LASERMETHANE™ — A Portable Remote Methane Detector

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ABSTRACT

Tokyo Gas Co., Ltd. and Anritsu Corporation jointly developed a new version of a portable remote methane detector. Using this detector, the operator can easily check a gas leak from a distance by hand-scanning the laser beam. To the best of the author's knowledge, an old version of the detector released in 2001 was world's first handheld device providing remote detection of methane leaks. In the present work, the author and his research group improved the user-friendliness and cost-effectiveness dramatically from the old version. Tokyo Gas Engineering (TGE) Co., Ltd. has introduced the new version (LASERMETHANE™: SA3C05A) into the international market since February 2004. This product is getting more and more popular in the gas industry, and its sales volume exceeds 100 as early as July 2004.

The portable remote methane detector transmits a laser beam to a target such as a gas pipe, subsequently receiving a fraction of backscatter deflected from the target. It thereby measures the concentration-length product of methane between the detector and target. To perform highly sensitive infrared absorption measurement, the device employs the second-harmonic detection of wavelength modulation spectroscopy using a near-infrared tunable diode laser (InGaAsP DFB laser) with a wavelength for $2\nu_3$-band R(3) line of methane (λ = 1.6537 μm).

The device has a minimum detectable of 100 ppm-m and the detection distance with most diffusive reflection targets are up to 10 meters. In this case, the device can detect and pinpoint a 10 ml-min^{-1} gas leak from an indoor exposed pipe from a distance. The detection distances can be extended up to 30 meters if the operator allows a minimum detectable of 1000 ppm-m. In addition when used with a retro reflector, the device extends the maximum distance up to 150 meters.

INTRODUCTION

Gas distribution companies use portable instruments for detecting natural gas leaks, in support of their emergency response and surveillance services. The conventional method used to detect gas leaks involves positioning instruments in close proximity to the area to be checked. However, this can be a difficult operation and often entails lengthy inspection periods particularly in elevated or narrow locations. To overcome these difficulties, optical methods, particularly laser based methods, were studied by lots of groups in the gas industry [1-9]. The laser based methods provides us with remote detection of methane leaks and thereby improves the operational efficiency and safety levels of the natural gas distribution facilities. In particular, Tunable Diode Laser Absorption Spectroscopy (TDLAS) is a promising method to lead a compact and cost-effective remote methane detector.

In previous works [4, 9, 10], the author and his research group presented a portable remote methane detector based on TDLAS. To the best of the author's knowledge, this detector was world's first product that is person-portable and capable of remote detection of methane leaks. In the present work, Tokyo Gas Co., Ltd. and Anritsu Corporation jointly developed a new version of the detector (Fig. 1). The author and his research group improved the user-friendliness and cost-effectiveness dramatically from the old version.

Tokyo Gas Engineering (TGE) Co., Ltd. has introduced the new version (LASERMETHANE™: SA3C05A) into the international market since February 2004. This product is getting more and more popular in the gas industry, and its sales volume exceeds 100 as early as July 2004.

Fig. 1 A New Version of Portable Remote Methane Detector
(LASERMETHANE™: SA3C05A)

Fig. 2 An Example of How LASERMETHANE™ Is Used

DETECTION PRINCIPLE

Concept of Remote Detection

Fig. 2 shows an example of how LASERMETHANE™ is used. The device transmits an infrared (IR) laser beam with the wavelength set at one of the absorption wavelength (absorption line) of methane. It then receives a fraction of the backscatter reflected from the target. In this configuration, the received power can be expressed by the Lambert-Beer law as

$$P = KS\exp(-D) = KS\exp(-\alpha \times 2C) \approx KS(1 - \alpha \times 2C) \qquad (1)$$

where P is the received power, K is the collection efficiency (the ratio of the received power and the initial power in the absence of methane), S is the initial power, D is termed "optical depth", α is termed "absorption coefficient" (ppm^{-1}-m^{-1}) of methane and C is the distance-integrated concentration (concentration-length product) (ppm-m) of methane. Since the laser light is received after round-trip propagation between the device and target, the concentration-length product is doubled in equation (1).

