International Journal of Natural and Engineering Sciences 3 (1): 29-34, 2009
ISSN: 1307-1149, www.nobel.gen.tr

Simultaneous intra-cavity detection of some physical effects in a CO_2 laser

M. I. ABU-TAHA F. A. ZHOUR

Physics Department, College of Science and Technology, Al-Quds University, P.O. Box 20002, Abu Deis, Jerusalem, Palestine

Corresponding Author on sabbatical leave at Al-Quds Open University, Palestine
E-mail: mtaha@qou.edu or mabutaha@science.alquds.edu.

Received: January 30, 2008
Accepted: September 26, 2008

Abstract

For the first time three physical effects were simultaneously detected in an intra-cavity of a conventional CO2 laser; namely: opotoacoustic (OA), photopyroelectric (PPE) and antenna (AE) effects. Simultaneous detection of the effects aimed to allow: relate the origins of their signals with respect to each other and facilitate a study of those phenomena that occur in the laser active material.The implications of the study are many useful applications, including: the monitor of laser power and new laser stabilization methods. Results show that the effect's signals follow to a good degree the laser power magnitude, but the PPE have the optimum correlation. This result enhances the future use of PPE as an in expensive internal laser power meter and constitutes a good reference signal for laser stabilization purposes. Contrary to the AE signal, the OA and PPE signals were found to have the same **origin** although they were detected using different sensors.

Key words: Conventional CO2 lasers; Optoacoustic, Photopyroelrctric and Antena effects; Intra laser cavity.

INTRODUCTION

Carbon dioxide laser is line tunable to hundreds of lines. This property made it useful in many applications, namely industry, agriculture, engineering, medicine and science. The active medium of a CO2 gas laser constitutes an active place too, many phenomena occur as a result of laser beam passing through the gaseous mixture. Effects, such as optoacoustic, photopyroelectric and antenna effects are expected to take place. We report for the first time the simultaneous detection of the above mentioned effects.

The OA effect is generated in a gas cell as a result of absorption of light energy by gas constituents, which is consequently transformed into sound energy when excited species decay none-radiatively to a lower energy state. Hence, in the intra-cavity of a laser, continuous modulation of the laser beam passing in between laser mirrors produce an alternating sound in the laser cavity, hence, the generated signals can be detected using a sensitive microphone. The OA effect was discovered as early as 1880 by Bell [1]. The effect found interest and application only after the discovery of lasers as it was first demonstrated by Kerr and Atwood [2]. Many researchers [3-15] have shown the versatility of OA technique for various physical and technological applications including detection of volatiles from seeds and natural plant parts [16-17]. The laser intra-cavity optoacoustic (LICOA) signal detection was first reported by (Abu-Taha and Laine') [18-20] in a conventional CO2 laser and later by Parslaw [21] in a Waveguide CO2 laser cavity. The OA theory is well-established [6] and acoustic resonators can be designed in different shapes [6, 22-23] for the sake of maximizing signal to noise ratio [24-25].

PPE effect is induced in a photopyroelectric film (PVDF), which became popular in recent years due to some unique properties. PVDF is a dielectric materials constituting pyroelectric sensor relying on its temperature-dependent dipole moment. When the film is subjected to a thermal heat wave it expands or contracts, thereby inducing secondary piezoelectric signals. It is a practical inexpensive sensor, easily handled and readily available in various thicknesses down to 25µm, sandwiched between two aluminum foils and can be easily attached to curved as well as flat surfaces [26]. It can be prepared in different ways depending on the required type of application [27-28] and has good potential for use to measure temperature change resulting from monochromatic [29-35] as well as broadband [36] radiation absorption. PPE technique is most famous in liquid characterization [30 -36], but recent results have proved it is sensitive for temperature change measurement resulting from radiation absorption in a gaseous medium [37].

