REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT DATE	3. DATES COVERED *(From - To)*
30-03-2001	Final Technical Report	01-01-1998 to 31-03-2001

4. TITLE AND SUBTITLE

PZT Hollow Sphere Transducers

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-98-1-0222

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Newnham, Robert, E. Alkoy, Sedat Meyer, Richard, J., Jr.
Hughes, W., J. Cochran, Joseph, K., Jr. Markley, Douglas, C.
Ritter, Timothy

5d. PROJECT NUMBER
01PR05127-00

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Materials Research Laboratory
The Pennsylvania State University
University Park, PA 16802 - 4801

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Program Officer Wallace A. Smith ONR 332
Ballston Centre Tower One
800 North Quincy Street
Arlington. VA 22217 - 5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Hollow sphere transducers 1 cm and larger made from PZT have been manufactured commercially for many years. The F-22 series of Navy hydrophones is typical. The spheres possess a stress amplification factor which imparts great sensitivity to the design while at the same time providing acceptable pressure tolerance.
In this study we have made spheres in sizes down into the millimeter range while retaining the same amplification factor and pressure tolerance characteristic of large hollow spheres. Our aim is to develop miniature hydrophones for studying flow noise, and for making shallow water arrays.

15. SUBJECT TERMS
piezoelectric, sphere, sonar, flow-noise, transducer, hydrophone, UBM, BB, composite, array, high frequency, ultrasound

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Dr. Robert E. Newnham
U	U	U	UU	22	19b. TELEPONE NUMBER *(Include area code)* (814) 865-1612

FY98

10/14/1998

FY98 End of Fiscal Year Letter
(01 Oct 1997 – 30 Sep 1998)

ONR CONTRACT INFORMATION

Contract Title :	PZT Hollow Sphere Transducers
Performing Organization :	Materials Research Laboratory / The Pennsylvania State University
Principal Investigator :	Prof. Robert E. Newnham (814) 865-1612 (814) 865-7593 – Fax bobnewnham@psu.edu
Contract Number :	N00014-98-1-0222
R & T Project Number :	
ONR Program Officer :	Dr. Wallace A. Smith

A. The technical research goals of this project includes:

(i) to develop miniature piezoelectric devices for underwater sonar and biomedical ultrasound applications from millimeter size ceramic hollow spheres,

(ii) to refine the fabrication techniques of these miniature transducers,

(iii) to characterize the dielectric, piezoelectric, and underwater properties of these devices,

(iv) model these devices as well as their response using finite element analysis techniques.

B. Significant research and development results :

(i) *Spherically focused high frequency piezoelectric transducers:* In clinical applications of ultrasonic transducers, higher axial and lateral resolution requires operation frequencies greater than 20 MHz, and a focused ultrasound beam. In our project focused transducers were prepared by machining shell sections of the hollow spheres with diameters from 3-4 mm and thickness from 40-100 μm.. The transducers were characterized in pulse echo mode and by using finite element analysis (FEA). FEA indicates the presence of two modes of vibration (1) a radial mode around 1 MHz utilizing the d_{31} coefficient where the spherical shell vibrates similar to a disk and, (2) a wall thickness mode above 30 MHz utilizing the d_{33} coefficient. From the measurements a thickness mode electromechanical coupling coefficient (k_t) of 0.51 is calculated. The pulse-echo characterization of the transducers indicates that they have a center frequency of ~ 48 MHz with a bandwidth of 22 % and a minimum insertion loss of – 44 dB. These results are promising in the development of a focused transducer. Since our fabrication process is flexible, it allows us to tailor the final properties by changing the dimensions and the materials used.