LASERMETHANE™ measures the concentration-length product of methane rather than the local concentration at a point. An operator of the device can easily check a gas leak from a distance by hand-scanning the laser beam. During operation a red laser pointer shows the point being aimed by IR laser, and the device issues an alarm if the concentration-length product exceeds a preset threshold (typically 100 ppm-m).

Selection of Absorption Wavelength and Light Source

To achieve high detection sensitivity in absorption spectroscopy, it is desirable to use as strong an absorption line as possible. Methane has two strong absorption bands, or groups of absorption lines, centered at 3.3 μm (ν_3 band) and 7.6 μm (ν_4 band). However since we use a near infrared diode laser for cost effectiveness, the available laser wavelength is limited lower than 2.2 μm. Below 2.2 μm, the strongest absorption band of methane is located at 1.64 to 1.70 μm ($2\nu_3$ band).

The author and his research group selected the R(3) line (λ = 1.6537 μm, ν = 6047 cm^{-1}) in the $2\nu_3$ band, and Anritsu Corporation developed a special laser (InGaAsP DFB laser) with a wavelength for this line. This line is suitable for methane leak detection since it is one of the strongest absorption lines in the $2\nu_3$ band and is free from absorption of atmospheric interference gases.

Wavelength Modulation Spectroscopy

LASERMETHANE™ has to measure very little power since it collects limited diffused reflections from a target. In a typical case, for example, it will receive as little as 100 nW from an initial laser power of 10 mW. In addition, it has to detect very weak absorptions. For example, 100 ppm-m methane corresponds to an optical depth of less than 10^{-4}. These are significant technical challenges of remote methane detection using a near infrared diode laser. To overcome them, LASERMETHANE™ employs the second-harmonic detection [11] of wavelength modulation spectroscopy (WMS).

As shown in Fig. 3 (a), the laser wavelength is modulated by a sinusoidal injection current at a frequency of f = 10 kHz and the modulation center is locked at the absorption center of the $2\nu_3$ band R(3) line of methane. As a result, the second-harmonic (2f) signal is produced in the detector output and measured sensitively by lock-in detection. This 2f signal is proportional to concentration-length product of methane and written as

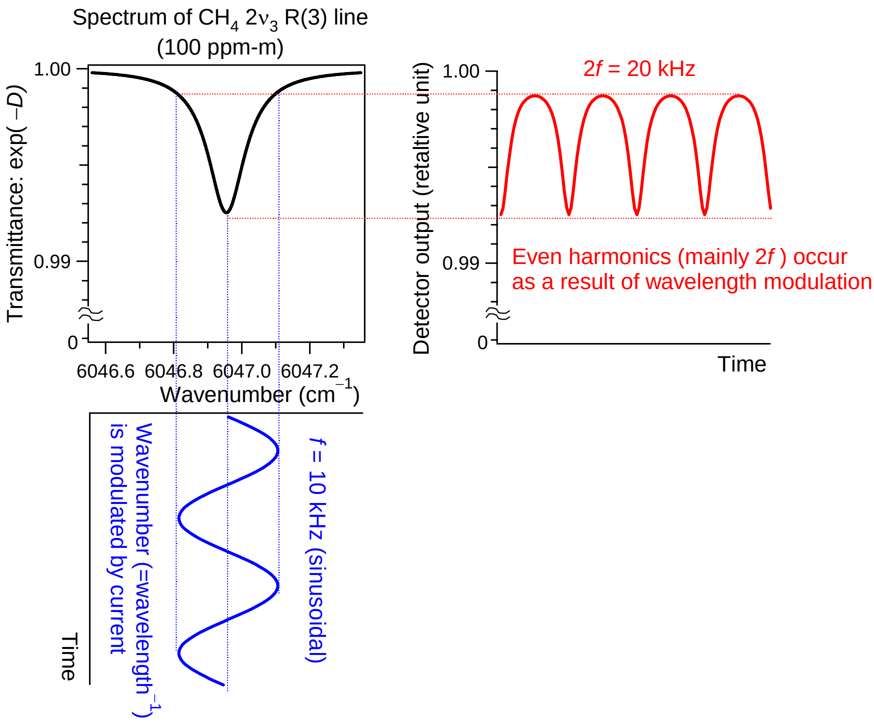
$$P_{2f} = KS_{DC} h\alpha_0 \times 2C \tag{2}$$