AE is an induction effect produced by the magnetic field generated as a result of the change in the discharge current during the lasing processes, hence the name antenna effect. It can be detected by winding a coil a round the laser tube at a point in between laser electrodes. Other effects happen in the laser cavity due to change in laser tube impedance, hence, result in the discharge current change and is called the optogalvanic effect (OGE). OGE shows it self as [38] a variation in the color of the laser plasma tube. Several ionization reactions can play a role in changing the discharge current; these reactions involve collisions between metastable atoms [39]. The change in the discharge current can be explained as a result of atoms transitions from excited level to other excited level with different ionization probabilities, in addition to other physical processes related to production and disappearance of ions. The change in discharge current is detected by different ways, but in any way the problem of high voltage isolation should be overcome. Suzuki [40] claimed the detection of the OG effect using a winding coil in an external cell. The question remains open whether OGE is the same as the AE; this is the subject of another study underway to prove this point. In the present study the AE effect is detected by winding a coil round the laser tube at a point in between laser electrodes as will be explained later. The coil hence acts as an antenna in converting the oscillating electromagnetic waves into an alternating current.

In the present work, we demonstrated for the first time the detection of the AE, PPE and OA effects simultaneously in the laser intra-cavity. This has many advantages: firstly it allows determining the origin of these effects with respect to each other and secondly; can assign the effect with optimum curve fit with laser power to be used as a suitable in-expensive laser power monitor, and/or a reference signal for possible laser frequency and power stabilizations.

EXPERIMENTAL METHODOLOGY

The advancement of technology, especially in data collection allows a computerized easy to handle processes, data collections, storing and data analysis simply and efficiently. At a rate of 10 readings per second a lot of data could be gathered ensuring efficient simultaneous detection of the three effects. Results are simultaneously recorded using interface units feeding data directly into a computer.

Laser System

A conventional line-tunable CO2 laser constructed in-house was used in this study. It was capable of delivering a power output in the rage 0.2 -2 watts. The desired CO2 laser line can be obtained by angle adjustment of the intra-cavity diffraction grating using a micrometer. In our system the grating is replaced by a 100 % reflectivity mirror, i.e. laser is operated on the strongest gain line, i.e. 10P20 line. A combined pressure of 14-20 torr of the gases He: N2: CO2 in ratios of 70: 24: 6 respectively gave a peak output power of 2 watts. The germanium output coupler mirror used was coated on the laser discharge tube side to enhance the reflectivity to 90%, while the output side was anti-reflective coated. The ordinary glass plasma tube terminated at one end in an O-ring mounted vacuum seal made to the output coupler optics. At the other end near the 100% reflectivity gold coated molybdenum mirror, the tube was terminated by a zinc selenide window set at the Brewster angle for low optical transmission loss. The germanium mirror has 1m radius of curvature, a thickness of 3 mm, and a diameter of 25 mm.

Detection cell design

A combined cell design for simultaneous detection of OA and PPE effects is built in, as a laser tube extension in the Brewster window side. Since both signals need to be detected simultaneously, their corresponding sensors were placed in the cell fitted in the laser intra-cavity; the optimum arrangement requires both sensors be as close together as possible. The cell is constructed as shown in Fig.1, it is consisted of a cylindrical plastic tube having the same laser tube internal diameter in which sensitive microphone and PVDF film fixed opposite to each other. The PVDF film is thermally isolated from the external medium, thermal isolation is important to obtain a temperature gradient between the two surfaces of the PVD film, which was stuck to surface of copper foil constituting a first electrode, while the other side is in contact with the laser gas and a wire attached to forming the second electrode. The electrodes were glued to the PVDF film surfaces using conducting silver paint. Detection of the AE effect is carried out by simply wounding an insulated copper wire of 1.5 mm in diameter around the laser tube at a part in which the electric discharge is running in. 85 turns were found enough, giving good strong detectable signal.

