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SIMULTANEOUS DETECTION OF PHOTOACOUSTIC WAVES IN GAS AND SOLID

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INTRODUCTION

The photoacoustic effect has recently gained increased attention due to its possible application in the calibration of AE transducers (1,2). For this purpose the source mechanism must be well characterised. There are three different physical phenomena contributing to optically generated sound: thermal expansion of the solid, heat diffusion and expansion of the surrounding gas and spallation of the surface which takes place mainly at higher light intensities. Each of these phenomena has been extensively studied separately, but for the complete characterization of the source a common treatment is necessary, which has been less emphasised in the literature (3,4). The purpose of this article is therefore to study simultaneously at low light intensities both the photoacoustic phenomenon in solid materials and in gases.

So far most experiments have been carried out with chopped light by detecting harmonic pressure fluctuations of a gas in a closed transparent cell (3). Fewer experiments have been done on solids utilizing a piezoelectric transducer attached directly to the sample (5). Recently transient techniques using excitations by high intensity laser pulses were introduced (6). This paper presents the simultaneous detection of the photoacoustic phenomenon by a piezoelectric transducer in contact with the solid sample and by a microphone in the gas. Experiments were performed in the open air as well as in the closed cell using relatively weak light pulses. It was observed that the signal in a solid sample is caused by the photoacoustic effect and by wave reflections in the gas cell. The analysis of corresponding signals leads to the identification of the photoacoustic mechanism in the solid and in the gas separately.

EXPERIMENTS

Experiments were carried out on aluminium samples in air and in a closed photoacoustic cell as shown in Figs. 1 and 2. A piezoelectric PZT transducer of resonant frequency 200 KHz, constructed for acoustic emission detection, was attached to the sample. The signal from it was preamplified and then led to a transient recorder - computer - plotter chain. The photoacoustic signal was detected by a wideband microphone placed in front of the specimen in the open air (Fig.1), or mounted in a cell-wall (Fig.2). A stroboscope was applied to generate light pulses of duration 10 µs and of energy density 1 J/m^2. The pulses were monitored by a photodiode. Samples of clean and candleblack covered surfaces were used. Figs.3 and 4 show the simultaneous records of signals obtained from the PZT transducer and microphone by illumination of the free sample corresponding to Fig.1. Both signals are of a compressive character. The PZT signal has a complex structure due to the resonance of the transducer and the sample. Its amplitude is linearly dependent on light intensity(7). The initial part of the microphone signal resembles the shape of the light pulse. It is then followed by a long tail corresponding to a rarefaction wave. Taking into account the response functions of both transducers and applying deconvolution to both signals the source can be completely characterized as will be published elsewhere.

Figs.5 and 6 show the records of PZT and microphone signals detected in a sample in a closed cell (Fig.2). The signals are now composed of sequences of pulses separated for periods corresponding to the double sound transition time of the cell. The microphone signal, being detected on the opposite wall of the sample, is therefore shifted for half of the period with respect to the PZT signal. The first pulse in each sequence is a direct consequence of the photoacoustic phenomenon, while the subsequent pulses are due to reflections of the sound propagating in the cell gas.

Thermoelastic generation and thermal expansion of the adjoining gas contribute to the photoacoustic phenomenon on the solid surface. With respect to these two mechanisms it is of special interest to analyse the structure of the PZT signal. The first pulse of the sequence is the consequence of the complex photoacoustic phenomenon while the subsequent pulses are determined only by pressure fluctuations in the gas. The PZT signal therefore contains information about both mechanisms taking part in the complex photoacoustic phenomenon on the solid surface, and could be applied for estimating their relative strengths. For this purpose the influence of reflection and attenuation should be specified, which is a cumbersome task. Another solution of this problem is to evacuate the cell and thus to eliminate the photoacoustic effect in the gas. Fig.7 shows the amplitudes of the first and the second pulse in the PZT signal, as obtained by demodulation, in their dependence on the air pressure in the cell. With diminishing pressure the first amplitude converges to a non-zero value, corresponding to the contribution of thermoelastic generation in the solid sample. The amplitude of the second pulse converges to zero value corresponding to the elimination of the gas component of the photoacoustic effect. It is important to note that the observed dependence on gas pressure is characteristic of the sample with a highly absorbing surface. The experiments on a clean aluminium surface show no reflections in the cell and no dependence on the pressure.

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CONCLUSIONS

Our experiments have confirmed that the photoacoustic signal in the solid sample is at low light intensities the consequence of two mechanisms acting in the gas and in the solid. Only simultaneous observation of both signals can lead to identification of the complex source mechanism. It is shown that a proper analysis of the PZT signal alone might be applied for this purpose. Work on the corresponding theoretical explanation is now in progress.

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FIGURE CAPTIONS

1. Scheme of experimental arrangement in open air.
2. Scheme of optoacoustic cell and sample
3. Signal from PZT transducer in open air for candleblack covered surface.
4. Signal from microphone in open air
5. Signal from PZT transducer for the sample in the cell.
6. Signal from microphone in the cell.
7. Dependence of amplitude on pressure for 1st. and 2nd. demodulated pulses in the PZT signal.