where P_{2f} is the 2f amplitude of the received power, S_{DC} is the DC component of the initial laser power, h is a coefficient depending on modulation depth and α_0 is the absorption coefficient at the absorption center.

As shown in Fig. 3 (b), the sinusoidal injection current modulates the laser power as well as the laser wavelength, and therefore the first harmonic (1f) signal is retained in the detector output and measured sensitively by lock-in detection. This 1f signal is independent of concentration-length product of methane and written as

$$P_{1f} = KS_{DC} m_{AM} \tag{3}$$

(a) 2*f* signal



(b) 1*f* signal

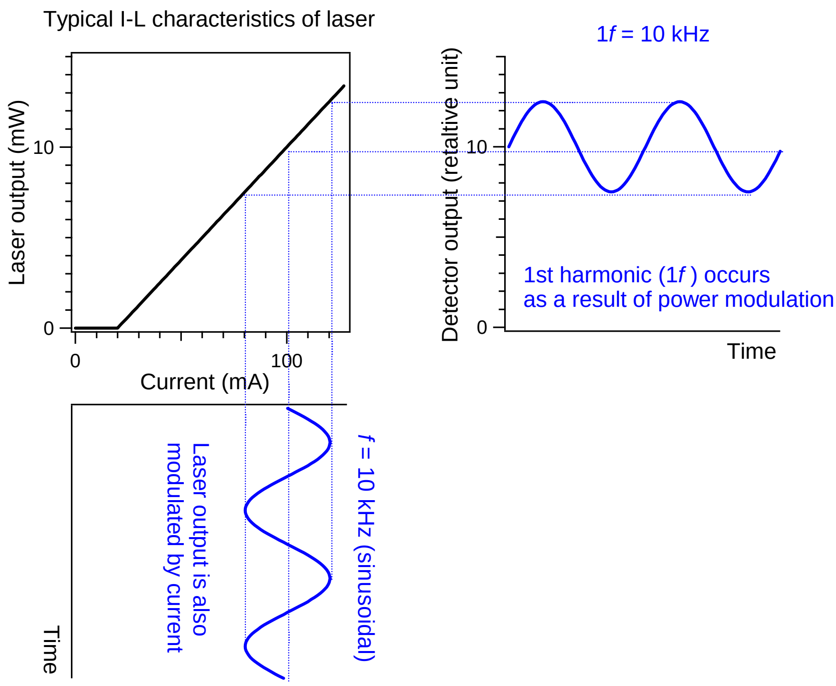


Fig. 3 Wavelength Modulation Spectroscopy for LASERMETHANE^{TM}

where P_{1f} is the 1*f* amplitude of the received power and m_{AM} is the power modulation ratio of the laser.

Dividing the 2*f* signal by the 1*f* signal, the collection efficiency, which changes as a function of target reflectance, distance and incident angle, will be cancelled [12, 13]. LASERMETHANE therefore calculates concentration-length product of methane from the ratio between the 2*f* and 1*f* signals as

$$C = \frac{m_{AM}}{2h\alpha_0} \times \frac{P_{2f}}{P_{1f}} \quad (4).$$

SPECIFICATIONS

Table 1 lists the specifications for the new and old versions of the portable remote methane detector. Both versions have a laser output power of 5 to 10 mW. This is established as Class 1 by the international classification of the International Electrotechnical Commission (IEC), but the entire device is classified as a Class 2 laser product due to the red laser pointer. The collimator has a full angle divergence of 1.6 mrad. This corresponds to a detection area of 8 mm diameter at 5 m distance. A Fresnel lens was used as the collection lens since it is lightweight and inexpensive. In the photo detector, an InGaAs PIN photodiode is packed with a low-noise pre-amplifier.

