.5		47(350)	0.002	23
R_I (36)"	214.7		33(250)	0.003	26

R_I (34)'	189.8	∥	40(300)	10^b	12
R_I (34)"	352.9	⊥	40(300)	0.4	30
R_I (26)'	274.8	⊥	27(200)	0.1	33
R_I (26)"	489.2	∥	27(200)	0.3	33
R_I (24)	500.6	∥	27(200)	1.3	31
R_I (22)	249.4	⊥	13(100)	0.03	31
R_I (20)	139.3	∥	40(300)	0.2	16
	229.1		27(200)	0.02	26
R_I (18)'	150.4	∥	53(400)	0.04	35
R_I (18)"	318.6[c]	⊥	40(300)	0.03	28
R_I (16)	248.1	∥	40(300)	0.1	30
R_I (14)	187.8	⊥	47(350)	1.0	34
	367.4	∥	27(200)	0.2	34
R_I (8)	393.0[c]	∥	53(400)	0.001	35
P_I (22)'	378.9	⊥	20(150)	0.3	35
P_I (22)"	643.5	∥	20(150)	0.03	35
P_I (32)	440.9	∥	20(150)	0.007	30

a. ' and " indicate different CO_2 laser frequency offsets.

b. The conversion efficiency $\left(CE = \frac{P_{FIR}}{P_{CO_2}} \times \frac{\nu_{CO_2}}{\nu_{FIR}}\right)$ of this line relative to the 184.3 μm line of CH_2F_2 pumped with the $R_{II}(32)$ line of CO_2 (and using the same FIR laser) is 0.5, and with respect to the 118.8 μm line of CH_3OH pumped with $P_{II}(36)$ is 4.6.

c. The frequency of this line was not measured.

Table II. Summary of the CD_2F_2 frequency measurements.

CD_2F_2 Laser Line $\lambda(\mu m)$	Measured Frequency (MHz) (Uncertainty: $\frac{\Delta\nu}{\nu} = \pm 5\times10^{-7}$)[a]	Vacuum Wavenumber (cm^{-1})[b]	CD_2F_2 Pressure Pa(mTorr)[c]	CO_2 Pump Line
120.5	2 488 553.4	83.009 207	31(230)	R_I (36)'
139.3	2 152 662.4	71.805 088	20(150)	R_I (20)
150.4	1 992 795.2	66.472 491	27(200)	R_I (18)'
166.9	1 796 461.7	59.923 513	17(130)	R_{II}(10)
187.8	1 596 174.9	53.242 662	33(250)	R_I (14)
189.8	1 579 250.3	52.678 119	40(300)	R_I (34)'
192.8	1 555 020.1	51.869 889	12(90)	P_{II}(8)'
207.8	1 442 454.3	48.115 095	27(200)	R_I (38)
214.7	1 396 238.8	46.573 514	17(130)	R_I (36)"
218.3	1 373 513.3	45.815 473	16(120)	R_I (38)
229.1	1 308 755.5	43.655 384	27(200)	R_I (20)
233.7	1 282 892.0	42.792 670	12(90)	P_{II}(10)
236.1	1 269 723.6	42.353 419	17(130)	R_{II}(34)
248.1	1 208 313.9	40.305 013	27(200)	R_I (16)
249.4	1 202 093.2	40.097 513	12(90)	R_I (22)
267.8	1 119 368.0	37.338 096	15(110)	P_{II}(18)
274.8	1 091 044.7	36.393 333	15(110)	R_I (26)'
280.5	1 068 733.7	35.649 121	10(75)	P_{II}(30)'
286.4	1 046 768.2	34.916 430	15(115)	P_{II}(8)"
314.6	952 793.3	31.781 763	8(60)	R_{II}(10)
317.1	945 562.5	31.540 569	22(165)	P_{II}(40)
320.6	935 107.5	31.191 827	7(55)	R_I (44)
323.2	927 636.8	30.942 632	15(115)	P_{II}(40)
331.0	905 742.6	30.212 321	7(55)	P_{II}(34)
342.1	876 261.3	29.228 932	17(130)	P_{II}(44)
352.9	849 506.4	28.336 483	27(200)	R_I (34)"
365.9	819 405.8	27.332 435	15(110)	R_{II}(34)
367.4	815 985.9	27.218 360	27(200)	R_I (14)
378.9	791 260.4	26.393 607	13(95)	P_I (22)'
417.2	718 505.6	23.966 768	13(95)	P_{II}(20)

440.9	679 979.8	22.681 684	10(75)	P_I (32)
488.3	613 981.5	20.480 218	13(95)	P_{II}(42)
489.2	612 774.8	20.439 967	22(165)	R_I (26)"
497.7	602 383.9	20.093 364	13(95)	P_{II}(28)'
500.6	598 893.7	19.976 943	17(130)	R_I (24)
593.3	505 314.1	16.855 463	13(95)	P_{II}(30)"
643.5	465 866.4	15.539 630	17(130)	P_I (22)"
1 714.1	174 894.8	5.833 863	10(75)	P_{II}(30)"

' and " indicate different CO_2 laser frequency offsets.

[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] Pressure at which each frequency was measured as determined by a thermocouple gauge calibrated with a capacitance manometer (1 Torr = 133.3 Pa).