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**Single Crystal Piezoelectric Tonpilz Elements for Small Footprint,
High Power Acoustic Sensors**

June 14, 2005

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SUBJECT: R&D Progress Report #1 for the Option under "Single Crystal Piezoelectric Tonpilz Elements for Small Footprint, High Power Acoustic Sensors" performed by TRS Technologies, Inc. under Contract No. N00014-04-M-0211

The status of this program is described below following a brief introduction to the proposed effort and an outline of the tasks.

INTRODUCTION

Tonpilz designs utilizing PMN-PT single crystal materials show improved performances over traditional PZT ceramic-based transducers. Higher potential source level and larger system bandwidths have already been demonstrated. Single elements have also been tested for their high power capability. The overall source level potential was found to be limited by the mechanical stresses and temperature rise in the stack, due to strain and polarization non-linearity, which accelerated heating and generated harmonic distortion. This increase in temperature also changes the dielectric constant of the crystal by more than 40 percent from room temperature to 50°C.

In the main Phase I STTR program, these issues, along with issues of material cost, availability, and crystal size were studied to continue development of single crystal technology. This STTR is exploring a few options to tailor the piezoelectric, dielectric, and mechanical properties in the PMN-PT system to improve the high drive characteristics, including the mechanical and dielectric quality factors and Curie temperature. A number of conclusions were made regarding the PMN-PT compositions after characterizing and modeling them, and the primary objective of this option is to directly compare the performances of prototype transducers made from the compositions, both between the different designs and with current tonpilz transducers used in high power applications.

STATUS OF THE PROGRAM

From the work in Phase I, both the PMN-28%PT (low-PT) and Cd-doped PMN-PT crystals showed promise as replacements for conventional PMN-32%PT (PMN32). Though these materials showed advantages in temperature stability, it is still difficult to determine the properties under high drive conditions, i.e. whether the elastic coefficients and losses will behave similarly to PMN32. Therefore, to insure an accurate analysis of the materials, a single element prototype transducer will be fabricated and tested from each one of the tailored materials and the PMN32, during the Phase I Option. A brief summary of the Phase I results pertinent to the Option, and the tasks in the Option are given below, followed by a description of the progress thus far.

Phase I Summary

Three different tailored compositions were grown and characterized for potential use in high drive tonpilz devices: PMN-28%PT (low-PT), Cd-doped PMN-PT and PMN-38%PT (tetragonal). Each tailored PMN-PT single crystal exhibited some improved properties over the conventional crystal material. The temperature dependence of each material was significantly improved in the range of 0-50°C, as seen in Figure 1, which corresponds well to the higher T_r and T_c of the compositions. Characterization of the elastic, dielectric and piezoelectric properties showed the PMN32 did have the largest d33 value, though the Cd-doped PMN showed a similar value. Taking into account the mechanical Q, elastic properties and better temperature dependence, the Cd-doped PMN and low-PT crystal showed promise in replacing the PMN32 for high power applications.

One dimensional modeling of transducers made from the different compositions showed that a slightly higher drive level was necessary for each of the tailored compositions, relative to the PMN32, as shown in Table 1. When driven to achieve the same source level, the bandwidths of the transducers were nearly identical to one another, with the exception of the tetragonal PMN-PT. This comparison is shown in Figure 2. Though the reduced bandwidth means the tetragonal PMN is not ideal for this application, the significantly higher mechanical Q and best temperature dependence means it could have much higher drive potential. Since the bandwidths of the other materials are all similar, heating and temperature dependence will play a critical role in deciding the best material.

