



International Workshop on Piezoelectric Materials and Applications in Actuators

*October 26-29th, 2021
7:00 am to 11:00 am EST*

Digital Agenda & Book of Abstracts

Due to the Covid Crisis IWPMA2021 is being organized as a web conference for a second time. The IWPMA-Board has decided to hold the 18th workshop in this series, as a web conference in order to give an opportunity for participation and presentation, for young scientists, who would otherwise have the risk of a delay in their career.

Special Session: *Electrocaloric Materials & Devices*

October 26th

This special session on electrocaloric materials and devices will cover the recent advances in research and development of both thin and thick film materials and their implementation in cooling technology. The topics to be presented include – Electrocaloric materials; Device architectures for cooling / heat pumping; Multiphysics coupled models for electrocaloric cooling devices; Thermal absorbers and heat sink designs for electrocaloric cooling devices; Numerical model for describing thermal circuits with respect to electrocaloric coolers; Control systems for electrocaloric cooling devices; Manufacturing approaches for subsystems; and On-chip cooling technology. Presentations will include mixture of invited (20 minutes) and contributed (10 minutes) talks.

Honorary Committee



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Acknowledgements



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Special Session - Electrocaloric Materials & Devices

October 26, 2021
7:00 am to 11:00 am EST

Electrocaloric Materials and Devices Part 1 Session Chair: Dr. Shashank Priya		
7:00 am - 7:20 am	Opening Remarks	Prof. Clive Randall
7:20 am - 7:50 am	Electrocaloric Refrigeration for a Sustainable World	Plenary Lecturer: Dr. Qiming Zhang
7:50 am - 8:10 am	Electrocaloric Cooling Systems Based on Multilayer Ceramic Capacitors (MLCCs)	Dr. David Schwartz
8:10 am - 8:30 am	Fatigue-Resistant and Giant Electrocaloric Effect at Ultralow Fields	Prof. Xiaoshi Qian
8:30 am - 8:50 am	Electrocaloric Heat Pumps	Dr. Ravi Anant Kishore
8:50 am - 9:00 am	Electrocaloric Effect of Entropy Stabilized Perovskite Thin Film	Mr. Yeongwoo Son
9:00 am - 9:10 am	Coffee Break and Discussion	
Electrocaloric Materials and Devices Part 2 Session Chair: Prof. Xiaoshi Qian		
9:10 am - 9:30 am	Piezoelectric PVDF, PVDF-TrFE Film, Sensors, and Test Instruments	Dr. Shihai Zhang
9:30 am - 9:50 am	The Role of Voltage-Driven Phase Transitions in Electrocaloric Devices	Dr. Emmanuel Defay
9:50 am - 10:10 am	Large Electrocaloric Effects in PST Multilayer Capacitors Over a Wide Range of Temperatures	Prof. Neil Mathur
10:10 am - 10:30 am	Achieving High Electrocaloric Effect Over a Wide Temperature Range	Prof. Jinghui Gao
10:30 am - 10:50 am	Solid State Cooling Devices Based on Electrocaloric Polymers	Prof. Qibing Pei
10:50 am - 11:00 am	Discussion	

