A proposed solution technique for telemetry of methane using of carbon dioxide laser with COMSOL simulator

Navid nasiri
Department of electrical and computer engineering, sepidan Branch Islamic Azad University, Sepidan, Iran
Navid_nasiri2@yahoo.com

Masoud jabbari
Department of electrical and computer engineering, marvdasht Branch, Islamic Azad University marvdasht, iran

Hossein Afkhami
Department of electrical and computer engineering, sepidan Branch Islamic Azad University, Sepidan, Iran

Gholam Reza Hadad
Corvosion Protection supervisor, tapping the city, fars gas Company, iran

Abstract

Detecting the presence, concentration and the ratio of gases, as well as the standardization of gas transfer especially methane is important for various reasons such as life threatening risks for people who are exposed to this gas and many ways to measure this gas are proposed and implemented. Among the variety of proposed contact and non-contact sensors (remote), contact sensors for reasons such as delay or short lifelong which is mainly due to the establishment of chemical bonds are restricted in application. However, these problems are solved in non-contact sensors, yet the use of this type of sensor need complex electronic circuits.

This article uses carbon monoxide gas laser, provided a new model for measuring methane. Results indicated the success of the model with the accuracy of 5ppm and time less than 1.4 seconds.

Keywords: gas laser, carbon, methane

Introduction

Because on the one hand contact sensors due to chemical bonds such as covalent and dative require time to display changes or return to their initial state and on the other hand, sensors such as optical sensors that are remote sensors (non-contact) have solved the problem because there are no bonds, they are always the same and are very fast in performance, therefore working on this type of sensor that are frequently used in the industry seems very important.

Materials:

1. Laser:

The laser is common source of light with particular characteristics and applications. Since its invention in the late 60's, it led high technology developments and removal of laser from many technologies today is no longer possible. [1] In general, lasers are divided into four main categories according to their type of active ingredient: laser doped with insulator, semiconductor lasers, gas lasers, color lasers. Gas Lasers are divided into three categories: atomic lasers, ion lasers and molecular lasers. [2]

2. Carbon dioxide laser:

Lasers that their active ingredient is gas are called gas lasers. Gas lasers are bulky and usually the more powerful they are their size will be larger. Since the atoms in gases have very narrow absorption lines, it is almost impossible to release energy in them with the help of light pump. Considering different kind of lasers and laser material, different methods of pumping are used. For example, in gas lasers such as carbon dioxide lasers, discharge method is used. This laser is of the most important lasers of its kind in terms of its technical application are classified among the most important lasers. This laser is built with high efficiency (30%) and continues high output power (several kV). The structure of a gas laser is shown in Figure 1.

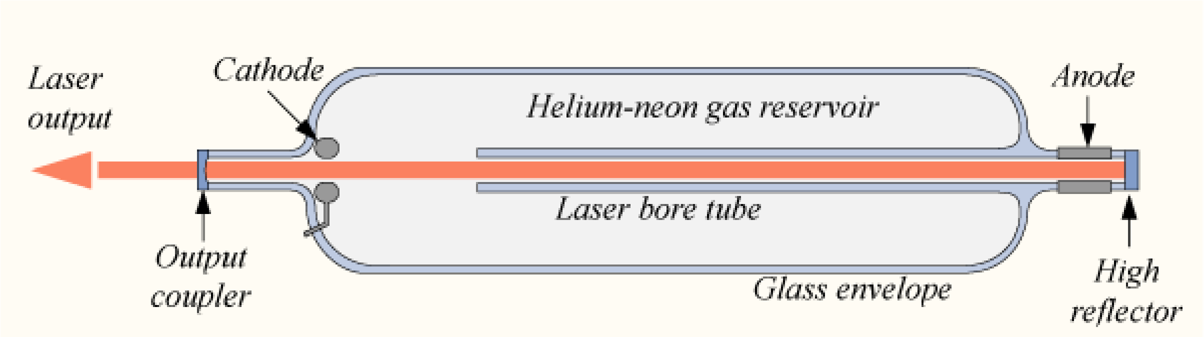


Figure 1. Structure of a gas laser

3. Methane:

With the molecular formula of CH_4 is a greenhouse gas and is used as fuel. The simplest alkane is methane. It is the main ingredient of natural gas that is formed from the breakdown of plant material in lagoon areas. Because of its ability to absorb large amounts of heat, the gas has greater greenhouse effect than carbon dioxide. In standard conditions of temperature and pressure, the gas is odorless, colorless, subtle and lighter than air and is the first combination of saturated hydrocarbons. The gas is produced from the decomposition and decaying of organic matter in nature, especially corruption of plants in the swamps, so it is called "swamp gas" as well. [3-5]

Lecture Review:

It can be said that for the first time Miss Murray et al at the Research Center of United States of America used carbon dioxide gas cylinder lasers to detect gas and the results obtained were remarkable. They found that by frequency changes, gas concentration up to 20ppm could be measured. [6] Extensive research was done in this regard after the conclusion of which the most are as follows.

