Additional cw FIR laser lines from optically pumped CH_2F_2

Artemio Scalabrin* and Kenneth M. Evenson

Time and Frequency Division, National Bureau of Standards, Boulder, Colorado 80303

Received May 7, 1979

Twenty-five new, cw, FIR lines from CH_2F_2, optically pumped by a CO_2 laser, have been found, using a variable-coupling, open-structure resonator. Accurate wavelength measurements have been made on the 47 known CH_2F_2 lines. The new lines are fairly uniformly distributed over a wide range, from 105 to 1448 μm.

This Letter reports 25 new, cw, FIR laser lines from CH_2F_2, optically pumped by a CO_2 laser, ranging in wavelength from 105 to 1448 μm. These 25 lines were discovered while performing accurate wavelength determination of the 22 CH_2F_2 FIR lines found previously.[1–3] Thus, wavelengths of these 47 lines accurate to about ± 0.1 μm are reported here. Many of the new lines are strong and in optimized waveguide cavities should yield high-output powers, as is the case for other CH_2F_2 lines.[1–3] This one laser medium itself nearly doubles the number of the very strong, optically pumped FIR laser lines in the 100–700-μm region.[4]

A Fabry–Perot resonator formed by two concave mirrors separated by 105 cm, with radii of curvature $R = 200$ cm and diameters of 12.5 cm, was used. The input pump radiation, from a grating and piezoelectric tunable CO_2 laser, is focused by an $R = 200$-cm mirror through a 1-mm-diameter hole. The hole was sealed by a ZnSe window, at the center of the stationary copper mirror. A gold-coated Pyrex mirror attached to a micrometer at the other end permits scanning the length of the cavity. This FIR cavity is tuned to resonance with the rotational transition lines of the active gas and can be scanned over a length of 15 mm to determine the wavelengths. Laser-pumped cascade lines are precluded from consideration since the laser cavity itself is used as the scanning Fabry–Perot.

A variable coupler is used to extract the FIR radiation. It consists of a 45° mirror formed by cutting and polishing a 6-mm-diameter copper cylinder. The cylinder can be positioned at various distances from the laser axis to vary the coupling. The radiation exits the laser through a polyethylene window opposite this coupling mirror. This coupling design has proved to be convenient and effective over the whole submillimeter range. Irises in front of both mirrors provide excellent discrimination of longer-wavelength lines.

The measured FIR laser lines are listed in Table 1. The wavelengths were determined by counting the number of modes over a calibrated 5-mm scan. The micrometer scale was calibrated from the known wavelength of the 118.8-μm line of CH_3OH. With this technique, an accuracy of ± 0.1 μm, which is needed for direct-frequency measurement, was obtained. Frequency measurement of all the lines listed in Table 1 are currently being performed. The polarization of the FIR lines indicated in Table 1 was measured by an external metal mesh polarizer relative to that of the pump beam. Most lines oscillate over a wide range of pressure, and the values given in Table 1 correspond to the maximum signals. The pressure was measured by a thermocouple gauge, which was calibrated with a capacitance manometer. The unit of pressure used is the pascal (Pa), and the equivalent in mTorr is also given in Table 1.

The intensities were measured with a diamond window Golay cell with a 0.24-mm-thick crystal-quartz filter to stop 10-μm radiation. Other calibrated attenuators were used to prevent saturation of the Golay detector. The intensities in Table 1 were obtained by adjusting the coupling mirror for each FIR line to give maximum output signal. The pump power for each CO_2 laser line was also measured at the pump frequency that gave maximum FIR output. The actual pump power coupled into the FIR cavity is somewhat lower than this value because of reflection losses at two external mirrors, the ZnSe window, and the hole coupling losses. We have measured the absolute FIR power of two strong lines: the 184.7-μm line pumped by $9R(32)$, which is the strongest FIR line in CH_2F_2, and the 289.4-μm pumped by $9P(4)$, which is the strongest of the new lines. The values measured by a cone calorimeter[5] with a nearly flat spectral response are 4 mW and 2.5 mW, respectively. These numbers were checked with another power meter, Scientech Model 3600,[6] and the values agree within 10%. The 289.4-μm line has the highest quantum efficiency of all lines for this open structure laser. Its value relative to the 184.3 μm is

$$\frac{(QE)_{289.4}}{(QE)_{184.3}} = \left(\frac{2.4 \text{ mW}}{4.0 \text{ mW}}\right)\left(\frac{289.4\ \mu\text{m}}{184.3\ \mu\text{m}}\right)\left(\frac{27 \text{ W}}{17 \text{ W}}\right) \simeq 1.5,$$

and it may be the most quantum efficient FIR laser line yet discovered. To check this, one has to measure its power in a laser optimized for maximum power output, such as the waveguide laser used to measure other strong lines in the preceding paper. The lines at wavelength longer than 500 μm are somewhat undercoupled and should yield more power with a larger coupling mirror. The cavity itself has less than 1% diffraction loss at wavelengths less than 1 mm. The 1448-μm line also suffers from high diffraction loss, and its relative strength probably would be much greater than the value measured from this particular cavity.

