edges of the fluid boundary. First, we investigated the effect of the reservoirs on the membrane resonances. Our results showed that in the presence of a reservoir the resonance frequency decreased, the quality factor of the resonance increased by a factor of 3. Secondly, the cavity resonances of the silicon wafer and the transducer were calculated. For optimum device operation, we matched these resonances with the membrane resonances by adjusting the height of the fluid reservoir and the distance between the transducer and the array. Moreover, our simulations showed that this distance should be larger than the focal distance of the transducer in order to achieve uniform membrane displacement over the whole array. By employing the results of the simulations we obtained ejection at 1.78MHz corresponding to a droplet size of 5\(\mu\)m.

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Session: P3J

TRANSDUCER MATERIALS III
Chair: Y. Takeuchi
Kagoshima University

P3J-1

MEASUREMENT OF ALL THE MATERIAL PROPERTIES OF PMN-PT SINGLE CRYSTALS GROWN BY THE SOLID-STATE-CRYSTAL-GROWTH (SSCG) METHOD
C. Y. JUNG*, S. H. LEE¹, S. S. LEE¹, Y. R. ROH¹, H. Y. LEE², and J. H. HAN³, ¹Kyungpook National University, Daegu, Korea, ²Sun Moon University, Asan, Korea, ³Prosonic Co., Ltd, Kyongju, Korea.
Corresponding e-mail: yryong@knu.ac.kr

Recent progress in the relaxor based piezoelectric single crystals such as PMN-PT has been an exciting issue for transducer, sensor and actuator community. Conventional methods to grow the PMN-PT single crystals include flux technique, Bridgman method and the combination of both. Solid-state-crystal-growth (SSCG) method is a rather new method to grow single crystal-like ceramics through typical sintering process, and has been known to be unsuitable to fully realize single crystals' ultrahigh performance. Recently, however, much progress has been made in the SSCG technology, and the method is expected to overcome the limitations of the conventional methods such as the crystal size, cost efficiency, and the large property variation along the boule axis. This paper is about the characterization of the PMN-32%PT crystals having the symmetry of tetragonal 4mm grown by the SSCG method. All the elastic, piezoelectric, and dielectric constants of the crystals were measured by the resonance method. For the tetragonal symmetry, a total of eleven independent material constants were measured such as six elastic compliance constants at constant electric field, two dielectric constants at constant stress, and three piezoelectric constants. Five sets of the crystal samples of different geometries were prepared for the measurement of thickness, thickness extensional, and thickness shear modes.
of vibration, respectively. In order to check the validity of the measurement method, experimental impedance spectra of the single crystals were compared with numerical impedance spectra calculated with the measured material constants. The measured properties of the PMN-PT crystals grown by the SSCG method were rigorously compared and discussed with those grown by the Bridgman method. The crystals from the two growing methods could provide almost the same performance, but for some specific properties such as the thickness extensional coupling factor, the crystal from the SSCG was inferior. However, the cost efficiency and property uniformity of the SSCG crystals was far superior to that of the Bridgman crystals.

P3J-2

HIGH TEMPERATURE MORPHOTROPIC PHASE BOUNDARY PIEZOELECTRICS

E. F. ALBERTA*1, P. W. REHRIG1, W. S. HACKENBERGER1, and T. R. SHROUT2,
1TRS Technologies, Inc., 2The Pennsylvania State University.
Corresponding e-mail: EdA@TRSTechnologies.com

