LANTHANUM AND GALLIUM CO-MODIFIED BIFEO$_3$-PBTIO$_3$ CRYSTALLINE SOLUTIONS: LEAD REDUCED MORPHOTROPIC PHASE BOUNDARY PIEZOELECTRICS AND MAGNETOELECTRIC CERAMICS

J. R. CHENG$^{1,3}$, S. DONG$^2$, D. VIEHLAND$^2$, and L. E. CROSS$^1$. $^1$The Pennsylvania State University, $^2$Virginia Tech., $^3$Shanghai University, P.R.China.
Corresponding e-mail: juc12@psu.edu

Crystalline solutions of (Bi,La)(Fe,Ga)O$_3$-xPbTiO$_3$ (BLFG-PT) have been developed using conventional mixed oxide ceramic processing. We have found that the BLFG-PT system has compositions with excellent piezoelectric properties comparable to conventional Pb(Zr,Ti)O$_3$ (PZT) ceramics, but in significantly lead reduced forms. A most attractive feature is that BLFG-PT was discovered to be a magnetoelectric ceramic with the simple perovskite structure, and BLFG-PT has insulation resistivity $\leq 10^{13}$ $\Omega \cdot$cm at room temperatures. The La substituent was also found to decrease the ferroelectric coercive field, resulting in significantly dielectric and piezoelectric properties. The optimum dielectric constant, loss factor, Curie temperature, remnant polarization and piezoelectric $d_{33}$ properties of 881, 0.037, 400°C, 30 $\mu$C/cm$^2$ and 163 pC/N, respectively, have been achieved for BLFG-0.4PT with 10 at% La, a composition in the vicinity of morphotropic phase boundary (MPB). BLFG-PT has been shown to have a large magneto-electric (ME) coefficient, $\alpha_p$. The room temperature value of $\alpha_p(2.5x10^{-9}$ s/m or C/m$^2$-Oe) is 10x greater than that of any other material at room temperatures, and many order(s) of magnitude higher than un-modified BiFeO$_3$ crystals. The value of $\alpha_p$ remains very high up to T>200°C. These results clearly demonstrate that BLFG-PT is a competitive and alternative piezoelectric material in applications for sonar, medical ultrasound and ultrasonics. In particular, the dramatic increase in the magnetoelectric coefficient offers new and important types of functional components for the electronics industry. Potential impacts are in (i) magnetic field and electric current sensors; (ii) components for power electronics; (iii) ability to spatially control magnetic field distributions using local electric fields.

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Recent progress in numerical simulation has put forth powerful finite element (FE) tools sustaining the design process of piezoelectric transducers. These require precise knowledge on the elastic stiffness constants, the dielectric constants and the piezoelectric constants of the piezoelectric ceramics. So far, these material parameters are usually determined by measurements of specially shaped test samples according to IEEE standard 176-1987. However, besides yielding too inexact approximations to the true parameters, this method is also unable to take into account nonlinear effects as they occur in the large signal behavior of piezoelectric transducers. In these effects, which play an important role in actuator applications, the material parameters themselves are functions of the mechanical strain and/or the electric field. We propose to identify these material nonlinearities by an automatic adjustment, fitting measured and simulated impedance curves. This principle, that is based on numerical simulation of piezoelectric transducers, was already successfully applied for the case of linear coefficients [1]. Determining the functional nonlinear material relations amounts to a parameter identification problem for the piezoelectric partial differential equations. This is an ill-posed problem in the sense that the searched for parameters depend in an unstable way on the measured data. Hence regularization has to be applied.

First, we will present our computational identification scheme which is based on
FE solutions of the piezoelectric partial differential equations
impedance measurements on appropriate test transducers
a regularized Newton iteration for extracting the searched for material parameters.

In the second part of the paper, we will demonstrate the practical use of the scheme by fitting measured material data of Pz27.

IMPROVING THE THERMAL STABILITY OF 1-3 PIEZOELECTRIC COMPOSITE TRANSDUCERS MANUFACTURED USING THERMALLY CONDUCTIVE POLYMERIC FILLERS

Corresponding e-mail: agnes@ultra.eee.strath.ac.uk

As a result of induced temperature increases, the performance of 1-3 piezoelectric composite devices is known to deteriorate. For example under certain conditions decoupling between the constituent materials can occur; leading to reduced uniformity of surface displacement. Such effects are particularly problematic in high power applications where more extreme operating conditions are typical.

Recent research by the authors has addressed these problems by varying the character of the polymeric filler material used in the manufacture of 1-3 piezoelectric composite transducers. By increasing the glass to rubber transition temperature (Tg) of the polymer filler material, the operational temperature range of 1-3 piezoelectric composites can be extended. However, subtle changes have been observed during detailed experimental examination of such devices. This has been attributed to the low thermal conductivity of these polymer materials. Consequently, incorporating a thermally conductive additive into a relatively high Tg polymer was considered a potential solution.

This paper describes the manufacture of 1-3 piezoelectric composites comprising polymer fillers that benefit from high Tg and thermal conductivity. In each case the advantage of such an approach is exemplified through a range of heat dissipation studies carried out in air and water. The elastic properties of each polymer material were characterised using an ultrasonic through transmission time-of-flight technique. This was coupled with analysis of the thermal characteristics of each resin system through a combination of dynamic mechanical thermal analysis, differential scanning calorimetry and a laserflash technique to determine thermal diffusivity. In addition, the PZFlex finite element modelling package was utilised to assess the thermal diffusivity of each polymer for a number of transducers configurations and was found to compare well with experiment.

