Materials Systems Inc.

R&D STATUS REPORT

CONTRACTOR: Materials Systems Inc.

CONTRACT AMOUNT: $1,077,052

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AMOUNT FUNDED: $593,606

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SHORT TITLE OF WORK: Advanced Piezomaterials for Transducer Applications

REPORTING PERIOD: 5 December 1998 thru 5 April 1999

• DESCRIPTION OF PROGRESS:

Task 1: High Volume Fraction 1-3 Composite

A semiautomatic ejection mechanism was designed and will be retrofitted into an existing MSI tool body. Semiautomatic ejection will minimize part distortion due to manual handling, decrease process time, and increase yields.

Task 2: High Displacement Piezoceramic

PLZT Compositions

More than fifty formulations of PLZT have been batched and tested to optimize the composition for the highest dielectric and piezoelectric properties with a target Curie temperature of 220 – 230°C. Each formulation was sintered in both air and oxygen. Materials were tested for dielectric and piezoelectric properties 24 hours after polarization. Promising compositions were then tested for Curie temperature.

Formulations were done in series of five compositions of various zirconia-titania ratios to determine exact position of the morphotropic phase boundary for each composition. Ten series were tested to determine the effect of various concentrations of three dopant types:

- lanthanum,
- lanthanum and antimony,
- and lanthanum and lead iron antimonide.

These compositional studies have bounded the dopant ternary for Curie temperature. To further enhance properties, several compositions have been selected for optimization of the sintering process (lead source and oxygen atmosphere). Based on these results, further compositional optimization within the dopant ternary may be required.

PNN Compositions

A new PNN material, PNN-1, was developed with the high piezoelectric constants (d_{33} = 930) and coupling (k_p = 0.66), an excellent dielectric constant (6230), and an equivalent Curie temperature (140C). These properties are superior to any commercially available PNN material. This material has excellent potential in 1-3 piezocomposite, medical imaging, actuator, and pseudo-single crystal conversion applications.

Five PNN compositions of various zirconia-titania ratios were formulated, batched, manufactured, and tested. The best composition gave the properties shown in Table 1. These properties may be improved by injection molding the material and optimizing the sintering process (lead source and oxygen atmosphere). As shown in Table 2, MSI's initial PNN material compares very favorably with other commercial PNN materials.

The first small (8-kg) production batch of PNN-1 material has been produced. This batch will be used to optimize the firing process, produce and evaluate IEEE standard test specimens. Subsequent batches will be used to evaluate the material in 1-3 piezocomposite configurations.

Table 1. 24-Hour Piezoelectric Properties of standard DoD Type VI material, MSI 5H equivalent (MSI 53HD), and the new PNN material.

Property	DOD VI	MSI 53HD	MSI PNN-1
K^T_{33}	3250 ± 12.5%	3550	6230
tan δ	≤ 0.025	0.018	0.021
Q_M	≥ 65	58	33
k_{33}		0.80	
k_t		0.63	
k_{31}		0.39	0.39
k_p	0.64 ± 8%	0.66	0.66
k_{15}		0.74	
d_{33}	575 ± 15%	780	930
d_{31}		-280	-371
d_{15}		960	
g_{33}		24.8	16.9
g_{31}		-8.9	-6.7
g_{15}		34.5	
N_1		1430	
N_{3a}		1850	
N_p	1940 ± 8%	1960	1880
s^E_{33}		30.1	
s^E_{11}		16.2	16.8
s^D_{33}		10.8	
s^D_{11}		13.7	14.3
Y^E_{33}		3.3	
Y^E_{11}		6.2	6.0
Y^D_{33}		9.3	
Y^D_{11}		7.3	7.0
density	≥ 7.40	> 7.5	7.97
T_c		200	140

Table 2. Comparison of PNN Materials.

Property	MSI PNN-1	Tokin N-10	Nagaoka C-9	Hitachi PC-23AM	Plessey TLZ-H	Morgan Matroc PZT-5K	Advanced Ceramics ACL 4055
K^T_{33}	6230	5440	6300	6350	4700	5700	5000
$\tan\delta$	0.021	0.020	0.052	0.018	0.020	0.020	0.03
Q_M	33	70	20	60	50	60	80
k_{33}		0.68	0.62	0.75		0.75	0.80 (?)
k_t		0.62 (?)	0.43	0.50		0.51	
k_{31}	0.39	0.34	0.32	0.39	0.38	0.36	0.36
k_p	0.66	0.57	0.56	0.67	0.65	0.62	0.62
k_{15}		0.66	0.47				
d_{33}	930	635	600	760	690	760	760
d_{31}	-371	-287	-300	-352	-310	-306	-309
d_{15}		930	550				
g_{33}	16.9	13.2	11.0	13.5	16.5	15.1	17.2
g_{31}	-6.7	-6.0	-5.6	-6.3	-7.4	-6.5	-7.0
g_{15}		21.0	13.0				
N_1		1410	1400			1380	
N_{3a}		1800	1940			1900	
N_p	1880	2040	2030	1980	1920	1940	
s^E_{33}		18.1	16.7	18.2		20.4	20.4
s^E_{11}	16.8	14.8	15.6	14.5	16.2	16.6	16.6
s^D_{33}		9.7	10.3	8.0		8.9	8.9
s^D_{11}	14.3	13.1	14.0	12.3	13.8	14.7	14.7
Y^E_{33}		5.5	6.0	5.5		4.9	4.9
Y^E_{11}	6.0	6.8	6.4	6.9	6.2	6.0	6.0
Y^D_{33}		10.3	9.7	12.6		11.2	11.2
Y^D_{11}	7.0	7.6	7.1	8.1	7.2	6.8	6.8
density	7.97	8.00	7.70		7.90	7.90	7.80
T_c	140	145	140	140	170	160	150

