

AD-A141 876

OPTICAL GENERATION AND DETECTION OF ACOUSTIC PULSE
PROFILES IN GASES FOR (U) IBM RESEARCH LAB SAN JOSE CA
A C TAM ET AL. 22 MAY 84 RJ-4312 N00014-83-C-0170

1/1

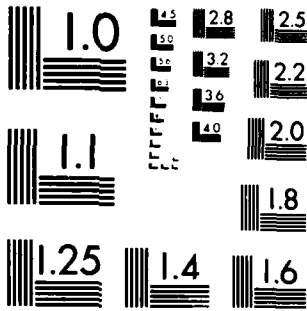
UNCLASSIFIED

F/G 20/6

NI



END
DATE
FORMED
7 84
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A141 876

RJ 4312 (47140) 5/22/84
Physics

12

Research Report

OPTICAL GENERATION AND DETECTION OF ACOUSTIC PULSE PROFILES
IN GASES FOR NOVEL ULTRASONIC ABSORPTION SPECTROSCOPY

A. C. Tam
W. P. Leung

IBM Research Laboratory
San Jose, California 95193

DTIC FILE COPY

DTIC
ELECTE
S JUN 07 1984 D
E

LIMITED DISTRIBUTION NOTICE

This report has been submitted for publication outside of IBM and will probably be copyrighted if accepted for publication. It has been issued as a Research Report for early dissemination of its contents. In view of the transfer of copyright to the outside publisher, its distribution outside of IBM prior to publication should be limited to peer communications and specific requests. After outside publication, requests should be filled only by reprints or legally obtained copies of the article (e.g., payment of royalties).

IBM

Research Division
Yorktown Heights, New York • San Jose, California • Zurich, Switzerland

This document has been approved
for public release and sale; its
distribution is unlimited.

84 06 06 004

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 9	2. GOVT ACCESSION NO. AD.A141876	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Optical Generation and Detection of Acoustic Pulse Profiles In Gases for Novel Ultrasonic Absorption Spectroscopy		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. C. Tam and W. P. Leung		8. CONTRACT OR GRANT NUMBER(s) N00014-83-C-0170
9. PERFORMING ORGANIZATION NAME AND ADDRESS International Business Machines, Corp. 5600 Cottle Road San Jose, CA 95193		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 633-844
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research 800 N. Quincy Street Arlington, VA 22217		12. REPORT DATE 5/22/84
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) This document has been approved for public release and sale; its distribution is unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Submitted for publication in Physical Review Letters		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Pulsed laser application, acoustic spectroscopy, ultrasonic spectroscopy, sound absorption, gas, Fourier Transform, opto-acoustic		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) -- We demonstrate a new all-optical, frequency-multiplexed and fast technique for gas-phase ultrasonic absorption spectroscopy. A pulsed laser produces a short-duration acoustic pulse in the gas sample, and the acoustic pulse profiles at two distances are monitored by focused continuous probe beams. Fourier decompositions of these probe deflection signals provide the absorption spectrum, and examples for CO ₂ and CO ₂ +H ₂ O mixture are given. Ultrasonic propagation speeds in the MHz regime are also obtained for several gases.		

RJ 4312 (47140) 5/22/84
Physics

**OPTICAL GENERATION AND DETECTION OF ACOUSTIC PULSE PROFILES
IN GASES FOR NOVEL ULTRASONIC ABSORPTION SPECTROSCOPY**

A. C. Tam
W. P. Leung*

IBM Research Laboratory
San Jose, California 95193

ABSTRACT: We demonstrate a new all-optical, frequency-multiplexed and fast technique for gas-phase ultrasonic absorption spectroscopy. A pulsed laser produces a short-duration acoustic pulse in the gas sample, and the acoustic pulse profiles at two distances are monitored by focused continuous probe beams. Fourier decompositions of these probe deflection signals provide the absorption spectrum, and examples for CO₂ and CO₂+H₂O mixture are given. Ultrasonic propagation speeds in the MHz regime are also obtained for several gases.

