Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Barium Titanate Transducers

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The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on barium titanate transducers and, more specifically, their use in Department of Defense organizations or their potential demand by such organizations. A DSIAC subject matter expert investigated open sources for relevant information and related organizations. This report includes a summary of barium titanate transducer technology and their applications, as well as manufacturers and potentially interested user organizations.

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ABOUT DTIC AND DSIAC

The Defense Technical Information Center (DTIC) collects, disseminates, and analyzes scientific and technical information to rapidly and reliably deliver knowledge that propels development of the next generation of Warfighter technologies. DTIC amplifies the U.S. Department of Defense's (DoD's) multibillion dollar annual investment in science and technology by collecting information and enhancing the digital search, analysis, and collaboration tools that make information widely available to decision makers, researchers, engineers, and scientists across the Department.

DTIC sponsors the DoD Information Analysis Center's (IAC's) program, which provides critical, flexible, and cutting-edge research and analysis to produce relevant and reusable scientific and technical information for acquisition program managers, DoD laboratories, Program Executive Offices, and Combatant Commands. The IACs are staffed by, or have access to, hundreds of scientists, engineers, and information specialists who provide research and analysis to customers with diverse, complex, and challenging requirements.

The Defense Systems Information Analysis Center (DSIAC) is a DoD IAC sponsored by DTIC to provide expertise in nine technical focus areas: weapons systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability; advanced materials; military sensing; autonomous systems; energetics; directed energy; and non-lethal weapons. DSIAC is operated by SURVICE Engineering Company under contract FA8075-14-D-0001.

A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information on barium titanate transducers and, more specifically, their use in U.S. Department of Defense organizations or their potential demand by such organizations. A DSIAC subject matter expert investigated open sources for relevant information and related organizations. This report includes a summary of barium titanate transducer technology and their applications, as well as manufacturers and potentially interested user organizations.

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1.0 TI Request

1.1 INQUIRY

What U.S. Department of Defense (DoD) programs use barium titanate (BT) transducers, and what is the DoD demand for those transducers?

1.2 DESCRIPTION

The inquirer was completing a review of BT transducers and knew that they, in addition to lead zirconium titanate transducers, were used within U.S. Navy sonars. However, the inquirer was interested in finding out more about the DoD uses of BT transducers and their demand.

2.0 TI Response

2.1 INTRODUCTION

Transduction indicates the transformation of energy from one matter to a different one. In general, ceramic transducers convert electrical energy to mechanical energy and/or vice versa. This conversion is achieved by the inclusion of active piezoceramic components in the transducer, and it can take place in a variety of mediums (e.g., air, liquid, etc.) using many different transducer orientations.

The piezo transducer's ability to convert mechanical energy to electrical energy (and vice versa) enables the generation and detection of sound waves. Transducers that produce hearable level sound waves can be used for speakers, buzzers, alarms, and anything of that nature. Transducers that generate ultrasonic-range sound waves (i.e., above 20 kHz) can be used to measure distance in various mediums, determine flow rates in fluids, monitor fluid levels in vessels, atomize liquids, perform medical imaging, weld plastics or metals, and monitor structural health.

The industrial and scientific communities have expressed a real need for pressure, acoustic, and vibration sensing at elevated temperatures. This review compares the various commercial methods and materials for acoustic transduction and identifies their advantages and limitations. "Techniques and devices include simple piezoelectric sensors, accelerometers, strain gauges, proximity sensors, fiber optics, and buffer rods [1,2]". Sensors with operating temperatures in excess of 650 °C are readily available from commercial sources. "Of the mechanisms investigated, the piezoelectric approach offers several advantages, including design cost and simplicity [1,2]". Therefore, most of this review concentrates on piezoelectric materials that are already available commercially and presently under development. The new

materials include perovskite layer-structure ferroelectric ceramics, which have the highest known Curie temperatures, which are reported to be piezo-active at 1150 °C [1, 2].

BT is a crucial perovskite oxide with formation ABO3. BT has applications in electro-optic devices, energy-storing devices such as photovoltaic cells, thermistors, multiceramic capacitors, Dynamic Random Access Memory, etc. BT is a nontoxic and environmentally friendly ceramic with high dielectric and piezoelectric properties, so it can be used as the substitute for lead zirconate titanate (PZT) and lead titanate ($PbTiO_3$).

