Photoacoustic signal generation based on self-oscillation method

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Abstract. In conventional photoacoustic experiments a signal generated by photoacoustic phenomenon is produced by a forced stimulation of the investigated sample by electromagnetic radiation energy (light) which intensity is modulated at a user selected frequency. Resultant photoacoustic signal has the same frequency as the light modulation frequency. The paper presents a new technique of photoacoustic signal generation, based on self-oscillations resulting from a loopback in the signal path consisting of a modulated light source, a photoacoustic chamber, a microphone, and an amplifier. Signal from the amplifier output was used to drive the light source. Gain of the amplifier was chosen in order to obtain total loop gain of the signal path greater than one and positive feedback operation. On contrary to conventional photoacoustic methods, frequency of the photoacoustic signal in the presented self-oscillation method is determined mainly by acoustic properties of the photoacoustic cell, which in the experiments was corresponding to the resonance frequency of the cell. Taking into consideration that resonance frequency of a photoacoustic cell depends on the speed of sound, which is affected by properties of the fluid filling the cell, the method based on self-oscillations can be applied e.g. to quantitative analysis of the investigated substance.

1 Introduction

From the very first photoacoustic experiments reported by Alexander Graham Bell at the end of the 19th century [1], photoacoustic signal has been produced in a similar manner. The main mechanism of photoacoustic phenomenon is well known – if a substance is irradiated with a light that contains wavelengths from the absorption spectrum of the illuminated substance, some of the light energy will be absorbed by the substance and then, due to relaxation, it will be converted into translational energy of the molecules, which in macroscopic scale will be observed as producing heat, leading to a pressure increase. Finally, periodical irradiation of the sample with the light will result with producing periodic pressure changes (sound), that can be then converted into electrical signal by means of a sensitive transducer (e.g. electret or condenser microphone).

The mentioned periodic irradiation can be implemented in many ways, but probably the most common is modulation of the light intensity, that can be also obtained by means of several methods. Bell used a simple mechanical modulator in form of a wheel with number of slots which chopped the light beam. The method, although very simple, gives quite reasonable results, and is still used in many experiments. Certainly, over a century of technological progress has resulted in many other solutions, e.g. electro-optic and acousto-optic modulators, electronically driven LED and semiconductor lasers, etc. [2] However until nowadays, all the reported photoacoustic experiments that are based on periodic light modulation have one thing in common – in all of these experiments modulation frequency is controlled externally to the process of producing the photoacoustic sound.

If the further discussion is limited to photoacoustic experiments that use a single modulation frequency, then the most common approach is based on a fixed modulation frequency (selected usually from a range of a few hundred Hz to a few kHz). Value of the frequency depends mainly on the application (e.g. in the case of some relaxation time measurements, the frequency can be quite low) and the hardware used for the experiments – in particular if a resonance photoacoustic cell is used, then the modulation frequency is usually set equal (or very close) to the resonance frequency of the cell, as use of the acoustic resonance increases overall sensitivity of the setup. As long as the quality factor of the cell is low or moderate, slight deviations from the resonance frequency do not have much influence on the sensitivity and accuracy of the setup. However, when a high Q-factor cell is used, the situation changes significantly. The main problem in such a case is that resonance frequency depends strongly on the sound velocity, which is strongly influenced by chemical composition of the fluid filling the cell, pressure and temperature (e.g. air temperature coefficient of the sound velocity is about 0.18%/°C). As a result, in order to obtain photoacoustic signal stability of ±1%, temperature deviations must be limited to the value smaller than Q/56 [3]. There are several solutions to the problem – e.g. stabilizing of the temperature by means of a thermostat, frequent scanning of the acoustical frequency response of the cell and adjusting the frequency modulation accordingly [4], monitoring current temperature of the cell and setting the modulation frequency to the value calculated from the known dependence of the speed velocity vs. temperature [5], active resonance tracking based on acoustic oscillations at higher eigenmodes [6], etc. It should be noted, however, that all the methods mentioned above are reactive, i.e. they are based on tracking actual conditions of the sample/cell.