*Present and Permanent Address: Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	



Conventional acoustic absorption spectroscopy¹⁻⁵ in gases has been performed using transducers such as quartz plates, microphones, *etc.* The use of transducers for gases causes several limitations. The frequency response is usually limited to ≤ 1 MHz. Also, the frequencies are scanned point by point, and is thus slow and unsuitable for transient conditions. Short-pulsed measurements are difficult because of transducer ringing. Furthermore, transducers cannot be used in hostile environments like flames. We describe here a new all-optical, pulsed and multiplexed technique that avoids the above limitations, and is useful for acoustic absorption spectroscopy of gases. This technique relies on the use of a short-duration laser pulse to generate reliably a narrow acoustic pulse containing a broad Fourier frequency spectrum; as this pulse propagates, the various Fourier components are absorbed differently, resulting in pulse distortion that is probed by a focused CW laser beam. Fast Fourier transform of the transient probe deflection signal provides the acoustic absorption spectrum; this is much faster than the conventional point-wise frequency measurement. Our technique can be called "Opto-acoustic spectroscopy of the second kind" (OAS II) because it exploits opto-acoustic pulse generation⁶⁻⁸ for *acoustic* spectroscopy. This should be distinguished from the well known opto-acoustic spectroscopy⁹ (understood to be the first kind), which exploits opto-acoustic pulse generation for *optical* spectroscopy.

Our experimental demonstration of OAS II is shown in Fig. 1. A pulsed laser is used to generate a short-duration acoustic pulse in the gas under study. This is commonly called a pulsed opto-acoustic (or photo-acoustic) generation⁶ which can be achieved via many mechanisms, including simple optical absorptions and nonradiative decay,⁹ optical breakdown¹⁰ and absorption at a solid surface with subsequent heat

flow to the fluid in contact.¹¹ The experimental arrangement in Fig. 1 uses the last mechanism, which does not require powerful or tunable laser source, but requires an opaque target surface to be placed in contact with the gas. Here, we use a nitrogen laser beam at 337 nm with 1 mJ energy and 8 nsec duration as the pulsed excitation source. The target is a polished silicon wafer which does not absorb the gases under study, and the optically flat surface produces a plane acoustic wavefront due to the pulsed laser heating of the Si surface. The laser spot size at the silicon surface is about 4 mm, which is much larger than the acoustic wavelengths (~ 0.3 mm at 1 MHz) in the gas presently studied, and diffraction effect of the acoustic pulse is small. The profile and the propagation velocity of the acoustic pulse can be detected with short rise-time and high spatial resolution by a tightly focused probe beam⁷ which is oriented parallel to the silicon surface (at separation x). In this way, the whole acoustic wavefront arrives simultaneously at the focused probe beam, causing a transient angular deflection $\phi(t)$ which is uniform across the probe cross section if the spatial extent of the acoustic pulse is much larger than the focused probe diameter (true for our present experiment). The probe deflection $\phi(t)$ is linearly converted into an intensity variation signal $S(x,t)$ by a fast photodiode of small active area located where the probe beam cross-sectional area is much larger. The photodiode and preamp assembly we used (Analogy Modules Model LNVA-O-S-100 MHz) has a bandwidth of 100 MHz. The output signal $S(x,t)$ is further amplified by a Tektronix 7854 scope with a 7A24 plug-in (which also provides a single-shot display of $S(x,t)$), and then accumulated on a transient recorder (Data Precision Model 6000 with Model 620 plug-in of bandwidth 30 MHz). Typically, $S(x,t)$ can be digitized for a single laser shot, or averaged for several laser shots for signal/noise improvement. A built-in fast Fourier transform feature in the transient recorder allows us to obtain the

Fourier spectrum $\tilde{S}(x,\omega)$ of the probe beam deflection signal $S(x,t)$, where ω is an angular frequency. The above measurement is repeated with the separation between the probe beam and the silicon target changed (by a micrometer adjustment) from x to x' , obtaining another Fourier spectrum $\tilde{S}(x',\omega)$ corresponding to the probe beam deflection signal $S(x',t)$. This stepwise measurement at two separations is presently used to derive the ultrasonic absorption spectrum. A much faster measurement is possible by using two probe beams¹² at separations x and x' from the target surface for single-shot detection of the deflections.