Day 2: October 27, 2021 7:00 am to 11:00 am EST

Devices and Systems Part 1 Session Chair: Dr. Shashank Priya		
7:00 am - 7:20 am	Opening Remarks	Prof. Christina von Haaren
7:20 am - 7:50 am	Crystal Structure and Piezoelectricity of (Na, K) (Nb, Sb)O ₃ -(Bi, Ag)ZrO ₃ -MZrO ₃ (M = Ba, Sr, Ca) Piezoceramics and Textured Thick Films	Plenary Lecturer: Dr. Sahn Nahm
7:50 am - 8:00 am	A Double-Stator Piezoelectric Actuator with Two Driving Modes: Design and Experiments	Dr. Yun Hao
8:00 am - 8:10 am	Micro Linear Ultrasonic Motor Using a Thin Stator	Mr. Shunsuke Izuhara
8:10 am - 8:30 am	Haptic Feedback Application for Different Devices by Using the Vibration from PZT Thin Films on Stainless-Steel Plates	Mr. Patrick Bach
8:30 am - 8:50 am	Evaluation of a Transducer for Micro Actuator Using Novel Preload Mechanism Under Cryogenic Condition	Prof. Takefumi Kanda
8:50 am - 9:00 am	Fabrication and Performance Improvement of Submillimeter-Scale Ultrasonic Motor	Dr. Kohei Kikuchi
9:00 am - 9:10 am	Coffee Break and Discussion	
Devices and Systems Part 2 Session Chair: Dr. Jens Twiefel		
9:10 am - 9:20 am	Design and Test of a Piezoelectric Actuator with Bimorph Film Based for Biological Cell Manipulation	Ms. Shengrong Lin
9:20 am - 9:30 am	Design Optimization of Traveling Wave Ultrasonic Motor Using Theoretical Contact Model	Mr. Tatsuki Sasamura
9:30 am - 9:40 am	Investigations on the Mechanisms of Ultrasonic Wire Bonding via a Piezo-Based Sensor Array	Dr. Yangyang Long
9:40 am - 9:50 am	Deep Reinforcement Learning Speed Control of Travelling Wave Ultrasonic Motor	Dr. Abdullah Mohamed Arafa Mustafa
9:50 am - 10:00 am	Multiharmonic Excitation for Optimum Control of Weld Quality	Mr. Andreas Sebastian Schmelt
10:00 am - 10:10 am	Study of the Mode Shapes of Ultrasonic Sonotrode with Quasi Phononic Crystal Structure	Mr. Yongyong Zhu
10:10 am - 10:30 am	Development of High Precision Piezoelectrics Locomotion Robot for Optical Systems	Dr. Andrius Čeponis
10:30 am - 10:40 pm	Investigations Regarding the Correlation Between the Driving Signals of an Ultrasonic Transducer and the Process Data During Ultrasonic-Assisted Laser Beam Welding	Mr. Christian Nowroth
10:40 am - 10:50 am	Vibrational Energy Harvesting Using Highly Coupled LiNbO ₃ Unimorphs	Dr. Giacomo Clementi
10:50 am - 11:00 am	An Approach to Design High Power Magnetolectric Transducers for Wireless Power Transfer Applications	Dr. Sumanta Kumar Karan

Day 3: October 28, 2021 7:00 am to 11:00 am EST

Devices and Systems Part 3 Session Chair: Prof. Dr.-Ing. Jörg Wallaschek		
7:00 am - 7:10 am	Autonomous Self-healing of Fracture in Piezoelectric Organic Crystals: Crystal Engineering	Mr. Surojit Bhunia
7:10 am - 7:30 am	Bubble-Driven Micromotors: Working Principles and Fabrications	Prof. Xiaolong Lu
7:30 am - 8:00 am	Bonding and Debonding of Hybrid Engineering Materials and Structures by Power Ultrasonics	Plenary Lecturer: Prof. Frank Balle
8:00 am - 8:10 am	Proposed Design and Development of an Automated System for Ultrasonic Velocity and Attenuation Measurement Using Pulse Transmission Technique	Dr. Saurabh Singh
8:10 am - 8:20 am	Ferroelectrically Enhanced Contact Electrification Enables Efficient Elastic Wave Energy Transfer Through Various Media	Mr. Hyun Soo Kim
8:20 am - 8:30 am	Minimize Temperature Influence on Micro-Ultrasonic Motors	Mr. Mohamed M. Khalil
8:30 am - 8:40 am	An Ultrasonic Linear Motor Control Method Considering the Driving Trajectory	Mr. Qiang Wang
8:40 am - 8:50 am	Research on Low Speed Driving Model of Ultrasonic Motor Based on Beat Traveling Wave Theory	Dr. Weijun Zeng
8:50 am - 9:00 am	Temperature Compensation for Multimodal Ultrasonic Transducer's Frequency Ratio	Mr. Fangyi Wang
9:00 am - 9:10 am	Coffee Break and Discussion	
Devices and Systems Part 4 Session Chair: Dr. Tobias Hemsel		
9:10 am - 9:20 am	Experimental Investigation of the Influence of Different Bond Tool Grooves on the Bond Quality for Ultrasonic Thick Wire Bonding	Mr. Oliver Hagedorn
9:20 am - 9:30 am	Integrated Composite Transducer Design for Impacts Estimation in Thin Plates	Mr. Nicolas Whittaker
Modeling and Characterization Session Chair: Dr. Tobias Hemsel		
9:30 am - 9:40 am	Combination of a Static Finite Elements Approach and Dynamic Lumped Model for Bistable Vibration Energy Harvester Modeling	Ms. Aya Benhemou
9:40 am - 10:00 am	Effects of Design Parameters on Compression Type Piezoelectric Acceleration Sensor	Dr. Mert Gül
10:00 am - 10:20 am	Nonlinear Modelling of Piezoelectric 31 and 33 Effect Vibration Considering Higher Order Elasticity	Dr. Susumu Miyake
10:20 am - 10:40 am	VIBRO3 (Vibro-supply, Vibro-Communication and Vibro-Inspection): a Global Multifunctional System for Wireless Supply, Communication and Sensing	Prof. Mickaël Lallart
10:40 am - 10:50 am	Statistical Performance Assessment of a Bistable Vibration Energy Harvester	Ms. Camille Saint-Martin
10:50 am - 11:00 am	Multi-Dimensional Constrained Energy Optimisation Applied to Piezoelectric Harvesters	Mr. Lucas Queiroz Machado

