Short-wavelength far-infrared laser cavity yielding new lines in methanol

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We report 16 new laser lines generated in a short-wavelength far-infrared Fabry–Perot laser cavity. The CO_2 pump laser is coupled into the far-infrared laser outside the far-infrared laser mode, and the cavity uses a 45° adjustable output coupling mirror; this combination results in a low-loss Fabry–Perot cavity for wavelengths below 150 μm. The new lines are of medium and strong intensity and have wavelengths in the region 26.2–125.7 μm.

Methanol (CH_3OH) and its isotopomers have produced more than 2000 far-infrared (FIR) laser lines when optically pumped by CO_2 lasers. These lines have been obtained with both Fabry–Perot and waveguide FIR lasers.[1] Both cw and pulsed CO_2 lasers have been used extensively for optically pumping methanol.[2,3] The absorption spectra of these molecules have been studied in the infrared and FIR regions, leading to assignments and predictions of many of the laser lines.[4] CH_3OH alone contributes more than 600 laser lines in the wavelength range 25.3–1223.7 μm.

We report the generation of 16 new FIR laser lines from optically pumped methanol oscillating in a low-loss Fabry–Perot laser cavity, shown in Fig. 1. The cavity has less than 0.5% diffraction loss at wavelengths below 150 μm and uses a folded confocal geometry. It consists of a 36-mm-diameter 2-m-long precision-bore Pyrex tube with a fixed copper flat mirror on one end and a movable 4-m radius-of-curvature gold-coated concave mirror on the other end. The concave mirror, attached to a micrometer, is moved to tune the cavity into resonance with the FIR laser modes. A 6-mm-diameter 45° copper mirror is situated on the side of the cavity and couples the FIR power out horizontally through a Brewster-angle silicon window on the opposite side. One varies the output coupling by moving the copper mirror in and out of the cavity mode. The generated FIR radiation is focused by an off-axis parabolic mirror onto a pyroelectric detector. In searching for new laser lines we rotated the polarization of the CO_2 pump radiation, permitting the observation of both perpendicular and parallel FIR laser lines. The precision-bore tube permits the laser to oscillate in a waveguide mode at longer wavelengths (to approximately a millimeter). This cavity is thus useful at all FIR wavelengths.

The CO_2 laser radiation is focused into the FIR laser cavity with a 4-m radius-of-curvature concave mirror 2 m from the laser. It enters the cavity through a 5-mm-diameter hole in the flat FIR laser mirror 14.5 mm above the laser axis. This coupling hole is outside the FIR Fabry–Perot mode waist and reduces FIR losses. The CO_2 radiation is aligned to hit the center of the curved mirror on the opposite end of the laser. It then reflects back to the flat mirror, hitting it at the bottom near the wall.

The CO_2 pump laser uses a ribbed tube, which increases the effective resolution of the grating in the cavity by preventing wall bounces. The laser uses zero-order output coupling from the grating. It is 1.5 m long and has a 135-line/mm grating with 5% reflectivity in zero order. It lases on ~137 lines, including regular and hot-band lines.[5] A high-reflectivity gold-coated 10-m-radius mirror is used on the other end. Both the 9- and the 10-μm branches exhibit high-J lines out to 9R(58), 9P(58), 10R(56), and 10P(60); furthermore, 30 hot-band lines operate in the 11-μm region. Regular laser lines reach powers up to 25 W, and hot-band lines up to 6 W.