As described in a recent opto-acoustic pulse profile study in liquids,⁷ the present probe-beam deflection signal $S(x,t)$ is related to the local acoustic pressure $P(x,t)$ (with Fourier transform $\tilde{P}(x,\omega)$) by

$$S(x,t) = K \partial P(x,t) / \partial t \quad (1)$$

where K is a constant depending on geometry, physical properties of the gas and detection sensitivity. Fourier transform of Eq. (1) yields

$$\tilde{S}(x,\omega) = Ki\omega \tilde{P}(x,\omega) \quad (2)$$

where i is the imaginary unit. The pressure amplitude $\tilde{P}(x,\omega)$ propagates with a frequency-dependent absorption coefficient $\alpha(\omega)$ and velocity $v(\omega)$, and so we write

$$\tilde{P}(x,\omega) = \tilde{P}(0,\omega) e^{-\alpha(\omega)x + i\omega x/v(\omega)} \quad (3)$$

Combining Eqs. (1)-(3), we have

$$\frac{\partial \ln[\text{Mag}\tilde{S}(x,\omega)]}{\partial x} = -\alpha(\omega) \quad (4)$$

where $\text{Mag}(\tilde{S}(x,\omega))$ is the magnitude of the Fourier transform of the observed probe deflection signal.

The signal $S(x,t)$ is as given by Eq. (1) only for a sufficiently small size of the detector in the direction of beam deflection, *e.g.*, this size should be $\leq 10\%$ of the diameter of the probe beam at the detector position. In such case, the magnitude and shape of the signal $S(x,t)$ critically depends on the exact position of the detector; $S(x,t)$ actually changes phase if the detector is moved along the direction of the beam deflection, and is nearly zero when it is located at the center of the probe beam cross-section, as shown in Fig. 2. Most of our experimental data are taken with the detector suitably located at a wing of the probe beam to maximize signal amplitude.

The delay time t_d with respect to the firing of the laser indicated in Fig. 2 is measured for several path lengths x for several gases at 22°C . We find that x changes linearly with t_d , and the gradient is the velocity v at the mean Fourier frequency f_m of the acoustic pulse. Some results are given in Table I. For the gases studied at 1 atmosphere and 22°C (Ar, N₂, O₂, CO₂, CF₂Cl₂, (*i.e.*, Freon 12) and their mixture with 20 Torr of water vapor), f_m is ~ 1 MHz, which is larger than the dispersive frequencies in the gases studied (except mixture of CO₂ or Freon with H₂O), so that the data in Table I are the ultrasonic velocities in the "high frequency limits."

While the observed signals $S(x,t)$ for Ar, N₂, O₂ or their mixtures with water vapor do not change significantly when x is changed by ~ 1 mm, we observe that $S(x,t)$ for the CO₂+20 Torr H₂O mixture changes drastically with x , as shown in Fig. 3. As given by Eq. (4), the Fourier transforms of the signals exemplified in Fig. 4 for at least two displacements x provide the ultrasonic absorption spectrum $\alpha(\omega)$. Some