Day 4: October 29, 2021 7:00 am to 11:00 am EST

Piezoelectric Materials and Structures Part 1 Session Chair: Takeshi Morita		
7:00 am - 7:10 am	Opening Discussion	
7:10 am - 7:40 am	Electrical Reliability of Lead Zirconate Titanate Piezoelectric Films	Plenary Lecturer: Prof. Susan Trolier-McKinstry
7:40 am - 7:50 am	Pb(Zr,Ti)O ₃ -Based Transparent Piezoelectric Devices on Glass Substrates	Dr. Sang Hyo Kweon
7:50 am - 8:00 am	Templated Grain Growth of Mn-Doped PYN-PMN-PT Piezoelectric Ceramics for High Power Applications	Mr. Dong-Gyu Lee
8:00 am - 8:10 am	The Effects of Low Melting BAO Doping on the Structure, Microstructure, Ferroelectric and Piezoelectric Properties of BCTZ Ceramics for Actuator Application	Dr. Kumar Brajesh
8:10 am - 8:30 am	Enhanced Energy Generation of Magneto-Mechano-Electric Harvester by Optimizing its Design and Concepts	Dr. Ajeet Kumar
8:30 am - 8:50 am	Energy Harvesting Concept Based on the Two Phase Flow: Pressure and Temperature Variations	Dr. Grzegorz Litak
8:50 am - 9:00 am	Low Temperature Sintering and Properties of (1-x) Pb(Zr,Ti)O ₃ -0.05Pb(Mn _{1/3} Sb _{2/3})O ₃ -xPb(In _{1/2} Nb _{1/2})O ₃ High-Power Piezoelectric Ceramics	Ms. Jingjing Shi
9:00 am - 9:10 am	Coffee Break and Discussion	
Piezoelectric Materials and Structures Part 2 Session Chair: Mickaël Lallart		
9:10 am - 9:20 am	Epitaxial Growth of Lead-Free Piezoelectric KNbO ₃ Thin Films Using Metal-Organic Chemical Vapour Deposition	Ms. Ishamol Labbaveetil Basheer
9:20 am - 9:30 am	Synthesis and Electrical Properties of Ex-Situ and In-Situ Sputtered BNT Thin Films	Mr. Arthur Hamieh
9:30 am - 9:40 am	Auxetic Partially 3D Printed Piezoelectric Structures	Dr. Etienne Lemaire
9:40 am - 10:00 am	Phase Field Modeling and Computational Study of Piezoelectric Materials and Magnetolectric Composites	Dr. Yu Wang
10:00 am - 10:10 am	Screen-Printed Low Temperature BaTiO ₃ Piezoelectrics for Integration on Eco-Friendly Substrates	Ms. Morgan McKay Monroe
10:10 am - 10:20 am	Enhanced Piezoelectric Properties of Grain Oriented (K,Na)NbO ₃ -based Piezoceramic	Dr. Yuvasree Puruthaman
10:20 am - 10:30 am	Design and Development of High-Power Piezoelectric Ceramics Through Integration of Crystallographic Texturing and Acceptor-Doping	Mr. Haoyang Leng
10:30 am - 10:40 am	In Vitro Drug Release in Gastric Mucosa Under Safe Human Temperature	Prof. Peng Hanmin
10:40 am - 11:00 am	Closing Remarks	Dr. Ying Yang
11:00 am - 11:30 am	Open Discussion	

Digital Book Of Abstracts

Special Session Abstracts

Dr. Qiming Zhang

Distinguished Professor of Electrical Engineering

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Electrocaloric Refrigeration for a Sustainable World

Plenary Lecturer (Day 1, Presentation 1)

Abstract:

Electrocaloric effect (ECE) refers to reversible temperature and entropy changes induced by variations of applied fields in insulation materials. Electrocaloric cooling emits zero greenhouse gases and EC cooling devices with large ECE materials have the promise of higher efficiency operation than the vapor compression cycle cooling technologies. The large interest in EC research in recent years owes to the findings of large ECE, i.e., $\Delta T > 12$ °C in ceramic thin films and polymers since 2006. This talk will review large ECE in ferroelectrics reported and EC cooling devices in the literature after 2006. The results reveal a key barrier in transitioning EC materials to high performance EC cooling devices: lack of EC materials that generate large ECE, $\Delta T > 5$ K, at electric fields that can be reliably operated in EC devices. This talk will present two recent EC materials breakthroughs, showing the potential of ferroelectrics in generating large ECE ($\Delta T > 10$ K) at fields for reliable operation of EC devices, which are far below the electric breakdown fields. Practical air conditioning and refrigeration require cooling systems with tons of cooling power and long operation life. The EC cooler working body is essentially electrical capacitors. A critical barrier for transiting high performance lab scale EC coolers to practical cooling systems is the electric breakdown at these large scale cooling devices. The strategies developed in the capacitor industry for mitigating electric breakdown of capacitor banks which can be used in large scale EC devices will be discussed briefly.





Dr. David Schwartz

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Electrocaloric Cooling Systems Based on Multilayer Ceramic Capacitors (MLCCs)

Invited Speaker (Day 1, Presentation 2)

Abstract:

Over the past decade, research into electrocaloric materials has yielded tremendous advances both in material performance and in the understanding of the underlying physicochemical phenomena. Nevertheless, realizations of practical cooling systems based on the electrocaloric effect have lagged, largely because of the challenges in fabricating reliable functional capacitors with electrocaloric dielectrics in sufficient volume. Such system demonstrations are needed to validate the potential of the technology and to stimulate investment to bring the technology closer to commercialization. PARC has developed several iterations of electrocaloric heat pumps based on multilayer ceramic capacitors (MLCCs) including a device that achieves a temperature lift five times greater than the adiabatic temperature change of each component MLCC. In this talk, I will give an overview of this work as well as an industry perspective on critical gaps that must be addressed to move the technology forward.

Prof. Xiaoshi Qian

Associate Professor

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Fatigue-Resistant and Giant Electrocaloric Effect at Ultralow Fields

Invited Speaker (Day 1, Presentation 3)

Abstract:

Active thermal management is the key component in numerous departments in the industry, i.e., the household air-conditioning (AC) and refrigeration, the thermal management for buildings, electric vehicles, the battery management systems, aviation and space operations etc. Electrocaloric (EC) refrigeration has shown its potential to offer GWP-free and highly efficient solid-state solution of active thermal management. However, the currently dominant materials require high electrical field to induce large cooling effect. The high-field cause issues in reliability and limits the scenario of applications. Here, we will show the recent development in PVDF-based electrocaloric polymers, which tripled the electrocaloric effect at low fields. We demonstrated that the polymer was in a loosely correlated, high-entropy state which showed a lower energy barrier for field-induced phase transition as well. The low-field, large electrocaloric effect exhibited an extended life time over one million cycles.



Dr. Ravi Anant Kishore

Research Engineer

National Renewable Energy Laboratory

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Electrocaloric Heat Pumps

Invited Speaker (Day 1, Presentation 4)

Abstract:

Vapor-compression systems are currently the most dominant heating, ventilation, air conditioning and refrigeration (HVAC-R) technology; however, the conventional refrigerants have high global-warming potential (GWP>1000). Low-GWP refrigerants have been proposed, but there are concerns related to toxicity, flammability, reduced efficiency, and increased equipment cost. Among technologies based on caloric effects, magnetocaloric heat pumps are the most explored. Unfortunately, magnetocaloric materials are typically rare-earth compounds, which are expensive and ecologically detrimental. In addition, large magnets are needed to generate required magnetic fields (2–5 T), which is currently a major practical constraint. Electrocaloric heat pumps are a promising alternative. They are based on electrocaloric effect, where a dielectric material exhibits reversible temperature change when exposed to an altering electric field. The recently reported electrocaloric heat pumps utilizing electric energy recovery cycle and heat regeneration demonstrate coefficient of performance comparable to that of vapor compression systems. In this presentation, we will discuss various aspects of electrocaloric cooling, including the working principle, the recent material developments, and the state-of-the-art devices.

Mr. Yeongwoo Son

Ph.D Candidate

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Electrocaloric Effect of Entropy Stabilized Perovskite Thin Film

(Day 1, Presentation 5)

Abstract:

Entropy Stabilized Oxides (ESOs) have garnered increasing attention as a new class of materials showing tailorable properties. ESO typically contains five or more elements in solid solution with equiatomic proportions on a lattice site; the system can be stabilized through entropy contributions, suppressing enthalpy driven phase separation.