Finally, it is worth mentioning that most of the lines of CH_2F_2 are very strong compared with those from

0146-9592/79/090277-03$0.50/0

Table 1. Submillimeter Laser Lines Obtained from CH_2F_2

CO_2 Pump	FIR (μm)	Relative Polarization	Pressure for Maximum Power, Pascal (mTorr)	Intensity (Relative)	CO_2 Power (W)	Ref.
9*R*(46)	588.1	—	8.0(60)	4.5	7	New
9*R*(44)	642.5	∥	6.7(50)	12	9	New
	1448.1	—	6.7(50)	0.3	9	New
9*R*(42)	230.1	⊥	9.3(70)	30	14	New
	540.8	∥	8.7(65)	6	14	New
9*R*(36)′	298.2	∥	13.3(100)	1.5	20	New
9*R*(36)″	381.8	∥	13.3(100)	4	22	New
9*R*(34)	214.5	⊥	9.3(70)	127	25	2
	287.7	∥	(90)	65	25	2
9*R*(32)	184.3	⊥	12.0(100)	170[a]	27	2
	235.7	∥	12.0(100)	55	27	2
9*R*(28)	511.3	⊥	9.3(70)	4	26	1
	567.5	—	9.3(70)	1	26	New
9*R*(22)′	122.4	⊥	30.7(230)	75	27	1
	166.6	∥	26.7(200)	30	27	1
9*R*(22)″	193.9	∥	9.3(70)	17	29	New
	270.0	⊥	8.7(65)	6	29	New
9*R*(20)	117.7	⊥	28.0(210)	110	29	1
	166.6	—	28.0(210)	80	29	1
9*R*(14)	326.5	⊥	10.7(80)	1	30	1
9*R*(12)	95.5	⊥	37.3(280)	2	25	1
	194.5	⊥	12.0(90)	1	25	1
	418.1	∥	10.7(80)	0.5	25	1
9*R*(6)	202.5	∥	9.3(70)	24	23	1
	236.5	∥	13.3(100)	120	23	1
	434.9	⊥	8.7(65)	27	23	1
	503.6	⊥	5.3(40)	20	23	New
9*P*(4)	289.4	∥	10.0(75)	120	16	New
	725.1	⊥	10.0(75)	20	16	New
9*P*(6)	394.7	∥	10.0(75)	40	25	New
	464.5	∥	9.3(70)	8	25	New
9*P*(8)	122.4	∥	17.3(130)	0.5	24	New
	355.2	∥	16.0(120)	1.5	24	New
9*P*(10)′	158.5	∥	14.7(110)	90	23	2
	272.2	⊥	10.0(75)	30	23	2
9*P*(10)″	382.9	∥	13.3(100)	45	25	New
	657.2	⊥	9.3(70)	20	25	New
9*P*(16)	105.5	∥	38.7(290)	15	29	New
9*P*(18)	227.6	⊥	16.0(120)	0.5	30	New
9*P*(20)	158.9	∥	11.3(85)	0.5	30	New
	293.9	∥	10.7(80)	0.5	30	New
9*P*(22)	134.0	⊥	30.7(230)	40	28	New
	191.8	∥	26.7(200)	54	28	New
9*P*(24)	109.3	∥	17.3(130)	30	27	2
	135.3	∥	17.3(130)	14	27	2
	255.9	⊥	21.3(160)	15	27	2
9*P*(38)	261.7	∥	12.0(90)	10	27	2

′ and ″ indicated different CO_2 laser frequency offsets.
[a] This power was measured with a cone calorimeter[5] and found to be 4 mW.

other submillimeter laser gases, and, also, they are uniformly spread throughout the spectrum from 105 to 725 μm. Thus, CH_2F_2 is probably the most useful FIR laser molecule discovered up to now and will be particularly useful for numerous applications.[5,7]

* Artemio Scalabrin is a postdoctoral fellow from FAPESP, São Paulo, Brazil. His permanent address is Instituto de Fisica, UNICAMP, Campinas, Brazil.

References

1. E. J. Danielewicz and C. O. Weiss, "New efficient cw far-infrared optically pumped CH_2F_2 laser," IEEE J. Quantum Electron. **QE-14,** 705–707 (1978).
2. T. A. Galantowicz, E. J. Danielewicz, F. B. Foote, and D. T. Hodges, "Characteristics of non-diffusion-limited optically pumped cw lasers—experimental results for CH_2F_2," presented at International Conference on Lasers 1978, Orlando, Florida, Dec. 11–15, 1978.
3. E. J. Danielewicz, T. A. Galantowicz, R. D. Reel, F. B. Foote, and D. T. Hodges, Opt. Lett. **4,** 280–282 (1979).
4. D. T. Hodges, "A review of advances in optically pumped far-infrared lasers," Infrared Phys. **18,** 375–384 (1978).
5. K. M. Evenson, D. A. Jennings, F. R. Petersen, J. A. Mucha, J. J. Jimenez, R. M. Carlton, and C. J. Howard, "Optically pumped FIR laser: frequency and power measurements and laser magnetic resonance spectroscopy," IEEE J. Quantum Electron. **QE-13,** 442–442 (1977).
6. Commercial equipment is identified in this Letter in order to specify adequately the experimental procedure. This identification does not imply recommendation or endorsement by NBS, nor does it imply that the equipment is the best available for the purpose.
7. B. L. Bean and S. Perkowitz, "Far infrared transmission measurements with an optically pumped FIR laser," Appl. Opt. **15,** 2617–2618 (1976).