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6. AUTHOR(S)

Julian D. Maynard

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Pennsylvania State University
Department of Physics
104 Davey Lab
University Park, PA 16802

8. PERFORMING ORGANIZATION REPORT NUMBER

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The goals of this project involve the use of innovative acoustic techniques to study new materials and new developments in solid state physics. Major accomplishments include a) the publication of two book chapters and three papers, including one in the prestigious journal Appl. Phys. Lett. on the measurement of the elastic constants of titanium diboride using resonant ultrasound spectroscopy (RUS); b) the successful completion of the Ph.D. degree for Philip S. Spoor and the distribution of his thesis as a technical report; c) the completion of preliminary calculations and experiments in the application of RUS for studying thin films; and d) a significant enhancement of the liquid coalescence experiment, providing new and interesting results.

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INNOVATIVE TECHNIQUES FOR STUDYING NEW MATERIALS AND NEW DEVELOPMENTS IN SOLID STATE PHYSICS

This annual summary report presents the accomplishments for ONR grant N00014-92-J-1186,"Innovative Acoustic Techniques for Studying New Materials and New Developments in Solid State Physics". Accomplishments include the publication of two book chapters and three papers, including one in the prestigious journal Appl. Phys. Lett. Graduate student Philip S. Spoor completed his Ph.D. degree and produced a thesis containing very useful information on the application of resonant ultrasound spectroscopy (RUS); this thesis is being distributed to the RUS community as an ONR technical report. Preliminary calculations and experiments have been undertaken to explore the application of RUS in the study of thin films; several physicist in the field of nanoscale systems at Penn State have expressed an interest in using RUS to characterize their films. A major improvement was made in the liquid coalescence experiment, and subsequent data suggests that significant results may be obtained as more of the hydrodynamic parameter space is explored. In the fracture experiment it was determined that many more channels of data acquisition were necessary for large samples; specialized electronic circuits were designed, fabricated, and successfully tested, and are in the process of being commercially produced in quantity for use in both the fracture data acquisition system and the imaging system for the liquid coalescence experiment.

Papers, Talks, etc.

Progress with respect to papers, etc. includes the publication of a paper in Appl. Phys. Lett. describing P. S. Spoor's measurement of the elastic constants of titanium diboride, a material whose hardness (nearly as hard as diamond) and high electrical conductivity make it useful in many technological applications. Two book chapters, entitled "Phonons in Crystals, Quasicrystals, and Anderson Localization" and "Acoustic Holography", were published in the *Encyclopedia of Acoustics.* Two additional refereed papers were published as international conference proceedings in the Czech. J. Phys. Precise references for the published papers are provided in the appendix. A paper on wave propagation in periodic, random, and quasicrystalline media, with a tutorial on Anderson localization, has been submitted to the J. Acoust. Soc. Am. as a Tutorial Review. As already mentioned, P. S. Spoor's Ph.D. thesis, *Elastic Properties of Novel Materials using PVDF Film and Resonant Ultrasound Spectroscopy,* was redrafted (with considerable effort) into a more compact format, for distribution as a ONR technical report. Spoor now holds a postdoctoral position at the Los Alamos National Laboratory, working under Gregory Swift. A draft of a paper on the use of a resonant photoacoustic method to establish the lowest measured optical absorption coefficient is currently undergoing revision; this paper will be submitted to Phys. Rev. Lett.

Five contributed papers were presented at meetings, and eight invited lectures were given, including several colloquia at prestigious universities, a plenary lecture at an international meeting on acoustical imaging, and a lecture series at a summer school on nonlinear science.

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During the past year the total research group has consisted of four graduate students (some with only partial ONR support) and two postdocs (currently there is only one); a number of outstanding undergraduates have made significant contributions to our research. A list of the publications, personnel, etc. is presented in the appendix.

In the sections which follow, a brief summary of the research accomplishments will be presented.