Electrocaloric materials, which enable temperature change induced by an electric field driven entropy change, have great potential for the future compact, environmentally friendly, and high efficiency cooling technologies. This paper reports of new relaxor-ferroelectric material with the perovskite crystal structure with the intent to understand the implication of ESO-like formulations on electrocaloric responses.

In order to induce B-site disorder on the system, two different sets of B-site precursors were utilized; Hf, Zr, Ti, Nb, and Mn (Mn precursor) or Hf, Zr, Ti, Nb, and Al (Al precursor). By using conventional solid-state method, single phase perovskite $\text{Pb}(\text{Hf}_{0.2}\text{Ti}_{0.2}\text{Zr}_{0.2}\text{Nb}_{0.2}\text{Mn}_{0.2})\text{O}_3$ (Mn-ESO) was achievable, but multiphase material with a design composition of $\text{Pb}(\text{Hf}_{0.2}\text{Ti}_{0.2}\text{Zr}_{0.2}\text{Nb}_{0.2}\text{Al}_{0.2})\text{O}_3$ (Al-ESO) was obtained at 900 °C for 240 minutes conditions. After calcination, both powders were uniaxially pressed into 1-inch pellets with 20% excess Pb followed by Cold Isotropic Pressing (CIP). The pressed sample was sintered at 850 °C for 120 minutes to be used as a target. Pulsed Laser Deposition (PLD) was used to deposit Mn-ESO and Al-ESO films on a 60 nm thick (100) oriented niobium doped lead zirconate titanate seed-layer on platinized silicon. Highly (100) oriented Mn-ESO and Al-ESO film were obtained with optimized processing conditions of 1.2 J/cm² laser energy density, 10 Hz laser frequency, 175 mTorr O₃/O₂ pressure, and 630 °C substrate temperature. Al-ESO film showed frequency-independent dielectric constants of ~2000 and < 5 % dielectric loss at room temperature from 100 Hz to 100 kHz. Mn-ESO were leaky based on Positive Up Negative Down measurement (PUND), while Al-ESO showed relaxor-type ferroelectric behavior with $P_{\text{max}} \sim 47 \text{ uC/cm}^2$ at 1200 kV/cm electric field. T_{max} of Al-ESO was 190 °C and the dispersion of temperature dependent dielectric constant was reduced above T_{max} with respect to below T_{max} . An electrocaloric temperature change of the Al-ESO was derived based on Maxwell relation by using the temperature dependent polarization-electric field measurement. The measurement was conducted from -50 °C to 280 °C with a step size of 10 °C. An electrocaloric temperature change and entropy change of ~8.35 K and 5.95 J/kg*K were achievable at 190 °C, respectively.



Dr. Shihai Zhang

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Piezoelectric PVDF, PVDF-TrFE Film, Sensors, and Test Instruments

Co-Authors: H. Zhang, B. Li

Invited Speaker (Day 1, Presentation 6)

Abstract:

Piezoelectric polymer films and sheets made with polyvinylidene difluoride (PVDF) and its copolymers with trifluoroethylene (PVDF-TrFE) have been used as pressure and acoustic sensors for many years due to their mechanical flexibility, low mechanical impedance and high g_{33} values. Recently emerging applications in Internet-of-Things (IoTs), wearable electronics, large-area health monitoring, and touchscreen electronics create new market opportunities for PVDF and PVDF-TrFE piezoelectric materials.

PolyK Technologies has been developing roll-to-roll manufacturing process to produce large quantity special grades of PVDF and PVDF-TrFE piezoelectric film products, such as high optical transparency, high operation temperature $> 120\text{ }^{\circ}\text{C}$, high piezoelectric d_{31} coefficient, both high d_{31} and d_{32} piezoelectric coefficient, and thin thickness, etc. We have also focused on producing large rolls of piezoelectric film with thickness below $10\text{ }\mu\text{m}$ or above $200\mu\text{m}$ for specific applications such as medical ultrasound transducers and underwater hydrophones. Such piezoelectric film can be used to fabricate miniaturized flexible actuators for haptics feedback systems in wearable electronics, transparent pressure sensors and loudspeakers deployed in front of touchscreen, pyroelectric fingerprint sensors, as well as energy harvesting for IoTs.

PolyK Technologies have also working on the developing piezo sensor fabrication capabilities so we can provide special piezo sensors based on customers' request with quantity from a few hundred units to over 100,000 units. Such capability include surface treatment, silver screen printing or gold sputtering, lamination, attaching wires, etc.