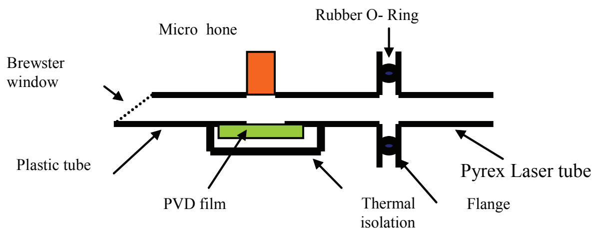

Fig. 1. Schematic snowıng the combined cell used for simultaneous detection of OA and PPE signals in an intra laser cavity.

Methodology

The experimental system is mainly formed of laser system and signal processing electronics. OA and PPE signals were connected to two different phase sensitive detectors referenced with the same chopper frequency, i.e. same modulation frequency. Signals then transferred to a computer using an interface automatic processing unit. AE signal is so large that it does not need amplification, so it is transferred directly to the computer through an interface unit. The system allows simultaneous detection of all effects or alternatively separate detection of each effect as required.

EXPERIMENTAL RESULTS

The AE, OA and PPE signals have been studied as a function of three variable parameters; laser tube cooling rate, laser beam modulation frequency and laser gas pressure. The laser power (P) together with the intended signals of AE, OA and PPE signals were monitored as one of the above parameters is changed. This allows relating the above effects to the laser power. It is known that the laser power is affected by laser tube cooling rate, laser gas mixture pressure and electrical discharge parameters. For analysis requirements, the four signals were averaged at the same time interval. Since laser system was not stabilized, hence, its power might drift during operation. The drift can be both ways, i.e. increase or decrease, but as the laser cavity gets hotter the power is likely to drop. To eliminate the effect of this parameter, the AE, OA and PPE signals were normalized with respect to the laser power. This has an extra advantage, i.e. eliminate any effects resulting from any abnormal transients in laser power. The laser operated in a single mode of the maximum gain 10P20 line. The power range was (0.2 – 2) W which was found enough for such study. The low range of laser power indicates the sensitivity of the experiment at low as well as high laser powers.

The effect of laser cavity cooling

Laser tube cooling affects laser performance in many ways, for example it drops cavity temperature, and hence many intra-cavity physical phenomena will be affected resulting in increased laser efficiency. The cooling effect was studied only by varying water flow rate through the laser tube cooling jacket.

Although, the range of variation expected is not as large as changing the coolant liquid temperature, but its effect was evident as shown in Fig.2. In the laser system used, it is noted that as the rate of water flow is increased from the minimum to maximum possible value, the laser power is increased by 1 W. This variation is quite enough for noticeable change of the effects under study.

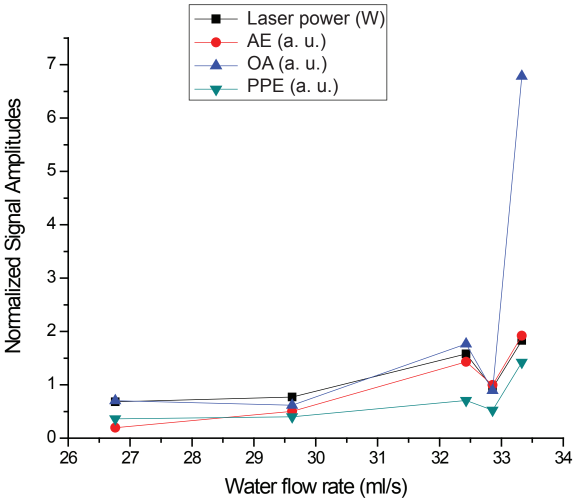

Fig.2. Variations of laser power, AE, OA and PPE signals vs. water flow rate in (mL/s) at a gas pressure of 14 torr and modulation frequency 250 Hz.

