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AN INTENSITY-MODULATED DUAL-WAVELENGTH He-Ne LASER FOR REMOTE SENSING OF METHANE

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1. Introduction

It is known that the 3.392-μm emission from a He-Ne laser is strongly absorbed by methane while the emission at a nearby wavelength, 3.391 μm, is only weakly absorbed. The differential absorption at these wavelengths is expected to provide sensitive methods of detecting the presence of methane in the atmosphere(1). A straightforward way of the remote sensing is to direct a pair of lasers, one emitting at 3.391 μm and the other at 3.392 μm, to the area being probed and to detect the backscattered radiation from topographical targets at the two wavelengths with two detectors. This method needs, however, not only a large volume of the whole system to include the two lasers, two detectors, two lock-in amplifiers and so on, but also precise alignment of the laser beams in order that they hit on the same target. Moreover, the laser output power has to be highly stabilized. One simplified method is to send two laser beams alternately using a chopper wheel and to monitor the returning radiation with a single detector coupled to a lock-in amplifier synchronized to the chopper. However, the laser-power stabilization and precise optical alignment are still essential.

In the present paper we describe a new type of dual-wavelength He-Ne laser in which the output power at each of the two wavelengths is modulated with equal amplitude and opposite phase to each other. This laser source can greatly simplify the setup and improve the sensitivity of the differential absorption measurements for the methane detection, as verified by a preliminary experiment. A simple scheme to measure the concentration of methane is also proposed.

2. Intensity-Modulated Dual-Wavelength He-Ne Laser

The structure of the intensity-modulated dual-wavelength He-Ne laser is shown in Fig.1. The principle of its operation has been reported elsewhere(2). Therefore, we mention it here only briefly. The alternate intensity modulation is accomplished by placing inside the laser cavity a cell filled with low pressure methane acting as a frequency-dependent loss to the 3.392-μm line and by vibrating one of the cavity mirrors. In Fig.2, if the cavity is tuned back and forth between A and B, the 3.391-μm emission increases when the 3.392-μm emission decreases and vice versa. The equal amplitudes and the opposite phases in the modulation of the two emissions are achieved by tuning the cavity automatically to a point which gives null intensity modulation in the total output power at the modulation frequency. It has been shown both theoretically and experimentally that the modulation amplitude of the individual emissions thus available is appreciably affected by the crude manual change of the cavity length and that the maximum modulation is obtained repeatedly at every 5.7-mm change of the cavity length(2).

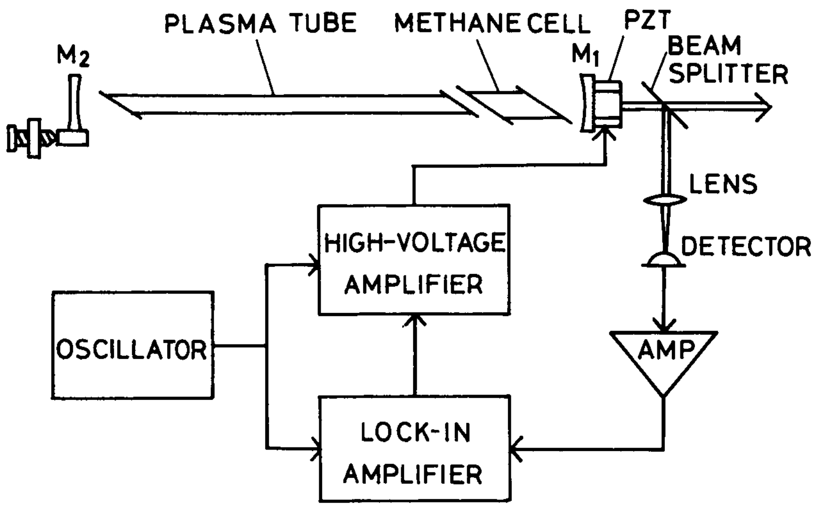

Fig.1 Schematic diagram of the intensity-modulated dual-wavelength He-Ne laser. Mirror M_2 is manually translatable by ±3 mm. Cavity length: 68 cm; plasma length: 50 cm; methane cell length: 4.2 cm.

So far the modulation amplitude of up to 0.7 mW peak-to-peak at 1 kHz for individual emissions has been obtained from a plasma tube of 50-cm effective length while retaining the residual total-power modulation as low as 0.25 μW peak-to-peak for 1 s of averaging. Therefore, in the ideal situation where the residual modulation in the total power is the dominant noise source, the minimum detectable methane density is estimated to be 0.02 ppm for a 10-m optical pathlength.