Regarding the response time, the device is much faster than conventional gas detectors. As the time constant for lock-in detection of WMS (equivalent to the response time of the detector) gets shorter, the detector responds faster but in doing so noise level increases. To balance this, the time constant is set at 0.1 seconds. The new version switches the gain factor of the pre-amplifier automatically, while the old version needed manual switching.

The new version was improved its user-friendliness dramatically from the old version, although both versions have basically the same performance for methane leak detection. For example the new version is lighter and smaller than the old version, and has a battery life of 1.5 times as long as the old version. In addition, the red laser pointer beam of new version travels on axis with the sensing laser beam, while the two beams of the old version were off axis. This will help much the operator of the new version detect and pinpoint of a leak. Regarding the detection distance, the new version extends it up to 50 meters (with a minimum detectable of 100 ppm-m) and 150 meters (with a minimum detectable of 1000 ppm-m) when used with a retro reflector.

The new version has two different types (SA3C05A and SA3C06A), and SA3C06A will be introduced into the international market by the end of 2004. Fig. 4 shows the

Table 1 The specifications of the portable remote methane detector

Terms	Old version [9]	**New version (this work)**
Detection principle	Second-harmonic detection of wavelength modulation spectroscopy for IR absorption using target backscatter return	
Detection object	Methane ($^{12}CH_4$)	
Light source	InGaAsP DFB laser (Wavelength: 1.6537 μm, Output: 5 to 10 mW)	
Laser Safety	Class 2 laser product (by IEC)	
Beam divergence	Full angle of 1.6 mrad (typical)	
Collection lens	Fresnel lens	
Photodetector	InGaAs PIN photodiode (packaged with a pre-amplifier)	
Response time	0.1 seconds	
Weight	4.4 kg	**1.3 kg**
Dimensions	Electronic Unit: W 195 x D 260 x H 88 (mm) Optics Unit: W 114 x L 244 x H 206 (mm)	**W 112 x D 250 x H 288 (mm)**
Power consumption	10 W (typical)	**5 W (typical)**
Battery	Nickel-metal hydrate battery	
Battery life	> 60 min (@ 25 degC)	**> 90 min (@25 degC)**
Explosion-Proof	No	
Raindrop-proof	No	**Yes**
Minimum detectable	< 100 ppm-m	< 100 ppm-m (Low range) **< 1000 ppm-m (High range)**
Maximum distance w/o retro reflector	< 10 m (30 m with ten-fold noise)	< 10 m (Low range) < 30 m (High range)
Maximum distance w/ retro reflector	No	**< 50 m (Low range)** **< 150 m (High range)**
Alarm threshold	Variable	**Fixed (SA3C05A)** **Variable (SA3C06A)**
Gain switching	Manual	**Auto**
Laser pointer path	Off-axis with IR laser	**On-axis with IR laser**
Display	Data on LCD	**Only LED (SA3C05A)** **Data on LCD (SA3C06A)**
Data strageand output	No	**No (SA3C05A)** **Yes (SA3C06A)**
CE-marking	No	**Yes**
Export	No	**Yes**

(a) SA3C05A

(b) SA3C06A

Fig. 4 Back panels of two types of LASERMETHANE™

back panels of (a) SA3C05A and (b) SA3C06A. The former is low cost but can not display the quantitative data. On the other hand, the latter displays the quantitative data and can output the time history of the data with its SD card port.

EXPERIMENTAL RESULTS

The sensitivity of the LASERMETHANE™ to methane was measured and the performance of the LASERMETHANE™ as a practical gas leak detector was demonstrated in a laboratory of Tokyo Gas. In the experiments, a concrete block was selected as the target, its distance from the detector was set to 5 meters and the incident angle was set at 60 deg. In this instance, the received light power was 100 nW.