Ceramics and single crystals in relaxor ferroelectric-PbTiO3 solid solution systems, such as Pb(Mg1/3Nb2/3)O3-PT [PMN-PT], are excellent candidates for ultrasonic transducers due to high electromechanical coupling and piezoelectric coefficients. Many of these materials systems are, however, limited by relatively low Curie temperatures (160°C or less, typically). Various strategies have been used to increase the temperature stability of the piezoelectric properties and, ultimately, the Curie temperature of these materials. A typical approach has been to form solid solutions with high temperature ferroelectric materials such as Na1/2Bi1/2TiO3 or Sr2Nb2O7. The properties of these solid solutions usually decrease with decreasing relaxor-PT content. In order to maintain the attractive properties of these materials it has been proposed that pseudo-binary solid solutions must be formed with other morphotropic phase boundary [MPB] containing high-temperature solid solutions. The recently-discovered BiMeO3-PT family of MPB-containing materials has allowed the development of such solid solutions. In this paper we will present the piezoelectric and dielectric data for ceramics in the PMN-BiScO3-PT solid solution. The MPB in this ternary system was found to trace out a nearly straight line between PMN-0.33PT and BS-0.64PT and the Curie temperatures ranged from 155°C to 450°C.
The research in the field of new piezoelectric materials has recently focused on the development of lead-free materials, the properties of which can compete with commercially available lead-based piezoelectric ceramics. Among the large variety of compositions, potassium sodium niobate (KNN) piezoelectric ceramics are of particular interest because of their attractive properties. The purpose of this paper is to present the comparative study of a single-element transducers based on KNN and on lead-based ceramics. The fabrication process of new KNN piezoelectric ceramics as well as the microstructure characterisation of the material are reported and discussed pointing out the effect of the sintering temperature on the density of the ceramic. Properties of KNN ceramic samples were then determined from electrical impedance measurements. In particular, a thickness coupling coefficient of 40 %, a sound velocity of 5800 m/s and a dielectric constant of 280 are found, which make this material suitable for medium and high frequency applications. Furthermore, we show that under certain conditions this material can exhibit a gradient of electromechanical properties that leads to generation of a second harmonic in impedance spectrum. On the basis of these electromechanical properties, we have used the KLM model to predict the electroacoustic behaviour of a 10 MHz single-element transducer with two matching layers. We show that KNN transducers have performances intermediate between those of PZT-based transducers and PMN-based transducers. This work is funded by the European Community through contract No. G5RD-CT-2001-00431 (RTD project LEAF, GROWTH programme).

High frequency (20 to 200MHz) transducers can be widely used in the medical imaging of the eye, skin, arterial walls, vascular and connective tissue, and small animals for biomedical research. One of the key technologies to develop these applications is the fabrication of piezoelectric thick films. In this work, we present the development of such materials using a sol-gel process. The electroacoustic performance of these thick films is compared to that of bulk ceramics.

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transducers is to produce piezoelectric PZT materials with the thickness about 10 to 100 μm, which are so-called as thick films. The current methods to make the films in such thickness range are either by polishing the bulk ceramic pieces down to the required thickness or using sol-gel composite method. The first method is a time-consuming and expensive process. The thick films obtained by the second method are difficult to be patterned, and the required annealing at 500 to 700°C limits the choice of substrates. In this paper we will present a novel technology to fabricate piezoelectric PZT thick films, which is based on the screen printing and laser liftoff concepts. Patterned PZT thick film elements will be first screen printed on a sapphire substrate and sintered at 1100 to 1350°C for densification. After sintering the PZT elements will be bonded to the required matching layer or backing material or a removable tape (for making free-standing PZT). Then the PZT elements will be released from the sapphire substrate by decomposing a thin surface layer of the PZT through an excimer laser exposure from the backside of the sapphire substrate. The sapphire substrate can be re-used after cleaning. This new technology allows to make PZT thick film single elements and arrays with arbitrary shapes on almost any kind of backing or matching materials, or free-standing PZT thick film elements, at large quantity and low cost. The dielectric, ferroelectric and piezoelectric properties of the PZT elements will be reported. Depending on the raw materials used, the dielectric constant can be from 500 to more than 1500, and the d33 can be from 100 to 250 pC/N. The pulse-echo and bandwidth characteristics of the single element transducers using the PZT thick film made from this method will also be presented.

P3J-5

A COMPLETE RANGE OF TAPE-CASTED PIEZOELECTRIC THICK FILMS FOR HIGH FREQUENCY ULTRASONIC TRANSDUCERS

F. LEVASSORT¹, T. BOVE², E. RINGGAARD², L.-P TRAN-HUU-HUE¹, T. WURLITZER*², W. W WOLNY², and M. LETHIECQ¹. ¹GIP ULtrasons/LUSSI, Blois, France, ²Ferroperm Piezoceramics A/S, Kvistgaard, Denmark. Corresponding e-mail: levassort@univ-tours.fr