Effect of modulation frequency

The effect of laser beam modulation frequency on AE, OA and PPE signal's levels were monitored at constant gas pressure and water flow rate. This is rather important since any further applications of the effects require frequency modulation. Fig.3. is an example of the dependence of the different effects on frequency change at frequencies 150 Hz and above. It is a straight forward conclusion that laser power level is not heavily affected by amplitude modulation at different frequencies. This experiment aimed at finding the effect among the three effects, that is most heavily dependant on frequency modulation and cavity shape rather on the laser power.

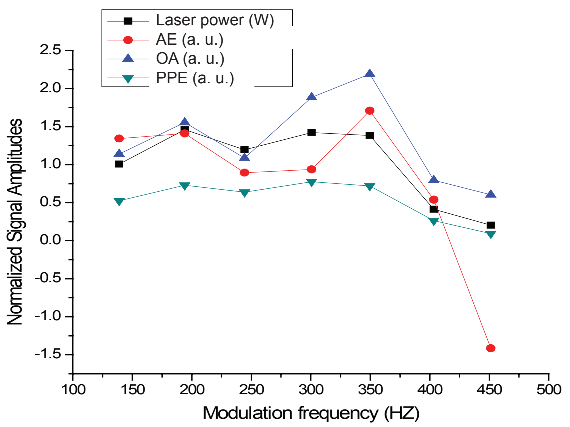

Fig 3. Variation of laser power, AE, OA and PPE signals as a function of modulation frequency at constant laser cooling rate and gas pressure

The effect of gas pressure

In this experiment the gas mixture pressure was varied from 13 – 22 torr. Fig.4. shows the laser power and AE, OA and PPE effects' signals as a function of gas pressure. Laser power is dependant on gas pressure; hence laser power will vary accordingly and tends toward an optimum value at a pressure ~ 18 torr for the laser system under study.

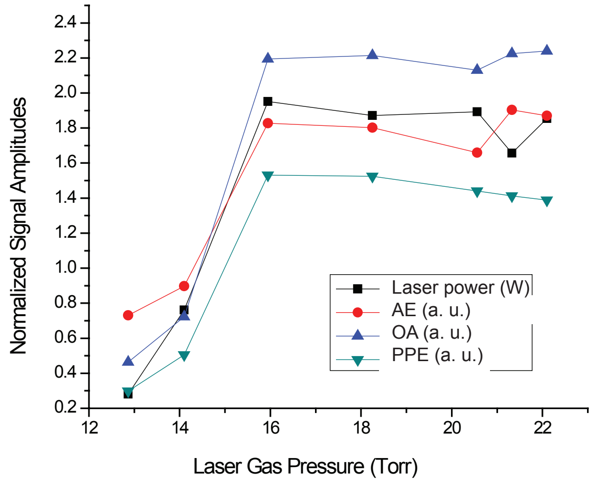

Fig 4. Fig.4. AE, OA, PPE and Power signals dependence on the gas pressure at constant water cooling rate and modulation frequency of 250 Hz.

Statistical treatments

From the data obtained a set of charts that relate the linear fits of the OA, AE, and PPE signals and their correlations with the corresponding laser power amplitude were produced. Fig.5. shows the correlation coefficients of the different effects to the laser power. In Fig.6. the standard deviations of the AE, OA, and PPE signals versus laser power curves at different varying parameters were presented. This is intended to identify all effects least affected by process or processes not related to the laser beam power variations. A conclusion of this sort assigns the effect that is most appropriate for future use for laser power monitor and stabilization.

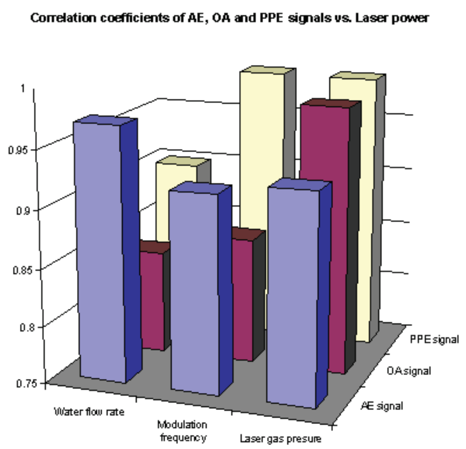

Fig 5. Chart showing the correlation coefficients of the AE, PPE and OA signals with the laser power.