Firstly, the sensitivity of the LASERMETHANE™ to standard gases was measured. In this experiment, an absorption cell with a length of 0.1 meters was set in front of the concrete target and standard gases of 0, 98, 298 and 988 ppm methane, balanced by standard air, were introduced into the cell sequentially. Fig. 5 shows the ratios between the $2f$ and $1f$ signals for 0, 98, 298 and 988 ppm methane (0, 9.8, 29.8 and 98.8 ppm-m methane), respectively. With the detection limit defined as the concentration-length product at which the signal-to-noise ratio (SNR) equals unity, the detection limit in this experiment is estimated to be 1.3 ppm-m.

Thereafter, the performance of the LASERMETHANE™ as a practical gas leak detector was demonstrated. In this experiment, a leak point was prepared using city gas (containing about 80 vol. % methane) in front of the concrete target and a flow rate of 10 ml-min^{-1}. Fig. 6 shows the time history of the detector output as the operator checked the leak point by hand-scanning the laser beam. As shown in Fig. 6, signals over 100 ppm-m were measured when the laser light passed through the leak point. These results show that the LASERMETHANE™ can detect a 10 ml-min^{-1} gas leak from an indoor exposed pipe.

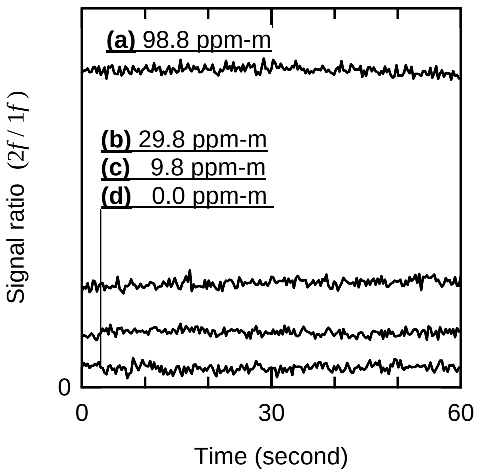


Fig. 5 Detector outputs for standard gases of methane

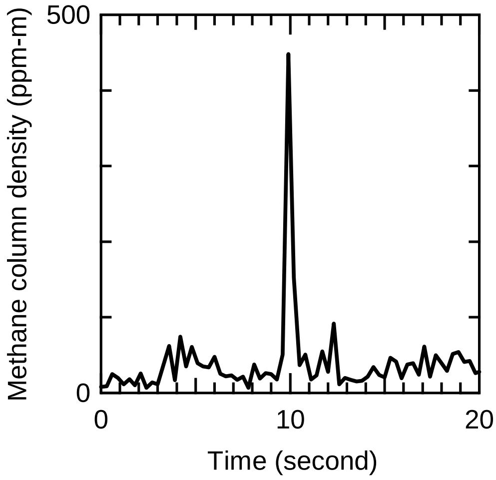


Fig. 6 Result of remote detection of a 10 ml-min^{-1} gas leak

CONCLUSIONS

Tokyo Gas Co., Ltd. and Anritsu Corporation jointly developed a new version of the portable remote methane detector (LASERMETHANE^{TM}: SA3C05A). This novel device enables us with remote detection of methane leaks from natural gas distribution facilities. The author and his research group have improved the user-friendliness and cost-effectiveness dramatically from the old version, and TGE has commercialized LASERMETHANE^{TM} for international market.

The device is handheld and the operator can easily check a gas leak from a distance by hand-scanning the laser beam. It has a minimum detectable of 100 ppm-m and the detection distance with most diffusive reflection targets are up to 10 meters. In this case, the device can detect and pinpoint a 10 ml-min^{-1} gas leak from an indoor exposed pipe from a distance of several meters. The detection distances can be extended up to 30 meters if the operator allows a minimum detectable of 1000 ppm-m. In addition when used with a retro reflector, the device extends the maximum distance up to 150 meters.

The author hopes that LASERMETHANE^{TM} will contribute to gas distribution companies all over the world by improving the operational efficiency of their emergency response and surveillance services.

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