19. CO_2レーザーによる大気中分子濃度の測定

Measurement of Molecular Densities in the Atmosphere Using a CO_2 Laser

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Introduction

Semi-tunable CO_2 lasers are useful for measuring the molecular density of atmospheric gases because their emission wavelengths can be made to coincide with the infrared absorption lines of various gases. The long-path absorption measurements of molecular densities offer the excellent sensitivity at the least required transmitted energy. Future wide spread use of remote monitoring will probably be limited to the infrared laser beams which meet the eye safety requirement. In this work the technique of differential absorption was studied in which the wavelength of a CO_2 laser output was tuned on and off the absorption line of the molecule to be measured. Wavelengths for molecular monitoring must be selected to avoid absorption lines of any interfering gases.

Experimental Setup

Measurements were performed at the roof of our Institute over an outdoor path of 100 meters. Fig.1 is a schematic of the direct detection for long-path absorption, showing the transmitting laser, recieving optics and the remote reflector. The CO_2 laser having a cavity of 150 cm length was capable to oscillate in a cw mode on the 001-100 band P(10)-P(36) and R(6)-R(28) lines, and the 001-020 band P(12)-P(32) and R(10)-R(20) lines. The transmitted beam with a TEM_{oo} mode was reflected by using a remote reflector placed at a distance of 50 meters from the laser radar system. The recieved radiation was collected by a 15 cm diameter concave mirror. A reference beam was passed through a beam splitter in order to monitor the output laser power. A pyroelectric detector (Molectron P301, NEP=$3x10^{-7}$ W/$Hz^{1/2}$ at 10.6μm), was used for the detection of both the returned signal and the reference beams alternatively.

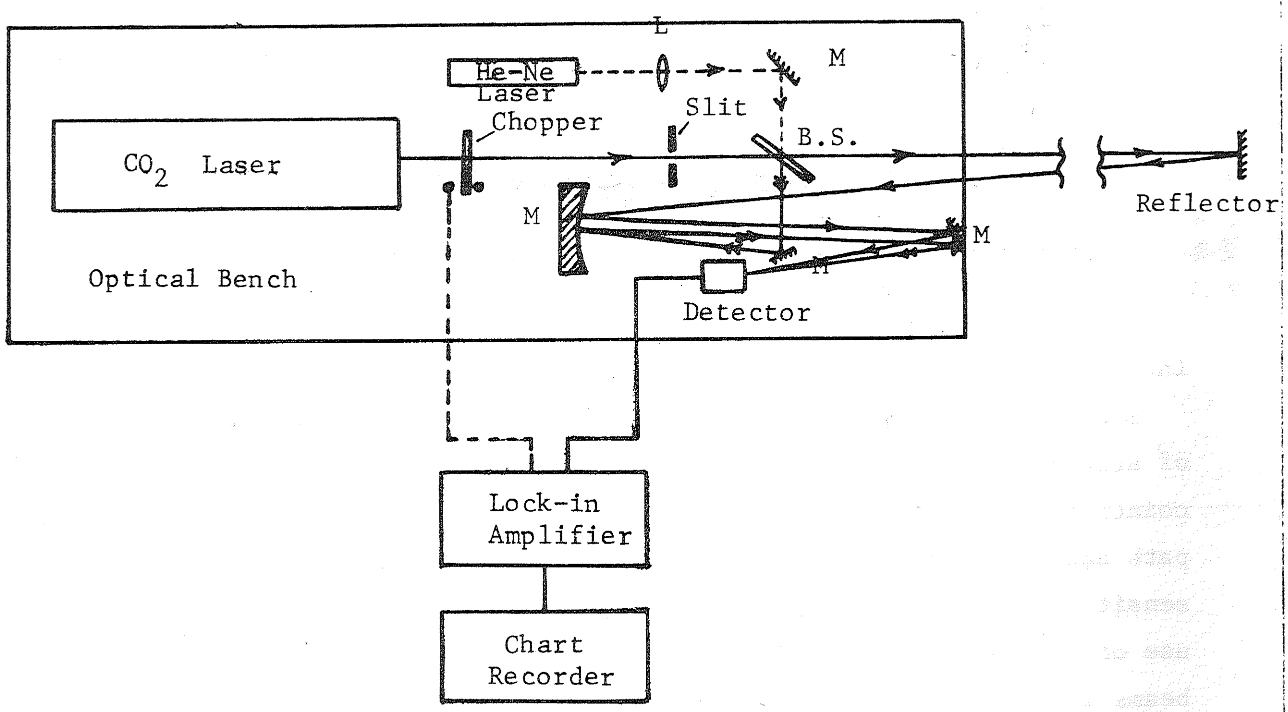

Fig.1 Schematic diagram of laser transmitter and optical system for long-path monitoring of atmospheric gases.

