VILNIUS TECH

Vilnius Gediminas Technical University

The 22nd International

Workshop on Piezoelectric Materials and Applications in Actuators

Abstract Proceedings

July 1–3, 2025

Vilnius, Lithuania

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This book constitutes the abstracts of presentations presented for the 22nd International Workshop on Piezoelectric Materials and Applications in Actuators – IWPMA 2025, which is being held in Vilnius from July 1 to July 3 2025 and organized by Vilnius Gediminas Technical University – VILNIUS TECH.

The aim of the conference is to provide a platform for sharing knowledge and fostering collaboration in the field of piezoelectric materials and their applications. It seeks to disseminate current research findings across this inherently multidisciplinary domain. Beyond presenting scientific advancements, the conference also serves to connect researchers and industry representatives from around the world, encouraging lasting international cooperation and future joint initiatives.

The abstracts are printed without editing as presented by their authors.

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MESSAGE FROM THE GENERAL CHAIR

Dear Colleagues, Professors, Scientists, and Students

Welcome to the 22nd International Workshop on Piezoelectric Materials and Applications in Actuators (IWPMA-2025), taking place from July 1st to 3rd, 2025, in Vilnius, Lithuania. It is our great honor to host this internationally recognized event and to continue fostering collaboration, knowledge exchange, and innovation in the dynamic field of piezoelectric materials and actuator technologies.

We are proud to feature keynote presentations by distinguished scientists and industry experts, including:

Prof. Dr. Habil. Vytautas Ostaševičius, Kaunas University of Technology, Lithuania
Dr. Aušrinė Bartašytė, FEMTO-ST Institute / UMLP, France
Dr. Andrei Shishkin, Riga Technical University, Latvia
Dr. Erling Ringgaard, CTS Denmark A/S

Their contributions will offer valuable insights and perspectives on current advancements and emerging trends in piezoelectric materials and their applications.

IWPMA-2025 is organized by **Vilnius Gediminas Technical University (VILNIUS TECH)**, with support from the Lithuanian research community and Vilnius Municipality. Lithuania boasts a rich tradition in vibroengineering and piezoelectric research, with roots going back nearly five decades. This legacy continues to inspire cutting-edge research and technological progress in the field.

Dear participants, we sincerely hope that your time at IWPMA-2025 will be both professionally enriching and personally enjoyable. We look forward to a successful workshop together.

Warm regards,

Conference Chairs
Prof. Habil. Dr. Piotr Vasiljev,
Prof. Dr. Dalius Mažeika

CONTENTS

MEDIA-FREE AND CONTACTLESS MICRO-POSITIONING SYSTEM USING ULTRASONIC LEVITATION AND MAGNETIC ACTUATORS

Berend DENKENA[1], Henning BUHL[1], Jens TWIEFEL[2], Chenglong DING[3]

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Abstract. Micro electro mechanical systems (MEMS) play a crucial role in modern applications, particularly in sensors for smartphones and vehicles. The growing market demand necessitates more efficient and high-productive manufacturing processes, especially in micro-production technology (MPT). However, current micro-manufacturing machines often rely on downscaled macro-machine concepts, which are constrained by low working speeds, ultimately limiting productivity. One of the key challenges in this field is the guidance system, which directly affects both precision and efficiency. To address this challenge, modern research focuses on functional integration and the development of novel guidance mechanisms. The presented approach investigates a media-free, contactless, active planar positioning system as an ultra-precise guidance system that integrates ultrasonic transducers and magnetic actuators. A double-acting ultrasonic transducer is used to improve positioning accuracy and ensures stability within the micrometer range by its self-stabilizing nature. In this paper the working principle, the achieved levitation forces and the micro-positioning capabilities of the micro-positioning system are introduced.

Keywords: MPT, micro-positioning system, double-acting ultrasonic transducer, electromagnetic actuator.

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TEMPERATURE-INDEPENDENT DIELECTRIC CHARACTERISTICS OF $KNBO_3$-$CA(Ti, Zr)O_3$ CERAMICS FOR THE X9R MLCC

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Abstract. $0.87KNbO_3$-$0.13CaTiO_3$ (0.87KN-0.13CT) ceramic showed a temperature-independent dielectric constant (ε_r) complying the specification of X9R multilayer ceramic capacitor (MLCC). This ceramic forms nano-domain structure with strong relaxor properties, but it does not have the core-shell structure. Hence, the good temperature-stable ε_r value of 0.87KN-0.13CT ceramic can be illustrated by its large relaxor properties. This ceramic displays comparatively small ε_r value which is approximately 765, indicating that the enhancement of the ε_r value of this ceramic is required for the practical application. A few fraction of Ti4+ ions in the 0.87KN-0.13CT ceramic were replaced by Zr^{4+} ions to increase the ε_r value and the $0.87KNbO_3$-$0.13Ca(Ti_{0.94}Zr_{0.06})O_3$ [KN-C($T_{0.94}Z_{0.06}$)] ceramic shows the increased ε_r value of approximately 1016 with a good temperature-stability satisfying the specification of X9R MLCC. The chip was produced utilizing the KN-C($T_{0.94}Z_{0.06}$) ceramic and the Ag_{70}-Pd_{30} used for inner electrode. The MLCC was well fabricated with the sharp interface between the ceramic thick film and electrode. This MLCC satisfied the specification of the X9R MLCC and it also exhibited outstanding supplied electric field stability. As a result, the KN-C($T_{0.94}Z_{0.06}$) is a good dielectric material for the X9R MLCC.

Keywords: dielectric ceramic, MLCC, relaxor, lead free ceramic.

BOLTED LANGEVIN TRANSDUCERS WITH LEAD FREE PIEZOELECTRIC CERAMICS

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Abstract. Lead-containing piezoelectric ceramics are still the base for today's ultrasonic transducers used in broad applications. This is partly due to missing powerful lead-free piezoelectric ceramic parts in the commercial market. There has been much research on lead-free materials but developing them into marketable parts seems to be an ongoing process. The actual exemption of ROHS has expired, but as the new exemption has already been requested, ceramic suppliers keep on selling lead containing products. Nevertheless, these should be replaced by lead-free alternatives for environmental and health issues.

This contribution focuses on exploring the technological readiness level of lead-free hard piezoceramics for prestressed ultrasonic transducers. A small series of bolted Langevin transducers was set up with standard PZT material and three commercial lead-free variants. Results of the building process from individual ring ceramic characteristics to transducer load tests are presented. The main finding of this study is that the lead-free materials technically can compete with the standard PZT for medium-power applications. Some adaptations in the ultrasonic system must be done: the geometry must be altered to fit resonance frequency, and higher voltages or thinner ceramics are needed to achieve the same vibration level at low load. For reaching same power, the volume of lead-free ceramics must be 1.5 to 3 times larger. As already promoted in literature, mechanical losses at high vibration levels are smaller for the lead-free materials. This might help to argument lead-free piezoelectric materials in some applications.

Keywords: lead free piezoelectric ceramics, bolted Langevin transducer, medium power ultrasound.

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HOMOGENIZATION-BASED MULTISCALE MODELING OF LIGHTWEIGHT PARTICULATE COMPOSITES

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Abstract. The demand for energy-efficient and sustainable construction materials has driven the development of lightweight particulate composites (LPCs) incorporating fly ash cenospheres (FACs) in calcium aluminate cement (CAC). LPCs exhibit enhanced mechanical properties, improved thermal insulation, and sustainability benefits, making them ideal for energy-efficient construction materials (Mačiūnas et al., 2023). To accurately predict LPCs effective properties, various multiscale modeling techniques are employed, including Computational Homogenization (FE2) (Oskay, 2015; Wen et al., 2016), Voronoi Cell Finite Element Method, Fast Fourier Transform (FFT) (Dong et al., 2021), and Interface Stress Models (Lee et al., 2021). FACs enhance compressive, flexural, and tensile strengths through their high specific strength and partial pozzolanic activity (Hanif et al., 2017), improve ductility (Zhou et al., 2019), and reduce thermal conductivity via optimized volume fraction and viscosity modifiers (Kilic et al., 2021; Sugama & Pyatina, 2021). Additionally, recycling FACs mitigates environmental impact (Hanif et al., 2017).

Homogenization serves as a key component in the multiscale techniques for heterogeneous materials (Elmasry et al., 2023; Noels et al., 2016). Results indicate that the proposed FEM homogenization-based multiscale approach tailored for heterogeneous LPC efficiently predicts LPC effective mechanical and thermal properties with high accuracy and low computational cost. Future work will focus on experimental validation and analytical comparisons to refine predictive capabilities further.

Keywords: particulate composite, thermo-mechanical properties, multiscale modeling, homogenization, finite element method.

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TEMPERATURE-STABLE DIELECTRIC PROPERTIES OF $(Ca, Ba)TiO_3$-$SmAlO_3$ CERAMICS FOR C0G MLCCS

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Abstract. Requirement of the temperature stable dielectric ceramics has been increased for the application to the devices operating at harsh conditions. Class-I C0G ceramics generally have the dielectric constant (ε_r) with the outstanding temperature-stability and a low dielectric loss. However, since the ε_r values of these ceramics are generally small (< 40), it is urgent to develop the C0G ceramics with large ε_r value. In this study, the (1-x)$CaTiO_3$-x$SmAlO_3$ [(1-x) CT-xSA] ceramics have been studied for the application to the C0G MLCCs. The (1-x)CT-xSA with $0.0 \le x \le 1.0$ have been well densified at temperatures between 1520 °C and 1570 °C. All the specimens showed the pure orthorhombic perovskite phase without the secondary phase. The ceramics ($0.28 \le x \le 0.3$) show the temperature-stable ε_r value satisfying the specification of the C0G MLCC that is smaller than ±30 ppm between −55 °C and 125 °C. They also provided the increased ε_r value ranged between 44 and 47 with low dielectric loss (< 0.03 %). A few Ca^{2+} ions in the 0.72CT-0.28SA ceramic has been replaced by the Ba^{2+} (B) ions to further enhance the ε_r value. The 0.72($C_{0.97}B_{0.03}$)-0.28SA ceramic sintered at 1560 °C provided the increased ε_r value of 52 with the excellent temperature-stability that fulfilled the C0G MLCC specification. In addition, the sintering temperature of this ceramic has been reduced for practical application and it will be also presented in this study.