(ii) *Omnidirectional microprobe hydrophones:* Increasing use of ultrasonic techniques in biomedical and underwater applications and the sophistication of these techniques has increased the need to characterize the acoustic fields created by ultrasonic transducers. Accurate mapping of an acoustic field requires that: (i) the physical dimensions of the probe should be smaller than the acoustical wavelength of interest, (ii) the resonance frequencies of the probe should be well above the frequency range of interest, (iii) adequate sensitivity with an acceptable signal-to-noise ratio and (iv) wide bandwidth. A compact miniature hydrophone is developed from the hollow ceramic spheres by radially-poling these using inside and outside electrodes. Hydrophones developed in this part of our project had diameters from 2 mm up to 4 mm with wall thickness in the 50-100 μm range. The resonance frequency of the fundamental vibration mode of these hydrophones is above 500 kHz. Characterization of these hydrophones is done through measurement of hydrostatic piezoelectric charge coefficients, free field voltage sensitivities (FFVS) and directivity beam patterns. Results indicate a FFVS of around -215 dB re 1V/μPa with a flat response between 5 kHz up to 90 kHz and omnidirectional properties from 5 kHz up to 70 kHz. These hydrophones are shown to be viable candidates as microprobes due to their small size and the stable sensitivity and omnidirectional receive characteristics they display over a broad frequency range.

C. Plans for next year's research and development:

(i) Refining the fabrication techniques of the two transducer designs discussed, as well as improving their device properties,

(ii) Developing directional transducers by preparing arrays of these spheres,

(iii) Developing piezoelectric ceramic - polymer composites from the hollow spheres with 0-3 and 1-3 connectivity.

D. List of Publications / Reports / Presentations

1. Papers Published in Refereed Journals :

Li, S., J. A. Eastman, R. E. Newnham and L. E. Cross. Diffuse Phase Transition in Ferroelectrics with Mesoscopic Heterogeneity: Mean Field Theory, *Phys. Rev. B*, 55, No. 18, 1-12 (1997).

Dogan, A., K. Uchino, and R. E. Newnham. Composite Piezoelectric Transducer with Truncated Conical Endcaps "Cymbal", *IEEE Trans. on Ultrasonics, Ferroelectrics, and Frequency Control*, Vol. 44, No. 3:597-605 (1997).

Tressler J. and R. E. Newnham. Doubly Resonant Cymbal-Type Transducers, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 44(5) 1175-77 (September 1997).

Alkoy, S, A. Dogan, A-C. Hladky, P. Langlet, J. K. Cochran and R. E. Newnham. Miniature Piezoelectric Hollow Sphere Transducers (BBs), *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 44(5) 1067-76 (September 1997).

Newnham, R. E. Molecular Mechanisms in Smart Materials, *Mat. Res. Bulletin*, 22, 5, 20-34 (May, 1997).

Steele, B. C. H., R. E. Newnham, and A. G. Evans. Ceramics, Composites and Intergrowths, *Current Opinion in Solid State and Materials Science* 2:563-565 (October, 1997).

Li, Shaoping, J. A. Eastman, J. M. Vetrone, R. E. Newnham and L. E. Cross. Dielectric Response in Ferroelectric Superlattices, *Philosophical Mag B*, 76(1) 47-57, (1997).

Newnham, R. E., V. Sundar, R. Yimnirun, J. Su and Q. M. Zhang. Nonlinear Electrostriction Electromechanical Coupling in Solid Dielectrics, *Journal of Physical Chemistry B* 101 10141-10150, Sir John Meurig Thomas Special Issue (1997).

R. E. Newnham and S. Trolier-McKinstry. Size Effects in Ferroics, Integrated Ferroelectrics, *Integrated Ferroelectrics*, 20: 1-13 Gordon and Breach Science Publishers (March, 1998).

Pan, X., W. D. Kaplan, M. Rühle, and R. E. Newnham. A Quantitative Comparison of TEM Techniques for the Study of Localized Ordering on a Nano-scale, *J. Am. Ceram. Soc.* 81(3) 597-605 (March, 1998).

McNeal, M. P., S-J. Jang, and R. E. Newnham. The Effect of Grain and Particle Size on The Microwave Properties of Barium Titanate, *J. Applied Phys.*, 83(6) (1998).