In 2010, AK Biswas et al., studied local development of 2 kW using CO_2 laser in axes with frequency disturbances. Constant power output of the laser in the short term (over 1 hour) was measured, which was 1.5% at 1 kW. [7]

In 2011, Lima. J. R. et al studied an optical acoustic laser spectrometer with CO_2 emissions and optical acoustic with resonance. Optical acoustic resonant frequency was 2.4 kHz cells, spectrometer for molecules of ethylene and ammonia were estimated about 16 and 42 ppbv respectively. [8]

Previously measuring methane using tunable laser diodes have been conducted and the results have been satisfactory. In 2014, W. Zhang et al at the University of Sheng Yang, and J. Shemshad in Australia presented tunable diode laser absorption spectroscopy technique. In their articles, tough environmental and thermal conditions to handle sensors are mentioned several times. [9]

In 2014, Zhang Wei Hua et al worked on methane gas detection using a tunable laser diode by fiber optic. Tunable laser absorption spectroscopy is a new method of measuring methane that has high stability and long lifetime. [9, 10]

In 2015, William B. Grant et al in an article worked on remote detection of gases using gas lasers. They proposed a table that the frequency and the capacity of different gases to be used as a laser are listed. [4, 11-14]

Table 1. Specific wavelength of gases

	Laser	The best gases detected	Frequency µm	Differences in absorption coefficient $Atm^{-1}cm^{-1}$	Laser Distance of sensors m	Sensitivity PPb
١	Argon ion optics	NO_2	٠,٥	٥,٧	٣,٥٤	١٣
٢	Parametric Oscillator	H_2O	١,٩	-	٠,٧٧٥	٢
٣	Hydrogen fluoride	HF	٢,٨ـ٢,٦	١٠٠	٠,٠٩٨	١٥٠
٤	deuterium fluoride	HCl	٣,٦٤	٥,٦	٠,٣	١٥٠
٥	carbon dioxide	CO	٤,٦٤	٢٥,٧	٢,٥	١٠
٦	Carbon monoxide	NO	٥,٢	٠,٧٩	٣,٧٥	٣٠
٧	carbon dioxide	NO	٥,٣٢	١,٢	٠,٥٥	٤٠

To measure the amount of ammonia in environment, CO2 gas laser sensor in acoustic condition using resonance spectroscopy that reveals gas environment effects on optical wave, can be used extensively. The system comes with 1% error with 32 parts per trillion, with a mean of 5 seconds and total measurement time is 40 seconds. [5, 12-16]

Methodology:

In this study, COMSOL software was used to measure methane and following steps were performed during the simulation.

The first step: First, as Figure 2 a chamber was simulated that on one side of it there was a hole to transmit light and on opposite side there was an optical receiver. Two lenses are located on this structure to parallel the light rays.

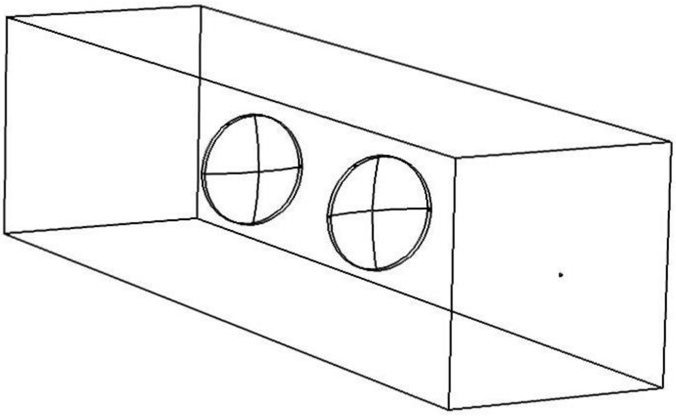


Figure 2. Simulated structure

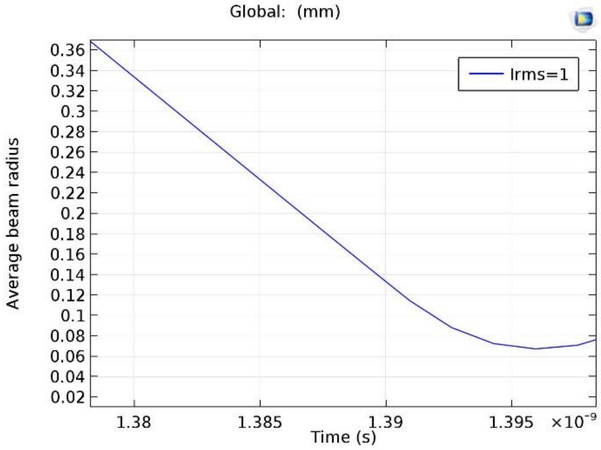
The second step: once the chamber was tested in vacuum and results were registered as a comparison reference.