Keywords: temperature-stable dielectric ceramics, class-I C0G ceramics, $CaTiO_3$-$SmAlO_3$ ceramic system, orthorhombic perovskite structure.

HYBRID TORQUE PREDICTION FOR ULTRASONIC MOTORS BASED ON THE PHYSICAL MODEL AND MACHINE LEARNING

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Abstract. Ultrasonic motors (USMs) have become key driving components in precision instruments, aerospace equipment, and advanced medical devices because of their unique advantages such as high-precision positioning, low noise operation, and small size. However, current torque control technology for ultrasonic motors still faces significant challenges: traditional control strategies usually depend on expensive torque sensors, which not only increase system complexity but also limit USMs' potential in applications with limited space. At the same time, the nonlinear dynamic characteristics and temperature sensitivity of USMs make pure physical prediction models difficult to achieve the precision standards needed in industrial applications.

For these technical problems, this research has developed an innovative hybrid prediction framework that combines the Hammerstein-Wiener physical model with advanced machine learning algorithms. This method first builds a physical-based torque model for ultrasonic motors, identifies key parameters through many experimental data, and establishes a basic prediction framework. After that, it uses a specialized machine learning network to compensate for model errors, which effectively improves system prediction accuracy and environmental adaptation ability in complex working conditions.

Experiment validation in the Shinsei USR-60 series ultrasonic motor shows this physics-guided hybrid prediction method can achieve high-precision torque prediction, as shown in Figure 2. The proposed method eliminates dependency on physical torque sensors, providing reliable solution without sensors for USM applications such as precision industrial control, human-machine interface and minimally invasive surgical instruments, which promotes innovative applications of ultrasonic motor technology in wider fields.

Keywords: ultrasonic motors, torque prediction, machine learning, Hammerstein-Wiener model.

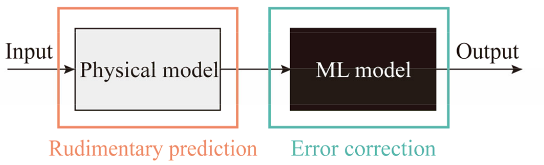

Figure 1. Framework of the proposed method

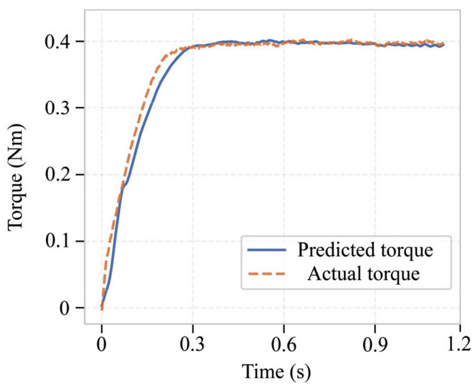

Figure 2. Prediction result of the hybrid model

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ADVANCING SELF-SENSING PIEZOELECTRIC ACTUATOR CONTROL: INCORPORATING PERMITTIVITY AND LEAKAGE CURRENT DATA THROUGH A NEURAL NETWORK FRAMEWORK

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Abstract. Piezoelectric actuator possesses fast response and high force generation; however, due to hysteresis and creep problems, positioning sensor becomes indispensable for precision control. In many cases, such precise position control using displacement sensors is impractical because of increased spatial and economic costs. To overcome these problems, our previous research developed a self-sensing piezoelectric actuator control system using a real-time permittivity detection method. This approach is based on the assumed one-to-one relationship between permittivity change and piezoelectric displacement. However, experimental results revealed that the permittivity change information is insufficient to fully eliminate the hysteresis. In this study, to address this limitation, we introduced additional leakage current information (reflecting resistance changes) and employed a Knowledge-based Neural Network (KBNN) to capture complex and subtle nonlinear relationships as shown in Figure 1.

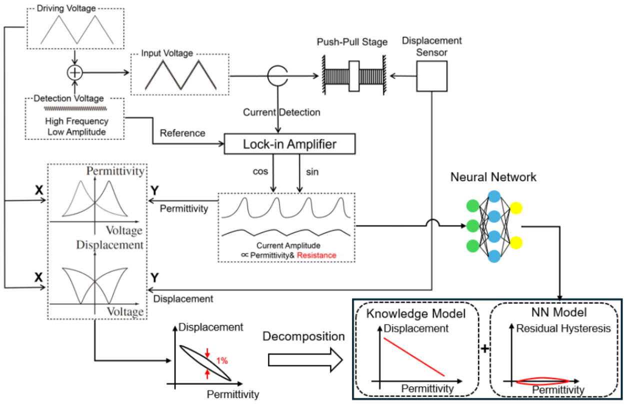

Figure 1. Structure of impedance detection system

Using the proposed method, our prediction model achieved an RMS error of 8.6 nm over a full scale of 8 μm, as shown in Figure 2, outperforming the previous polynomial fitting method based on permittivity detection.

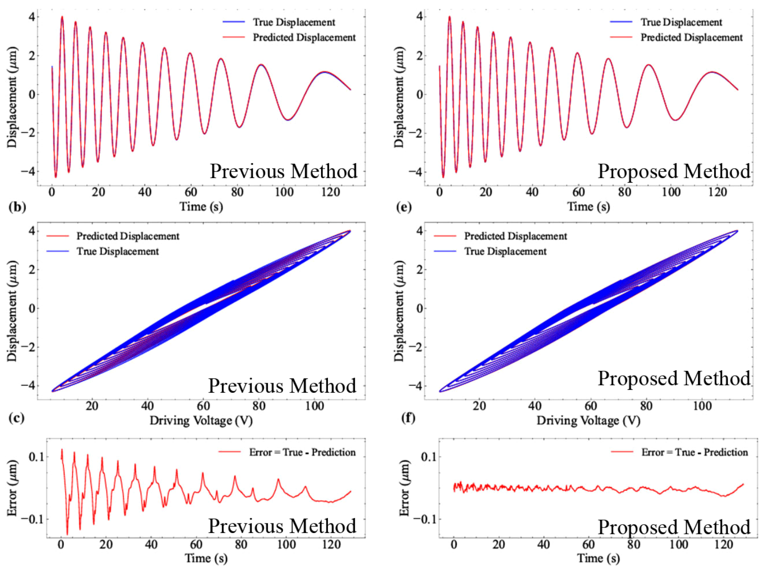

Figure 2. Prediction comparison between the previous method and proposed method

Keywords: piezoelectric actuator, self-sensing, neural network, impedance detection.

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DIELECTRIC PROPERTIES OF THE (1-x)$KNbO_3$-x$SrTiO_3$ CERAMICS SYNTHESIZED UNDER VARIOUS SINTERING CONDITIONS

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Abstract. (1-x)$KNbO_3$-x$SrTiO_3$[(1-x)KN-xST] ceramics have been produced under various sintering conditions and their structural and dielectric properties were investigated for the application to the X9R multilayer capacitors (MLCCs). The (1-x)KN-xST ceramics ($0.08 \le x \le 0.1$) exhibited temperature-independent dielectric constant (ε_r) satisfying the requirement of the X9R MLCC. The Curie temperature of these ceramics significantly decreased and broadened with the increase of x and nanodomains were observed in these ceramics, suggesting that they have large relaxor properties. However, TEM analysis showed that the core-shell structure does not exist in these ceramics. Therefore, the good temperature-stability of ε_r value of (1-x)KN-xST ceramics ($0.08 \le x \le 0.1$) ceramics can be explained by their large relaxor properties. Moreover, the 0.91KN-0.09ST ceramic was sintered in a reduced atmosphere at 1110 °C for 2 h and this ceramic also exhibited good temperature stability fulfilling the X9R MLCC requirement. Therefore, it is considered that the 0.91KN-0.09ST ceramic is a good candidate for the X9R MLCC. In this study, the structural and dielectric properties of the 0.91KN-0.09ST ceramic sintered under a reduced atmosphere will be also discussed in detail.

Keywords: temperature stable dielectric ceramic, relaxor, reduced condition.

EFFECT OF [001]-TEXTURING ON THE PIEZOELECTRIC PROPERTIES OF THE (K, Na)NbO_3-BASED PIEZOCERAMICS FOR PIEZOELECTRIC ENERGY HARVESTER

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Abstract. The output power of piezoelectric energy harvester (PEH) is dependent on the k_p and the d_{33}×g_{33} values at resonance and off-resonance frequencies, respectively. The k_p is proportional to $d_{33}/(\varepsilon^T{}_{33})^{1/2}$ and the g_{33} is equivalent to $d_{33}/\ \varepsilon^T{}_{33}$, indicating that the piezoceramics for the PEH should have a large d_{33} and a small $\varepsilon^T{}_{33}$. The [001]-texturing can be used for developing piezoceramics for PEH because it generally increases the d_{33} value without the enhancement of the $\varepsilon^T{}_{33}$ value. In this study, the $0.96(K_{0.5}Na_{0.5})(Nb_{1-z}Sb_z)O_3$-$0.01SrZrO_3$-$0.03(Bi_{0.5}Ag_{0.5})ZrO_3$ [$KN(N_{1-x}S_x)$-SZ-BAZ] piezoceramics were textured along the [001] direction. The piezoceramic (x = 0.01) showed a large k_p of 0.77, which is the largest k_p for KNN-related piezoceramics reported in the literature. The cantilever-type PEH manufactured using the $KN(N_{0.99}S_{0.01})$-SZ-BAZ piezoceramic exhibited a large output power density of 7.86 mW/cm^3 at resonance frequency because of its large k_p. To date, this is the largest power density for PEHs manufactured utilizing lead-free piezoceramics. In addition, the PEH produced using the piezoceramic (x = 0.05) exhibited the maximum output power of 4.57 μW at off-resonance frequency of 200 Hz because of its large $d_{33} \times g_{33}$. Hence, the [001]-textured $KN(N_{1-x}S_x)$-SZ-BAZ piezoceramics are excellent candidates for PEH, and [001]-texturing is a very efficient method for developing piezoceramics for PEH.