McCauley, D., R. E. Newnham and C. A. Randall. Intrinsic Size Effects in a Barium Titanate Glass-Ceramic, *J. Am. Ceram. Soc.*, 81 (4):979-87 (1998).

Newnham, R. E. Creativity and Lifetime Learning, *J. Jap. Ceram. Soc.*, 33(5):341-344 (1998).

Fernández, J. F., A. Dogan, J. T. Fielding, K. Uchino, R. E. Newnham. Tailoring the Performance of Ceramic-metal Piezocomposite Actuators, 'Cymbals', *Sensors and Actuators A Physical*, 65:228-237 (1998).

Tressler, J. F., W. Cao, K. Uchino, and R. E. Newnham. Finite Element Analysis of the Cymbal-Type Transducers, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 45:1363-1369 (1998).

Sundar, V., R. Yimnirun, B. G. Aitken and R. E. Newnham. Structure Property Relationships in the Electrostriction Response of Low Dielectric Permittivity Silicate Glasses, *Mat. Res. Bull.* 33:1307-1314 (1998).

Accepted for publication:

Zhang, J., W. J. Hughes, A. C. Hladky-Hennion and R. E. Newnham. Concave Cymbal Transducers, accepted in October 1998 for publication in the *Materials Research Innovations.*

S. Alkoy, A. Dogan, A.C. Hladky, J.K. Cochran and R.E. Newnham, "Piezoelectric hollow spheres for microprobe hydrophones", accepted in August 1998 for publication in the *Ferroelectrics.*

J.F. Tressler, S Alkoy, A. Dogan and R.E. Newnham, "Functional composites for sensors, actuators and transducers", accepted in July 1998 for publication in the *Composites: Part A Applied Science and Manufacturing.*

J.F. Tressler, S Alkoy and R.E. Newnham, "Piezoelectric sensors and sensor materials", accepted in March 1998 for publication in the *Journal of Electroceramics.*

2. Non-Refereed Publications and Published Technical Reports:

S. Alkoy, Patrick D. Lopath, A. C. Hladky, J. K. Cochran, Jr. and R. E. Newnham, "Focused spherical transducers for ultrasonic imaging", *Proc. of the 1997 IEEE International Ultrasonics Symposium*, pp. 991-994

S. Alkoy, J.K. Cochran, and R.E. Newnham, "Miniature hydrophones from hollow ceramic spheres", to be published in the *Proc. of the 1998 IEEE International Symposium on Applications of Ferroelectrics*,

Hladky-Hennion, A. C., A. Dogan and R. E. Newnham. Finite Element Modeling of Transduction Materials with Application to Cymbal Actuators and Sensors, *Proceedings 1998 Actuators Meeting.*

Tressler, J. F., S. Alkoy, A. Dogan and R. E. Newnham. Functional Composites for Sensors, Actuators, and Transducers, *Proceedings of the 6th International Symposium on Ceramic Materials & Components for Engines*, 79-84, Arita, Japan, (October, 1997).

Newnham, R.E., V. Sundar, R. Yimnirun, J. Su, and Q. M. Zhang. Electrostriction in Dielectric Materials in *Advances in Dielectric Ceramic Materials*, K. Nair and A. Bhalla, Eds. Am. Cer. Soc. Pub., 15-39 (1998).

Newnham, R. E. Composite Sensors and Actuators in *Mathematics of Multiscale Materials*, edited by G. Milton, K. Golden, G. Grimmett, R. D. James, G. W. Milton, and P. N. Sen, Springer-Verlag, NY, pp. 209-211 (1998).

3. Presentations:

a. Invited

10/19-24/97 Functional Composite Sensors, Actuators and Transducers (invited talk), R. E. Newnham, 6th International Symposium on Ceramic Materials and Components for Engines, Arita, Japan.

10/27/97 Piezoelectric Crystals and Composites, (invited seminar), R. E. Newnham, NGK Insulators Company, Nagoya; Molecular Mechanisms in Smart Materials, (invited seminar), R. E. Newnham, Asian meeting of the International Center for Actuators and Transducers (ICAT), Tokyo, Japan.