2 Description of the method

Instead of setting a tracking method that would control the light modulation frequency and adjust it accordingly to the current conditions in order to obtain possibly greatest amplification of the photoacoustic signal due to acoustic resonance, it is possible to design a photoacoustic setup working in a self-oscillation mode. A similar approach can be found in the field of electronics, where oscillators design is based on proper use of an LC circuit (resonator), an active component (amplifier) and a loopback network. Generation is obtained if the following two conditions are fulfilled: gain factor of the active element greater than losses introduced by the rest of the circuit (total gain of the open loop at the frequency of oscillations must be grater than 1) and positive feedback (negative feedback would damp the oscillations instead of having them amplified).

In the proposed method of photoacoustic signal generation the system is formed from an electrically controlled light source (e.g. an LED or a laser diode), a photoacoustic cell containing the investigated substance, a sound detector converting the photoacoustic response of the cell into electrical signal (e.g. a condenser or electret microphone), and an amplifier that drives the mentioned light source with the amplified signal taken from the microphone output (fig. 1). Signal from the preamplifier can be recorded/measured in a computer-controlled system. Frequency of oscillations of such a photoacoustic setup signal is determined mainly by the resonant frequency of the photoacoustic cell. As a result, as long as the photoacoustic signal produced by the sample is above a threshold level (defined by fulfilling mentioned amplitude and phase conditions) the system working in self-oscillation mode will always work at optimal conditions (with maximum acoustic amplification resulting from the resonance properties of the cell).

3 Experimental results

The described concept of the photoacoustic signal generation based on self-oscillation method was experimentally tested. For this purpose a 50 mW LED diode was used as the light source irradiating a Helmholtz photoacoustic cell (total volume of approx. 2 cm^3) equipped with a small electret microphone, and a self-made microphone preamplifier (gain of approx. 100 000) followed with an LED diode driver.

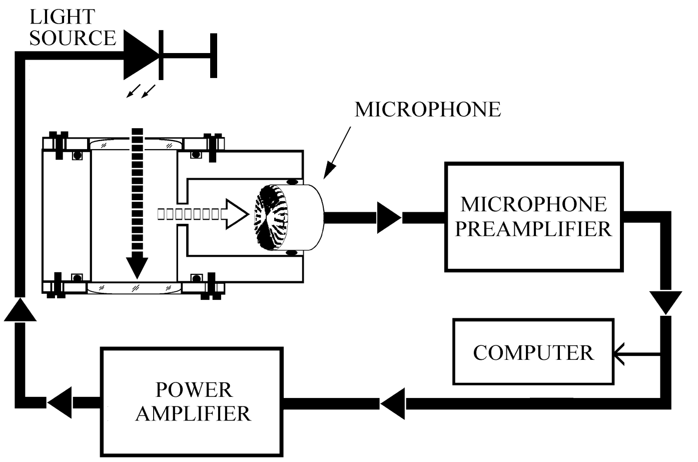

Fig. 1. Schematic diagram of a photoacoustic system in which photoacoustic signal generation is based on the self-oscillation method

Output of the preamplifier was connected to an oscilloscope and a frequency counter (in order to monitor regularity, shape and frequency of the photoacoustic signal induced in the cell).

When the feedback loop was opened, the produced photoacoustic signal was random, while when the feedback loop was closed – strong, stable acoustic oscillations were observed. Frequency of the self-oscillations was about 750 Hz, which was corresponding to the acoustic resonance frequency of the cell.

4 Conclusions

All known reported photoacoustic experiments that use high-Q resonators apply also some mechanisms of temperature stabilizing and/or resonance tracking that adjust light modulation frequency to the momentarily resonance frequency of the cell. Solution presented in the paper relies on a self-oscillation method, that makes such stabilizing/tracking of the temperature and/or other factors that have influence on the sound velocity (which directly affects resonance frequency of the cell) unnecessary. Due to use of a loop consisting of the cell (as a resonating component), an amplifier and a light source working in a positive feedback configuration, the whole setup works as a photoacoustic generator, self-adjusting to the resonance frequency of the cell, and as a result, working all the time at optimal conditions (at the resonance frequency of the cell, resulting in maximum acoustic amplification of the photoacoustic signal). Some preliminary tests proved proper operation of such a system. The method seems to be perfectly suitable for use with high-Q resonators and can be applied e.g. for measurements of the sound velocity of the fluid filling the cell, which can be further used for calculation of thermodynamic parameters of the fluid.

References

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