Keywords: piezoelctric energy harvester (PEH), [001]-texturing, piezoceramics, lead-free.

TIME DEPENDENT MATERIAL CHARACTERISTICS OF PRESTRESSED PIEZOELECTRIC CERAMICS IN LANGEVIN TRANSDUCERS

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Abstract. The precise knowledge of piezoelectric material parameters is essential for the model-based design of ultrasonic transducers. The known analytical approaches to determine these parameters according to international standards, e.g. European Committee for Standardization and the European Committee for Electrotechnical Standardization (2002), IEEE (1987), Japan Electronics and Information Technology Industries Association (2015), require impedance measurements on specific sample geometries, which do not correspond to the geometry used in ultrasonic transducers (ring shape) directly. To reduce the experimental effort and to ensure that the material parameters accurately describe the properties of the piezoceramics used in transducers, new methods for determining the parameters are desired and are part of a current research project (Paderborn University, n.d.; Friesen et al., 2024). It is known that prestress being applied within bolted Langevin transducers has an impact on the resonance frequency of the transducer (Arnold & Mühlen, 2001a) and that material parameters are altered (Arnold & Mühlen, 2001b). But there is a lack of information in literature on how the full material parameter set, which is needed for Finite Element Method based design, changes with prestress and as well with time.

In order to investigate the time dependent influence of mechanical prestress, a test setup has been built to apply a defined homogenous stress on ring shaped ceramics and to monitor their electromechanical coupling behavior over time. In this contribution, the experimental setup and measurement results of long-term admittance measurements are shown. A methodology to identify full material parameter sets is presented. The resulting time dependent changes of the material parameters are discussed. The rise of resonance frequency with time shows a decadic characteristic. The distance of resonance and antiresonance frequency decreases over time. This indicates that the electromechanical coupling decreases. These effects must be considered for tuning the different parts of an ultrasonic system (converter, booster, sonotrode, load, electronics) to receive an optimum.

Keywords: ring-shaped piezoceramics, prestress dependency, ultrasonic actuators, material parameter identification.

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CRYSTALLOGRAPHIC TEXTURING OF ACCEPTOR DOPED PMN-PT BASED CERAMICS FOR HIGH-POWER APPLICATIONS

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Abstract. High-power piezoelectric materials require a balance between enhanced piezoelectric properties and thermal stability. This study investigates the development of Mn-doped $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT) and $Pb(Yb_{1/2}Nb_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PYN-PMN-PT) ceramics through crystallographic texturing. The template grain growth (TGG) method utilizing (001)-oriented $BaTiO_3$ (BT) seeds was employed to enhance the piezoelectric response.

Key objectives included achieving high mechanical quality factors (Q_m) and optimized piezoelectric coefficients (d_{33}), while addressing the low Curie temperature (T_C) limitations of PMN-PT-based materials. The texturing process significantly improved the Lotgering factor, leading to enhanced electromechanical coupling and piezoelectric performance. Additionally, the vibration velocity, a critical parameter for high-power actuator applications, exhibited substantial enhancement compared to conventional PZT-based ceramics. These findings highlight the potential of Mn doped PMN-PT and PYN-PMN-PT (001) textured ceramics in high-power ultrasonic transducers and actuator applications.

Keywords: piezoelectric ceramics, acceptor doping, crystallographic texturing, PMN-PT, high-power applications.

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PIEZOELECTRIC DC GENERATOR THROUGH SEQUENTIAL IN-PHASE POLARIZATION VARIATION

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Abstract. Over the past decades, changing patterns in electricity generation and consumption have brought new life to the debate on the use of Alternating Current (AC) vs. Direct Current (DC) electricity supply in distributed generation systems. Direct Current is native to battery storage, low-power household and commercial applications, such as LED lighting, and consumer electronics (e.g. TV, radio, mobile phones). With an increasing reliance on these components and applications, DC systems have, in many cases, become a technically and economically viable alternative to 'traditional' AC systems. Thus, there is a growing discussion about the use of DC mini-grid in small areas.
Unlike the increasing demand for DC distribution, no concrete solution for DC power generation has been proposed so far. Considering that most power generation is made by rotating electric turbines using thermal, wind, or hydraulic energy, the kinetic DC power generating mechanism is required. In this talk, I will introduce a novel kinetic DC generation mechanism employing the piezoelectric effect. The operation principles of the piezoelectric DC generation will be discussed based on both experimental and theoretical analysis. The rotary type piezoelectric DC generator was demonstrated in real environmental applications. The piezoelectric DC generation exhibited continuous namely continuous output, no direction dependency, and high power density, and is expected to play a major role in the DC grid era.

Keywords: direct current, generator, piezoelectric effect, DC grid.

LEAD-FREE PIEZOELECTRIC POLYMER-CERAMIC FILMS FOR GREEN ENERGY HARVESTING

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Abstract. Lead-free smart piezoelectric materials hold the promise of playing a crucial role in energy harvesting devices for autonomous smart sensing systems and address major environmental challenges like reducing fossil energy consumption and battery replacement while zeroing hazardous waste.

Among emerging solutions for obtaining high-efficiency capacitors, flexible piezoelectric harvesters, and portable self-powered electronics, smart polymer-matrix composites are gaining growing attention. These materials are fabricated by properly embedding functional ceramic inclusions in a suitable polymer matrix in order to integrate the polymer's flexibility, ease of processing and high breakdown strength with the exceptional dielectric and piezoelectric properties of perovskite ceramics. A particularly promising system is made up of the poly(vinylidene fluoride) (PVDF)-$BaTiO_3$ (BT) pair, which stands out not only for its functional performance but also for the non-toxicity of both components. From previous research studies, PVDF-BT composite films containing 30 vol% of the ceramic inclusions were proven to have an optimal composition for synergistically merging the PVDF and BT properties (Padurariu et al., 2023; Craciun et al., 2023).

The main goal of this work is to compare the performance of composite films obtained through traditional solvent casting followed by hot pressing, with alternative processing methods, easier and industrially scalable, less time consuming, and with no need to use solvents: namely, melt blending and microwave heating both followed by compression moulding and direct hot pressing. A thorough multi-scale characterization was conducted to investigate the composites microstructure, morphology, mechanical behaviour, and functional properties.

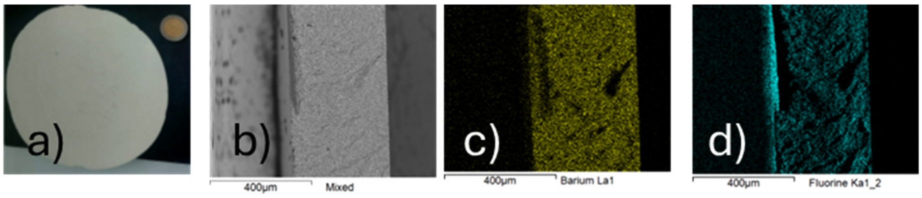

Figure 1. Picture of a composite PVDF-BT film (a), SEM image of fragile cross-section (b), and EDX mapping of Ba (c) and F (d) elements

The gathered results allowed us to identify the melt blending and microwave techniques -both solvent-free and easy-scalable- as the most suitable methods to achieve the envisaged smart materials. These techniques facilitate the formation of composite films well-suited for the subsequent poling process, which is essential for piezoelectric response and practical applications. Insights acquired so far contribute to the process optimization to achieve lead-free, highly-flexible piezoelectric composite films, thus paving the way for next-generation energy harvesting technologies.

Keywords: composites, piezoelectrics, smart materials, energy harvesting.

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THERMAL BEHAVIOR OF PIEZOELECTRIC MATERIALS

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Abstract. The increasing global energy consumption has driven the demand for advanced thermal management technologies, as a significant portion of consumed energy converts into waste heat. Thermal management have emerged as a promising solution for active and reversible control of heat flow in various applications, such as refrigeration systems, batteries, and aerospace operations. Among these, piezoelectric materials stand out for their fast response times, and durability. Studies have demonstrated mechanisms like electric-field-induced thermal conductivity changes, enabling precise heat flow control. In this presentation, the study on measuring thermal behavior changes in piezoelectric materials through the utilization of the electric field application-based thermal property measurement system is introduced.

Keywords: thermometry, piezoelectrics, thermal conductivity, thermal switching.

SYNTHESIS OF PYROCHLORE-FREE KNBT NANOPOWDERS USING A COATING APPROACH

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Abstract. Potassium sodium bismuth titanate (KNBT, $K_{0.5}Bi_{0.5}TiO_3$ – $Na_{0.5}Bi_{0.5}TiO_3$) piezoelectric composition, with its field-induced giant strain value, is a promising alternative to lead-containing systems (Quan et al., 2014; Zhou et al., 2021). During KNBT powder production, alkali ions and titanium can preferentially react and lead to the formation of pyrochlore phases. $K_4Ti_3O_8$ and $Na_2Ti_6O_{13}$ can be given as two examples of pyrochlore phases which are undesirable in piezoelectric ceramic compositions since they deteriorate the piezoelectric characteristics (Kainz et al., 2014).
In this study, a synthesis method using a coating approach that can yield to a pyrochlore-free KNBT powder was demonstrated. Powder synthesis was achieved in three steps. First, sol-gel derived TiO_2 nanoparticles (anatase, D50 ≅ 33 nm) were coated in a Bi-precursor solution (Bi@TiO_2). Then, the coated particles were suspended in a precursor solution of Na and K to form a slurry. In the last step, the slurry was dried and calcined to achieve the final powder. Preventing the formation of the pyrochlore phases was associated with the separation of alkali ions and titanium by the Bi@TiO_2 coating in the first step (Luo et al., 2007).
Calcination temperature for the dried powder was identified using DSC-TG analysis. Based on the analysis data, KNBT perovskite crystallization started at 650 °C. This value is lower than the conventional calcination temperature of 850–900 °C for KNBT-based powders prepared using the mixed-oxide method (Kainz et al., 2014; Kalem, 2016). Calcined KNBT powder was characterized using Raman, FTIR, DLS, XRD, and FE-SEM (STEM). Experimental results showed that single phase KNBT powder with an average size of ~100 nm could be produced with a single calcination treatment at 700 °C for 3 h.