Ceramic materials such as BT are characterized as being ferroelectric because the crystal domains of the material may be polarized through the application of a large electric field, and a residual polarization will remain in the material when the field is removed. These substances, when polarized, convey piezoelectric effects. However, materials such as BT have relatively low Curie temperatures at which they become depolarized and lose their piezoelectric properties. The Curie temperature of BT varies from 120 to 130 °C. These materials are heated when an alternating field is applied, which produces the ultrasonic energy when they are used as a transducer; therefore, the maximum power output of ceramic transducers is limited by the Curie temperature. Thus, it is desirable to use ceramic materials having high Curie temperatures in ultrasonic transducers [3, 4].

Some of the early works at the Titanium Alloy Manufacturing Company revealed that certain titanates, BT in particular, exhibited anomalous piezoelectric effects. Further studies at the Laboratory for Insulation Research at the Massachusetts Institute of Technology (MIT) established BT as a new class of ferroelectric material. The polarized polycrystalline BT showed certain analogies to ferromagnetic materials and exhibited properties which usually had been associated with single piezoelectric crystals. Until now, the implementation of high strength to ultrasonic transducers of the piezoelectric kind had been restricted by the delicate characteristic of the piezoelectric material and by the high electricity needed. Quartz, for example, is a firm material, but it has a substantially high impedance and is notably costly and hard to mass produce. In comparison, Rochelle Salt has a low impedance, a low Q (qualitative factor representative of oscillation dampening in a circuit), but is relatively unstable and has definite temperature and humidity limitations. Thus, BT seemed to present a partial solution to these problems. It is relatively stable below 80 °C and has a low impedance, it is unaffected by humidity, and the basic material is relatively inexpensive and available in a great quantity [5].

To understand and further explore the piezoelectric properties, particularly from the crystallography standpoint, research began on phase transition behavior and temperature-dependent dielectric properties, as well as composition-dependent ferroelectric properties. This research included the substrate-based crystallization response of BT that adopted a hexagonal structure under substrate-free conditions as opposed to the observed tetragonal phase under substrate-supported conditions. Nevertheless, opposite of the studied hexagonal BT, the substrate-free crystallized films demonstrated a small-scale but quantifiable

pyroelectric result. It did not exhibit phase transitions in the 25–423 °K temperature range [6–9].

2.2 BT APPLICATIONS

A keyword search for "Barium Titanate" within the *Ceramic Industry* magazine website [10] revealed information about following companies that manufacture ceramic materials:

- Ferro Corp.
  - Address: 6060 Parkland Blvd., Ste. 250, Mayfield Heights, OH 44124, United States.
  - Website: http://www.ferro.com [11].
- Machined Ceramics Inc.
  - Address: N. Industrial Park 629 N. Graham St., Bowling Green, KY 42101.
  - Website: http://www.machinedceramics.com [12].
- CerPoTech.
  - Address: Kvenildmyra 6, Tiller, 7093, Norway.
  - Website: http://www.cerpotech.com [13].
- BassTech International.
  - Address: 400 Kelby St., Fort Lee, NJ 07024.
  - Website: http://www.basstechintl.com [14].
- The Jet Pulverizer Company, Inc.
  - Address: 1255 N. Church St., Moorestown, NJ 08057-1166.
  - Website: http://www.jetpulverizer.com [15].
- Reade Advanced Materials.
  - Address: P.O. Drawer 15039, Riverside, RI 02915.
  - Website: https://www.reade.com [16].
- Ceramic Color & Chemical Manufacturing Company, Inc.
  - Address: P.O. Box 297, New Brighton, PA 15066.
  - Website: http://www.ceramiccolor.com/ [17].
- Precision Ferrites & Ceramics (PFC).
  - Address: 5432 Production Drive, Huntington Beach, CA 92649.
  - Website: https://semiceramic.com [18].