In addition, to support the R&D in piezoelectric and dielectric materials, we also provide low-cost test instruments such as polarization loop and dielectric breakdown test system (with option to measure piezoelectric strain), four-channel dielectric measurement system (vs temperature and frequency), high voltage leakage current and TSDC test system, and capacitor charge-discharge test system.

Dr. Emmanuel Defay

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The Role of Voltage-Driven Phase Transitions in Electrocaloric Devices

Invited Speaker (Day 1, Presentation 7)

Abstract:

Caloric materials stand for a more and more convincing alternative to standard vapour compression systems for cooling, as recently suggested in the literature with for instance a colossal barocaloric effect in plastic crystals (Lloveras et al., Nat Comms. 2019) or electrocaloric prototypes with large variation of temperature (Torello et al., Science 2020). In this talk, I will focus on electrocaloric materials in which the caloric effect is triggered with an external electric field. I will then detail the role played by voltage driven phase transitions in electrocalorics. Finally, applicative aspects will be described with a focus on heat pumps and coolers that recently attracted some attention.



Prof. Neil Mathur

Professor of Materials Physics

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Large Electrocaloric Effects in PST Multilayer Capacitors Over a Wide Range of Temperatures Including Room Temperature

Invited Speaker (Day 1, Presentation 8)

Abstract:

I will describe electrocaloric multilayer capacitors (MLCs) of PST that outperform the Gd working bodies in magnetocaloric prototypes. These MLCs display large voltage-driven changes of temperature (up to 5.5 K) over a wide range of starting temperatures (over 3 K across 176 K) [1]. I will also highlight other recent work: electrocaloric cooling cycles with true regeneration via field variation [2]; quasi-indirect measurements of electrocaloric temperature change via comparison of adiabatic and isothermal electrical polarization data [3]; and a review article on magnetocaloric, electrocaloric and mechanocaloric effects [4]. [1] Nature 575 (2019) 468. [2] PRX 9 (2019) 041002. [3] APL Materials 9 (2021) 010701. [4] Science 370 (2020) 797.

Prof. Jinghui Gao

Professor

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Achieving High Electrocaloric Effect Over a Wide Temperature Range

Co-Authors: Yang Yang, Zhonghua Dai, Ming Wu, Xiaobing Ren

Invited Speaker (Day 1, Presentation 9)

Abstract:

Electrocaloric effect, originating from field-induced polarization switching and the associated entropy change in ferroelectrics, has attracted significant attention in recent years due to its potential in solid-state refrigeration. A major challenge for applying such effect for actual solid-state refrigeration is that significant electrocaloric effect can only be achieved over a very narrow temperature range around the Curie temperature (T_c) of the ferroelectric material, and this drawback limits the usefulness of such effect. In this talk, we report several strategies to achieve high electrocaloric effect over much wider temperature range. Firstly, by fabricating a laminated material consisting of a series of tricritical ferroelectrics, we obtained a stable electrocaloric effect from 30 °C to 85°C in a BaTiO₃-based ceramic system; it is ascribed to successive occurrence of tricritical transition at different layer of the material so that high electrocaloric effect is maintained over a broad temperature range. Secondly, by designing a crossover composition region between tricritical transition and relaxor transition, we obtained an electrocaloric temperature change above 0.45 K over a wide temperature range of 21 K in a BaTiO₃-based ceramic. Microstructure observation and phase field modeling suggest such an effect arises from temperature-sluggish polar nano-regions with multiple crystal symmetries. Thirdly, by manipulating acceptor defect dipoles through aging we are able to broaden the temperature range to ~ 75°C with only 10%-25% reduction of the effect from the peak value. These strategies may help to overcome the bottleneck issue with electrocaloric refrigeration.



Prof. Qibing Pei

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Solid State Cooling Devices Based on Electrocaloric Polymers

Invited Speaker (Day 1, Presentation 10)

Abstract:

Electrocaloric cooling is a solid-state cooling technology, directly converting electrical energy for heat pumping. Major progress are required in device temperature lift, specific cooling power, and coefficient of performance (COP) before the material advantages could be fully utilized. We have developed solution processes to fabricate poly(vinylidene fluoride-trifluoroethylene-chlororfluoroethylene) terpolymer thin films and electrocaloric film stacks. Several EC cooling device designs with compact and flexible form factors have been investigated to transfer heat between a heat source and heat sink, with the ultimate objective to pave the way for new applications that cannot be obtained using existing technologies.