Keywords: KNBT, lead-free, pyrochlore, coating method.

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VISUAL FEED BACK SYSTEM FOR ROTALY MINIATURE ULTRASONIC MOTOR DRIVEN BY LOW-ORDER VIBRATION MODE

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Abstract. In this research, we develop and control an omni directional camera system consisting of a 2 mm ultrasonic motor and a camera. The stator has a piezoelectric element attached to the backside of a metal plate with a through hole. There are four electrodes at the bottom of the stator. The rotor, which is mounted on top of the stator, has a chamfered cylindrical shape. Its top is cut at a 45-degree angle. We can observe the 360-degree surface of the wall by rotating the rotor and capturing the image from above.

The driving principle of the motor is based on exciting the bending vibration mode of the stator. When AC voltages are applied to electrodes of the piezoelectric element, a traveling wave is generated on the top surface of the stator by the combination of two bending vibration modes. At this time, the elliptical motion generated in the stator is transmitted to the rotor through friction, causing the motor to rotate. This motor achieves a torque of 0.12 μNm and a steady-state angular velocity of 15 rad/s when the input voltage amplitude is 100 Vp-p. In the visual feedback control system, a camera captures the markers attached to the rotor, allowing the PC to control the rotation angle to any desired value.

Keywords: miniature ultrasonic motor, ultrasonic motor, motor, actuator, piezoelectric element.

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MULTI-DOF ULTRASONIC MOTOR FOR NEEDLE MANIPULATORS

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Abstract. The micromanipulation of small components or cells requires compact actuators capable of precisely controlling the position and orientation of needle-shaped end effectors. For instance, in cell manipulation, cells can be finely adjusted by rotating, translating, or tilting the tip of a needle-shaped end effector. Traditionally, electromagnetic motors combined with link or gear mechanisms have been used to achieve these motions, but this approach often increases system size. In contrast, piezoelectric actuators offer advantages, such as a simple structure and precise control, enabling multi-directional motion through the appropriate design of the stator shape and vibration mode, which serve as the driving principle. For example, existing techniques use multiple annular stators to rotate a sphere in three dimensions or a rod-shaped stator to induce two degrees of freedom of motion in a plane. These motors require multiple stators or guide mechanisms to support the motion of the rotor or slider, leading to larger system sizes. By optimizing stator design, a compact multi-degree-of-freedom ultrasonic motor can be realized with a single stator, eliminating the need for guide mechanisms.

This study proposes an ultrasonic motor that simultaneously drives two sliders with a single stator, generating rotational, linear, and tilt motions. The stator, rectangular in shape, measures 10.5 mm in height, 13.0 mm in width, and 14.0 mm in length, and features a semicircular groove with a 10 mm diameter. Two semi-cylindrical sliders are inserted into the stator, each connected to a link mechanism. When AC voltages are applied to the stator, the sliders exhibit linear or rotational motion, which is transmitted through the link mechanism as rotational, linear, or tilt motion. In driving experiments, linear and tilting motions occur at 98 kHz, while rotational motions are achieved at 105 kHz. These frequencies correspond to the points where the vibration modes required for each motion are maximized, closely aligning with simulation results. The link mechanism's motion closely follows ideal kinematics; however, a slight speed difference between the sliders introduces minor errors. To address this, visual feedback control is implemented using a camera, and a control system is developed to enable the link mechanism to follow arbitrary trajectories, achieving precise motor motion control.

Keywords: piezoelectric actuator, ultrasonic motor, resonant mode, Multi-DoF actuator.

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ACTIVE TUNING OF THE RESONANCE FREQUENCY OF A TRANSDUCER UTILIZING A SYNTHETIC IMPEDANCE ON NON-DRIVEN PIEZOS

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Abstract. In terms of manufacturing technology, it is a challenge to build several ultrasonic transducers whose resonance frequencies are identical. If these ultrasonic transducers are driving a system parallel, unwanted effects can occur: If each ultrasonic transducer is driven at its individual resonance frequency, disturbing low-frequency beats can occur. If all ultrasonic transducers are driven at the same frequency, a reduction in amplitude has to be accepted, which results in a loss of performance. With help of passive electrical components, such as coils or capacitors, on non-driven piezoelectric elements, the effective stiffness and thus the resonance frequency of the ultrasonic transducer can be tuned. However, with passive elements it is not possible to actively tune the resonance frequency during the process. To overcome this issue, this study investigates how active tuning of the resonance frequency of an ultrasonic transducer during the process can be realized. The idea is to use synthetic impedances on non-driven piezoelectric elements to extend the usable shift of the resonance frequency. The first step of the study is to provide a proof of concept. Later the system will be extended so that the resonance frequency can be controlled to a desired frequency.

To implement the synthetic impedance, to get the behavior of negative resistances, inductivities, and capacities, a four-quadrant amplifier with a suited control was used. In addition to investigate the process related behavior, a load emulation was used. A model was set up and parameterized which can be used to calculate the shift of the resonance frequency and the key values at the electrical terminals as a function of the synthetic impedance using the transfer matrix method. The model was experimentally validated using different loads. The possible range for the shift of the resonance frequency was determined, which includes shifts in the positive and negative directions. Furthermore, the costs due to the synthetic impedance were estimated.

The control was extended so that the resonance frequency can be actively shifted to a desired frequency inside the possible shift range. For various synthetic impedances and loads, the control was tested and evaluated using step responses. The evaluation includes the advantages and disadvantages between the various synthetic impedances.

Keywords: active resonance tuning, synthetic impedance, load emulation, transfer matrix model.

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PIEZOELECTRIC PROPERTIES OF PZT EPITAXIAL THIN FILMS DEPOSITED BY RF-SPUTTERING

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Abstract. In a variety of piezoelectric MEMS devices, polycrystalline PZT thin films on Si substrates have been mainly used because of the compatibility of the MEMS fabrication process. On the other hand, epitaxial PZT thin films have simple crystal structures and thus it is easier to design the piezoelectric properties by controlling domain structure. In this study, we have deposited c-axis oriented PZT epitaxial thin films on ZrO_2-buffered Si substrates by rf-magnetron sputtering, and investigated their crystal structures and piezoelectric properties.

The PZT thin films with the morphotropic phase boundary (MPB) composition were deposited on the epitaxial (001) SRO/Pt/ZrO_2/Si substrates. The thickness of the PZT thin film was 2.5 µm. The polycrystalline PZT thin films were also deposited for comparison. The crystal structure was measured by XRD and epitaxy was confirmed by reciprocal space map (RSM) measurements. The dielectric, ferroelectric and piezoelectric properties were measured, and by comparing these results, the relationship between of crystal structure and deposition process are discussed.

In the RSM image around the PZT 004, spotty peaks of the PZT004/400 are observed. This indicates that the PZT thin film was epitaxially grown on the (001)SRO/Pt/ZrO_2/Si substrate. The tilted a-domain peak in a PZT tetragonal structure is geometrically caused by the 90° domain with the {101} domain wall. From the peak positions of PZT 004 and PZT 204, the lattice constants of a- and c-axes were calculated as 4.08 and 4.14 Å, respectively. It indicates that the c/a ratio is 1.015, representing that the PZT thin film has a tetragonal structure.

The relative dielectric constants (ε_r) of the polycrystalline PZT and epitaxial PZT thin films were 970 and 318, respectively. The epitaxial PZT thin films showed about 1/3 smaller relative dielectric constant than polycrystalline PZT thin films. It is attributed to the in-plane compressive stress of the epitaxial PZT thin films. The P–E hysteresis loop for the epitaxial PZT thin films was a well-saturated and square-shaped hysteresis loop, indicating that the polarization reversal abruptly occurred according to the applied electric field due to the c-axis orientation of the PZT thin films. The hysteresis curve of the sputtering PZT thin film shifted slightly toward the positive side. This asymmetric P–E hysteresis curve is attributed to the defect dipoles at the interface. In addition, the remanent polarization (P_r) of the epitaxial PZT thin film on Si substrate was measured as 48.6 µC/cm^2, which is about two times larger than that of the polycrystalline PZT thin films because of the dominant c-axis orientation with tetragonal structure.

The transverse piezoelectric coefficients $e_{31,f}$ were measured from the converse piezoelectric effect using the cantilever method. The output tip displacement of the epitaxial PZT/Si cantilever increased proportionally with the applied voltage, and the calculated $|e_{31,f}|$ values of the epitaxial PZT/Si cantilever are almost constant in the range of 14.0–14.3 C/m^2 regardless of the applied voltage. On the other hand, for the polycrystalline PZT thin film, $|e_{31,f}|$ was in the range of 7.1–9.0 C/m^2 which was smaller than that of the epitaxial PZT thin films. The larger and stabler piezoelectric properties of the epitaxial PZT thin films are attributed to the contribution of the intrinsic piezoelectric effect which can be maximized by the *c*-axis orientation. In addition, the $|e_{31,f}|$ of polycrystalline PZT showed an increment with the applied voltage. This nonlinear piezoelectric response was probably due to the extrinsic effect in the polycrystalline piezoelectric film such as the domain wall motion or the field-induced transition of crystal phases.

Keywords: piezoelectric thin film, PZT, epitaxial, MEMS.