Thin film characterization using resonant ultrasound spectroscopy

With the development of mesoscopic and nanoscale electronic systems, there is currently great interest in the properties of the thin films which form the environment for the electrons. Diamond-like carbon films have also attracted attention for use as a protective coating against physical damage to delicate electronic components. As with bulk solids, important properties include elastic constants and acoustic attenuation, which may be related to the electron-lattice coupling and magnetic effects. Existing methods to determine these properties yield inaccurate results because they are mostly based on the measurement of displacement in response to an applied force, a quantity not as readily measurable as frequency. Examples include the bulge test, where a differential gas pressure is applied to a film attached across a hole in a rigid plate and the deflection of the film due to the pressure is measured with laser interferometry. The uniaxial tension test is another force/displacement method commonly used to obtain Young's modulus by placing a free-standing film in a tensile tester. The nanoindentation technique has the advantage that the film can be tested while remaining on the substrate; a diamond-tipped stylus is pressed into the surface of the film and the load-deflection curve is measured, yielding an indication of the hardness of the film coating. One technique that has overcome the unreliability of deflection measurements involves the use of Brillouin scattering, which measures the photon-phonon interaction in a film. Although accurate, Brillouin scattering requires the availability of high-quality surfaces for measurement. Surface Acoustic Waves (SAW) have been used to probe the properties of thin films, but with limitations since SAW cannot excite every elastic mode of the film, a limitation that can be overcome with Resonant Ultrasound Spectroscopy (RUS). With the ability to perform RUS measurements on samples as small as tens of micrograms, the possibility of probing thin films is being pursued.

In order to detect the properties of a thin film, it is necessary that the substrate supporting the film not dominate the measurement. Assuming a RUS measurement reproducibility of a part in 10^4, numerical estimates have shown that a film of 100 nm on a 100 μm substrate could be studied. The numerical studies were done using a modified version of Visscher's sandwich problem in which a rectangular parallelepiped sample has an elastic tensor discontinuity in one direction. Because more than plate modes would be needed to determine all of the elastic constants and associated attenuation, the lateral dimensions of the substrate would also have to be small.

Using 9 micron thick piezoelectric film transducers in RUS, we are testing silicon substrates having sizes on the order of 500 x 400 x 100 microns. Having mass on the order of 50 micrograms, the silicon samples can be supported by the corners with only the elastic force of the Polyvinylidene Fluoride (PVDF) film transducers, eliminating the need for a bonding agent which often affects ultrasonic measurement. The piezoelectric film has been plated with cadmium followed by gold on both sides, overlapping in a thin strip approximately 0.5 mm in width. This overlapping region forms the capacitance transducer used both for driving the sample and detecting its response. The gold/cadmium coating has shown to be effective in reducing crosstalk and prolonging the life of the transducer; it is a significant improvement over the aluminum coatings used previously.

By comparing the normal mode frequencies of a specimen before and after film deposition, the elements of the elastic tensor and attenuation coefficients of the thin film material may be determined. For anisotropic (crystalline) thin films, the RUS technique will offer a significant improvement over the existing method involving SAW, because the SAW technique cannot determine the complete elastic tensor. Future experiments include the performance of RUS in a partial vacuum to examine the effects of gas loading on the attenuation of sample resonances.

Studies of Liquid Coalescence

The underwater noise of rain, involving liquid coalescence, is important for environmental and military as well as scientific reasons. Significant theoretical and experimental studies have been done with water, and it would be of interest to extend measurements to a different fluid such as liquid helium. Helium has some interesting features in that the fluid and surface parameters may be varied over a wide range, and the liquid-vapor interface is particularly clean and well documented.

Pumphrey, Crum et. al.[1] studied the impact of water droplets on a water surface by using acoustic techniques and high-speed imaging. They showed that only a small range of raindrops (about 0.8 - 1.1 mm in size) forms entrained bubbles in water. The oscillations of these entrained bubbles contribute to the major acoustic power of the underwater noise. The numerical study by Oguz and Prosperetti[2] showed that for small drops, the drop crater is not deep enough to "pinch" an air bubble, while for higher energy drops, the inward lateral velocity is not sufficient to close the cavity before the bottom jet shoots out of it to prevent the bubble formation. They gave an empirical formula for the boundaries of the entrainment region, which depends on the water droplet size and its impact velocity and other physical properties of water. A severe difficulty in experimental studies of instabilities lies in eliminating or determining the effects of impurities or defects on the onset of the instability. An important feature of our experiments using liquid helium is that the fluids and the interfaces are more impurity-free than for any other system.

Our experiment for studying drops impinging on the surface of bulk liquid helium employs a cell containing the bulk liquid with a free surface and a mechanism for producing drops; a microphone located below the bulk liquid surface detects the stress waves generated by the drop coalescencing with the surface and possible "ringing" generated if a bubble is formed.