Day 2 Abstracts

Dr. Sahn Nahm

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Piezoelectric PVDF, PVDF-TrFE Film, Sensors, and Test Instruments

Co-Authors: Dae-Su Kim, Su-Hwan Go, Jae-Min Eum, Hero Kim, Seok-June Chae, Sun-Woo Kim, Eun-Ji Kim, Jong-Un Woo, and Sahn Nahm

Planery Lecturer (Day 2, Presentation 1)

Abstract:

It has been reported that the piezoelectricity of (Na, K)NbO₃ (NKN)-based piezoceramics can be improved through the formation of multi-structure with nanodomains. The largest value of d_{33} (650 ± 20 pC/N) has been reported for NKN-based piezoceramics with an R-O-T multi-structure and nanodomains. The reactive template grain growth method is another useful technique for increasing the piezoelectricity of NKN-based piezoceramics. The NaNbO₃ templates have generally been used to texture the grains of the NKN piezoceramic along the [001] direction. A significantly large d_{33} value of 700 pC/N from a [001]-orientated NKN-based thick film has been reported.

In this study, the crystal structure, domain structure, and their effects on the piezoelectricity of the (Na, K)(Nb, Sb)O₃-(Bi, Ag)ZrO₃-MZrO₃ (NKNS-BAZ-MZ) (M = Ba, Sr, Ca) piezoceramics were investigated. Moreover, the effect of crystal structure on the piezoelectric properties on the textured NKNS-BAZ-MZ thick films has also been discussed. The NKNS-BAZ-MZ piezoceramic, which has the R-O-T multi-structure and nanodomains with relaxor properties, showed a high d_{33} value (680 ± 10 pC/N). Moreover, the [001]-textured NKNS-BAZ-MZ thick film exhibited very high d_{33} values (780 ± 20 pC/N). Therefore, the NKNS-BAZ-MZ piezoceramics and textured thick films showed excellent d_{33} values that are higher than the maximum d_{33} values reported in the literature for similar materials.



Dr. Yun Hao

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A Double-Stator Piezoelectric Actuator with Two Driving Modes: Design and Experiments

(Day 2, Presentation 2)

Abstract:

In this study, a non-resonant piezoelectric actuator based on double stators is proposed to be used for some specific precision positioning fields, where a smooth motion without slipping, low speed with a large stroke, and high positioning resolution are required at the same time.

The proposed actuator can work stably under two driving modes of walking and angled pushing when sinusoidal and triangle waveform voltages were applied to the piezoelectric stacks on the double stators, respectively. A prototype of the actuator is fabricated to evaluate the output characteristics of two driving modes through a series of experiments. The experimental results indicate that under the walking mode, a maximum thrust of 3.1 N was obtained at a voltage of 50 V_{p-p}, driving frequency of 100 Hz, and preload of 8.6 N; With increasing driving frequency from 10 to 500 Hz, the no-load speed of the slider increases from 0.06 to 1.2 mm/s under the walking mode and 0.007 to 0.3 mm/s under the angled pushing mode; At an applied voltage of 50 V_{p-p} and a driving frequency of 10 Hz, the actuator can realize a stepping displacement ΔL of 1.8 and 0.6 μm under the walking and angled pushing modes, respectively. This actuator is expected to be applied to high-precision positioning fields.

Mr. Shunsuke Izuhara

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Micro Linear Ultrasonic Motor Using a Thin Stator

(Day 2, Presentation 3)

Abstract:

The miniaturization of camera modules is required to meet the rising demand for thinner and more compact structures in various fields, such as cellphones, drones, and endoscopes. For example, a camera module for endoscopes must be designed to be miniature because the diameter is strictly limited by their specifications. In these, miniature linear actuators play an important role in controlling optical systems, such as zoom and autofocus features, to allow camera modules to obtain clearer images. It is difficult to satisfy both requirements, a smaller size and the desired thrust force, simultaneously owing to the decrease in the energy density. In this study, we present a miniature linear ultrasonic motor. The size of the prototype stator with piezoelectric elements measures 1.6 mm in height, 1.6 mm in width, and 0.3 mm in depth (the length in slider travel direction). There is a hole of 0.6 mm in diameter at the stator center, and the slider inserted into the hole moves back and forth when voltages are applied to the piezoelectric elements. A maximum motor thrust force of 8.5 mN has been obtained when voltage amplitude is 140 Vp-p, which is a practical force for moving small objects, such as small lens.