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AN INCHWORM-TYPE MOVING ROBOT DRIVEN BY MICRO-GEARED ULTRASONIC MOTORS

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Abstract. Small creatures, such as geckos and inchworms, can easily move on slopes and walls using their light weight and specialized gripping forces like seta-based adhesion. Biomimicry seeks to emulate these efficient designs in robots, but it's hard to miniaturize actuators and motors. This size difference limits robots' ability to replicate the agile, stable movement of small creatures. This research aims to develop a robot, about 25 mm in length, comparable in size to an actual insect. The robot is driven by cubic micro ultrasonic motors, measuring approximately 2 mm per side, and integrated gears. This enables a compact and lightweight design. Micro geared motors at each joint drive inchworm-like movement by converting rotational motion into articulated bending. A planetary gear mechanism, integrated with the motor output, amplifies torque further. Both the gear mechanism and robot components were fabricated using an optical 3D printer. The assembled robot, equipped with silicone grippers, was tested on a horizontal glass surface to verify walking performance. In the future, the scaffold will be gradually inclined, and the robot will eventually be able to move on walls and ceilings.

Keywords: microrobot, ultrasonic motor, piezo actuator, inchworm, adhesion.

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TAILORING COMPOSITIONAL GRADIENTS FOR HIGH PIEZOELECTRICITY IN SOL-GEL DERIVED HETERO-LAYERED EPITAXIAL PZT THIN FILMS ON SILICON SUBSTRATE

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Abstract. We deposited epitaxial $Pb(Zr,Ti)O_3$ (PZT) thin films with a hetero-layered configuration (HL-PZT) on Si substrates using the sol-gel method and investigated the effects of the heterostructure on transverse piezoelectric properties. The HL-PZT thin films consisted of alternating PZT layers with Zr/Ti ratios of 45/55 and 60/40 (PZT(45/55) and PZT(60/40), respectively). To investigate the impact of stacking sequence on piezoelectric properties, two types of HL-PZT thin films were fabricated: HL-PZT45, where PZT(45/55) was the first layer, and HL-PZT60, where PZT(60/40) was the first layer on the substrate. These were subsequently compared to a PZT film solely stacked with Zr/Ti ratio of 52/48 layers (PZT(52/48)). It was found that distinct crystal structures evolved in HL-PZT45, HL-PZT60 and PZT(52/48), leading to variations in piezoelectric properties, despite their nearly identical overall composition. Particularly, HL-PZT45 demonstrated the converse piezoelectric coefficient ($|e_{31,f}|$) of 15.9 C/m^2 under a negative unipolar oscillation of 20 V_{pp}, which was the largest among the PZT thin films in this study. This result suggests that the piezoelectric properties of sol-gel derived epitaxial PZT thin films can be enhanced in a simple yet effective manner by optimizing the composition of PZT layers and the stacking sequence within hetero-layered structure.

Keywords: PZT thin film, epitaxial growth, hetero-layered, sol-gel, piezoelectric property, Si substrate.

NON-CONTACT MEASUREMENT SYSTEM FOR YOUNG'S MODULUS AND SHEAR MODULUS

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Abstract. For improving various products in industries, the precise measurement of material properties such as Young's modulus and shear modulus is essential. This study aims to simultaneously determine Young's modulus and shear modulus of a cylindrical metal rod by employing the resonance method, a type of dynamic testing, based on its longitudinal vibrations.

Longitudinal waves propagating in cylindrical elastic bodies are called Pochhammer–Chree waves, named after formulations by Pochhammer (1876) and Chree (1889). The propagation velocity of these waves depends on both Young's modulus and the shear modulus, and they have dispersive characteristics. At sufficiently low frequencies, where the wavelength is longer than the diameter of the cylinder, the phase velocity asymptotically approaches that of longitudinal wave propagation in thin rods. In this case, the velocity is primarily determined by Young's modulus and material density, with the contribution of the shear modulus being negligible. In contrast, at higher frequencies, the wavelength becomes shorter relative to the diameter, increasing the contribution of the shear modulus and resulting in a decrease in phase velocity. Based on this relationship, it was hypothesized that Young's modulus and shear modulus could be simultaneously determined by measuring the resonance frequencies of multiple longitudinal vibration modes, and a corresponding calculation method was developed.

In this study, the resonance frequencies of longitudinal vibrations in a cylindrical elastic rod were measured. To eliminate the influence of mechanical contact at the support points on the resonance frequencies, a non-contact excitation system was employed for the measurements. As shown in Figure 1, the system employed non-contact excitation using an Electromagnetic Acoustic Transducer (EMAT) with non-contact support achieved through near-field ultrasound generated by Langevin transducers, as developed in previous research (Tsuchida & Morita, 2024). The vibration velocity at the end face of the cylindrical rod was measured using a Laser Doppler Vibrometer. The experiments were conducted on a stainless steel (SUS304) rod with a diameter of 10 mm and a length of 100 mm.

Resonance frequencies corresponding to the 1st, 3rd, 5th, and 7th longitudinal modes were observed at 24.44 kHz, 73.00 kHz, 120.46 kHz, and 165.70 kHz, respectively (Figure 2). From these results, Young's modulus and shear modulus were calculated as 188.5 GPa and 72.9 GPa. These values are approximately 95% of the reported Young's modulus and shear modulus for SUS304 (Ledbetter et al., 1980), indicating that the proposed method is capable of reliably determining both elastic constants.

In conclusion, the results demonstrate that it is feasible to determine both Young's modulus and shear modulus simultaneously by exciting longitudinal vibrations in a cylindrical metal rod and analyzing multiple resonance modes. Future work will explore applications of this method to mechanical quality factor (Q-factor) measurements.

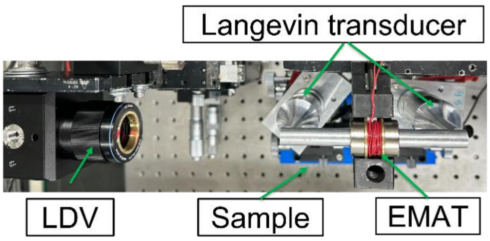

Figure 1. Image of measurement system

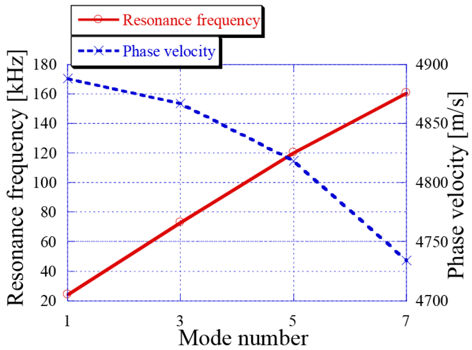

Figure 2. Resonance frequency and phase velocity

Keywords: Young's modulus, shear modulus, Pochhamer–Chree waves, EMAT.

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SCALABLE AND SUSTAINABLE EXTRUSION-BASED MANUFACTURING OF ECO-SAFE 3D-PRINTED BIOPOLYMERIC PIEZOCOMPOSITE

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Abstract. 3D printing has emerged as a viable method of fabricating custom-designed mechanical sensors and energy harvesters based on piezoelectric hybrid organic-inorganic materials (piezocomposites). Compared to conventional manufacturing techniques, 3D printing enables cost-effective manufacturing of geometrically complex piezoelectric devices with improved electromechanical properties (Li et al., 2024; Zeng et al., 2021). Fully biobased, biocompatible, and naturally biodegradable biopolymers have gained extensive attention as an alternative to fossil-based polymers in green (additive) manufacturing of eco-safe smart devices (e.g. biodegradable sensors and energy harvesters). Among them, elastomeric grades of biopolyesters polyhydroxyalkanoates (PHAs) are highly suitable as a ductile biopolymeric matrix in next-generation 3D-printed piezocomposites for various applications related to green (piezo)electronics (Siddiqui et al., 2024; Mehrpouya et al., 2021).

Solvent-based manufacturing processes are widely used in other works on piezocomposites. However, such processes are usually not cost-effective for large-scale industrial production of composites since solvents and their processing equipment are costly, many solvents are harmful to human health and the environment (Haleem et al., 2023). This work presents a solvent-free extrusion-based process for cost-efficient, scalable, and sustainable manufacturing of biopolymeric piezocomposite filaments for 3D printing by using easily accessible budget-friendly extrusion and printing equipment. The piezocomposites are filled with the widely available and moderately priced lead-free piezoceramics (barium titanate (BTO)). The implemented re-extrusion process ensures uniform distribution of high BTO fraction (≥50 wt%) within the elastomeric PHA matrix, aiming to achieve consistent printability (FFF technology) without thermal degradation, to ensure sufficient strength and ductility together with usable piezoelectric properties of 3D printed piezocomposite.

The dry mix of PHA and BTO powders was fed into a Noztek Touch single-screw extruder to fabricate the filaments, which were then pelletized and re-extruded to achieve homogenous dispersion of BTO particles and ensure consistent filament diameter (1.75 ± 0.05 mm). The filaments (with 50 wt% and 80 wt% BTO) were 3D printed to determine effective FFF parameters and to measure mechanical properties and poling-induced longitudinal piezoresponses (piezoelectric charge coefficient d_{33}). Optical microscopy was used to analyze the quality of the single-extruded and double-extruded filaments, along with printed specimens. Prusa MK3S+ was used to print specimens (ISO 527-3 standard), which were then subjected to tensile testing using Tinius Olsen H25KT machine. A quasi-static piezoelectric meter (PolyK PKD3-2000-F10N) was used to measure d_{33} values of printed piezocomposites, which were thermally poled under a wide range of electrical field intensities using short and long poling durations.

It was determined that agglomerations and voids were more prominent in the single-extruded piezocomposite filaments compared to the double-extruded filaments. During printing, the double-extruded filaments exhibited smoother melt deposition, resulting in a more uniform surface on the printed specimens. The re-extrusion had a minimal positive influence on tensile strength due to more uniform BTO distribution within the elastomeric PHA matrix. An increase in the d_{33} values was observed with increasing BTO content. The 50/50 wt% PHA/BTO piezocomposite generated only ~1.7 pC/N, while the 20/80 wt% PHA/BTO piezocomposite reached ~8 pC/N, which is among the highest d_{33} values reported in the scarce literature on PHA-based piezoelectric materials. The experimental results indicate that the developed eco-safe biopolymeric lead-free piezocomposite may be successfully applied for multi-material 3D printing of environmentally safe (either biodegradable or non-biodegradable) mechanical sensors and energy harvesters having intricate structural designs, enabling the development of more sustainable self-powered electronic devices (e.g. for environmental monitoring).