In the original design of our experiment, the cell was made of high thermal conductivity material in order to maintain equilibrium conditions in the cell. Liquid drops were to be formed by passing helium through a fine capillary at the top of the cell. Later it was learned that a better way to make drops was to establish a temperature gradient between the ceiling of the cell, on which a needle is mounted, and the lower part of the cell containing the bulk liquid. The problem was that the high thermal conductivity of the cell precluded making a localized temperature gradient, and the formation of the drops was difficult to control; in some situations larger drops would fall from the ceiling rather than the needle. To overcome these problems, the cell was redesigned as shown in Fig. 1.

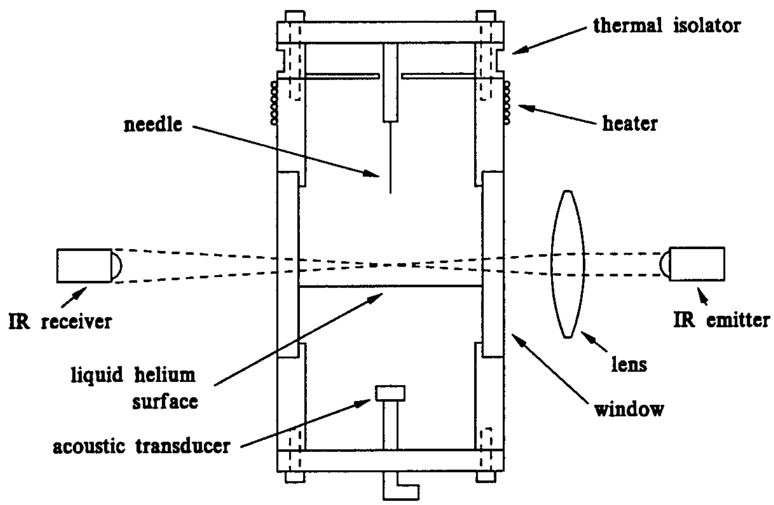

Fig. 1. The new design for the liquid coalescence experimental cell. The ceiling with the needle for forming drops is thermally isolated from the lower part of the cell. Liquid drops falling from the tip of the needle are produced on command by passing a current through a heater located below the thermal isolator.

In this design, the ceiling of the cell, with the needle, is separated from the lower part of the cell with a thermal isolator, and a heater is wound around the cell just below the isolator. The cell is allowed to come to thermal equilibrium, and in this condition no drops are formed. By passing a current through the heater, the temperature of the bulk helium in the lower part of the cell increases slightly and the vapor pressure increases. The extra helium in the vapor then condenses on the colder ceiling of the cell, runs down the needle, and falls off as a drop. Since the heater current is controlled outside the Dewar, drops may be produced on command. To guard against the effects of any drops which might be produced on the ceiling and fall without running down the needle, a sub-ceiling, containing a hole just larger than the needle support, is attached to the lower part of the thermal isolator; any liquid not flowing down the needle support would be re-evaporated by the higher temperature sub-ceiling.

In initial tests of the new cell it was found that during the initial cooling of the cell, where large temperature gradients are formed without using the heater, drops were produced which gave large signals in the microphone; these signals, shown in Fig. 2, resembled the ringing signals generated when bubbles are formed, as observed in water. However, as the cell reached equilibrium, it was found that the large signals disappeared, even though it could be observed visually that controlled drops were being produced with the heater. The problem was that any signals generated by the controlled drops were small and lost in the noise in the microphone circuit. In order to recover the small signals from the noise, it would be necessary to signal average with the digital oscilloscope, and to do this it is necessary to trigger the oscilloscope with some signal, other than the microphone signal, synchronous with the drop event.

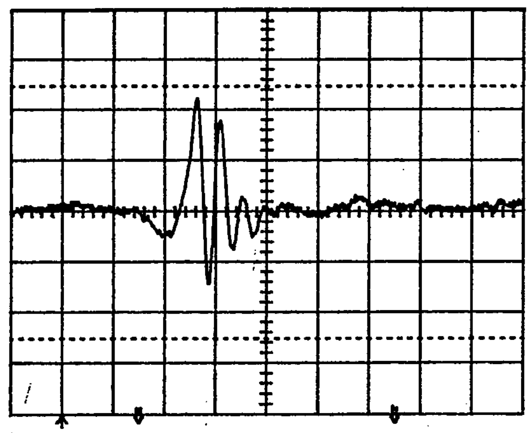

Fig. 2. Signal generated when the cell is not in equilibrium, and the heater used to produce controlled drops in not is use. It is believed that this large signal is due to bubble entrainment by large drops formed on the ceiling rather than on the needle.