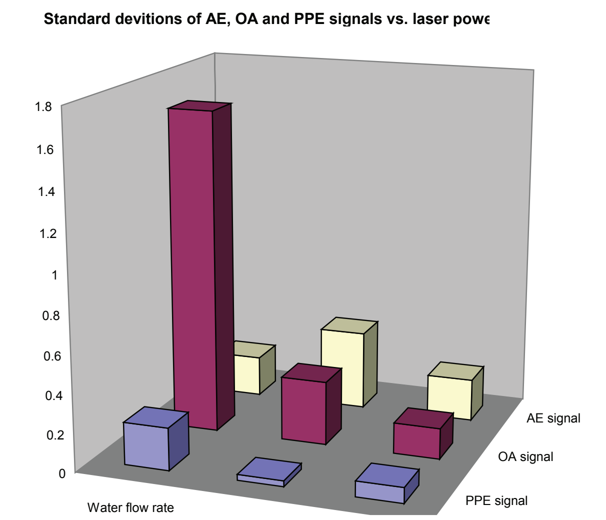

Fig 6. Chart showing standard deviations of the AE, PPE and OA signals versus laser power linear fits.

The chart of Fig.7 shows the errors for all experiments to all signals. Calculations assumed a linear relationship between the different effects and their dependence on the power. Once again the effect with non linear dependence does not satisfy the experimental conditions for use as a laser power monitor and stabilization**.**

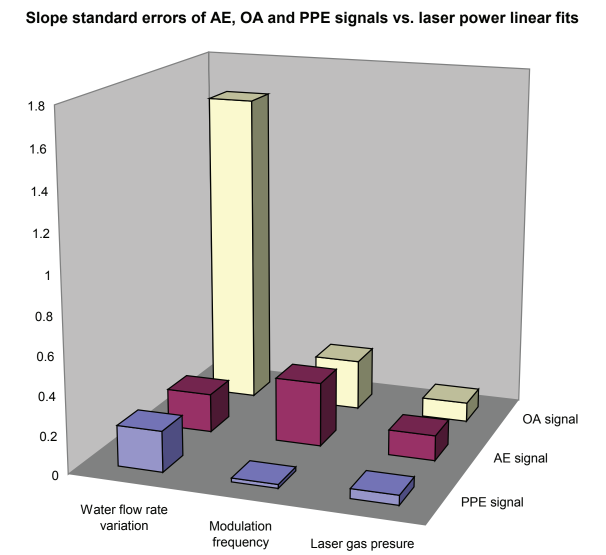

Fig 7. Chart showing the slope standard errors of the AE, OA, and PPE signal versus the laser power curves.

DISCUSSION

Set of parameters were changed to introduce a correspondingchange in the intra-cavity physical processes. For examplelaser tube cooling affect laser performance in many ways; it drops heat, increasing the laser efficiency. As water flow rate reached the maximum possible value, laser output power almost doubled. Results of Fig.2 show that the three effects follow the laser power pattern; this means that laser power increase introduced an effect that is similar in nature and could be detected with AE, OA and PPE methods to a large extent. As the cavity cools, when the maximum cooling rate is introduced a noticeable increase in the OA signal is obvious, this is explained as being due to temperature change of the laser gas mix leading to change in the speed of sound; hence OA is most affected by that.

Laser beam modulation frequency does not have much effect on the physical processes going on in the laser cavity. All effect's signal levels are expected to follow the laser power to some degree as shown in Fig.3. Laser gas mixture pressure do affect the value of the laser power, every laser system have an optimum gas pressure depending on many factors. For the system used in the present study a pressure of 18 torr is optimum under the operating conditions of laser length, diameter and discharge voltage. It is noticed that all effects follow the laser power curve when laser gas pressure changed from the threshold pressure value, i.e. 13 torr for this laser system and up to 22 torr.