Keywords: fused filament fabrication (FFF), solvent-free, elastomeric PHA, printable piezocomposite, piezoelectric properties.

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ALTERED CURRENT PROFILES FOR PIEZOELECTRIC ULTRASONIC COPPER WIRE BONDING TO REDUCE TOOL WEAR

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Abstract. Copper wire interconnect demonstrates superior current-carrying capacity, higher mechanical strength, and more stable thermal expansion characteristics than their aluminum counterparts, making them particularly suitable for the high-power electronic component packaging applications. However, it necessitates higher loading forces and longer process time during the ultrasonic wire bonding process to achieve high quality joints, which can increase the interfacial friction and directly correlate acceleration in tool wear.

The present investigation proposes three altered current profiles for piezoelectric transducer excitation in ultrasonic wire bonding to replace conventional constant current profile, optimizing tool longevity while preserving joint quality. The three strategies include: a stepwise-decreasing constant current profile (e.g., 100% → 60% → 40% current magnitude), a two-stage profile with constant-hold and linear ramp-down magnitude, and a continuous linear ramp-down profile. The excitation current magnitude decides the transducer's vibration displacement amplitude through piezoelectric constitutive relationships, serving as the fundamental parameter of the process. In the study, experimental methodology integrates high-speed videography with advanced image processing to quantitatively analyze interfacial dynamics between wire/tool and wire/substrate interfaces. The energy flow during ultrasonic during the process under different current profiles is analyzed based on the interfacial dynamics. The bonding quality assessment is conducted by shear strength measurement.

Experimental results demonstrate that implementation of the two-stage current profile significantly reduces the accumulated relative displacement between the tool and wire without compromising joint shear strength. Its reduction in interfacial friction contributes to the reduction of tool wear. Furthermore, a two-phase bonding mechanism when using this two-stage current profile is recognized: The initial high amplitude of ultrasonic vibration displacement is critical for breaking native oxide layers and establishing primary metallic bonds, while subsequent declining vibration profiles maintain interdiffusion process with much less disrupt of formed interfaces. The study investigates on quantitative correlations between current profile parameters, interfacial dynamics, and tool wear mechanisms, providing a scientific foundation for optimizing copper wire bonding processes in power electronics manufacturing.

Keywords: piezoelectric, ultrasonic wire bonding, contact and friction, relative motion, wear reduction, image processing.

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MITRAL VALVE MODELING FOR CLINICAL APPLICATIONS

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Abstract. Mitral valve insufficiency is one of the most common cardiovascular diseases, which in many cases require open heart surgery to fix the valve and prevent further damage.

The purpose of the research is to create a simplified mitral valve model that surgeons can use to visualize the patient's anatomy in 3D, customizing the model to each patient without the need for high computing power.

In the research process a simulation in the software COMSOL was created and adjusted to ultrasound images of patients.

Results. The parametric model of the valve can be easily adjusted to the varying anatomy of the patients and use as a visualization tool for the surgeons, as the simulation can follow the movements of the valve comparable to ultrasound images.

Keywords: mitral valve model, finite element, mitral valve simulation, medical imaging.

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INVESTIGATION OF OPTIMAL DRIVING CONDITIONS FOR PARTICLE EXCITATION FLOW CONTROL VALVE USING TORSIONAL VIBRATION

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Abstract. Actuators that use pneumatic pressure as a power source are widely used in the fields of soft robotics and soft actuators (Suzumori, 2022). Research has been carried out on compact control valves that use piezoelectric elements for application in pneumatic equipment (Yun et al., 2008; Hirai & Kato, 2015). We have proposed a flow control valve using piezoelectric vibration (Hirooka et al., 2009) and are conducting research to make it smaller (Hirooka et al., 2011) and achieve proportional flow control (Hirooka et al., 2017a). In this control valve, particles act as the valve plug, and in order to open the orifice, an external force is applied to the particles by vibrating the orifice plate using piezoelectric element. As the particles are pressed against the orifice by air pressure, there is no need for a mechanism to hold the valve plug, allowing the control valve to be reduced in size. Since a piezoelectric element is used for the drive of the valve, the valve has high responsiveness (Hirooka et al., 2017b). In these studies, the direction of the piezoelectric vibration was opposite to the direction of the applied air pressure, and the vibration required for flow control needed to be large. As a solution to this problem, a driving principle that uses torsional vibration to apply a force that is orthogonal to the air pressure was proposed (Takasaki, et al., 2018). Using this driving principle, the effectiveness of applying a force that is orthogonal to the air pressure in the micro flow rate range where a gap occurs between the orifice and particles has been demonstrated (Hirooka et al., 2019). On the other hand, the conditions for the orifice to open completely could not be confirmed, and sufficient controlled flow could not be obtained. Therefore, in this study, we confirm the optimal vibration conditions for controlling high flow rates.

In this study, we use torsional vibration as vibration in a direction orthogonal to the air pressure and deflection vibration as vibration in a direction opposite to the air pressure to confirm the optimal vibration conditions for flow control. Using a prototype machine capable of generating torsional and deflection vibrations at the orifice, we confirm the conditions under which the orifice opens completely. As a result, it is confirmed that there is an optimal combination of torsional vibration and deflection vibration. The results show that it is possible to save energy in control valves by using vibrations in the optimal direction for air pressure.

Keywords: piezoelectric elements, flow control valve, pneumatic, torsional vibration, deflection vibration.

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AN ALUMINUM NITRIDE PIEZOELECTRIC THIN FILM FOR BIOSIGNAL MONITORING

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Abstract. Non-invasive biosignal monitoring is crucial for health screening and diseases prevention. Although wearable devices are well-established, technological advancements are driving the focus of the scientific community towards the development of electronic epidermal patches. Offering better measurement accuracy than wearable devices, these thin, flexible, and compact systems provide a less obstructive and more body-conforming interface, expected to improve data quality (Gao et al., 2020).

Recognizing their potential in health monitoring, researchers are investigating epidermal patches for various applications and functionalities like drug delivery, wound care, hemodynamic and metabolic biomarkers, among others (Sempionatto et al., 2021).

The objective of our research is the development of an epidermal patch designed for monitoring biomechanical parameters. Particularly, cardiovascular research focuses on blood pressure and blood flow, which are the parameters reflecting the mechanical behavior of the heart. Therefore, we aim to detect these parameters noninvasively to provide aid to the healthcare system for population screening, facilitating telemedicine applications.

To enable the epidermal patch to monitor blood vessel pulses, we need a sensor capable of detecting very small skin deformations. Thus, the proposed solution is a flexible thin-film sensor made from aluminum nitride (AlN) piezoelectric material. It has excellent physical properties, such as thermal stability, high longitudinal velocity, good dielectric and piezoelectric properties, and it is compatible with CMOS integration (Sierra et al., 2024).

To shape the sensor, a multi-step fabrication process, employing optical lithography, thin film deposition, and lift-off techniques, was adopted to achieve the result.

The fabricated sensor has a layered structure on an Upilex® substrate. A 350 nm thick AlN film, deposited via high power impulse magnetron sputtering (HiPIMS), is sandwiched between two 90 nm thick titanium (Ti) electrodes above and below it. These Ti electrodes were applied using thermal evaporation.

During the sputtering coating process, an optical emission spectroscopy (OES) probe was used to monitor the AlN deposition progress and ensure consistent coating stoichiometry. Through X-Ray diffraction analysis (XRD), the crystallographic structure was investigated, and the (002) orientation growth for the AlN piezoelectric thin film was confirmed.

Morphological and piezoelectric properties of the sensing element were studied to characterize the sensor. This investigation was carried out using an atomic force microscope (AFM) in contact mode. By measuring the piezo response at various voltages, we were able to fit the amplitude as a function of the applied voltage. This fitting yielded a piezoelectric coefficient consistent with values reported in the literature.

To conclude, the objectives of this study are to analyze the development methods for the AlN piezoelectric thin film and to show the characterization findings of the sensor.

Keywords: aluminum nitride, piezoelectric thin film, HiPIMS, sensor characterization.

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LEAD-FREE PYROCHLORE CERAMICS FOR OPTIMIZED DIELECTRIC PROPERTIES AND BREAKDOWN PROPERTIES BY GRAIN REFINEMENT APPROACHES

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Abstract. In the quest to develop high-performance dielectrics suitable for high-power applications, its microstructure engineering and understanding the effect on the property have become crucial. However, the trade-off relationship between saturated polarization and breakdown strength with respect to the average grain size complicates defining the ideal microstructure for high-performance energy storage dielectrics. In this study, we investigates the impact of the microstructure of $(Bi_{1.5}Zn_{0.5})(Zn_{0.5}Nb_{1.5})O_7$ (BZN) pyrochlore ceramics on their energy storage characteristics by adjusting sintering temperatures. Interestingly, dielectric properties, energy storage capabilities, and electrical fatigue characteristics exhibit minimal change, maintaining a high dielectric constant (~160) and a low dielectric loss ($< 10^{-4}$). Moreover, BZN ceramics demonstrate quasi-linear dielectric properties up to 250 kV cm^{-1}, with slight fluctuation in energy density as the function of grain size (1.08–1.26 J cm^{-3}). This weak dependence of energy storage on microstructure underscores that the enhancement of BZN ceramics for energy storage devices is more effectively achieved by improving breakdown strength through microstructural refinement rather than grain enlargement, which has limited impact on energy density in BZN systems. The findings from this study offer valuable insights into optimizing the microstructures of multilayer systems that are targeted at augmenting volumetric energy density, laying the groundwork for further advancements in dielectric materials.

Keywords: pyrochlore, dielectric energy storage, ceramic capacitor, microstructure, breakdown strength.