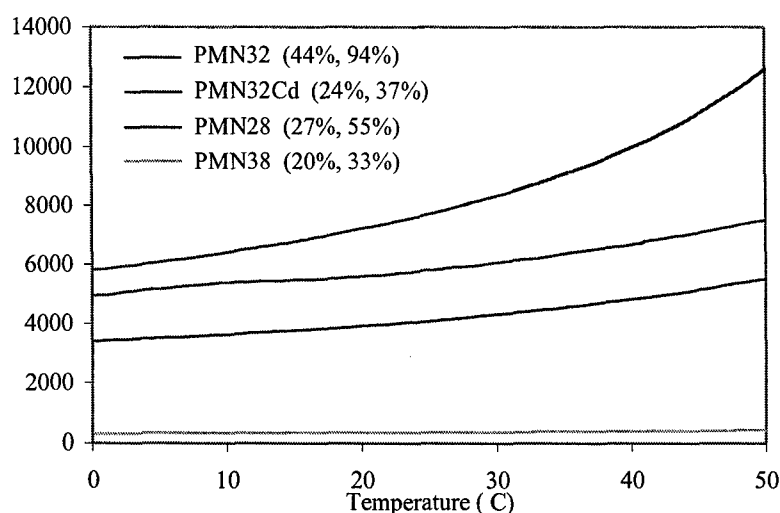


Figure 1. Dielectric constant temperature dependence for PMN compositions. Percents in black and blue represent change in dielectric constant from 2-35°C and 0-50°C, respectively (20°C nominal).

Table 1. Summary of the results for the one-dimensional transducer models.

Material	keff ^p	Q ^r	SL Freq. peak ^{+,**}	SL peak (dB)	Crystal Length ⁺	Drive Level ⁺ (dB)	Drive Field (V/mil)
PMN32*	0.81	6.0	1.02	200	1	--	--
PMN32	0.87	5.5	1	201	1	0	3.0
PMN28	0.82	4.6	1.19	199	1	--	--
PMN28 ⁺⁺	0.84	6.1	1	200	1.39	1.1	3.4
PMN32Cd	0.83	6.0	0.92	199	1	--	--
PMN32Cd ⁺⁺	0.82	5.2	1	198	0.83	2.9	4.2
PMN38	0.63	4.1	1.62	189	1	--	--
PMN38 ⁺⁺	0.72	7.5	1	193	2.59	8.2	7.8

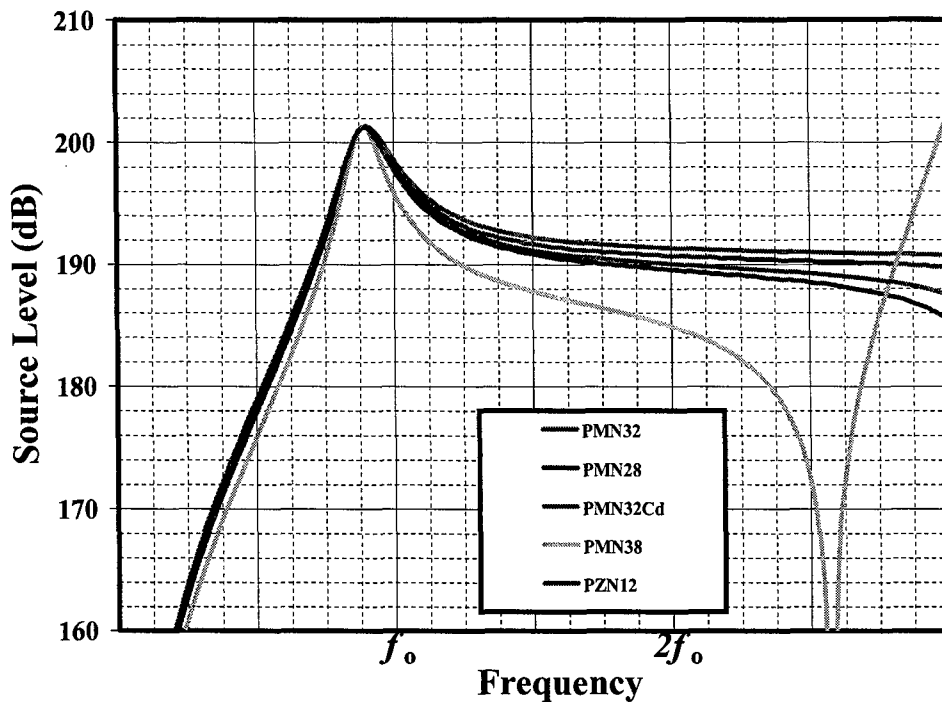


Figure 2. Source level plotted as a function of frequency for each composition. Each tailored compositions drive level was adjusted to provide baseline performance at the fundamental resonance.

