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NEW FIR LASER LINES AND FREQUENCY MEASUREMENTS IN CD_3OD

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Twenty-four new submillimeter laser lines in fully deuterated methyl alcohol (CD_3OD) in the wavelength range from 52 to 328 μm have been obtained in a Fabry-Perot FIR resonator by optically pumping the methanol with a cw CO_2 laser. We have made accurate wavelength measurements and have determined the relative polarization of most of the known CD_3OD laser lines. The frequencies of 13 of the strongest lines were also measured.

Key words: CD_3OD, optically pumped FIR laser, CO_2 laser, laser frequency measurements, relative intensity, relative polarization.

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Submillimeter wave laser action in fully deuterated methyl alcohol (CD_3OD) was first observed by Kon et al. who reported eight short wavelength lines pumped by laser lines in the R-branch of the 10.4 μm band of CO_2 (1). A new line pumped by the $R_I(18)$ line was obtained by Duxbury and Herman at a wavelength of 869 μm (2). Herman and Prewer (3) later reported seven additional new laser lines in CD_3OD pumped by various CO_2 lines from $P_I(10)$ to $R_I(36)$. In this work, we report 24 additional submillimeter laser lines in CD_3OD in the wavelength range from 52 to 328 μm. All were obtained by optically pumping 99% fully deuterated CD_3OD in a 1 m Fabry-Perot FIR resonator with various cw laser lines in the R-branches of the 9 and 10 μm bands of CO_2. This This FIR laser, described previously by Scalabrin and Evenson (4), is useful for detecting lasing over the wavelength range from about 35 to 1200 μm.

The measured wavelength, relative polarization, optimum operating pressure, and output power for 34 FIR CD_3OD laser lines are listed in Table I. On each pump line, the CO_2 frequency was scanned within the gain profile to maximize the FIR output power. Different optimum pump frequencies within the same line are denoted by prime and double-prime. The wavelength measurements were made with ±0.1 μm accuracy by counting the modes in a calibrated 5 mm scan of one end mirror of the Fabry-Perot resonator. The polarizations of the FIR lines relative to the CO_2 laser lines were determined by using a metal mesh or stacked plate polarizer in front of the FIR detector. Pressures were measured with a thermocouple gauge calibrated with a capacitance manometer, and the values presented in Table I are those to obtain maximum FIR output power. Output powers were measured with either a Golay or pyroelectric detector, each provided with an X-cut crystal quartz filter (0.24 mm thick) to block the CO_2 pump radiation. In addition, calibrated attenuators were used to prevent saturation of the detectors. The strongest FIR line obtained is the 184.8 μm line pumped by the $R_I(24)$ CO_2 laser line. This line exhibited approximately the same power as the 118.8 μm CH_3OH line in this same laser with optimum coupling for each line.

We have also measured the frequency of 13 strong lines. The measurements were performed as described previously (5) and are listed in Table II.

Since there are some differences in the wavelengths and relative polarizations for certain lines as reported by various authors, we show these in Table III. It is worth mentioning that Duxbury and Herman (2) used a circular waveguide cavity, while Kon et al. (1) used an open structure cavity similar to ours.

Finally, we want to mention that the wavelengths of 17 lines out of the 24 new ones obtained are in the frequency region below 150 μm. Thus, these new lines in CD_3OD contribute to a region of the electromagnetic spectrum which is somewhat sparsely populated by known laser lines (6).

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Table I. Summary of observed submillimeter laser lines from $^{12}CD_3{}^{16}OD$ pumped by the normal laser bands of $^{12}C^{16}O_2$. FIR laser output power from the 1 m Fabry-Perot resonator under the specified pump conditions and for optimum output coupling was measured either with a Golay or pyroelectric detector and adjusted for wavelength dependence. Response is assumed to be independent of intensity level over the ranges used. For intensity comparison, this same laser produced 2.5 mW from the 118.8 μm line of CH_3OH pumped by 22 W of $P_I(36)$ radiation.