results for CO_2 and CO_2+20 Torr H_2O mixture at 22°C and 1 atm pressure are given in Fig. 5. As done traditionally, the vertical axis is absorption per wavelength, *i.e.*, the product of $\alpha(\omega)$ and the wavelength $2\pi v/\omega$. Our results in Fig. 5 represent the first ultrasonic absorption spectra obtained all optically in a Fourier-multiplexed manner. Previous results were obtained by point-wise frequency measurement with the use of transducers for generation and detection; the long risetimes of most transducers is a reason why high frequency data are lacking in Fig. 5. It is already well known^{1,2} that "relaxational absorption" of sound at frequency ω occurs for an inelastic collisional rate on the order of ω ; this is probably the reason for the large absorption feature for the CO_2 and H_2O mixture in the range of ~ 1 to 5 MHz. The inelastic cross-section for H_2O and CO_2 collision is unusually large (close to geometrical cross-section), and the inelastic collisional rate for the $\text{CO}_2/\text{H}_2\text{O}$ mixture studied is $\sim 10^7$ per sec. Such relaxational ultrasonic absorption at lower H_2O concentration (corresponding to lower frequency absorption) has been observed previously.^{13,14,20}

This work is supported in part by the Office of Naval Research. We are indebted to H. Coufal for very helpful discussions.

Table 1

Some Ultrasonic Velocities in Gases at 1 atm and 22°C,
Measured by Optical Acoustic Pulse Generation and Detection

Gas	Pure Gas		Gas + 20 Torr H ₂ O	
	Mean Frequency (MHz)	Acoustic Velocity (10 ⁴ cm/s)	Mean Frequency (MHz)	Acoustic Velocity (10 ⁴ cm/s)
Ar	2.5	3.218(3)	1.5	3.240(8)
N ₂	2.5	3.512(5)	1.5	3.526(6)
O ₂	2.5	3.295(5)	1.5	3.312(5)
CF ₂ Cl ₂	0.7	1.504(10)	0.7	1.524(10)
CO ₂	2.5	2.796(3)	1.0	2.752(6)

REFERENCES

1. R. B. Lindsay, "Relaxation Processes in Sound Propagation," in *Physical Acoustics* (edited by W. P. Mason and R. N. Thurston), Vol. 16, p. 1 (Academic, New York, 1982).
2. K. F. Herzfeld and T. A. Litovitz, "Absorption and Dispersion of Ultrasonic Waves" (Academic, New York, 1959).
3. C. R. Petts and H. K. Wickramasinghe, *Electronics Lett.* 16, 9 (1980).
4. A. J. Zuckerwar and R. W. Meredith, *J. Acoust. Soc. Am.* 71, 67 (1982).
5. H. E. Bass, F. D. Shields and W. D. Breshears, *J. Chem. Phys.* 79, 5733 (1983).
6. A. C. Tam and H. Coufal, *J. de Physique (Paris) Colloque C6*, 9 (1983).
7. B. Sullivan and A. C. Tam, *J. Acoust. Soc. Am.* 75, 437 (1984).
8. M. K. Sigrist and F. K. Kneubuhl, *J. Acoust. Soc. Am.* 64, 1652 (1978).
9. C. K. N. Patel and A. C. Tam, *Rev. Mod. Phys.* 53, 517 (1981).
10. A. C. Tam, W. Zapka, K. Chiang and W. Imaino, *Appl. Opt.* 21, 69 (1982).
11. G. C. Westel, Jr., S. A. Stotts and C. G. Clark, *J. de Physique (Paris) Colloque C6*, 67 (1983).
12. W. Zapka, P. Pokrowsky and A. C. Tam, *Opt. Lett.* 7, 477 (1981).
13. F. D. Shields, *J. Acoust. Soc. Am.* 47, 1262 (1969).
14. Yu A. Bashlachev and A. Kerimov, *Sov. Phys. Acoustics* 18, 257 (1972).
15. F. D. Shields, *J. Acoust. Soc. Am.* 29, 450 (1957).
16. W. H. Pielemeier, H. L. Saxton and D. Telfair, *J. Chem. Phys.* 8, 106 (1940).
17. W. H. Pielemeier, *J. Acoust. Soc. Am.* 15, 22 (1943).
18. F. A. Angona, *J. Acoust. Soc. Am.* 25, 1116 (1953).
19. J. W. Lewis and K. P. Lee, *J. Acoust. Soc. Am.* 38, 813 (1965).
20. V. O. Knudson and E. J. Fricke, *J. Acoust. Soc. Am.* 12, 255 (1940).