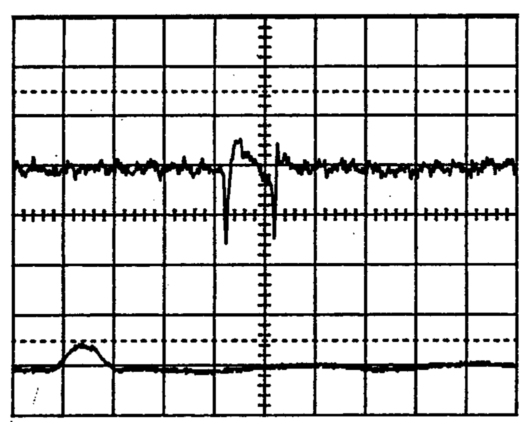

Fig. 3. Signal produced by controlled drops formed on the needle. The vertical scale is smaller than that of Fig. 2 by a factor of ten. Recording the signal requires triggering with optical detection of a drop event and signal averaging for aver 100 events.

Our method for producing a trigger signal from a drop event is illustrated in Fig. 1.

An infrared emitter and detector are positioned (outside the windows of the dewar) on either side of the cell; the beam from the emitter is focused on a region inside the cell through which the liquid drop should pass. The passing of a drop defocuses the beam and generates a pulse in the detector, which is used to trigger the oscilloscope. Such a trigger pulse is shown in the lower trace in Fig. 3. The upper trace is the microphone signal after averaging for over 100 drop events. The microphone signal is delayed by the amount of time required for the drop to fall from the beam height to the liquid surface. It should be noted that the vertical scale in Fig. 3 is a factor of ten smaller than that of Fig. 2., thus the signal and the noise (through signal averaging) are smaller, by a factor of ten, than those recorded during the off-equilibrium situation.

It is believed that the larger, bubble-like signals produced during the off-equilibrium condition are due to larger drops which form and fall from the sub-ceiling, just as was found in the earlier version of the cell. Thus, by using a larger diameter needle and forming large drops under controlled conditions, it should be possible to observe the transition from no bubble entrainment to entrainment. In any case, the liquid drop production and coalescence signal detection, as in Fig. 3, is in complete control under equilibrium conditions. It is now possible to commence data acquisition while varying temperature, drop size, and drop height, and obtain an independent and clean test of the theoretical predictions for drop coalescence and bubble entrainment.

Acoustic Studies of Brittle Foam Fracture as a Model for Current Theories in Statistical Physics

The objective of our research project in fracture is to improve models which predict fracture in brittle materials with random bond strength distributions, such as concrete, ceramics, etc. Recently, theorists from condensed matter physics have been developing analogies between fracture and contemporary physics problems involving directed polymer growth in a random medium, viscous fingering, diffusion limited aggregation, self-organized criticality, etc. In the theory, the brittle material is modeled as a network of bonds which are distributed randomly in the network with some probability distribution. Fracture is simulated by applying a stress or strain at the boundaries of the bond network; at some value of the boundary load, one of the internal bonds will break, increasing the load on the remaining bonds, and the process continues, ending in a catastrophic avalanche when the sample breaks in two.

In order to provide a test of the theories, it is necessary to have a measurement which can detect individual bonds breaking during the catastrophic avalanche. For the usual materials used in the study of fracture (glasses, resins, etc.), it would be impossible to detect individual atomic bonds breaking. However, it would be possible in a macroscopic model of a brittle solid. For this purpose we have been studying an open cell carbon foam material consisting of a network of struts with lengths on the order of 1-2 mm. The struts play the role of the random bonds in the statistical physics models. Samples of varying cross-sectional area are placed in a water tank, and when applied stress is increased, acoustic signals from breaking bonds are detected with an array of transducers surrounding the sample.

For larger diameter samples, it was found that acoustic pulses from bond-breaking events within the interior of the sample were becoming Anderson localized within the disordered sample, and signals were too weak to be detected at more than the nearest transducer, precluding triangulation to localize the event. A solution involving the use of transducers inside cavities bored in the plates bonded to the ends of the sample is being pursued. This solution requires more data acquisition channels, and the digital storage oscilloscopes are already at full capacity. As a remedy we have designed, built, and tested our own digital data acquisition electronics; a prototype of the printed circuit board is shown in Fig. 4. Each board has four parallel 15 Ms/s channels, with 64 Kb of storage per channel. These data acquisition boards will also be used in the high speed imaging system for the liquid coalescence experiment. A number of boards are being fabricated commercially.