In addition to a host of other ceramic materials, BT was listed on the PFC website (https://semiceramic.com) in relation to development and manufacturing contracts for DoD and Department of Energy programs that involve radar systems, test and equipment components, electronic surveillance, infrared (IR) systems, and precision electromechanical devices. Additionally, other security, defense, and military applications supplied by PFC include the following [18]:

- Airport security systems
- Body armor

- Chemical agent monitors
- Decoys
- Dipping sonar
- Electronic countermeasures
- Fingerprint scanners or sensors
- Gyroscopes
- Image intensifiers (e.g., night vision)
- IR detectors
- Laser range finders
- Proximity switches
- Scanners
- Sonar buoys
- Submarine and surface sonar
- Torpedo guidance
- Towed arrays
- Vehicle armor

The report "Ad Hoc Subcommittee Report on Piezoceramics – Revision of DOD-STD-1376A (SH)" [19] provides the shared ideas of government agencies, research laboratories, industrial manufacturers, and universities that reviewed and critiqued existing standards. It also provides information on suggested areas for clarification and improvement of piezoelectric ceramic material (including BT, type IV) and measurements for sonar transducers, in addition to the inclusion of other materials, expanding user rules, and hydrophone and projector specifications integrated for coherence. The report also provides a usable document to both the Navy and contractors to more accurately specify piezoceramic material. The Program Manager (NRL-Underwater Sound Reference Detachment [USRD] Code 5977) for the Sonar Transducer Reliability Program (STRIP) and the sponsor (Naval Sea Systems Command [NAVSEA] 63X5) have approved the specification for distribution to Navy agencies and support contractors [19].

In the report, the following members of the subcommittee also provided some reference to the stakeholder interests about potential users of the BT ceramics [19], including the following organizations:

- NAVSEA.
- Naval Underwater Systems Center (New London, CT and Ft. Lauderdale, FL).
- NRL and ONR (Arlington, VA).
- NRL-USRD (Orlando, FL).
- Naval Ocean Systems Center (Norfolk, VA).
- AT&T Technology/Bell Labs.
- EDO Corporation, Western Division.
- Channel Products, Inc.
- Vernitron Piezoelectric Division.

Additional affiliations were solicited and included in the report, including the following [19]:

- Naval Coastal Systems Center (Panama City, FL).
- Naval Undersea Warfare Engineering Station (Keyport, WA).
- Naval Weapons Support Center (Crane, IN).
- Transducer Repair Facility, Mare Island Naval Shipyard (Vallejo, CA).
- Battelle Instrument (Richland, WA).
- Bendix Corporation (Sylmar, CA).
- Dyna-Empire, Inc. (Garden City, NY).
- General Electric (Syracuse, NY).
- Gould, Inc. (Cleveland, OH).
- General Instrument Co. (Westwood, MA).
- International Transducer Corporation (Goleta, CA).
- Raytheon Co., Submarine Signal Division (Portsmouth, RI).
- Sanders Associates (Hudson, NH).
- Magnavox Co. (Ft. Wayne, IN).
- Honeywell, Inc. (Everett, WA).
- Ametek-Straza (El Cajon, CA).
- Hughes Aircraft Co. (El Segundo, CA).
- Hazeltine, Inc. (Braintree, MA).
- Sparton Corporation (Jackson, MI).
- Westinghouse Electric Co. (Annapolis, MD).
- Texas Research Institute, Inc. (Austin, TX).
- Material Research Laboratory, Penn State University (University Park, PA).
- Applied Research Laboratory (Austin, TX).

The subcommittee also looked toward future improvements in piezo technology. There are many areas that need continuing Navy sponsorship and government or industry investigation; most of these are in the areas of measurement and test techniques, such as the following [19]:

- Measurement technique for d_{33} optimization.
- Measurements of other shapes (other than discs and rings).
- Strength of materials and test methods (for shock hardening).
- Measurement of piezo properties under multiple constraints (e.g., voltage, temperature, pressure, etc.).
- Corona measurements.
- Mechanical stress dependency (i.e., the influence of static stress).
- Temperature (i.e., the influence of heat stabilization after polarization).
- Additional compositions.
- Optimization of adhesion (e.g., tape tests, etc.).

Additionally, the NAVSEA Enterprise Long-Range Acquisition Forecast for 2019−2021 is shown in the Appendix and includes HLF-1 low-frequency transducers ($5M−$50M; N66604-13-D-1222) and ceramic stacks ($5M−$50M; GXP-21-3362) [20].

The Acoustic Transduction Materials and Devices Program (Division 332) within the ONR supports basic and applied research on materials and device technologies that primarily focus on Navy sonar and developing innovative systems that generate, detect, and suppress undersea sound for navigation, threat reduction, weapons guidance, and communication [21, 22].