The third step: the chamber were tested once by air, once with methane and once by combination of these two gases.

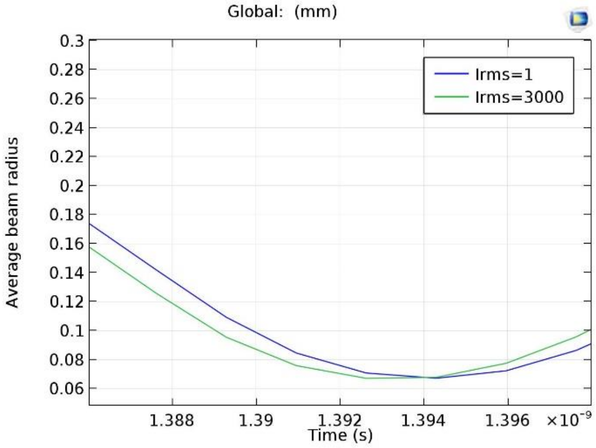
In this test, sending light beams was in the carbon dioxide laser wavelength range, which is between 9.6 and 10.4, micrometers [13], the optical receiver receives it, and measuring the received power was at 3 seconds interval.

Conclusion:

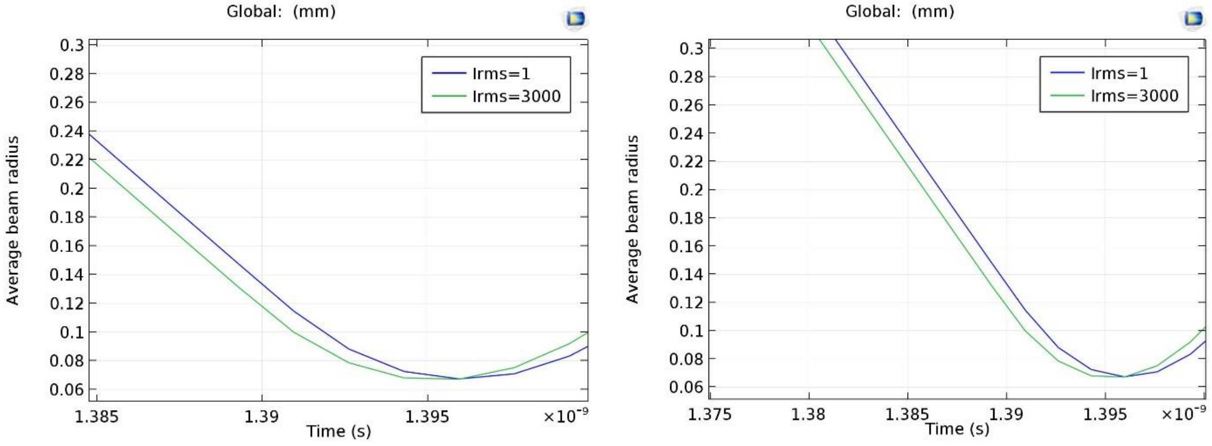
Figure 3 indicates the intersection differences in gas conditions with the reference one where the blue one is related to vacuum and green is related to the existing gas conditions.



A



B



C D

Figure 3. Results of simulating A) vacuum B) the presence of air C) the presence of methane D) equal mix of air and methane.

The numerical values of these points are given in Table 2.

Table 2. Achieved outputs

Condition	Air	equal mix of air and methane	Methane
Time (s)	1.39405	1.396.3	1.39604
Value (micrometer)	67.54	67.46	67.41

These differences show that the carbon oxide laser is capable of detecting methane gas and can measure methane concentrations in the environment very well with high accuracy of 5 ppm. In addition, in terms of detection time in all the cases, it was less than 1.4 seconds, which is a good rate compared to previous research.

