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Project Summary

An Investigation of Resonant Optoacoustic Cells

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A theory describing the optoacoustic signal is presented; dependence on both cell and gas parameters are given and the advantage of operating at a resonant frequency is discussed.

Three elliptical cells with major axes 5.8, 12.7, and 15.2 cm (corresponding minor axes 5.5, 11.0, and 7.6 cm) were utilized as resonant optoacoustic cells. Longitudinal standing waves and standing waves analagous to radial resonances for a cylindrical cell were driven by passing the beam from a CO_2 laser along one focus of the ellipse. A Knowles electret microphone (model 1754) located at the other focus of the ellipse detected the pressure variations associated with the absorption of laser radiation by the gas.

Plots of optoacoustic signal *vs* frequency are presented for frequencies up to approximately 5500 Hz; several resonances are observed. In order to determine a minimum detectable absorption coefficient, the P(14) line of the 10.6 μm CO_2 band was used to detect absorption by dilute ethylene samples. Plots of optoacoustic signal *vs* concentration are presented for each cell; a minimum detectable absorption coefficient of about 3×10^{-8} cm^{-1} was obtained. Results are compared with measurements on a Helmholtz cell for which the minimum detectable absorption coefficient was about 2×10^{-7} cm^{-1}. Windowless operation was attempted, and the results indicate that further improvement is possible.

This Project Summary was developed by EPA's Environmental Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Over the past several years, there has been an interest in detecting very low concentrations of various pollutants. One method which holds much promise in this area involves the use of laser illuminated optoacoustic cells. These cells can be very sensitive, and extremely selective.

A major advance in optoacoustic detection occurred with the development of lasers. Previously the only available sources of light had been thermal sources for which the output cannot exceed that of an ideal blackbody at the temperature of the source. Lasers made available very intense sources of monochromatic light which were not constrained by the limitations of thermal sources. Lasers were first used in optoacoustics in 1968 and extinction coefficients as low as 1.2×10^{-7} cm^{-1} were measured.

The use of acoustically resonant chambers was reported in 1973. By utilizing standing wave amplification in the sample cell, the signal is greatly increased. The increase in signal is directly proportional to the acoustic quality or Q value of the cell and Q's of up to 1800 have been reported. For simple cylindrical cells a Q value of 900 has been reported. The smallest extinction coefficient that has been detected is 9×10^{-9} cm^{-1} using a longitudinally resonant open cell. Elliptical cells could be more attractive since a lower chopping frequency can be used. [Subsequent to the completion of this work Patel and Tam published an article suggesting the use of an elliptical geometry: Appl. Phys. Lett., 36,7 (1980)]

Results

A carbon dioxide laser operating on the P(14) laser line of the 10.6 μm band was used as the source, and ethylene was used as the sample gas in the elliptical cell since this gas has a strong absorption at the wavelength of the P(14) line. The laser beam traversed the cell along one focus of the ellipse, and the photoacoustic signal was produced by a small electret microphone (Knowles model 1754) placed at the other focus. The beam was modulated with a mechanical chopper, and the frequency was varied to match the various resonant frequencies of the cell. A typical plot of photoacoustic signal *vs* chopping frequency for a cell with a 15.2 cm major axis and a 7.6 minor axis is shown in Figure 1. Most resonances can be identified and are compared with calculated values; for example, the resonance with the lowest frequency results from a standing wave having a wavelength equal twice the major axis. The acoustic quality Q, determined by dividing the resonant frequency by the width at half maximum, is about 240.

Figure 2 shows a plot of signal *vs* concentration for the above cell operating at the lowest resonant frequency with a laser power of 0.24 watts. A small airborne signal emanating from the chopper was detected by the microphone in the cell; this signal was very stable and could be subtracted from the total signal. However, a background signal arising from the windows of the cell was observed; this signal corresponds to a level of about 35 parts per billion of ethylene and tends to cause the signal to be insensitive to concentration changes for low concentrations. By comparing signals from cells with and without ethylene, it was determined that approximately one part per billion could be detected. In an effort to avoid the signal arising from the windows, the windows were removed and the cell was placed in a chamber designed to isolate it from room noise; however, since the meter used to monitor laser power was contained in the chamber and was the source of a small signal, only a small improvement in sensitivity was observed. The sensitivity of the elliptical cell was compared with that of a Helmholtz resonator and found to be greater by a factor of about eight. Improvements in both cells appear feasible through changes in cell design and acoustic isolation.