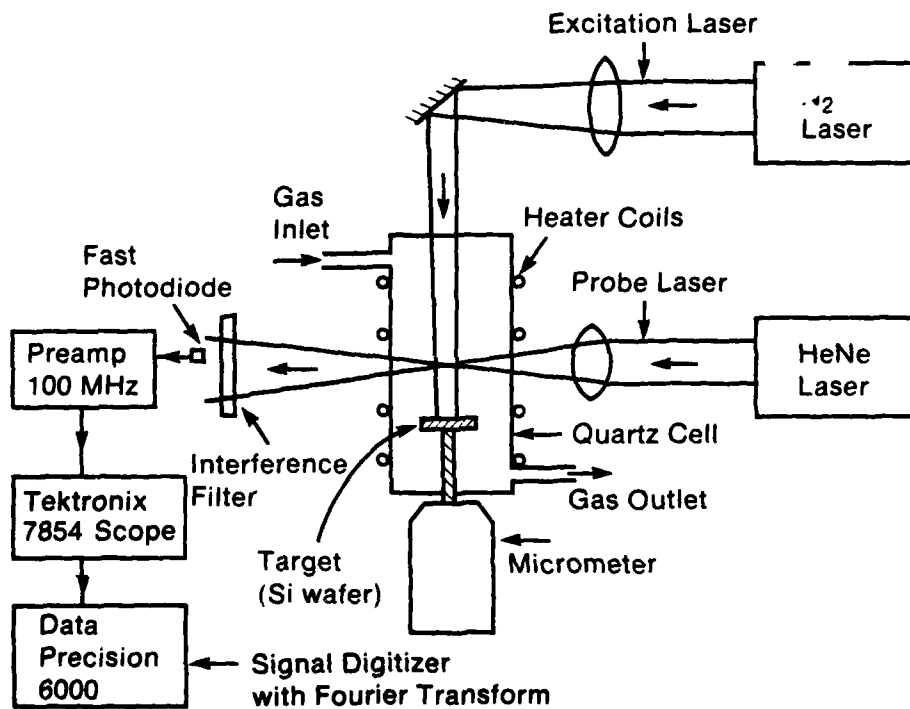


Figure 1. Experimental arrangement for the new opto-acoustic spectroscopy of the second kind. The probe deflection signal is Fourier analyzed, and the difference between two Fourier spectra at different displacements x provide the ultrasonic absorption spectrum.