The chart presented in Fig.5, shows the high correlation coefficients of the three signals with the laser power. The PPE signal has the highest correlation coefficient for modulation frequencies and laser gas pressures variations, it is obvious that the signal is affected mainly by heat. The OA signal has low correlation coefficients with laser power as the laser tube is cooled and frequency modulation varied, due to its high dependence on speed of sound in the laser cavity, the laser cavity shape and volume. The AE has its highest correlation coefficient value during tube cooling rate variations; this means contrary to PPE and OA effects, the AE effect is dependant on different set of parameters, mainly due to gas constituents interactions and the net number of ions produced. Correlation coefficients of the AE signal with the laser power for water flow and modulation frequency variations are more than that for the OA signal.

Fig.6. shows the standard deviations of the AE, OA, and PPE signals versus laser power curves at different varying parameters. In the three experiments and for the three signals the standard deviations are small except for the OA signal during the laser cooling rate change experiment. It is noticed that under constant cooling and gas pressure the PPE has an extremely low error, i.e. the signal correlation with the laser power is very good. This result leads to the conclusion; that the PPE signal could be used as a laser power monitor and reference stabilization signal.

The chart of Fig.7 shows that the errors are low for all experiments for all effects except for the OA signals obtained during the water flow rate change experiment. From the chart, it can be concluded that the linear relation is valid to represent the three signals with laser power except the OA signal in the case of water flow rate i.e. when there is a variation in the temperature of the laser gas mixture.

CONCLUSION

Simultaneous intra-cavity detection of the three effects; i.e. AE, PPE and OA in a laser cavity was successful. In General, all effects respond to the physical conditions in the laser cavity, but with some differences. PPE and AE are found to have greater response to the laser power change than the OA effect. OA is found [19-20] to be dependent on other cavity parameters, such as: volume, temperature, shape, etc. The experimental data are successful and form the basis for understanding and explaining the nature and the origins of the AE, OA and PPE signals and their relations to other physical intra-cavity processes and phenomena.

Detection of the three effects can help understand the physical phenomena that take place in a laser cavity, hence can be used to look for laser efficiency improvements. The effects can be employed in many other useful applications related to lasers and their corresponding active mediums studies.

Many conclusions could be drawn: heat waves produced by irradiative decay to the laser ground states is the source of the PPE and OA signals. It was found that the OA signal depends on many factors such as the level of absorption of light power, the interior laser cavity shape, the modulation frequency, cavity resonances and the type and number of atomic species being de-excited or none-radiatively decayed. This suggests the possibility of OA signal use for improving laser cavity design through monitor of the intra-cavity physical processes. The change in discharge current, i.e. rate of ions movement is the main source of AE effect. Number of ions and their rate of production is dependant on many parameters related to laser efficiency; hence more thorough study of the AE effect and its relation to the known OGE is still needed. AE, OA and PPE signals are to some extent linearly proportional to the laser power signal and OA and PPE signals are linearly proportional to each other. PPE signal has the highest linear correlation with the laser power signal. In addition, PPE signal is dependent on the frequency of modulation; hence an optimum frequency could be sought for most sensitive PPE detection.

In conclusion, the PPE signal represents the laser power signal with high resolution and low standard deviations error; this suggests its usefulness among other signals as an internal power meter and reference for laser power stabilization.

REFERENCES

[1] Bell AG. 1880. On the Production and Reproduction of Sound by Light. Am. J. Sci.;20:305- 324.

[2] Kerr E, Atwood J. 1968. The Laser Illuminated Absorptivity Spectrophone: A Method for Measurement of Weak Absorptivity in Gases at Laser Wavelengths. Appl. Opt. 7: 915-921.

[3] Dewey C, Kamm R, Hackett C. 1973. Acoustic amplifier for detection of atmospheric pollutants. Appl. Phys. Lett.;23:633-636.

