Study of Optical Sound Generation and Amplification

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This project involves four separate tasks with the following titles: Task I Generation of low frequency sound from optical pulses. Task II Propagation of sound through a gas with an overpopulation of vibrationally excited states, Task III Opto-acoustic studies in liquids and Task IV Non linear oscillation of gas bubbles. The first three tasks funded by the physics division of ONR represent a three pronged study of the generation of sound by the absorption of light. The fourth task, funded by the mathematics division of ONR is a continuing study of cavitation in liquids.
Study of Optical Sound Generation and Amplification
Annual Report
1 January 1984 - 31 October 1984

by

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General Comments

During the period covered by this contract, the Physical Acoustics Research Laboratory has awarded one Ph.D., one student has completed all requirements for the Ph.D., and two students should complete all requirements by the end of this year. This will leave the laboratory with three Ph.D. candidates and four M.S. candidates. Two Ph.D. students and one M.S. student are not U.S. citizens. All our present Ph.D. students have accepted jobs upon graduation or, in the case of two foreign students, will return to their home institution.

Plans to move the Physical Acoustics Research Laboratory into a renovated space large enough to house all projects is preceding slowly. Estimates of renovation costs exceed $800,000. Funds of that magnitude have not been identified.
Task 1

Generation of Low Frequency Sound from Optical Pulses

H.E. Bass

The objective of this task is to generate audible frequency sound from a series of short optical pulses modulated in time and amplitude.

The pulsed spectrophone work is near completion. The study of pressure pulse generation in a nearly transparent gas ($CO_2$) has been published (see attachment). Measurements of pressure pulse generation in a highly absorbing gas ($SF_6$) are near completion and will serve as the basis for Mr. Manaf Ali's Ph.D. dissertation ("Aug. 85). Highly absorbing $SF_6$ more nearly simulates an absorbing fluid or black surface than does $CO_2$. A large optical attenuation coefficient does complicate measurements as outlined in the $CO_2$ paper.

While the mechanism for pressure pulse generation is being studied in gases, we are simultaneously pursuing modulation schemes to produce audible sound. This summer, Dr. Dwynn LaFleur, a visiting professor, used a broad band dielectric speaker driven with short pulses of variable repetition rates and amplitudes to examine audible sound generation schemes. Mr. Ali is now putting together a circuit to modulate the output of a high power strobe lamp using Dr. LaFleur's modulation scheme.
Task II

Propagation of Sound Through a Gas with an Overpopulation of Vibrationally Excited States

F. Douglas Shields

Theoretical studies by Bass and Bauer showed some years ago that a sound wave should be amplified upon passage through a gas with an over population of vibrationally excited states. This task seeks to study this phenomenon (SACER) in a situation that is amenable to experimental measurement i.e. a gas in a metastable excited state that is decaying slowly on the scale of the sound period.

During the past year measurements have been made on N₂ and mixtures of N₂ with He and H₂. The N₂ is vibrationally excited by an electric discharge. Due to a large collision cross section the electron-molecule collisions in the discharge cause 90% or more of the discharge energy to be deposited in the vibrational mode of N₂. As a result the N₂ is left with vibrational temperatures in the thousands of degrees while the translational temperature is changed very little.

By terminating the electric discharge on a screen a short distance from the end of the discharge tube, a shock wave is generated at the hot/cold gas junction at the screen. The wave reflects back and forth in the tube and is detected and Fourier analyzed at the end of each round trip. By performing this analysis for different lengths of the discharge (and therefore the sound path) it is possible to get both the sound absorption and sound velocity as a function of frequency.
During the past year this technique has been perfected to the point that we can now use the measured sound velocity to determine the variation of translational temperature of the gas with time after the discharge.

With pure N₂ it has been observed that the discharge changes the temperature very slightly. This discovery was at first a surprise but is now understood. In pure N₂ not enough of the discharge energy gets into translation to produce an observable initial change in translational temperature and the vibrational energy is relaxing so slowly it is being conducted to the walls without raising the translational temperature.

When He or H₂ are added to the N₂, initial increase in translational temperature is observed due evidently to the fact that the He and H₂ cause more of the discharge energy to go directly into translation. We are now studying the decay of this translational temperature in an effort to extract the vibrational relaxation time and the thermal diffusion time.

Even more exciting, we have now observed and measured the gain in the sound amplitude produced by the relaxing vibrational specific heat. In fact we are also measuring this gain as a function of time and hope to get a consistent measurement of the vibrational relaxation time from this also.

At present we are planning on trying to make measurements on N₂/H₂O mixtures. If successful these measurements would give a much needed value of the temperature dependence of the H₂O/N₂ transition rate.

CO is similar to N₂ in that an electric discharge will also leave
it highly vibrationally excited. However, since CO has a dipole moment it will be possible to observe the variation in vibrational temperature by the radiation from the excited vibrational states. Therefore, we will try to make measurements on this gas next. If it is possible to measure the gain and vibrational temperature simultaneously we will be able to get an accurate test of the theoretical equations reported earlier.
Task 3
Opto-Acoustic Studies of Liquids
H.E. Bass

The goal of this task is to identify the microscopic mechanism for pressure pulse generation when a liquid absorbs a laser pulse. This work is similar to the spectrophone studies in the gas phase except on a much shorter time scale consistent with the shorter time between interactions characteristic of liquids.

Our initial goal is to reproduce the recent work by Tam of IBM. He subjected a liquid to a pulse from a \( \text{N}_2 \) laser with a pulse length \( 
\frac{1}{1} \) nsec and observed structural relaxation. His electronics limited resolution to a few nsec. Though we now have electronics capable of resolution to 50 psec, we will initially restrict our attention to the 1-100 nsec time regime. In this time regime, we will examine the effect of laser power density on the amplitude of the observed pressure pulse. If Tam was observing structural relaxation, we would expect to see step-like behavior as the laser pulse energy becomes sufficient to detach one, two, three, etc. molecules from the cluster. Macroscopically, this would be seen as a non-linear behavior of the thermal expansion coefficient and corresponding improved optical to acoustic conversion efficiency.

The \( \text{N}_2 \) laser, high speed oscilloscope, probe laser, and optical table have arrived. The high speed (50 GHz) photo-detector was received in August but tests showed that the fiber-optic pigtail was detached from the photo-diode. The assembly has been returned to the manufacturer for repair and recalibration.
Task 4

Nonlinear Oscillation of Gas Bubbles

L.A. Crum

The goal of this task is to examine the dynamics of gas bubble oscillations at large driving amplitudes.

We are pleased to report a dramatic breakthrough. Our consultant theoretician, Andrea Prosperetti, has discovered a mathematical way to describe the bubble oscillations exactly (actually, the approximations made are very good). In order to obtain useable solutions, however, we must numerically solve a set of three coupled equations (2DE's and 1 PDE). We made a crude attempt this fall to obtain a computer code to give us some initial results, and have found them both exciting and troublesome. Exciting because the results indicate that much higher pressures and temperatures are present within the bubble than we had expected; troublesome because the results are not stable, having long transients in them, and so we may have been generating a lot of nonsense. Unfortunately, to write a precise code will take a couple of months, and although we have started work immediately, are disappointed.

We anticipate a flurry of publications once the numerical results are available; however, we now must wait until we are sure of the numbers.
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G.M. Hansen, "Mie-scattering as a Technique for the Sizing of Air Bubbles," Applied Optics, Co-sponsored by the National Science Foundation.
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HONORS/AWARDS/PRIZES

Mr. Anthony Atchley has been unofficially notified that he will be offered the prestigious Hunt Fellowship in Acoustics for 1985-86.
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