The laser beam was chopped at 200 Hz and a lock-in amplifier(NF model Ll-574) was used to provide synchronous detection.

Discussions

The atmospheric molecular densities can be monitored by transmitting several selected laser wavelengths over the known atmospheric path and measuring the differential absorption of these wavelengths. Table 1 contains a compilation of various CO_2 laser wavelengths which can be used in a series of the measurements. Absorption coefficients of various atmospheric constituents at these wavelengths under atmospheric pressure are also listed.

Table 1. CO_2 Laser Wavelengths for Molecular Monitoring in the Atmosphere[1,2)]

Laser Line	λ vac. (μm)	Absorption coefficient(km^{-1})				
		NH_3 (1 ppm)	O_3 (1 ppm)	C_2H_4 (1 ppm)	H_2O (10 torr)	CO_2 (330 ppm)
P(14)	9.504		1.25		0.11	0.123
P(20)	9.552		0.56		0.11	0.126
P(24)	9.586		0.08		0.09	0.112
P(14)	10.532			2.98	0.12	
P(16)	10.551			0.46	0.12	
P(20)	10.591			0.15	0.11	
P(32)	10.719	3.20				
P(34)	10.741	1.58				
P(36)	10.764	0.48				

The column content n (in units of,e.g.,atm·cm),of the constituent of interest is related to the differential absorption by the equation

$$n = \frac{1}{\Delta\alpha} \ln \left(\frac{P_{r1} / P_{ref1}}{P_{r2} / P_{ref2}} \right)$$

where $\Delta\alpha = \alpha_1 - \alpha_2$ is the difference in absorption coefficients due to the constituent at wavelengths λ_1 and λ_2 and $P_{r1}, P_{r2}, P_{ref1}, P_{ref2}$ are the recieved and reference powers at wavelengths λ_1 and λ_2,respectively.

The measurements were made in its first stage at the roof of our Institute(20 meters altitude). The remote measuring system shown in Fig.1 was operated and checked using the wavelengths of interest listed in Table 1. The results obtained from the chart recorder showed that the ratio of P_r/ P_{ref} is constant over a few neighboring oscillating wavelengths of the CO_2 laser. For example the ratio of P_r/ P_{ref} was constant over the three laser lines P(14),P(16) and P(20) of the 001-100 band, but not the same as the other constant ratio of P_r/ P_{ref} over the other three laser lines P(14),P(20) and P(24) of the 001-020 band. The accuracy of these measurements was approximately 10%. This differences in the ratio of P_r/P_{ref} over the 001-100 band and the 001-020 band were due to the wavelength dependence of the optical system used. For accurate measurements of atmospheric molecular densities, it is preferable to use the 001-100 P(14) line, the 001-020 P(14) line and the 001-100 P(32) line as an on resonance line for C_2H_4, O_3 and NH_3, respectively. For the off resonance line the use of the 001-100 P(20) line, the 001-020 P(24) line and the 001-100 P(36) line for C_2H_4, O_3 and NH_3, respectively, seems to be suitable. This choice will reduce the measurement errors due to the wavelength dependence of the optical components and detector used.

Conclusion

The laser monitoring system described above appears to be capable of measuring atmospheric molecular densities with a 10% accuracy. Concentrations as low as 0.3 ppm for C_2H_4, 0.8 ppm for O_3 and 0.3 ppm for NH_3 will be detected using our system over a path length of 100 meters. Effort is now being done in order to increse the measuring accuracy of the system and the capability of measuring lower concentrations.

References

1. Robert T.Menzies and Michael S.Shumate, Appl.Opt.15,2080(1976).
2. P.L.Hanst, in Advances in Environmental Science and Technology Vol.2., J.N.Pitts, Jr. and R.L.Metcalf, Editors, Wiley-Interscience.