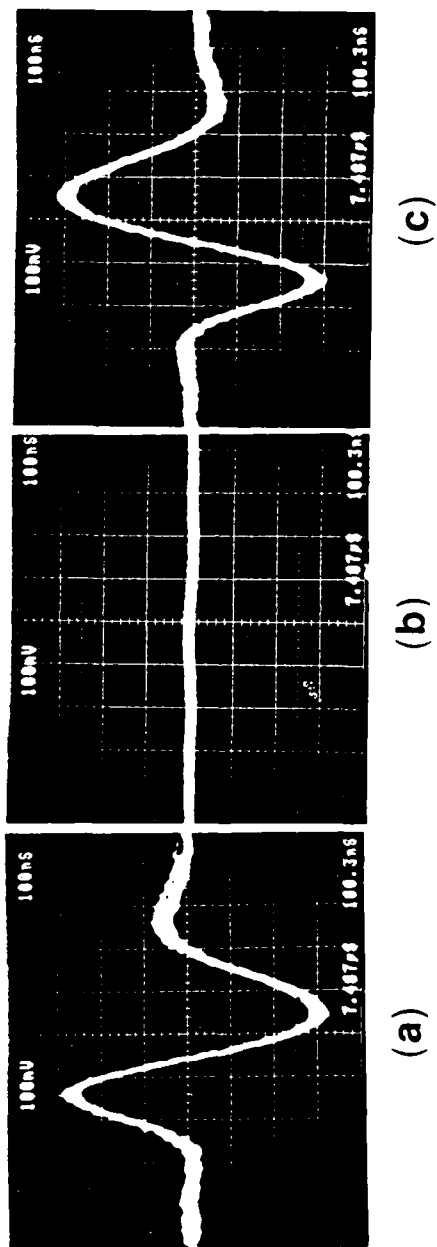


Figure 2. Observed probe deflection signal $S(x,t)$ for dry N_2 at 22°C and $x=2.7$ mm. The photo-diode is located at one wing, at center and at the other wing of the probe beam cross-section for (a), (b) and (c), respectively. Each scope picture is delayed by $7.487 \mu\text{s}$ from the laser pulse, and horizontal scale is 100 ns/division.

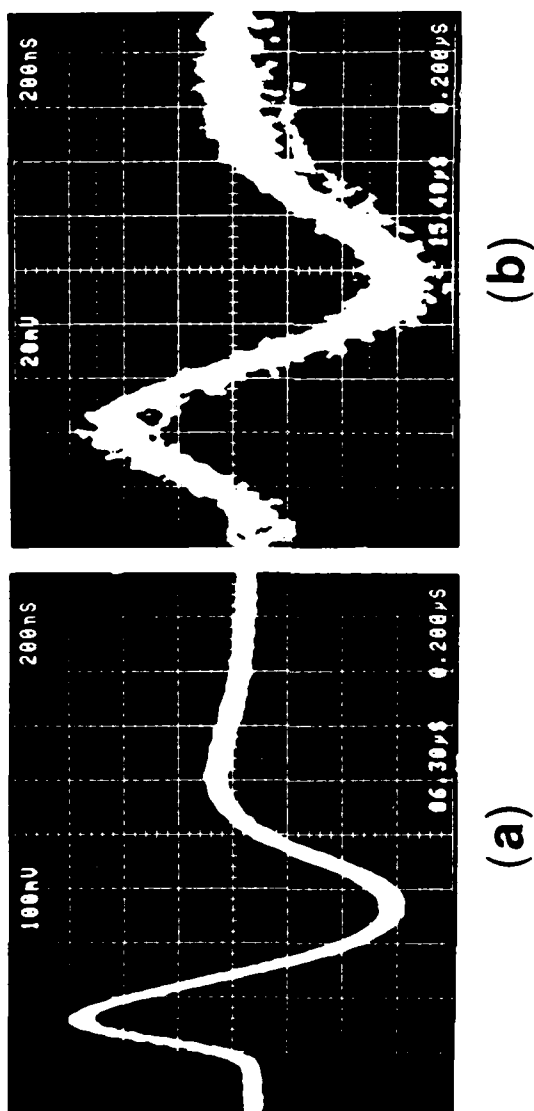


Figure 3. Observed probe deflection signal $S(x,t)$ for $\text{CO}_2 + 20$ Torr H_2O at 1 atm total pressure and 22°C . In (a), $x = 1.816$ mm and scope delay time is $6.30 \mu\text{s}$; in (b), $x = 4.356$ mm and scope delay time is $15.40 \mu\text{s}$. Horizontal scale is 200 ns/division for both.