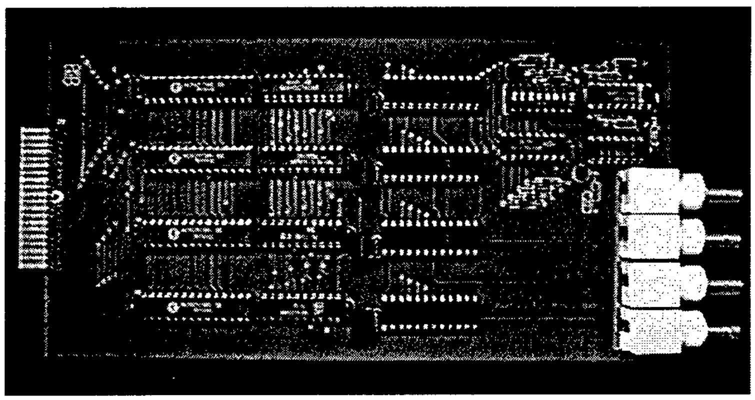

Fig. 4. Custom developed data acquisition card. A number of printer circuit boards are being fabricated commercially.

Current and Other Funding

Other research grants include:

1. ONR 331, October 1, 1996 to September 30, 1999, 240,000/3 yr, in one year increments; "Stack/heat-exchanger research for thermoacoustic heat engines"; includes 1 man-month of time for the principle investigator, distributed over 12 months.

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1. H. C. Pumphrey, L. A. Crum, L. Bjono, J. Acoust. Soc. Am. (1989) Vol. 85, 1518-26; H.C. Pumphrey, L. A. Crum, J. Acoust. Soc. Am. (1990), Vol. 87, 142-48.

2. H. N. Oguz, A. Prosperetti, J. Fluid Mech. (1990), Vol. 219, 143-79; A. Prosperetti, H. N. Oguz, Annu. Rev. Fluid Mech., (1993), Vol. 25, 577-602.

APPENDIX

OFFICE OF NAVAL RESEARCH
PUBLICATIONS / PATENTS / PRESENTATIONS / HONORS REPORT
for
01 JUNE 1996 through 31 MAY 1997

Contract/Grant Number:	N00014-92-J-1186/N00014-97-1-0008
Principal Investigator:	Julian D. Maynard
Mailing Address:	104 Davey Lab University Park, PA 16802
Phone Number:	814-865-6353
Facsimile number:	814-865-3604
E-Mail Address:	maynard@phys.psu.edu

a. Number of papers submitted to refereed journals but not yet published:	1
b. Number of papers published in refereed journals:	3
c. Number of books or chapters submitted but not yet published:	0
d. Number of books or chapters published:	2
e. Number of printed technical reports & non-refereed papers:	1
f. Number of patents filed:	1
g. Number of patents granted:	0
h. Number of invited presentations at workshops or prof. soc. meetings:	8
i. Number of contributed presentations at workshops or prof. soc. meetings:	4
j. Honors/awards/prizes for contract/grant employees:	0
k. Number of graduate students supported at least 25% this year:	4
l. Number of post docs supported at least 25% this year:	2

Grad Students FEMALE:	0	Post-Docs FEMALE:	1
Grad Student MINORITY:	0	Post_Docs MINORITY:	0
Grad Student ASIAN E/N:	1	Post-Docs ASIAN E/N:	1
Undergrad FEMALE:	2		

PUBLICATIONS, PRESENTATIONS, ETC.