We made the FIR wavelength measurements by tuning the FIR Fabry–Perot cavity with the movable end mirror and measuring the mirror displacement for 10 wavelengths of that laser mode. The value thus obtained is accurate to within a few parts in 10^3. A chart recording of the scan helps in sorting out different modes and wavelengths. The use of sets of absorbing papers calibrated with wavelength provides discrimination against CO_2 laser radiation reaching the detector and helps to distinguish different FIR wavelengths. The relative polarizations of the

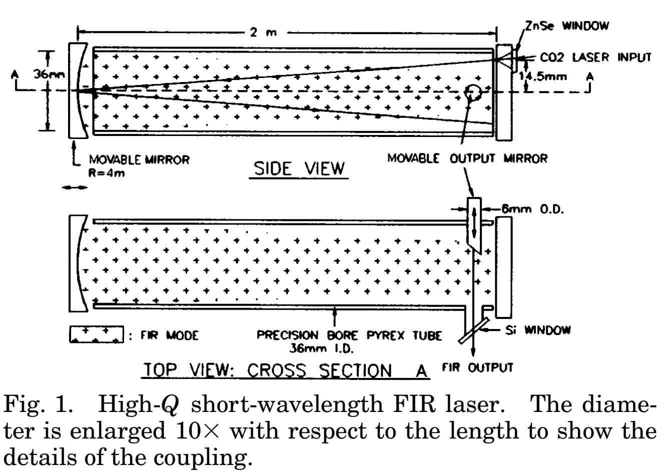

Fig. 1. High-Q short-wavelength FIR laser. The diameter is enlarged 10× with respect to the length to show the details of the coupling.

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Table 1. New FIR Laser Lines from Optically Pumped Methanol

CO_2 Pump	Wavelength (μm)	Optimum Pressure [Pa (mTorr)][a]	Relative Polarization	Relative Intensity
9P(32)	42.2[b]	44 (330)	∥	42.0
9P(34)	26.2	45 (340)	∥	8.0
	29.2	44 (330)	∥	3.5
	39.3[b]	44 (330)	∥	4.0
	44.3[b]	21 (160)	∥	30.5
	70.5[b]	21 (160)	⊥	94.0
9P(36)	118.8[b]	33 (250)	⊥	100.0
9P(56)	60.8	41 (310)	⊥	6.5
	68.4	32 (240)	∥	4.5
	66.9	31 (230)	∥	2.0
	102.2	31 (230)	∥	2.0
10R(54)	62.2	60 (450)	⊥	0.2
10R(52)	49.9	29 (200)	∥	0.5
	55.0	41 (310)	–	0.2
	61.1	44 (330)	⊥	2.0
10R(48)	69.8	49 (370)	∥	1.5
10R(46)	41.8	29 (220)	∥	9.0
	49.6	31 (230)	⊥	9.0
	62.1	27 (200)	⊥	4.5
	81.5	32 (240)	∥	7.5
	125.7	23 (170)	⊥	1.0

[a]Determined by an extended Pirani gauge (1 Torr = 133.3 Pa).
[b]Previously reported laser lines for intensity-level reference. The output power for the 118.8-μm line was 20 mW in this laser.

laser lines were measured with a multi-Brewster-angle polarization selector.

Table 1 lists the wavelengths of the 16 new FIR laser lines along with the CO_2 laser pump line, the relative polarization, the relative intensity, and the operating pressure for each line. The wavelengths of the new lines are in the range 26.2–125.7 μm. The lines all have wavelengths below 150 μm because we had adjusted the coupling for that wavelength. Most of the new laser lines are medium to strong compared with the very strong 119-μm laser line of methanol.

Several already reported high-frequency FIR laser lines operate with high intensity in this cavity: the strong 70.5-μm line pumped by 9P(34) has approximately the same intensity level as that of the 119-μm line; the 42.2-μm line pumped by 9P(32) has nearly half the intensity of the 119-μm line, and the 44.3-μm line pumped by 9P(34) has one third of the 119-μm intensity. The last-named value is significant considering that the reported offset of -87 MHz for the 44-μm line is not reached by the ± 50 MHz tuning range of our CO_2 laser. The measured power for the 119-μm laser line was 20 mW in this laser.

The results obtained so far indicate that high-frequency laser lines may have been missed in previous studies, probably both because of the use of FIR laser cavities overcoupled at short wavelengths and because of losses at the CO_2 coupling holes. These newly discovered short-wavelength lines help to fill the frequency gaps in the 25–100-μm region and will be useful sources for atomic and molecular spectroscopic studies.

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