10/28-31/97 Composite Piezoelectric Sensors and Actuators, (invited talk), R. E. Newnham, Fifth Japan International SAMPE Symposium and Exhibition, Tokyo, Japan.

8/23-27/98 Electroceramics in the 21st Century (plenary lecture) R. E. Newnham; Symmetry and Physical Properties (tutorial lecture) R. E. Newnham ISAF ECAPD and Electroceramics VI, in Montreux, Switzerland

9/14-15/98 Molecular Mechanisms in Smart Materials (invited talk) R. E. Newnham, Seminar at the Dept. of Materials and Nuclear Engineering, University of Maryland.

9/21-25/98 Lectures in Modern Chemistry Series (invited talks) R. E. Newnham, University of British Columbia and Simon Fraser University.

9/29/98 Biomimetic Transducers (invited talk) R. E. Newnham, Tokyo Institute of Technology, Tokyo, Japan.

10/6/98 Smart Materials and Smart Structures (invited talk), National Academy of Engineering Annual Meeting, Washington

10/8/98 Ceramic Engineering in the 21st Century (invited talk) Future of Ceramics Meeting, Corning, NY.

b. Contributed

11/13/97 Cymbal Transducers, J. Tressler, R. E. Newnham and J. Hughes, MURI Review Meeting, Penn State University.

11/19/97 Predicting Electrostriction in High and Low Permittivity Dielectrics. R. E. Newnham, CDS Fall Meeting, Penn State University.

1/21/98 Molecular Mechanisms in Smart Materials, seminar at Raychem Corporation, Menlo Park, CA.

1/22/98 Molecular Mechanisms in Smart Materials, Materials Science Department Seminar, University of California at Berkeley.

2/13/98 Molecular Mechanisms in Smart Materials, Physics Department Seminar, Indiana University of Pennsylvania.

2/27/98 Molecular Mechanisms in Smart Materials, Seminar, Materials Department, Virginia Polytechnic Institute.

3/19/98 Molecular Mechanisms in Smart Materials, Seminar, Alfred School of Ceramics, Alfred, NY.

3/27/98 Smart Composites, Seminar, Lincoln University

4/20/98 Ceramic Engineering in the 21st Century: Scaling Up and Scaling Down, International Center for Actuators and Transducers Dinner Banquet, Penn State University.

5/4-6/98 Ceramic Engineering in the 21st Century: Scaling Up and Scaling Down, R. E. Newnham; Centennial Symposium of the American Ceramic Society, Cincinnati, Ohio.

5/4-6/98 Interferometric and Compressometric Studies of Electrostrictive Propeties in Low-K Ceramics, (poster) R. Yimnirun, P. Moses, V. Sundar and R. E. Newnham; Centennial Symposium of the American Ceramic Society, Cincinnati, Ohio.

5/4-6/98 PZT-Polymer Composite Hydrophones Prepared from Hollow Ceramic Spheres, (talk), S. Alkoy, R. E. Newnham, Centennial Symposium of the American Ceramic Society, Cincinnati, Ohio.

5/12-14/98 Concave Cymbal Transducer (poster), J. Zhang, J. F. Tressler, A. Dogan, and R. E. Newnham; Office of Naval Research Review Meeting, Penn State University.

5/12-14/98 Hollow Sphere Microprobe Hydrophones, (poster) S. Alkoy, A. C. Hladky-Hennion, J. K. Cochran, Jr., and R. E. Newnham, Office of Naval Research Review Meeting, Penn State University.

5/13/98 Composite Transducers, Philips Laboratory Seminar, Eindhoven, Holland

5/14/98 Molecular Mechanisms in Smart Materials, RWTH Seminar, Aachen, Germany.

5/18-29/98 Two Week Short Course on Piezoelectrics, Upsala University, Sweden

5/25/98 Molecular Mechanisms in Smart Materials, Chalmers University, Goteborg, Sweden

5/27-29/98 Finite Element Modeling of Tranduction Materials with Application to Piezoelectric Hollow Sphere Transducers, A. C. Hladky-Hennion, R. Bosout, S. Alkaoy, and R. E. Newnham, IEEE Frequency Control Symposium, Pasadena, Ca.