PAPERS SUBMITTED TO REFEREED JOURNALS BUT NOT YET PUBLISHED

J. D. Maynard, "Wave propagation in periodic, random, and quasiperiodic media, with a tutorial on Anderson localization" submitted as a Tutorial Review to J. Acoust. Soc. Am., June, 1997

PAPERS PUBLISHED IN REFEREED JOURNALS

1. T. Zhang, B. Bennett, V. A. Hopkins, and J. D. Maynard, "Effects of finite amplitude fields on superfluidity", Proc. 21st Intl. Conf. Low Temp. Phys., Czech. J. Phys. **46**, 145 (1996).
2. T. Zhang, B. Bennett, V. A. Hopkins, and J. D. Maynard, "Using liquid helium to study fluid interface coalescence effects", Proc. 21st Intl. Conf. Low Temp. Phys., Czech. J. Phys. **46**, 377 (1996).
3. P. S. Spoor, J. D. Maynard, M. J. Pan, D. J. Green, J. R. Hellman, and T. Tanaka, "Elastic constants and crystal anisotropy of titanium diboride", Appl. Phys. Lett. **70**, 1959-1961 (1997).

BOOKS OR CHAPTERS PUBLISHED

1. J. D. Maynard, "Phonons in Crystals, Quasicrystals, and Anderson Localization", in *Encyclopedia of Acoustics* , ed. M. J. Crocker (John Wiley and Sons, New York, 1997), pp 651-660.
2. J. D. Maynard, "Acoustic Holography", in *Encyclopedia of Acoustics* , ed. M. J. Crocker (John Wiley and Sons, New York, 1997), pp 1281-1290.

PRINTED TECHNICAL REPORTS AND NON-REFEREED PAPERS

Philip S. Spoor, Physics Ph.D. Thesis, 1997; *Elastic Properties of Novel Materials using PVDF Film and Resonant Ultrasound Spectroscopy*

PATENTS/APPLICATIONS

Patent Disclosure, "Anisotropic stack/heat-exchangers for thermoacoustic heat engines" (Upgraded version, June, 1997).

INVITED PRESENTATIONS AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

1. Lecture Series, 1996 Physical Acoustics Summer School, Asilomar Conference Center, Pacific Grove, CA, June 21-28, 1996. Host: Henry E. Bass. "Periodic, random, and quasiperiodic media"

2. Lecture Series, UCLA Nonlinear Science Summer School, Los Angeles, CA, June 28-29, 1996. Host: G. A. Williams, "Anderson localization of nonlinear waves"

3. Thermoacoustics Review Meeting, Asilomar Conference Center, Pacific Grove, CA, November 13-15, 1996 "Anisotropic heat-exchanger/stack configurations for thermoacoustic heat engines"

4. Plenary Lecture, XXIII Internation Meeting on Acoustical Imaging, Boston, MA, April 13-16, 1997. "Acoustic Imaging of Active Sources" Chairperson: Sidney Lees. 57 Park Plaza Hotel

5. Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997. "Determining the radiation impedance for arbitrarily shaped surfaces"

6. Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997. "Resonant photoacoustic spectroscopy of optical materials"

7. University of Toronto, Department of Physics, Toronto, CANADA, September 12, 1996 Host: Steve Morris "Tuning-up a quasicrystal"

8. University of Maryland, Department of Physics, College Park, MD 20742-4111. April 22, 1997 Host: J. Robert Anderson "Tuning-up a quasicrystal"

CONTRIBUTED PRESENTATIONS AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

1. B. Bennett, T. Zhang, V. Hopkins, and J. D. Maynard, "Using liquid helium to study fluid interface coalescence effects", APS Division of Fluid Dynamics, 49th Annual Meeting, Syracuse University, Syracuse, NY 13244, November 23-26, 1996

2. D. C. Zhang and J. D. Maynard, "High power, high efficiency drives for annular thermoacoustic refrigerators", J. Acoust. Soc. Am. **100**, 2816 (1996). December 2-6, 1996. Sheraton-Waikiki Hotel, Honolulu, HI

3. L. C. Krysac and J. D. Maynard, "Statistical and deterministic dynamics during fracture of brittle carbon foam", Bull. Am. Phys. Soc. **42**, 460 (1997). Kansas City, MO

4. B. Bennett, V. Hopkins, T. Zhang, and J. D. Maynard, "Studies of liquid interface impact using helium", Bull. Am. Phys. Soc. **42**, 615 (1997). Kansas City, MO

5. P. J. White and J. D. Maynard, "Thin film characterization using resonance ultrasound spectroscopy", Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997.