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APPENDIX: NAVSEA Long Range Acquisition Forecast [20]

*For HQ POC, see "Deputy Program Manager List" on NAVSEA website.
For all others, see "Warfare Centers Small Business Contacts" on NAVSEA website.

NAVSEA Enterprise
Long Rang Acquisitino Forecast (LRAF)

N00178-14-D-7295-0005	N00178 - NSWC DAHLGREN	N00178 - NSWC DAHLGREN	V Dept Systems Administration	Systems Administration - Provides computer operaton, syster administration, software development, Information Assurance and Helpdesk functions for multiple commercial-off-the-shelf (COTS) and Government off-the-shelf (GOTS) hardware and software solutions and tactical systems i both classifed and unclassifiec environments.	See Note Above	See Note Above	$5M to $50M	2019	QTR 4	2020	QTR 4
N00178-14-D-7295-0004	N00178 - NSWC DAHLGREN	N00178 - NSWC DAHLGREN	V Dept Lab Ops	Lab Operatons - Provides technical support in the areas of syster engineering support services, which include requirements identification, information assurance (IA) network operations, change control, acquisition, logistics, simulation, operations and maintenance (O&M), and facilitie support.	See Note Above	See Note Above	>$50M to $100M	2019	QTR 3	2020	QTR 3
N00178-04-D-4079-0022	N00178 - NSWC DAHLGREN	N00178 - NSWC DAHLGREN	V Dept EAS	VA sites Engineering and Activation Services (EAS). The EAS tasl order provides engineering reach back to the AEGIS Combat System Development Agent (CSDA) and ATRC facility activation services for the Sites Planning Agent (SPA)	See Note Above	See Note Above	$5M to $50M	2019	QTR 3	2020	QTR 3
N00178-04-D-4127-0013	N00178 - NSWC DAHLGREN	N00178 - NSWC DAHLGREN	V Dept ECM	Enterprise Configuration Management	See Note Above	See Note Above	>$50M to $100M	2019	QTR 3	2020	QTR 3
N00178-04-D-4066 EH10, 4024 EH03, 4013 EH02, 4042	N66604 - NUWC NEWPORT	N48160 - PROGRAM EXECUTIVE OFFICER SUBMARINE	(CODE 2) Team SUB/EWCSS SWFTS Support	Team SUB/EWCSS SWFTS Support	See Note Above	See Note Above	>$100M	2020	QTR 3	2021	QTR 1
N00178-04-D-4066 EH10, 4024 EH03, 4013 EH02, 4042	N66604 - NUWC NEWPORT	N48160 - PROGRAM EXECUTIVE OFFICER SUBMARINE	(CODE 2) Team SUB/EWCSS SHAPM PMS 397 and 450 Support	Team SUB/EWCSS SHAPM PMS 397 and 450 Support	See Note Above	See Note Above	>$100M	2020	QTR 4	2021	QTR 4
N66604-15-C-1068	N66604 - NUWC NEWPORT	N66604 - NUWC NEWPORT	(CODE 10) Mail Room Support	Mail Room Support	See Note Above	See Note Above	>$100M	2019	QTR 4	2020	QTR 2
N66604-13-D-1222	N66604 - NUWC NEWPORT	N66604 - NUWC NEWPORT	(CODE 15) HLF-1 Low Frequency Transducer	HLF-1 Low Frequency Transducer	See Note Above	See Note Above	$5M to $50M	2019	QTR 3	2019	QTR 3
	N66604 - NUWC NEWPORT	N66604 - NUWC NEWPORT	(CODE 15) C15 RAPID PROTOTYPING	C15 RAPID PROTOTYPING	See Note Above	See Note Above	$5M to $50M	2019	QTR 3	2019	QTR 4
N66604-16-D-0845	N66604 - NUWC NEWPORT	N66604 - NUWC NEWPORT	(CODE 15) Towed Array IPT (TAIPT) Telemetry Support	Towed Array IPT (TAIPT) Telemetry Support	See Note Above	See Note Above	$5M to $50M	2019	QTR 3	2020	QTR 1
N00178-14-D- [illegible]	N66604 - NUWC	N66604 - NUWC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WXP-20-0809 W X	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	Engineering and Technical support services for Radar Division	engineering, technical, programmatic, and configuration support for efforts associated with Radio Frequency (RF) and Microwave (MW) technologies, Radar Systems, and associated electronics supported within the division.	See Note Above	See Note Above	$5M to $50M	2020	QTR 1	2020	QTR
WXS-20-1041 P X	N00164 - NSWC CRANE	N00019 - NAVAL AIR SYSTEMS COMMAND	Engineering Services & Repairs	Communications Countermeasures Set (CCS) Engineering Services & Repairs related to EA-18G FST & Depot. Follow on effort	See Note Above	See Note Above	$5M to $50M	2019	QTR 4	2020	QTR
WXQ-20-1950 WIP	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	Engineering, Technical and Logistics Support Services for Division	Follow on Effort for Engineering, technical, logistics support services for Division.	See Note Above	See Note Above	>$50M to $100M	2019	QTR 3	2020	QTR