Option Task 1: Prototype Ring Fabrication (TRS)

TRS will use the optimized modeling results and analysis from the main Phase I program to fabricate a set of prototype transducer rings for each tailored material. The rings will be oriented in the $\langle 001 \rangle$ direction. The size and number of the rings for each transducer will be determined from the analysis. Low signal coupling coefficient and dielectric constant for the transducer rings will be measured using an impedance analyzer. In Phase II of the program, assembly technology will be transferred from ARL to TRS for the purpose of optimizing the transducer assembly procedure and focusing on the commercialization possibility of the elements. This will include potting of the element into a housing and lead termination for testing purposes. TRS has experience from previous research programs in fabricating various shape and size components from PMN-PT single crystals. TRS also has significant experience assembling and electrically connecting stacked actuators. Examples of these are shown in Figure 3.

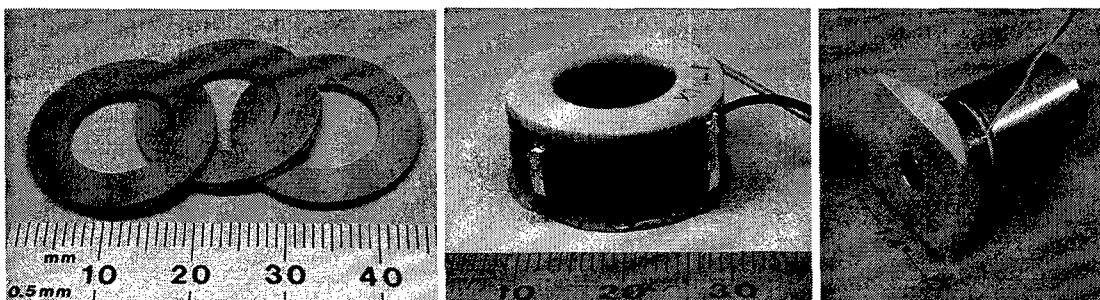


Figure 3. Transducer rings (left), assembled ring stack (middle) fabricated from PMN-PT single crystal piezoelectric material, and crystal Tonpilz constructed from a PMN-PT ring stack (right).

Option Task 2: Fabricate and Test element built using best candidate material(s) (ARL)

Using the results of the modeling data, transducer designs will be fabricated with the candidate material. The advanced material will then be evaluated for its small signal acoustic performance. In-water tests will be completed on a single element transducer to obtain the transmit and receive calibrations that will be used to compare to current transducers. Parameters measured will be efficiency, transmit voltage response, transmit current response, transmit power response, free field voltage sensitivity, directivity index, and impedance magnitude and phase. This data will be analyzed and compared to currently available single crystal material and ceramic devices.

Current Progress

Using the data collected during Phase I, the sizes of the rings were chosen. The OD of each ring is 0.43 inches (10.9 mm) and ID is 0.13 inches (3.30 mm). The OD allows for use of the standard W tails, electrodes and insulators for the stack, since they are aligned by the OD, and should provide relatively quick fabrication of the tonpilz transducers. The thickness and number rings in each tonpilz transducer are shown in Table 2. These values are based on the compliance of the compositions, and the frequency of interest.

Rings are currently being electroded with chrome/gold and core-drilled from boule sections which have been oriented in the $\langle 001 \rangle$ direction. Extra rings are also being made for each composition to insure the properties of the chosen rings are as close as possible. After drilling, the slices will be poled at 10kV/cm at room temperature and the properties will be measured using direct and resonance methods. Out of all the rings, the ones with the most uniform properties will be used for implementation into the tonpilz transducers.

Table 2. PMN ring thickness and number of rings in each tonpilz transducer.

Material	Thickness (mm)	Number of rings
Cd-doped	3.175	2
PMN-28PT	2.794	3
PMN-32PT	2.591	2
PMN-38PT	2.870	5