References

[1] F. Duarte, Tunable Lasers, Rochesrer, New York: Eastman Kodak Company, 1995.
[2] werle, peter; slemr, franz; maurer, karl; kormann, robert; mucke, robert; janker, bernd;, "Near- and mid-infrared laser-optical sensors for gas analysis," ELSEVIER, pp. 101-114, 2002.
[3] Peet, Mary M; Krizek, Donald T;, "Carbon Dioxide," in Carbon Dioxide, 1995, pp. 65-79.
[4] M. G. Allen, "Diode laser absorption sensors for gas-dynamic and combustion flows," IOP, pp. 545-562, 1998.
[5] ZHANG, Wei-hua; WANG, Wen-qing; ZHANG, Lei; DAI, Xin; LIU, Xiao-lu; JIANG, Ling;, "Methane Gas Detection Based on Tunable Diode Laser Absorption Spectroscopy and Optical Fiber Sensing Ne," International Conference on Intelligent Computation Technology and Automation, pp. 365-369, 2014.
[6] Consolino, Luigi; Bartalini, Saverio; Beere, Harvey E; Ritcher, David A; Serena , Mirian Vitiello; Natale, Paolo De;, "THz QCL-Based Cryogen-Free Spectrometer for in Situ Trace Gas Sensing," SENSORS, pp. 3331-3340, 2013.
[7] Gao, Qiang; Zhang, Yungang; Yu, Jia; Wu, Shaohua; Zhang, Fu; Lou, Xiutao; Guo, Wei;, "Tunable multi-mode diode laser absorption spectroscopy for methane detection," ELSEVIER, pp. 106-111, 2013.

[8] Nicolas, Jean Christophe; Baranov, Alexei N; Cuminal, Yvan; Rouillard, Yves; Alibert, Claude;, "Tunable diode laser absorption spectroscopy of carbon monoxide around 2.35 mm," APPLIED OPTICS, pp. 7906-7911, 1998.

[9] WEI, Huang; XIAOMING, Gao; XIAOYUN, Li; WEIZHENG, Li; TENG, Huang; SHIXIN, Pei; JIE, Shao; YONG, Yang; JUN, Qu; WEIJUN, Zhang;, "Near-IR diode laser-based sensor for remote sensing of methane leakage," optica applicata, pp. 23-32, 2005.

[10] Tittel, Frank K; Lancaster, David G; Richter, Dirk; Curl, Robert;, "Laser based absorption sensors for trace gas monitoring in a spacecraft habitat," Society of Automotive Engineers, pp. 102-201, 1999.

[11] Upschulte, Bernard L; Sonnenfroh, David M; Allen, Mark G;, "MEASUREMENTS OF CO, CO2, OH, AND H2O IN ROOM TEMPERATURE AND COMBUSTION GASES USING A BROADLY CURRENT-TUNED MULTI-SECTION InGaAsP DIODE LASER," PSI-SR, pp. 1-19, 1999.

[12] Sun, Zaicheng; Zussman, Eyal; Yarin, Alexander L; H, Joachim; Wendorff; Greiner, Andreas;, "compound core-shell polymer nanofibers by co-electrospinning," ADVANCED MATERIALS, pp. 1929-1932, 2003.

[13] Werle, Peter; Slemr, Franz; Maurer, Karl; Kormann, Robert; Mucke, Robert; Janker, Bernd;, "Near- and mid-infrared laser-optical sensors for gas analysis," ELSEVIER, pp. 101-114, 2002.

[14] Lima, G R; Sthel, M S; Silva, M G da; Schramm, D U S; Castro, M P P de; Vargas, H;, "Photoacoustic spectroscopy of CO2 laser in the detection," IOP SCIENCE, pp. 1-9, 2011.

[15] Gao, Qiang; Zhang, Yungang; Yu, Jia; Wu, Shaohua; Zhang, Zhiguo; Zheng, Fu; Lou, Xiutao; Guo, Wei;, "Tunable multi-mode diode laser absorption spectroscopy for methane detection," ELSEVIER, pp. 106-110, 2013.

[16] BISWAS, K A; BHAGAT, M S; RANA, L B; VERMA, A; KUKREJA, L M, "Indigenous development of a 2 kW RF-excited fast axial flow CO2 laser," PRAMANA, pp. 907- 913, 2010. [8] E. Franz Fuchs, "Theoretical and experimental analyses of photovoltaic systems with voltageand currentbased maximum power-point tracking," IEEE TRANSACTIONS ON ENERGY CONVERSION, pp. 513-523, 2003.

[9] Ullah , K.R. ; Saidur, R.; Ping, H.W.; Akikur , R.K.; Shuvo, N.H.;, "Renewable and Sustainable Energy Reviews," ELSEVIER, pp. 499-514, 2013.

[10] Natshe, M. E.; Albarbar, A.;, "Solar power plant perfomance evaluation: simulation and expermental validation," IOP Publisher, vol. 012122, no. 364, pp. 1-14, 2015.

[11] Ameri, Mohammad; Behbahaninia, Ali; Tanha, Amir Abbas;, "Energy," ELSEVIER, pp. 2203-2210, 2010.

[12] A. Garlisi, "Self-Cleaning Coatings Activated by Solar and Visible Radiation," Advanced Chemical Engineering, pp. 103-106, 2015