WXQ-20-1986 W A	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	Field Service Representatives (OCONUS)	Field Services Representatives (OCONUS) to support fielded electronic warfare systems	See Note Above	See Note Above	>$50M to $100M	2019	QTR 4	2020	QTR
GXP-20-3375	N00164 - NSWC CRANE	N00030 - STRATEGIC SYSTEMS PROGRAMS	Professional Engineering Support Services	Research and development; system/software/safety engineering, analysis, design, and test and evaluation; support prototyping, preproduction and fabrication; reliability and maintainability; logistics and configuration management, quality assurance; in-service engineering and field service; material handling, maintenance, and inventory management support services. These support services are required for the development, maintenance, and sustainment of systems, sub systems, equipment, and components under the cognizance of the Platform and Launch Systems Division.	See Note Above	See Note Above	>$50M to $100M	2020	QTR 4	2021	QTR
GXP-21-1996	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	Connectors and Mating Receptacles	Connectors and Mating Receptacles	See Note Above	See Note Above	$5M to $50M	2020	QTR 4	2021	QTR
GXP-21-2005	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	GPS Receivers	GPS Receivers	See Note Above	See Note Above	$5M to $50M	2020	QTR 4	2021	QTR
GXP-21-3362	N00164 - NSWC CRANE	N00024 - NAVSEA HQ	Ceramic Stacks	Ceramic Stacks	See Note Above	See Note Above	$5M to $50M	2021	QTR 1	2021	QTR
GXT-20-1031	N00164 - NSWC CRANE	N63184 - SPECIAL OPERATIONS COMMAND	Professional Engineering Support Services	Engineering and Technical Support Services for Electronic Security Systems and Lock Shop support fot the strategic Missions Systems Engineering Division	See Note Above	See Note Above	$5M to $50M	2020	QTR 1	2020	QTR
GXT-20-3260	N00164 - NSWC CRANE	N00030 - STRATEGIC SYSTEMS PROGRAMS	Hypersonic Technology Systems Engineering	Engineering, technical assessments and special studies, and management support services required by the Strategic Missions Systems engineering Division. Support is required for Model Based Systems Engineering (MBSE), Model Based Engineering (MBE), Engineering and system integration, Test Engineering, Reliability Maintainability and Availability (RM&A) Engineering, Quality Assurance Engineering, System Engineering, Modeling and Simulation, Prototyping oversight, system design documentation, interface management, Configuration Management, Requirements Management, and Program Management.	See Note Above	See Note Above	>$50M to $100M	2020	QTR 1	2021	QTR
N00178-14-D-7616-FC01 - #1	N00164 - NSWC CRANE	N00164 - NSWC CRANE	Global Department Admin Support	Non-personal professional, technical and management suppo services in the areas of document review, data entry, data maintenance and distribution, document and image processing, human resources support, financial management support, property	See Note Above	See Note Above	$5M to $50M	2019	QTR 4	2020	QTR

BIOGRAPHY

Mahesh Rao, Ph.D., is a Senior Image Scientist at MTEQ and an adjunct professor at the University of Mary Washington, Virginia. He has 18+ years of professional experience in environmental applications of remote sensing and geospatial analysis. Prior to joining MTEQ, he has served as a faculty member at three universities researching and teaching image processing and geospatial sciences at both undergraduate and graduate levels. He has served as a principal investigator on several site characterization projects funded by several local, state, and federal agencies on change detection analysis and impact assessment of land management practices using a suite of electro-optical, hyperspectral imaging, and active sensor data including lidar and radar. More recently, he has focused efforts on workflow development and implementation of machine learning techniques for geospatial intelligence applications involving situational awareness and military sensing.