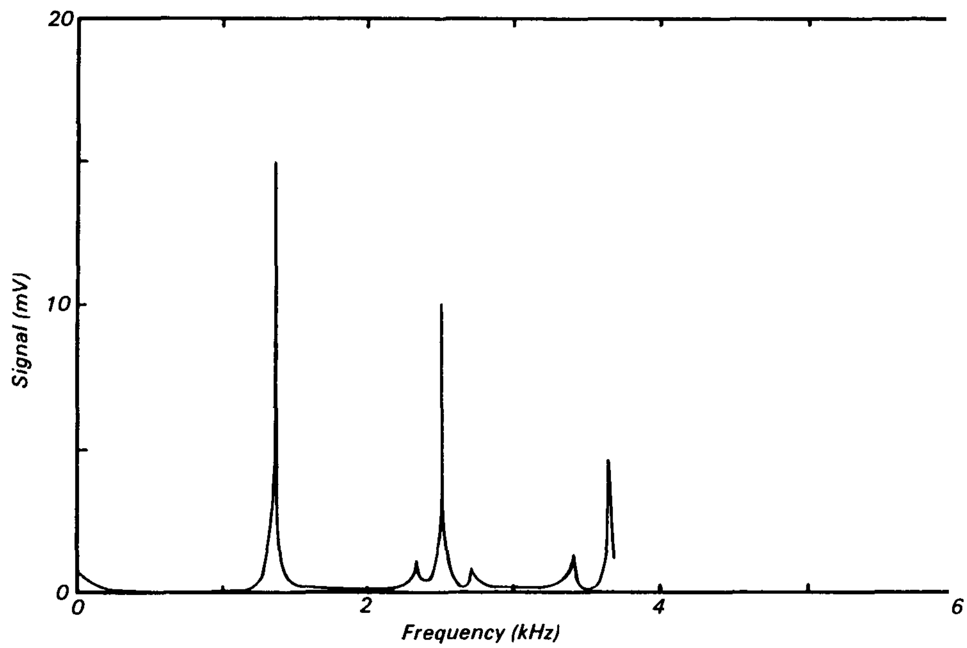

Figure 1. *Plot of signal* vs *frequency for an elliptical cell using* C_2H_4 *in* N_2.

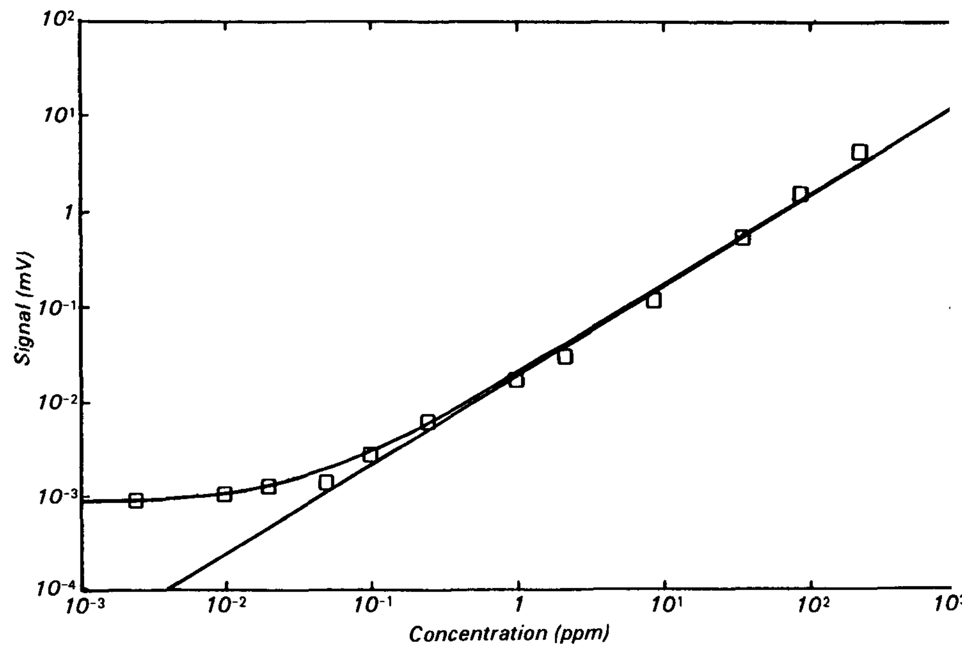

Figure 2. *Plot of signal* vs *concentration of* C_2H_4 *in* N_2 *at lowest resonant frequency.*

Conclusions

The results of this study show that the elliptical cell has promise as an optoacoustic detector for use in detecting low concentration pollutant gases. Using a windowless cell, it has been possible to detect slightly less than one part per billion of ethylene; this corresponds to an extinction coefficient of 2.8×10^{-8} cm^{-1} Although this is somewhat higher than the minimum reported in the literature, improvements can be anticipated by limiting the laser noise (short term power fluctuations) and by removing the laser power meter (a source of background signal) from the chamber that encloses the elliptical cell.

Comparison of the elliptical cell with a Helmholtz resonator indicated that the elliptical cell was a factor of eight more sensitive; improvements in both cells are possible. Although some turbulence may be set up, the combination of a low flow rate and phase sensitive detection would minimize the noise associated with turbulence; thus, a system involving the flow of gas through a chamber containing a windowless cell appears feasible.

Recommendations

Limited further study of resonant optoacoustic cells should be undertaken to include the following:

1. Additional measurements using resonant windowless cells which are better isolated from ambient noise and power measuring devices.
2. Measurements using resonant cells for which the laser beam enters and leaves at a pressure node.
3. Measurements using an annular resonant cell. An annular cell would support a standing wave which would be analagous to a longitudinal standing wave, but the driving radiation would be entirely located at an antinode. There is an additional advantage of low cell volume, and windowless operation is attractive.
4. Additional studies of Helmholtz cells. Various optical arrangements involving two cells could reduce window signals.

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***William A. McClenny** is the EPA Project Officer (see below).*
The complete report, entitled "An Investigation of Resonant Optoacoustic Cells," (Order No. PB 83-251 637; Cost: $8.50, subject to change) will be available only from:
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