6/1/98 Molecular Mechanisms in Smart Materials, Institute for Solid State Physics, Riga, Latvia

7/19-23/98 Persistent Disequilibrium in Smart Materials, Gordon Research Conference on Disorder in Materials, New London, NH.

7/19-22/98 Predicting Electrostriction, R. Yimnirun, V. Sundar, P. Moses, and R. E. Newnham, Innovations in Materials Conference, Washington, D. C.

8/23-27/98 Electrostriction Measurements on Low Permittivity Ceramics and Polymers, (poster) R. Yimnirun, S. Eury, V. Sundar, P. Moses, S.-J. Jang, ISAF ECAPD and Electroceramics VI, in Montreux, Switzerland;

8/23-27/98 Concave Cymbal Transducers (poster), J. Zhang, J. F. Tressler, A Dogan and R. E. Newnham; ISAF ECAPD and Electroceramics VI, in Montreux, Switzerland;

8/23-27/98 Miniature Hydrophones from Hollow Ceramic Spheres (poster), S. Alkoy, A. C. Hladky-Hennion, J. K. Cochran, and R. E. Newnham, ISAF ECAPD and Electroceramics VI, in Montreux, Switzerland;

4. Books (and sections thereof)

Newnham, R. E. Functional Composites for Sensors and Actuators in *Neue Werkstoffkonzepte*, edited by H. Schmidt and R. F. Singer. DGM-Informations Gesellschaft Verlag, Frankfurt, Germany, pp. 27-34 (1997).

Muller, R. S., M. Albin, P. W. Barth, S. B. Crary, D. D. Denton, K. W. Markus, P. J. McWhorter, R. E. Newnham, and R. S. Payne. *Microelectromechanical Systems: Advanced Materials and Fabrication Methods,* NMAB-483, National Academy Press, Washington, DC, 61 pp. (1997).

Newnham, R. E. Functional Composites for Sensors and Actuators, Chapter in *The Era of Materials*, edited by S. Majumdar, R. Tressler, and E. Miller, 259-275, Pennsyvlania Academy of Science (1998).

E. LIST OF HONORS / AWARDS

Name of Person Receiving Award	Recipient's Institution	Name, Sponsor and Purpose of Award
Robert E. Newnham	Pennsylvania State Univ.	Materials Science and Engineering Service Award presented by the Pennsylvania State Univ.
Robert E. Newnham	Pennsylvania State Univ.	Alcoa Corporation Award presented by the Alcoa Corporation

H. SUMMARY OF FY98

PUBLICATIONS / PATENTS / PRESENTATIONS / HONORS / PARTICIPANTS

(Number Only)

			ONR	non ONR
a.	Number of Papers Submitted to Refereed Journal but not yet published		4	-
b.	Number of Papers Published in Refereed Journals		6	10
c.	Number of Books or Chapters Submitted but not yet published		-	-
d.	Number of Books or Chapters Published		2	1
e.	Number of Printed Technical Reports & Non-Refereed Papers		5	1
f.	Numbers of Patents Filed		2	-
g.	Number of Patents Granted		1	-
h.	Number of Invited Presentations at Workshops or Professional Society Meetings		7	2
i.	Number of Contributed Presentations at Workshops or Professional Society Meetings		18	7
j.	Honors / Awards / Prizes for Contract / Grant Employees		-	2
k.	Number of Graduate Students and Post-Docs Supported At least 25% this year on contract grant		1	-
	Grad Students :	TOTAL	1	-
		Female	-	-
		Minority	-	-
	Post Doc :	TOTAL	-	-
		Female	-	-
		Minority	-	-
l.	Number of Female or Minority PIs or CO-Pis			
		New Female	-	-
		Continuing Female	-	-
		New Minority	-	-
		Continuing Minority	-	-