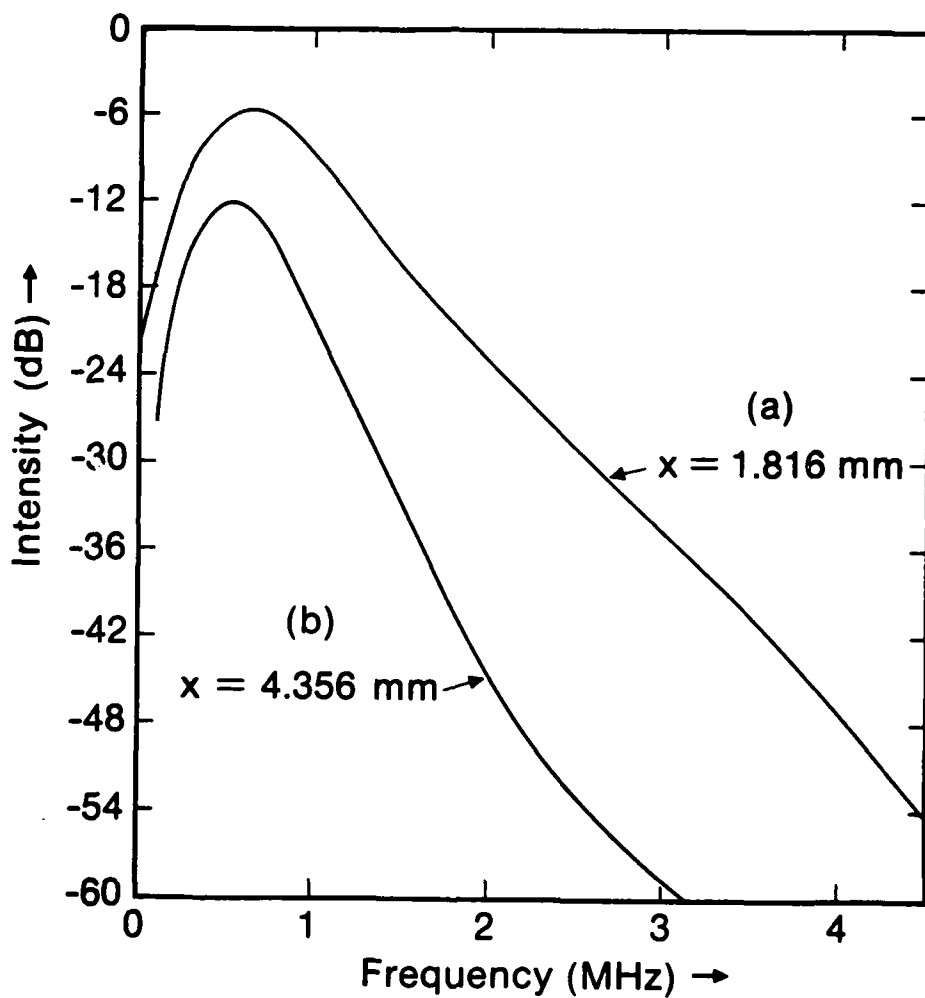


Figure 4. Magnitude of the fourier transform of signals in Fig. 3 as provided by the Data Precision 6000.