[4] Rosengren L, Max E, Eng S. 1974. A study of laser-acoustic air pollution monitors. J. Phys. E: Sci. Instrum.7: 125-133.

[5] Goldan P, Goto k. J. 1974. An acoustically resonant system for detection of low-level infrared absorption in atmospheric pollutants. App1. Phys.;45:4350-4355.

[6] Rosencwaig A. Photoacoustics and photoacoustic spectroscopy. N. Y: John Wiley and Sons; 1980.

[7] Chao-Kang Liao1 and Pai-Chi Li Liao C-K, Li P-C. 2005. Reconstruction of Optical Energy Deposition for Backward Optoacoustic Imaging. opt. Quant. Elect.;37: 1339-1351.

[8] Viscovini R, Cruz F, Scalabrin A, Pereira D. 2004. Infrared Optoacoustic Spectroscopy of CHD2OH Around 10R and 10P CO2 Laser Lines. Int. J. Infrared and Millimeter Waves.25(2). 257-275.

[9] Viscovini R, Scalabrin A, Pereira D. 2000. Infrared Optoacoustic Spectroscopy of 13CD3OD Around 9P CO2 Laser Lines. Int. J. Infrared and Millimeter Waves.;21(4): 621-632.

[10] Kopp C, Niessner R. 1999. Optoacoustic sensor head for depth profiling; Applied Physics B: Lasers and Optics, 68: 719-725.

[11] Esenaliev RO, Karabutov AA, Oraevsky A A. 1999. Sensitivity of laser opto-acoustic imaging in detection of small deeply imbedded tumors. IEEE J Selected Topics Quant Elect 5: 981-988.

[12] Foster NS, Amonette JE, Autrey T, Ho JT. 2001.Detection of trace levels of water in oil by photoacoustic spectroscopy. Sensors and Actuators B 77: 620-624.

[13] Andreev VG, Karabutov AA, Oraevsky AA. 2003.Detection of ultrawide-band ultrasound pulses in optoacoustic tomography, IEEE Trans Ultr Ferro Freq Control. 50: 1383 -1390.

[14] Viscovini RC, Cruz FC, Scalabrin A, Pereira D. 2004. Infrared optoacoustic spectroscopy of CHD2 OH around 10R and 10P CO2 laser lines. Int. J. Infrared and Mill. Waves. 25: 257-275.

[15] Bicanic D, Harren F, Reuss J, Woltering E, Vosenek L, Snel J, Voesenek LACJ, Zuidberg B, Jalink H, Bijnen F, Blom CWPM, Sauren H, Kooijman M, van Hove L, Tonk W. 1989. Trace detection in agriculture and biology. In: Photoacoustic, Photothermal and Photochemical Processes in Gases. Hess P. (ed). Springer-Verlag, Berlin. 46: 213-245.

[16] El-Kahlout A, Al-Jourani MM, Abu-Taha MI, and Lainé DC, 1998. Laser photoacoustic detection of the essential oil vapours of thyme, mint and anise. SPIE 3405: 578-583.

[17] Abu-Taha M, Laine¢ D. Sept 1987: Proc. 8th int. Conf. Quant. Elec. St. Andrew University, UK, P 18.

[18] Abu-Taha M, Laine¢ D. 1989, Patent: Frequency Stabilization of a CO2 Laser. USA patent No. 235062(1990), UK patent No 8981926-4 and Canadian Patent No. 575602(1990).

[19] Abu- Taha M. 1987. Optoacoustic Frequency Stabilization Of A carbon Dioxide Laser, PhD. Thesis, University of Keele, UK.

[20] Parslow D.1993. Intracavity optoacoustic detection in a CO2 waveguide laser using a Helmholtz cell. PhD. Thesis, University of Keel, UK, (1993). 43 F. A. Zhour et al / IJNES, 3 (1): 39-44, 2009[4] Maridass M, De Britto AJ. 2008. Origins of plant derived medicines. Ethnobotanical Leaflets. 12: 369-383.