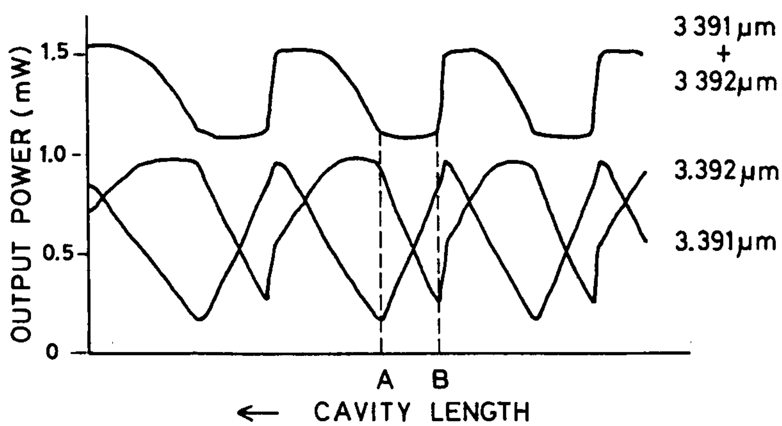

Fig.2 Variation of the output power of the individual emissions and the sum of both vs. cavity length. One cycle of the variation corresponds to a $\lambda/2$ change in the cavity length. Note that the total power is nearly equal at A and B while the individual emissions change appreciably.

3. Remote Differential Absorption Measurements

Fig.3 shows the schematic diagram of the DIAL system for methane sensing using the intensity-modulated dual-wavelength He-Ne laser. A laboratory simulation has been done using short-range targets and an absorption cell inserted between the mirrors M and M' instead of between M' and a target. The returning beam is collected by a spherical mirror of 10-cm diameter and focused by a lens onto an InSb detector cooled to 77 K. The detected signal is sent to a lock-in amplifier synchronized with the laser modulation frequency. Fig.4 shows an example of the signals recorded when a rough wood block as a target is placed at a distance of 5 m and a CH_4-N_2 mixture of 1% CH_4 concentration is introduced into the absorption cell 5 cm long and then evacuated. The signal averaging time is 3 s. Noting that the laser beam passes through the cell only once in this setup, the observed signal-to-noise ratio (~30) gives the minimum detectable concentration-pathlength product to be 8 ppm·m.

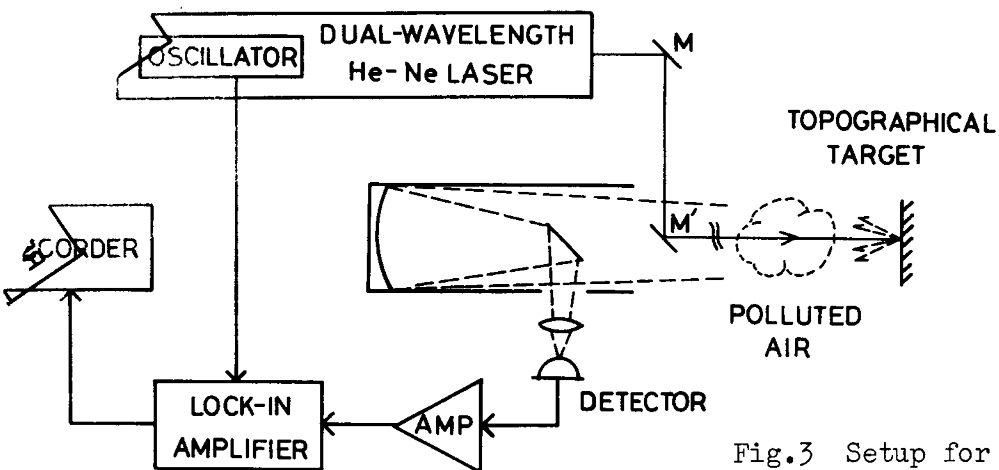

Fig.3 Setup for the remote differential absorption measurements.

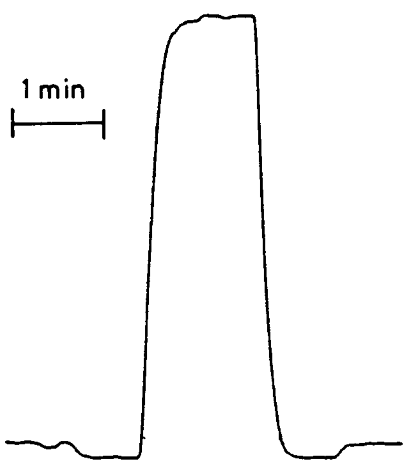

Fig.4 A recorded differential absorption signal. The effective concentration-pathlength of methane is 250 ppm·m.

4. Discussions

In this preliminary experiment the signal-to-noise ratio was limited by the amplifier noise. Therefore, a collecting mirror of 30-cm diameter will improve the sensitivity by a factor of ~10.

The average concentration of methane can be determined by a calibration if the probe beam hits only some definite targets. When the targets cannot be specified as in a scannable system the quantitative measurement is possible by splitting the collected beam onto two detectors coupled to lock-in amplifiers. A methane cell is placed in front of one detector to monitor only the 3.391-μm radiation. The average methane concentration in the probed area is determined from the ratio of the signal strengths of the two lock-in amplifiers.

When a detector remote from the beam transmitter is usable to measure the transmittance through the probed area a very high sensitivity limited only by the laser noise is expected.

References

1. C. B. Moore: Appl. Opt. 4, 252(1965).
2. K. Uehara: Appl. Phys. B 38, 37(1985).