CERAMIC/POLYMER 2-2 COMPOSITES FOR HIGH FREQUENCY TRANSDUCERS BY TAPE CASTING

Corresponding e-mail: seongtae@tr3technologies.com
In order to overcome the limiting technology of dice-and-fill for high frequency array transducers, PZT ceramic/polymer 2-2 composites were fabricated using tape casting technology. PZT tapes were printed with a fugitive phase (carbon) to define voids which were then backfilled with epoxy after the carbon was removed by thermal treatment at 1250 °C. Final dimensions of the 2-2 composite were in the range of 25 micrometers for the ceramic bar and 5 micrometers for the epoxy-filled kerf. Specific emphasis was placed on achieving uniformity and straightness of the ceramic beam and kerf thicknesses. Theoretical assessment of the array transducer was performed using a center frequency of 35 MHz with both 2-dimensional finite element modeling PZFlex and radiation pattern modeling (Field II) in Matlab. Fourteen array elements were modeled along the azimuth. The PZ Flex Code modeling of the narrowband beam profile in the range of 35-50 MHz revealed a fairly wide acceptance angle throughout the passband and low sidelobes. Furthermore the spatial impulse response was calculated using the Field II program. It showed a -6 dB radiation pattern of 6-7° for a composite with slightly curved elements and less than 2.5° for straight composite elements. Since the electrical interconnects for an array transducer based on this 2-2 composite could not be realized by lithographic methods, four ceramic bars were connected by masking and subsequent sputtering combining them into one array element. The preliminary results indicate a -6 dB bandwidth of > 40% and crosstalk in the range of -25 dB.

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3D-5  9:30 a.m.  
(Ivited)  
MODERN ELECTRETS

S. BAUER*, S. BAUER-GOGONEA, M. DANSACHMÜLLER, I. GRAZ, H. LEONHARTSBERGER, H. SALHOFER, and R. SCHWÖDIAUER, Soft Matter Physics, Johannes Kepler University, Altenberger Str. 69, A-4040 Linz, Austria. Corresponding e-mail: sbauer@jku.at

Electrets are dielectric materials exhibiting a quasipermanent electrical charge or dipolar polarization. The best known electret materials are polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF). PTFE is a charge electret with an exceptional thermal and long-term stability of excess charges trapped at the surface or in the bulk of the polymer. PVDF is a ferroelectric polymer exhibiting significant piezoelectric responses. In recent years cellular space charge electrets have emerged as a novel class of materials for electromechanical devices. After suitable charging, cellular space charge electrets behave like ferroelectric materials, and can be used for novel devices that convert mechanical into electrical signals and vice versa. They offer very high d_{33} transducer coefficients, typically 20 times larger than that of ferroelectric polymers like PVDF, and comparable with ferroelectric ceramics. Cellular space charge electrets therefore offer a huge potential for the development of large area sensors, as well as for acoustical, ultrasonics, biomedical, underwater and nondestructive testing applications. Cellular space charge electrets have been called “ferroelectrets” and their material behaviour “ferroelectretic” in view of the fundamental
difference to traditional ferroelectric materials. Here we summarize our present understanding of ferroelectrets.

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Session: 4D

PHYSICAL ACOUSTICS II
Chair: S. Schneider
Marquette University

4D-1 8:30 a.m.

EXPERIMENTAL STUDY OF BAND GAPS AND DEFECT MODES IN A TWO-DIMENSIONAL ULTRASONIC CRYSTAL
Corresponding e-mail: abdelkrim.khelif@lpmo.edu

Acoustic band-gap materials, also called phononic crystal, are composite elastic media, constituted of two- or three-dimensional periodic repetitions of different solids or fluids. Similarly to photonic band gap materials where the propagation of light is prohibited in some frequency range, these elastic periodic composites can exhibit large acoustic band gaps where the propagation of the phonons is forbidden. A phononic crystal can, therefore, behave like a perfect mirror for the propagation of vibrations in some frequency range and have potential applications in transducer technologies, filtering and guidance of acoustic waves. When a defect or a cavity is introduced in the otherwise perfect crystal, localized modes can be created that are associated with the defect in the band gap of the phononic crystal. We present an experimental and numerical investigation of the properties of band gaps and a variety of defect modes in a two-dimensional array of steel cylinders immersed in water. The 2.5-millimeter-diameter steel cylinders are clamped at one end into a rigid steel plate perforated with a 3-mm period and a ten-micron precision. Two wide-bandwith acoustic transducers operating around 500 kHz and launching short pulses are used to measure the transmission and reflection of acoustic waves propagating in the structure. We observe that acoustic waves cannot propagate within certain frequency ranges. We also demonstrate that by removing a single rod from an otherwise perfect lattice we create a highly localized cavity mode. This mode splits into two resonance modes when two consecutive single rods are removed. The results are discussed in relation with numerical simulations performed with a finite difference time domain (FDTD) method. It is found that theoretical predictions fairly account for the observed spectra.