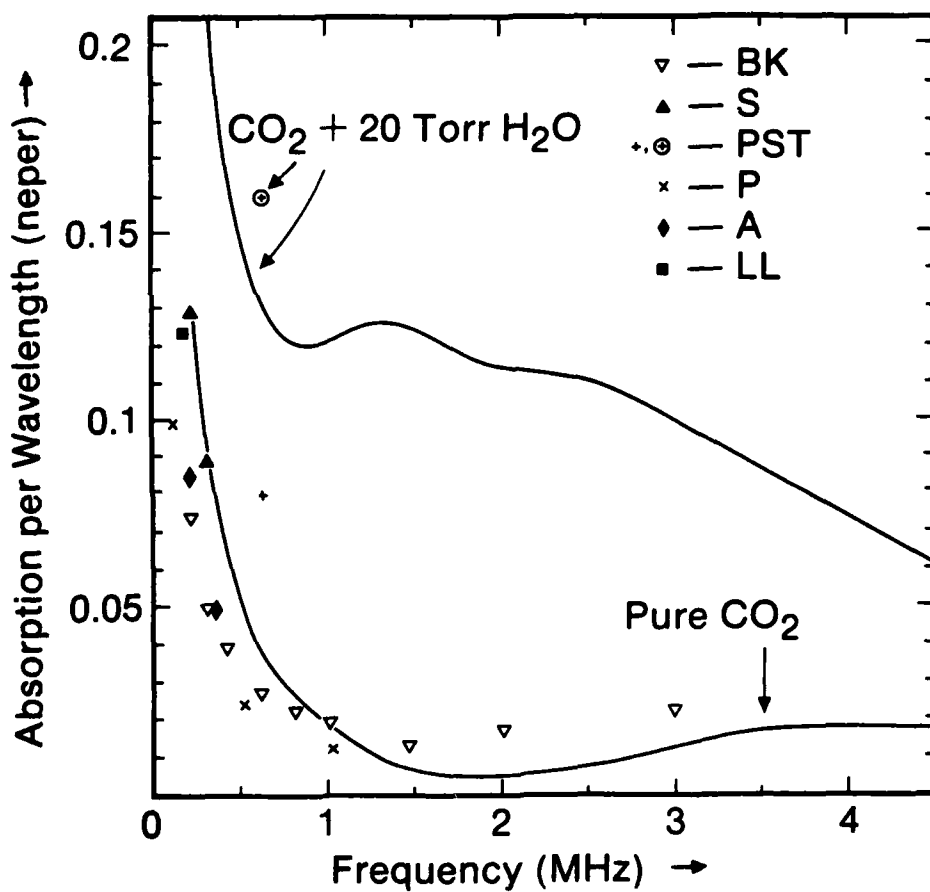


Figure 5. Ultrasonic absorption spectra derived by the use of Eq. (4) for pure CO₂, and for CO₂+20 Torr H₂O at 22°C and 1 atm total pressure. Previous data for comparison are: BK (Ref. 14), S (Ref. 15), PST (Ref. 16), P (Ref. 17), A (Ref. 18), LL (Ref. 19). Most of these previous data are for pure or nearly pure CO₂, except for one indicated data point.

DL/413/83/01
GEN/413-2

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	<u>No. Copies</u>		<u>No. Copies</u>
Office of Naval Research Attn: Code 413 800 N. Quincy Street Arlington, Virginia 22217	2	Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	1
ONR Pasadena Detachment Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1	Naval Weapons Center Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1	Dean William Tolles Naval Postgraduate School Monterey, California 93940	1
Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12	Mr. Vincent Schaper DTNSRDC Code 2830 Annapolis, Maryland 21402	1
DTNSRDC Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1	Mr. A. M. Anzalone Administrative Librarian PLASTE/ARRADCOM Bldg 3401 Dover, New Jersey 07801	1

DL/413/83/01
633/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 633

Dr. Henry Freiser
Chemistry Department
University of Arizona
Tucson, Arizona 85721

Dr. Gregory D. Botsaris
Department of Chemical Engineering
Tufts University
Medford, Massachusetts 02155

Dr. J. H. Hargis
Department of Chemistry
Auburn University
Auburn, Alabama 36849

~~Dr. Andrew Tam
IBM San Jose
5600 Cottle Road
San Jose, California 95193~~

Dr. Timothy L. Rose
EIC Laboratories, Inc.
111 Chapel Street
Newton, Massachusetts 02158

Dr. Lynn Jarvis
Code 6170
Naval Research Laboratory
Washington, D.C. 20375

Dr. Richard Hollins
Code 385
Naval Weapons Center
China Lake, California 93555

Dr. Christie G. Enke
Department of Chemistry
Michigan State University
East Lansing, Michigan 48824

Dr. Ronald S. Sheinson
Code 6180
Naval Research Laboratory
Washington, D.C. 20375

Dr. Edward J. Poziomek
Chief, Research Division
Chemical Research and
Development Center
ATTN: DRDAR-CLB
Aberdeen Proving Ground, MD 21010

**OFFICE OF NAVAL RESEARCH
Contract N00014-83-C-0170
Task No. 633-844**

TECHNICAL REPORT No. 9

**Optical Generation and Detection of Acoustic Pulse Profiles
In Gases for Novel Ultrasonic Absorption Spectroscopy**

by

**A. C. Tam
W. P. Leung**

**IBM Research Laboratory
San Jose, California 95193**

**Reproduction in whole or in part is permitted for
any purpose of the United States Government**

**This document has been approved for public
release and sale, its distribution is unlimited**