Task 3: Continuous Net-Shape Molding

Applications of serpentine actuators have been studied under separate programs funded by DARPA, ARO, and NASA for a variety of resonant and nonresonant applications. Serpentine actuators are useful for low force, high displacement nonresonant devices. No applications for devices meeting this criteria are currently identified. The net shaped molding process for fabricating serpentine structure was therefore put on hold.

Task 4: 1-3 Piezocomposite Arrays for Surface Combatant Small Object Avoidance Sonar

Funding has been received for a new task to explore piezocomposites for surface combatant small object avoidance sonar. The effort has been broken out into six tasks described below. These will begin soon.

Task 4-1. Increase Piezocomposite Capacitance

MSI will investigate methods for increasing the electrical capacitance of the piezocomposite material used in the Small Object Avoidance (SOA) receive array, so that the preamplifier can be located up to 10 feet from the array elements. This is necessary so that the electronics modules will not interfere with the acoustic performance of the low frequency sonar. Capacitance will be increased while also maintaining an adequate receive sensitivity by one or more of the following: (a) increase PZT volume fraction in the piezocomposite, (b) decrease piezocomposite thickness, (c) use of a modified PZT formulation with a higher dielectric constant, or (d) use of multilayer piezocomposite configuration. Subscale arrays will be fabricated and tested in air at MSI.

Task 4-2. Array Bonding Optimization

MSI will modify the most promising methods developed previously for attaching the array panels to the designated sonar dome material(s). The bond method(s) will be optimized with respect to bond strength (both tensile and flexure) and acoustic performance. The bonding process optimization will include adhesive selection, surface preparation for both the piezocomposite and dome materials, adhesive application method, and curing cycle. Both commercially available and custom formulated adhesive systems will be investigated. Bond strength will be tested in the laboratory at MSI using test coupons. Acoustic, vibration, and shock performance will be evaluated on panel samples by Northrop Grumman. Shock testing will done either using a shock tube facility or by piggy-backing on a full scale, in-water shock test.

Task 4-3. Piezocomposite Optimization for Surviving High Sound Pressures

In this task, MSI will further optimize the receive array design and fabrication methods for surviving exposure to near cavitating sound pressure levels within or near the sonar dome. Issues to be addressed include selection of piezocomposite polymer phase, polymer phase adhesion to the ceramic rods, and face plate adhesion. Coupon samples will be prepared at MSI and tested at representative sonar dome intensity levels by Northrop Grumman.

Task 4-4. Develop Conformal Projector Panel

In this task, MSI will design, fabricate, and test a 1-3 piezocomposite prototype projector array panel for use with the surface ship SOA system. The design phase of this task will include selection of PZT type, polymer type, PZT volume fraction, piezocomposite thickness, number of piezocomposite layers, backing layer and matching layer (if necessary), and panel area required to meet the projector source level and bandwidth specifications the SOA system. The design will be consistent with conformability and electrical power requirements as well as the environmental conditions representative of surface ship sonar domes. Subscale projector samples will be fabricated at MSI and tested by Northrop Grumman. One (1) full scale conformal projector panel will then be fabricated at MSI and tested by Northrop Grumman. (It is anticipated that multiple projector panels may be needed to meet the source level and beam pattern requirements of SOA systems.)

Task 4-5. Minimize Acoustic Distortion

In this task, MSI and Northrop Grumman will investigate approaches to minimize the acoustic distortion caused by possible multipath errors due to the anisotropic characteristics of the rigid, fiber-reinforced sonar dome. Appropriate isolation/decoupler materials and methods will be developed and tested using subscale samples. Multiple design-build-test iterations will be carried out. In-water tests will be conducted by Northrop Grumman to evaluate and minimize acoustic distortion.

Task 4-6. Absorber Optimization

MSI will design and fabricate an optimized acoustic absorber material for the SOA sonar receive arrays. The optimized absorber material will minimize reflections from and maximize transparency to the low frequency active sonar located behind the SOA arrays, while preserving desired array performance Absorbance and transparency of developmental materials as a function of frequency will be measured at MSI over the bands of interest to guide the material optimization in an iterative manner. Preliminary testing will be carried out in water at Northrop Grumman on coupon samples to guide development of the absorber materials. The optimized materials will then be evaluated in water at Northrop Grumman.

• CHANGE IN KEY PERSONNEL:

none

• SUMMARY OF SUBSTANTIVE INFORMATION DERIVED FROM SPECIAL EVENTS:

none

• PROBLEMS ENCOUNTERED AND/OR ANTICIPATED:

none

• ACTION REQUIRED BY THE GOVERNMENT:

none