[21] Bruce C, Sojika B, Hurd B, Watkins W, Derzko Z.1976. Application of pulsed- source spectrophone to absorption by methane at DF laser wavelengths. Appl. Opt.;15:2970-2972.

[22] Shtrikman S, Slatkine M. 1977. Trace-gas analysis with a resonant optoacoustic cell operating inside the cavity of a CO2 laser. Appl. Phys. Lett. 31:830-832.

[23] Jalink H, Bicanic D. 1989. Concept, design, and use of the photoacoustic heat pipe cell. Appl. Phys. Lett. 1989;55:1507- 1510.

[25] Randal R. 1951. An introduction to acoustics. UK: Addison- Wesley Press;.p.108.

[26] Zott H, Heusinger H. 1978. Intermediates of radiation-induced polymerisation of maleimides studied by ESR. European Polymer Journal.;14: 89-92.

[27] Chen Y, Li Y, Li J.. 2007. Preparation of PVDF Membranes via TIPS Method: The Effect of Mixed Diluents on Membrane Structure and Mechanical Property Journal of Macromolecular Science, Part A, 44: 305 - 313.

[28] Dang ZM, Xu HP, Xie D, Li L, .2007. Study on dielectric behavior of the ferroelectric polyvinylidene fluoride / Li and Ti doped NiO composites. Materials Letters, 61: 511-515.

[29] Mandelis A, Zver M. 1985. Theory of photopyroelectric spectroscopy of solids. J. Appl. Phys. 57, 4421- 4426.

[30] Dadarlat D, J. Gibkes, Bicanic D, Pasca A. 1996. Photopyroelectric

[31] Wang C, Mandelis A, Garcia J. 1999. Pd/PVDF thin film hydrogen. sensor system based on photopyroelectric purely-thermal-wave interference. Sensors and Actuators B 60: 228- 237
[32] Frandas A, Bicanic D.1999. Thermal properties of fruit juices as a function of concentration and temperature determined using the photopyroelectric (PPE) method. J. Sci. Food Agric. 79: 1361-1366.
[33] Frandas A, Paris D, Bissieux C, Chirtoc M, Antoniow J, Egee M. 2000. Classical and photopyroelectric studies of optical and thermophysical properties of starch sheets: dependence on water content and temperature. Appl. Phys. B 71: 69- 75.
[34] Wang C, Mandelis A, Au-Ieong KP. 2001. Physical mechanism of reflectance inversion in hydrogen gas sensor with Pd/PVDF structures. Sensors and Actuators B. 73:100-105.
[35] Chirtoc M, Bentefour E, Glorieux C, Thoen J. 2001. Development of the front-detection photopyroelectric (FPPE) configuration for thermophysical study of glass-forming liquids. Thermochimica Acta 377: 105-112.
[36] M. Abu-Taha, A. Saleh and Y. Sarahneh," Photopyroelectric monitoring of olives ripening conditions and olive oil quality using pulsed wideband IR thermal source", Accepted for publication in Int. J. Mod. Phys. B 2007.
[37] M. I. Abu-Taha, M. M. Abu-Teir, A. J. Al-Jamal and H. Eideh, " Simultaneous photoacoustic and photopyroelectric detection of trace gas emissions from some plant parts and their related essential oils in a combined detection cell "Accepted for publication in Int. J. Mod. Phys. B 2007.
[38] Moeller G, Rigden J. (1966). Observation of laser action in the R-branch of CO2 and N2O vibrational spectra. Applied Physics Letters. 8: 69- 72.
[39] Goldsmith J, Lawler J. 1981. Optogalvanic spectroscopy. Contemporary Physics. 22: 235 – 248.
[40] Suzuki T. 1981. Optogalvanic spectroscopy with rf discharge. Optics Communications. 38:364-368.