Tape casting technology has been used to produce stand-alone thick films (i.e. 50 to 200 micrometers) of piezoceramics with net final shape for high frequency ultrasonic transducer applications. Four commercially available powder compositions (Pz21, Pz27, Pz29 and Pz34 from Ferroperm Piezoceramics) were used, the fabrication processes of which are described. The tape casting technology is then described, including electroding and poling. The samples are characterised using electrical impedance measurements and a fitting method based on KLM model. Bulk samples of the same compositions are also characterised by a similar method, and electromechanical constants are compared. Results show that the thick films exhibit electromechanical coupling factor very close to those of classical bulk ceramics: kt from 40% (Pz34, lead titanate) to 50% (Pz29, lead
zirconate titanate); clamped relative dielectric constant from around 200 (Pz34, lead titanate) to 2000 (Pz21, PNNZT). These results are finally used as inputs of a transducer model in single element, linear and 2D array configurations. The simulated transducer properties, i.e. sensitivity, bandwidth and electrical input impedance demonstrate that these new thick films are well adapted to high frequency transducer applications, since performance is similar to those of bulk ceramic based devices, but with much less machining required, namely lapping, which can significantly reduce fabrication costs. Pz34 appears as the best candidate for single element devices, while Pz21 and Pz29 perform better in array configurations.

P3J-6

MULTILAYER 1-3 PIEZOCOMPOSITES—THEORETICAL AND EXPERIMENTAL STUDY OF PILLAR MISALIGNMENT

J. F. SAILLANT*, S. COCHRAN¹, R. BERRIET², K. KIRK¹, and G. FLEURY²,
¹University of Paisley, Paisley, United Kingdom, ²IMASONIC SA, Besancon, France.
Corresponding e-mail: sail-ph0@paisley.ac.uk

The use of 1-3 piezocomposite technology is widely accepted nowadays because of its many advantages, including good acoustic matching to water and tissue, a good compromise between sensitivity and bandwidth, the capability to mechanically shape the material and a reduction in lateral modes. However, if this material is to be used in high density arrays, especially 2D designs, there is an increase in electrical impedance of the elements because of their small active area combined with a reduction in permittivity of the piezocomposite material by a factor typically between 2 and 5. One way to solve this problem is to use multilayer piezocomposite technology, in which layers in a single array element are connected mechanically in series and electrically in parallel. This allows the electrical impedance of the transducer to be decreased arbitrarily, subject to a maximum number of layers, while maintaining good electroacoustic performance.

Unlike stacks of piezoelectric ceramics and multilayer 2-2 piezocomposites, multilayer 1-3 piezocomposites have not yet been very well documented and issues such as pillar misalignment remain to be fully explored. This paper reports an investigation of such misalignment carried out with the PZ Flex finite element analysis package. A suite of 2D, 2.5D and 3D models was set up, utilising different symmetry constraints. These clarified theoretically how various thickness and lateral modes were generated, including some requiring full 3D analysis. The results were compared with 2 MHz prototypes specially manufactured with correctly aligned pillars and with full pillar misalignment. They showed good correspondence and allowed us to estimate the degree of acceptable pillar alignment more effectively than has been possible with previous results in the literature.
DEFORMATION IMAGING BY ULTRASOUND FOR THE ASSESSMENT OF REGIONAL MYOCARDIAL FUNCTION

Corresponding e-mail: jan.dhooge@uz.kuleuven.ac.be

The assessment of regional myocardial force development, i.e. regional myocardial function, remains an important goal in clinical cardiology as it gives important diagnostic and therapeutic information. Currently, a direct non-invasive measurement of regional force development is not feasible. However, regional function can be approximated by regional myocardial deformation as local force development and local deformation are closely linked.

Instantaneous tissue deformation is measured by ultrasound as the spatial gradient in local tissue motion between two acquisitions. Tissue motion can be estimated using several techniques such as the auto- and cross-correlation methodologies. Normalization of the instantaneous deformation to time gives a measure of the regional rate of deformation, i.e. strain rate. Integration of the strain rate curve over the cardiac cycle results in the total tissue strain.

In our laboratory, the applicability of ultrasonic strain and strain rate imaging in cardiology has been studied extensively. Different methodologies towards ultrasound based strain (rate) estimation have been developed and validated by prototyping on simulated ultrasound data sets and subsequently testing these methodologies in gel phantoms and animals using modified ultrasound scanners. Moreover, the clinical use of these techniques has been evaluated in a wide range of pathologies.

In this paper, an overview of our work will be given. Different methodologies towards cardiac strain (rate) estimation by ultrasound will be described. Typical image artefacts of the current methodologies will be discussed together with possible solutions. Clinical examples of the practical use of the technique will be shown. Finally, it will be demonstrated that the combination of ultrasound cardiac deformation data with mechanical models of the left ventricle can actually estimate regional myocardial force development.

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