GRADUATE STUDENTS SUPPORTED AT LEAST 25%

1. Philip Spoor (Ph.D. candidate, acoustics) began Fall 1989, Elastic Constant Measurements for Quasicrystals
2. Brian Bennett (Ph.D. Candidate, Acoustics Program) began summer 1994, Fluid coalescence
3. David Chao Zhang (Ph.D. candidate, physics) began summer 1994, Thermoacoustic heat engines
4. Jason White (Ph.D. candidate, physics) began summer 1994, Resonant Ultrasound Spectroscopy

POSTDOCTORALS SUPPORTED AT LEAST 25%

1. Tian-ming Zhang, Postdoctoral Scholar, 1994-1996
2. Cindy Krysac, Postdoctoral Scholar, began July, 1994

MISCELLANEOUS

Undergraduates Involved in Research:

1. Joseph Buck, Senior, 1994-96
2. John Lelii, NSF Research Experience for Undergrad. student 1995-96
3. Patrick Johnston, 1994-96
4. Christina D'Arrigo, WISER student, 1996,97
5. Ivonne D'Amato, WISER student, 1996,97
6. Bill Siddall (REU student), 1997

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c. Number of books or chapters submitted but not yet published:	0
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f. Number of patents filed:	1
g. Number of patents granted:	0
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3. Thermoacoustics Review Meeting, Asilomar Conference Center, Pacific Grove, CA, November 13-15, 1996 "Anisotropic heat-exchanger/stack configurations for thermoacoustic heat engines"
4. Plenary Lecture, XXIII Internation Meeting on Acoustical Imaging, Boston, MA, April 13-16, 1997. "Acoustic Imaging of Active Sources" Chairperson: Sidney Lees. 57 Park Plaza Hotel
5. Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997. "Determining the radiation impedance for arbitrarily shaped surfaces"
6. Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997. "Resonant photoacoustic spectroscopy of optical materials"
7. University of Toronto, Department of Physics, Toronto, CANADA, September 12, 1996 Host: Steve Morris "Tuning-up a quasicrystal"
8. University of Maryland, Department of Physics, College Park, MD 20742-4111. April 22, 1997 Host: J. Robert Anderson "Tuning-up a quasicrystal"

CONTRIBUTED PRESENTATIONS AT TOPICAL OR SCIENTIFIC/TECHNICAL SOCIETY CONFERENCES

1. B. Bennett, T. Zhang, V. Hopkins, and J. D. Maynard, "Using liquid helium to study fluid interface coalescence effects", APS Division of Fluid Dynamics, 49th Annual Meeting, Syracuse University, Syracuse, NY 13244, November 23-26, 1996
2. D. C. Zhang and J. D. Maynard, "High power, high efficiency drives for annular thermoacoustic refrigerators", J. Acoust. Soc. Am. **100**, 2816 (1996). December 2-6, 1996. Sheraton-Waikiki Hotel, Honolulu, HI
3. L. C. Krysac and J. D. Maynard, "Statistical and deterministic dynamics during fracture of brittle corbon foam", Bull. Am. Phys. Soc. **42**, 460 (1997). Kansas City, MO
4. B. Bennett, V. Hopkins, T. Zhang, and J. D. Maynard, "Studies of liquid interface impact using helium", Bull. Am. Phys. Soc. **42**, 615 (1997). Kansas City, MO
5. P. J. White and J. D. Maynard, "Thin film characterization using resonance ultrasound spectroscopy", Resonance Meeting, Asilomar Conference Center, Pacific Grove, CA, May 11-15, 1997.

GRADUATE STUDENTS SUPPORTED AT LEAST 25%

1. Philip Spoor (Ph.D. candidate, acoustics) began Fall 1989, Elastic Constant Measurements for Quasicrystals
2. Brian Bennett (Ph.D. Candidate, Acoustics Program) began summer 1994, Fluid coalescence
3. David Chao Zhang (Ph.D. candidate, physics) began summer 1994, Thermoacoustic heat engines
4. Jason White (Ph.D. candidate, physics) began summer 1994, Resonant Ultrasound Spectroscopy

POSTDOCTORALS SUPPORTED AT LEAST 25%

1. Tian-ming Zhang, Postdoctoral Scholar, 1994-1996
2. Cindy Krysac, Postdoctoral Scholar, began July, 1994

MISCELLANEOUS

Undergraduates Involved in Research:

1. Joseph Buck, Senior, 1994-96
2. John Lelii, NSF Research Experience for Undergrad. student 1995-96
3. Patrick Johnston, 1994-96
4. Christina D'Arrigo, WISER student, 1996,97
5. Ivonne D'Amato, WISER student, 1996,97
6. Bill Siddall (REU student), 1997