CO_2 Pump Line	CD_3OD Laser Line λ(μm)	Relative Polarization	CD_3OD Laser Press. Pa(mTorr)	FIR Output Power** (mW)	CO_2 Pump Power (W)	Reference
R_I (4)	344.8*	∥	13(95)	0.6	27	1
R_I (6)	130.5	∥	11(85)	0.008	30	New
R_I (10)	86.5	∥	14(105)	0.2	42	New
	227.7*	⊥	14(105)	0.2	42	1
	314.8*	∥	10(75)	0.2	42	1
R_I (12)'	104.3	∥	21(160)	0.2	37	New
	107.5*	∥	24(180)	0.3	37	New
	108.7	∥	17(125)	0.2	37	New
R_I (12)"	410.7*	∥	15(115)	0.5	37	1
R_I (16)'	52.4	∥	10(75)	0.02	30	New
	82.2	∥	7(55)	0.006	30	New
	354.2*	∥	11(85)	0.2	30	3
R_I (16)"	87.3	∥	9(65)	0.006	30	New
R_I (20)	80.5	⊥	18(135)	0.2		New
R_I (22)	165.6*	⊥	11(85)	0.08	32	3
R_I (24)	184.8*	⊥	20(155)	2	37	1
	298.7*	∥	20(155)	0.4	37	1
	486.5	⊥	20(155)	0.01		3
R_I (26)'	119.1*	⊥	24(180)	0.03	32	3
	124.8*	⊥	17(130)	0.008	32	New
R_I (26)"	97.5	⊥	15(115)	0.03		New
R_I (28)'	122.3*	⊥	17(130)	0.2	25	New
R_I (28)"	73.8	∥	13(100)	0.005	25	New
	80.5	∥	13(100)	0.007	25	New

R_I (30)'	192.5	⊥	14(105)	0.03	38	New
R_I (30)"	232.4	∥	12(90)	0.01	38	New
R_I (40)	210.5	∥	6(45)	0.01	26	New
	255.3	⊥	6(45)	0.03	26	New
R_{II}(4)	124.5	⊥	5(40)	0.002		New
	152.5	⊥	5(40)	0.003		New
R_{II}(8)	141.3	⊥	7(50)	0.01	18	New
	270.7*	⊥	10(75)	0.02	18	New
R_{II}(28)	327.8	⊥	6(45)	0.005	20	New
R_{II}(38)	64.4	∥	10(75)	0.002	13	New

' and " indicate different CO_2 laser frequency offsets.

* Frequency measured and listed in Table II. Wavelengths have been corrected where necessary from frequency measurements.

**Power output is for coupling the pump laser to the FIR laser with a 2 m radius mirror through a 0.75 mm diameter hole. It was later found that power output could be increased by about a factor of seven by use of a 0.6 m radius mirror and a 2 mm diameter coupling hole. Optimum pressures were then about a factor of two larger than those listed in the table.

Table II. Summary of the CD_3OD frequency measurements.

CD_3OD Laser Line $\lambda(\mu m)$	Measured Frequency (MHz) (Uncertainty: $\frac{\Delta\nu}{\nu} = \pm 5\times10^{-7}$)[a]	Vacuum Wavenumber (cm^{-1})[b]	CD_3OD Pressure Pa(mTorr)[c]	CO_2 Pump Line
107.5	2 787 789.4	92.990 646	12(90)	R_I (12)'
119.1	2 518 067.7	83.993 698	14(105)	R_I (26)'
122.3	2 451 203.1	81.763 335	17(130)	R_I (28)
124.8	2 402 224.0	80.129 568	16(120)	R_I (26)'
165.6	1 810 294.3	60.384 919	5(40)	R_I (22)
184.8	1 622 555.2	54.122 615	14(105)	R_I (24)
227.7	1 316 838.7	43.925 013	10(75)	R_I (10)
270.7	1 107 337.9	36.936 818	7(55)	R_{II}(8)
298.7	1 003 536.6	33.474 377	11(85)	R_I (24)
314.8	952 203.9	31.762 105	11(85)	R_I (10)
344.8	869 522.7	29.004 156	9(70)	R_I (4)
354.2	846 450.3	28.234 542	9(70)	R_I (16)'
410.7	729 932.8	24.347 937	15(115)	R_I (12)"

' and " indicate different CO_2 laser frequency offsets.

[a] Estimated uncertainty in the reproducibility of the FIR laser frequency.

[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).

Table III. FIR lines from CD_3OD previous to this work.

CO_2 Pump Line	λ(μm)	Rel. Polarization	Ref.	This Work λ(μm)	This Work Rel. Polarization
$P_I(10)$	78		3		
$R_I(4)$	339	⊥	1	344.8	∥
$R_I(10)$	229	⊥	1	227.7	⊥
	312	⊥	1	314.8	∥
$R_I(12)$	406	⊥	1	410.7	∥
$R_I(16)$	354		3	354.2	∥
$R_I(18)$	41	⊥	1	*	
	869		2	*	
$R_I(22)$	165		3	165.6	⊥
$R_I(24)$	184	⊥	1	184.8	⊥
	299	⊥	1	298.7	∥
	495	∥	3	486.5	⊥
$R_I(26)$	119		3	119.1	⊥
$R_I(28)$	35		3	**	
$R_I(30)$	150		3	**	
$R_I(36)$	255	⊥	1	*	

* FIR laser lines at 41.4, 43.7, and 858.3 μm pumped by $R_I(18)$ and 253.7 μm pumped by $R_I(36)$ were observed. However, these four lines lased much more strongly in CD_3OH and, thus, probably originate from this molecule.

** These FIR laser lines did not oscillate in our laser.