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HIGH-EFFICIENCY DEEP-TISSUE ULTRASOUND POWER TRANSFER USING PLIABLE AND BIOADHESIVE LEAD-FREE PIEZOELECTRIC RECEIVER

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Abstract. Ultrasound energy transfers have already been shown to be a promising non-invasive wireless power transfer for implantable bioelectronics recharging. Piezoelectric nanogenerators (PENGs) are an important category of hybrid/non-hybrid ultrasonic receivers, which are still being studied for their performance in wide bio-applications. However, current ultrasound-driven PENGs (US-PENGs) lack the environmental sustainability required to reduce toxicity. It is challenging to fabricate a small device that harvests adequate power output for deep tissue applications while being flexible and bioadhesive to overcome the mechanical discomfort of the body tissue and the device. To address this issue, we propose a tissue-adhesive and shape-morphing US-PENG device including highly efficient and lead-free $0.977(K_{0.48}Na_{0.52})(Nb_{0.94}Ta_{0.06})O_3$-$0.02(Bi_{0.5}Na_{0.5})ZrO_3$-$0.003BiFeO_3$ crystal-based ceramic pills for deep-tissue wireless high-power/piezoelectricity harvesting. These lead-free textured ceramics confirmed significant piezoelectric properties, including d_{33} of 540 ± 30 pC/N and ultralow d_{33} change rate at high temperatures (≤1.2% up to 335 °C), even superior to the Pb-based piezoelectric ceramics. Hereby, the fabricated device can generate a high and stable output in deep porcine tissue (up to 20 cm), comparatively under various bending conditions, and is usable for the body's curved positions. The harvested output was approximately ~3 mW_{RMS} for remote charging of a rechargeable battery at a 40 mm distance. Based on these results, power-augmented US-PENG demonstrates a feasible and stable deep-tissue wireless battery charging with flexing conditions. This work presents a new strategy for developing potential wireless energy transfers within medical safety.

Keywords: ultrasound-driven, piezoelectric nanogenerator, lead-free, flexibility, bio-adhesive, bioelectronics.

TOUCH PEN-TYPE PIEZOELECTRIC SENSOR

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Abstract. The report presents the design of a tactile piezo sensor designed to detect and preliminarily determine the intensity of ultrasonic vibrations of the object. This investigation clarifies the usage goals of touch probe sensor in particular situations, operating principle, construction, possibilities and areas of application. The goal of the research was to create a simple, lightweight and ergonomic device that enables quick (with one short touch – up to 1 s) detection and testing of ultrasonic vibrations on objects (ultrasonic concentrators, their interchangeable tips, concentrator mounting structures, device housings, etc.). This tool wasn't created for precise measurement, but for a quick and reliable detection of the points with minimum and maximum vibrations of vibrating objects and further considerations for detailed measurements. The detection range of this particular piezo sensor identifies vibrations of 20–100 kHz. This is the most commonly used range in ultrasonic vibration systems (UVS). The goal of the study was to optimize the design of probe to be reliable in this frequency range and do not enter into resonances of lower modes of the sensor's structural elements that could distort the testing results.

Keywords: piezo, electric, sensor, ultrasonic, vibrations, modal, analysis, probe, prototype.

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ULTRASONIC AGGLOMERATION OF SOLID PARTICLES IN AIRFLOW: EFFECTS OF HARMONIC AND NON-HARMONIC ACOUSTIC FIELDS AT VARYING ANGLES

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Abstract. This study presents the results of numerical and experimental investigations on ultrasonic agglomeration of fine and ultrafine solid particles in airflow, using a piezoelectric acoustic pressure source excited by sinusoidal and square-shaped electrical signals. The applied signals generated harmonic and non-harmonic acoustic fields, which were directed into the airflow at various angles. Numerical simulations demonstrated that excitation at 25.83 kHz using different signal types produced distinct acoustic field patterns and intensities. Adjusting the angular orientation of the acoustic source relative to the airflow significantly enhanced the particle agglomeration process. Experimental results revealed that square-shaped signals with a 50% duty cycle produced sound pressure levels up to 130 dB, exceeding those of harmonic signals and square-shaped signals with a 75% duty cycle by 14.1% and 9.6%, respectively. Moreover, directing the acoustic field at angles of 135° and 35° using the 50% duty cycle square signal achieved particle reduction rates of up to 42.1% for 2 μm particles and 27.2% for 0.3 μm particles. These findings confirm that both the waveform and orientation of the acoustic field are critical factors in optimizing ultrasonic agglomeration efficiency.

Keywords: ultrasonic agglomeration, piezoelectric acoustic source, non-harmonic acoustic fields, airborne particle reduction, acoustic field orientation.

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PIEZOELECTRIC BIODEGRADABLE K-CARRAGEENAN FILM FORCE SENSOR FILM

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Abstract. Organic piezoelectric materials have received significant research interest in biomedical applications and implantable biomedical devices manufacturing because of their excellent biocompatibility and biodegradability (Li et al., 2025). The biodegradable k-carrageenan-based film for force sensor demonstrates about 0.038MΩ and 0.27 ± 2 mS/cm after the crosslinking procedure. The film's sensitivity to impact was investigated by dropping the ball from defined heights (0.15 m, 0.3 m, 0.6 m, 0.9 m). Film deformation acts as a signal amplifier, then the first hit causes a change of 0.08 V, the second hit – 0.16 V, and the third hit – 0.28 V (Bučinskas et al., 2024). The GF of the film varies from 0.67 to 10.47, depending on composition, especially influenced by plasticizer concentration (Petronienė et al., 2024). Samples without plasticizer demonstrate the sensitivity changes after 120 hours (Žaimis et al., 2023). The piezoelectric and piezoresistive effect in the carrageenan film was provided by iron (III) oxide particles and their interaction with charge-transferring functional groups in the biopolymer molecule. Piezoelectric k-carrageenan-based film exhibits antimicrobial effect through the generation of an electrical field triggered by mechanical energy (Majinyari & Singh, 2025). The mechanical properties of polymer reinforced composites depend on the microstructures used and the amount, which can facilitate uniform dispersion in the matrix.

Results. Determined parameters of elaborated piezoresistive force film. The optimal proportions of ingredients have been determined. The parameters of the film meet the requirements for force film sensors. This biodegradable film converts tensile and compressive forces into measurable potential. Also, the film demonstrates a quick response to an applied constant-distance mass hit to the surface. The hit of 7 7-gram ball from a distance of 0.6 m is represented in Figure 1.

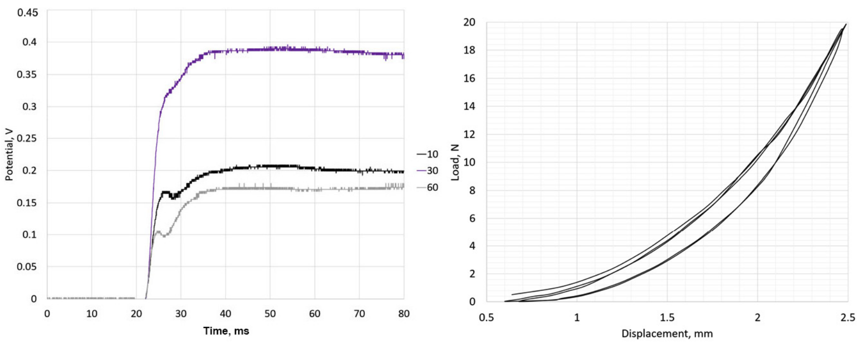

Figure 1. a – Measured potential dependence on applied force hit by ball from surface 0.1 m, 0.3 m, 0.6 m, the film response to impact in time; b – Dependence of applied force *vs* displacement of k-carrageenan film

As it is represented in Figure 1a, the k-carrageenan film reacts to the applied force hit by generating a measurable electrical potential change: in the first millisecond, we measured a potential less than 0.02V, and after 2–4 milliseconds, we measured an electric potential of opposite charge values, depending on the distance from which the ball was dropped. The influence of ball bouncing decreases with increasing applied potential energy. In Figure 1b, the dependence of applied force on displacement of the film shows low hysteresis and stability of the film.

Keywords: piezoresistive sensor, piezoelectric sensor, k-carrageenan, force sensor, biodegradable sensor, hydrogel force sensor.

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RETHINKING COMPOSITES: MATRIX-LESS CERAMIC FOAMS FOR EXTREME APPLICATIONS IN AEROSPACE AND DEFENCE

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Abstract. The increasing demand for ultralight, thermally resilient, and mechanically robust materials in aerospace and defence sectors necessitates a departure from conventional composite architectures. Our many-years study introduces a novel approach to ceramic syntactic foams – matrix-less structures composed entirely of sintered cenospheres – that radically rethinks composite design by eliminating the need for a traditional binding phase. Utilizing spark plasma sintering (SPS), these materials are fabricated as highly porous, interconnected networks of hollow ceramic microspheres, offering high strength-to-weight performance tailored for extreme environments.

The core material system a fly-ash-derived hollow ceramic microspheres – cenospheres was extensively characterised across multiple studies to evaluate thermal stability, chemical composition, morphological uniformity, and functional tunability. SPS processing parameters, particularly sintering temperature, mould geometry, and microsphere size, were systematically varied to understand their effect on densification behaviour, microstructure, and mechanical response.

Since 2017, our research has pioneered a transformative approach to lightweight structural ceramics through the development of matrix-less ceramic syntactic foams. These materials are fabricated not by embedding fillers in a matrix, but by sintering cenospheres directly, creating an interconnected porous framework. This architecture fundamentally rethinks composite design, eliminating weak interfacial zones and enabling superior strength-to-weight performance attributes essential for aerospace and defence applications.

In contrast to traditional syntactic foams or fiber-reinforced ceramics, these materials are consolidated by SPS into a monolithic, yet highly porous body. Our most recent study (Eiduks et al., 2024) demonstrated that increasing the sintering temperature from 1050 °C to 1300 °C reduced porosity from 61.5% to 3.9% and increased compressive strength from 11 MPa to 312 MPa. These results closely follow the Rice model for porous ceramics and show that the mechanical performance scales exponentially with porosity reduction. Apparent density increased from 0.64 to 2.24 $g \cdot cm^{-3}$, and samples exhibited specific strengths up to 68 $MPa \cdot cm^{-3} \cdot g^{-1}$, exceeding many fiber- and matrix-based lightweight ceramics.

Early work with clay-based ceramic syntactic foams etestablished that cenospheres enhance interface integrity, reduce stress concentrations, and promote mullite formation improving both mechanical and thermal performance (Rugele et al., 2017). More recently, embedding $CoFe_2O_4$ nanoparticles into the cenosphere structure enabled EMI shielding properties, while maintaining structural and thermal stability (Abramovskis et al., 2023). Another 2023 study (Eiduks et al., 2024) emphasized the importance of cenosphere morphology, confirming that sphericity (AR ≈ 1.1–1.3) and shell uniformity are crucial for densification and performance.

Two modes of specific strength evaluation based on $MPa \cdot cm^{-3} \cdot g^{-1}$ and the square root-based $MPa^{0.5} \cdot cm^{-3} \cdot g^{-1}$ were employed following Ashby's materials indices for lightweight design. These indices place our materials on par with advanced ceramics and even some polymer-derived composites in terms of mechanical efficiency at low densities. This highlights the dual advantage of structural strength and functional tunability, achievable via scalable, rapid SPS processing from industrial waste-derived cenospheres.

Altogether, this research direction opens a new pathway toward ultralight, thermally resilient, multifunctional ceramic components with no matrix phase, targeting applications in hypersonic vehicles, thermal shields, aerospace insulation, and electromagnetic shielding systems. Ongoing work is expanding toward graded porosity control, impact resistance, and anisotropic property tailoring, anchoring matrix-less foams as a platform technology in next-generation ceramic engineering.

Keywords: matrix-less syntactic foams, cenospheres, spark plasma sintering, specific strength, lightweight ceramic composites.

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HYBRID HIGH POWER PIEZOELECTRIC DRIVE FOR MICRO-STEPPING APPLICATIONS

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Abstract. High-power piezoelectric motors used in stabilization systems, such as spacecraft control moment gyroscopes (CMGs), must achieve nanometric resolution and ensure stable operation. During continuous operation, stabilization adjustments are performed through microscale displacements of the motor within the same contact region. This type of operation causes intensive local wear, and as a result precision and durability of the piezoelectric motor are reduced. Moreover, the wearing of the contacting surface is non-uniform along the stator, potentially resulting in unpredictable rotor accelerations or even rotor locking.

This study proposes a novel hybrid piezoelectric stabilization system that integrates a high-power inertial ultrasonic motor for rapid rotation of the CMG frame with a piezoelectric multilayer actuator that is used for high-precision positioning. The multilayer actuator is mounted on the inertial motor and serves a dual function: enabling precise micro-displacements and periodically shifting the contact zones along the stator to mitigate localized wear. Harmonic type excitation of the piezoelectric actuator induces nanometric scale displacements and allows achieving high precision motion of the system. By applying non-harmonic, pulse-type excitation to the actuator, inertial rotation of the motor is induced, enabling redistribution of the contact zones during fine-tuning operations. This approach allows previously unused, unworn stator surfaces to be employed, thereby maintaining motion precision and durability of the device.

The concept of the novel hybrid stabilization system is presented along with numerical simulations and experimental investigations. The dynamic characteristics of the inertial motor and piezoelectric actuator were studied under micro-stepping conditions at both resonant and non-resonant modes. Motor dynamics were analyzed in response to various types of electrical input signals and load conditions. Results are presented and discussed, demonstrating the feasibility of the proposed system.

Keywords: piezoelectric actuator, hybrid actuation system, precise positioning.

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LITHIUM NIOBATE FILMS FOR ELECTRO-ACTIVE DEVICES

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Abstract. Currently, $LiNbO_3$ (LN) and $LiTaO_3$ (LT) thin films are fabricated from single crystals through top-down methods such as polishing (film thickness > 400 nm) or crystal ion slicing (300 nm < film thickness < 1 µm) and wafer bonding techniques. The polishing steps in top-down LN film fabrication induce difficulties in achieving uniform & controlled film thickness, leading to inaccuracies in device response and irreproducibility making challenging their implementation for industrial-scale devices and requiring time consuming trimming steps. The direct growth of LN/LT films could offer better thickness control and homogeneity (< 1%), reduced costs in line with the ability to produce thicknesses < 250 nm overcoming limitations inherent in ion-slicing and polishing methods and to fabricate resonators with frequencies up to 24 GHz (Bartasyte et al., 2017).

The state-of-the-art control/tuning/measurement of Li nonstoichiometry in deposited LN films were addressed for the first time and the stoichiometry homogeneity of <0.05 mol% /reproducibility of high-quality LN films at 4" wafer scale (never demonstrated before) was attained by direct liquid injection (DLI) CVD (Micard et al., 2024). The Li content in the films is adjusted roughly by adjusting the Li/Nb ratio in the precursors and then the stoichiometry is finely tuned by varying other deposition conditions. Nearly stoichiometric LN films were deposited for the first time. CVD growth also assured highly homogeneous thickness on the wafer scale.

The epitaxial growth of LN films with unique orientations in the substrate plane (necessary for guided wave applications) in the case of X, Y, and Z orientations (according to IEEE convention) was optimized. In addition, we have succeeded in epitaxially growing new Y128° and Y52° orientations of LN with a single orientation in the plane of the substrate, this is the most used LN crystal orientation for RF SAW filters. We have shown a high acoustical performance (K^2 up to 8% at 5.4 GHz) in SAW devices operating in the frequency range from 3.5 GHz up to 6 GHz (Almirall et al., 2019).

In the literature, only the epitaxy/texture of the Z orientation, (not having good piezoelectric properties) on bottom electrode has been successful. We have obtained the epitaxial growth of Y33°-LN (the orientation offering optimized electromechanical coupling for thickness mode of bulk acoustic waves) on the Si substrate using an intermediate layer of $SrTiO_3$ obtained by MBE (Bartasyte et al., 2024). Furthermore, Y33°-LN film orientation was also obtained by using sputtered $LaNiO_3$ seed layer and any substrate/structure and electrode, able to withstand LN deposition conditions, can be used in this case (Bartasyte et al., 2020). However, the Si substrate was replaced by sapphire substrate in these HBAR and SMR devices in order to reduce thermal stresses and to eliminate chemical interactions of LN with Pt adhesion layers (Ta, Ti, TiO_2) and SiO_2/Si. We have demonstrated high-overtone bulk acoustic wave resonators (HBARs) employing highly coupled Y33°textured LN thin films grown via DLI-CVD (Boujnah et al., 2024). These films, with thicknesses ranging from 100 nm to 300 nm, achieved resonance frequencies between 4.5 GHz and 7.3 GHz. The fabricated solidly mounted resonators (SMRs) based on grown LN films directly on sputtered (111) Pt and SiO_2/Ta_2O_5 mirror operated at 6.96 GHz and longitudinal mode presented K^2 of 6% (Boujnah et al., 2024). Further effort was done to stabilize the heterostructures based on grown LN layers, electrodes and Si substrates by introducing new adhesion layers for Pt electrode and by stress engineering. In order to bring epitaxial LN films towards the acoustic devices requiring single crystalline LN films on standard platforms, the layer transfer process is under development. This includes epitaxial growth of LN films on LN substrates with sacrificial layer then bonding on freely chosen structure and liberation of LN film from the growth template by chemical etching.

Keywords: lithium niobate, thin films, CVD, acoustic resonators.

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LEAD-FREE PIEZOCERAMIC MATERIALS AND THEIR APPLICATIONS

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Abstract. The development of lead-free piezoelectric materials for replacing lead zirconate titanate (PZT) has been a subject of intensive research for over twenty years. Several promising material systems have been identified, and since it is extremely difficult to match the versatility of doped PZT, it is quite unlikely that one single of these will be able to take over, meaning that the future market will be much more diverse than today.

The most interesting lead-free piezoelectrics will be introduced, highlighting well-known systems such as potassium sodium niobate (KNN), bismuth sodium barium titanate (BNT-BT), and barium titanate-derived systems such as barium calcium titanate zirconate (BCTZ), as well as less common systems specialized for high power or high temperature. To simplify the comparison with PZT, a simplistic ”soft” and ”hard” classification will be used for these material systems. The second part of the talk will be an overview of applications of lead-free piezoelectric materials, recalling the most relevant properties in each case. The main categories covered will be low-power applications including medical imaging, high-power applications including various industrial piezoelectric transducers and therapeutic ultrasound, and finally high-temperature applications. Representative examples will be given, either as results from literature or as more detailed cases.

Keywords: applications, ferroelectricity, lead-free, piezoelectricity, transducers.

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PIEZO DEVICES FOR HUMAN THERAPY

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Abstract. The medical community and people with disabilities need non-invasive smart technologies and tools that can be applied to improve health outcomes. Since human organ systems work according to the laws of physiology, dynamic activation of these processes increases the therapeutic effect. The revealed characteristics of the therapeutic effect allow us to choose the most appropriate modes of ultrasound or other effects for therapy. The focus is on low-cost, portable therapy equipment adapted to the clinical and patient home environment. The results of the influence of low-frequency ultrasound acoustic waves on physiological parameters of blood are presented. These acoustic waves, manifested as pulsating positive-negative acoustic pressure in the blood, cause shear forces. These forces break up blood aggregates by separating erythrocytes into single cells and reducing blood viscosity, which lowers blood pressure and pulse rate. The surfaces of the single disaggregated erythrocytes become active for gas exchange. As a result, the affinity of hemoglobin for inhaled oxygen, which is transported to the tissues through the arteries, increases and facilitates breathing. The results of in vitro studies, confirmed by in vivo experiments, led to the creation of a human-friendly low-frequency ultrasound transducer, which, thanks to deeper and more accurate penetration of the acoustic signal into tissues, allows quickly relieve a person's condition without medication.

Keywords: dynamic activation, therapeutic effect, red blood cells, aggregation, dissociation, low-frequency ultrasound.

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