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Haptic Feedback Application for Different Devices by Using the Vibration from PZT Thin Films on Stainless-Steel Plates

Co-Authors: Isaku Kanno

Invited Speaker (Day 2, Presentation 4)

Abstract:

The purpose of this research is to develop a haptic feedback application by using PZT thin films. In the earlier experiment with a unimorph cantilever of PZT thin films on stainless-steel, we were able to generate vibrations that could be felt in a low frequency range with an input voltage of 12 V. For this reason we decided to improve our previous PZT thin film unimorph cantilever for a better stimulus on the human skin. These haptic feedback is generated by vibrations of PZT thin film unimorph actuators. The used stainless-steel plates for the PZT thin film have a base size of 20 mm x 20 mm and a thickness of 30 μm and 100 μm , on which 3 μm thick PZT thin films were deposited by rf-magnetron sputtering. The vibration frequency is adjusted to around 200~380 Hz which is suitable for the tactile stimulus to human skin.

We fabricated two types of the vibrators, as shown in Fig. 1 and Fig. 2. The type in Fig.1 is a 30 μm thick stainless steel spring with a PZT thin film on the upper side. Fig.2 shown a 100 μm thick stainless steel plate with a PZT thin film on the upper side. In both cases we are able to generate vibrations that can be felt in a frequency range between 200 Hz and 380 Hz. The Input voltage was 12 V and we used a sinusoidal and rectangular input signal form on the different upper electrodes. For the vibrator in Fig. 2, we measured a displacement of 3.5 μm at a frequency of 280 Hz, while at the resonance frequency of 1950 Hz a displacement of 44.6 μm was reached. Next, we tested the tactile stimulus of these vibrators by touching on the backside, with different persons. All of this person's confirmed a clear feeling of the vibration. But the best frequency for the clearest feeling was different for each person, these frequencies are between 250 Hz and 361 Hz.

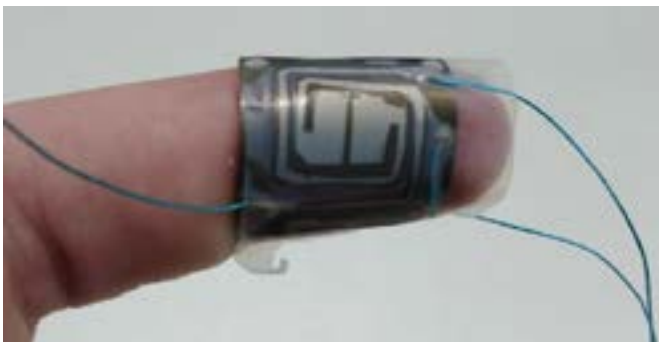


Figure 1 .: Stimulus testing of a PZT thin-film on a 30 μm thick stainless steel spring

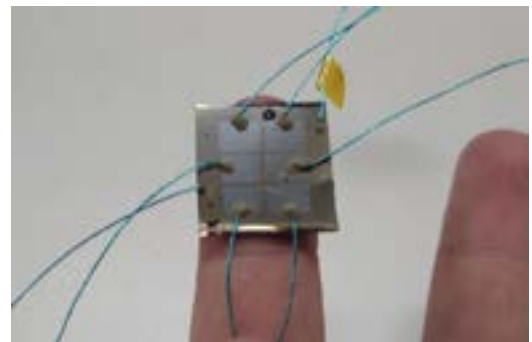


Figure 2 .: Stimulus testing of a PZT thin film on a 100 μm thick stainless steel plate

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Evaluation of a Transducer for Micro Actuator Using Novel Preload Mechanism Under Cryogenic Condition

Invited Speaker (Day 2, Presentation 5)

Abstract:

Recent years, there is a great demand for a micro actuator which can be driven under ultralow temperature condition. For example, a manipulation in the measuring instruments under cryogenic condition needs a micro actuator to control the manipulator. The fuel hydrogen system needs valves driven by small actuators under liquid hydrogen temperature.

In some previous works, we proposed ultrasonic transducers which can be used in cryogenic condition and succeeded in driving piezoelectric actuators including some ultrasonic motors under cryogenic environment. Although a piezoelectricity of piezoelectric material decreases in cryogenic condition, we used the structure of Langevin type transducer and the preload was applied by clamping the piezoelectric elements with a bolt to obtain higher vibration performance. However, the structure using bolt needs larger volume and it is difficult to miniaturize the transducer. In this study, an ultrasonic transducer for micro piezoelectric actuator using novel preload mechanism under cryogenic condition has been proposed and evaluated. The purpose of this study is to realize the ultrasonic transducer for the micro piezoelectric actuator.

We have proposed a simple structure for applying preload under cryogenic condition to miniaturize the transducer. As a temperature decreases, the preload is applied on the piezoelectric elements by the difference of the thermal expansion coefficients between the metallic and ceramics materials. We have estimated the preload value by formulas and the finite element method. By the simulation with the finite element method, the result shows that the preload is applied effectively to drive the transducer under the cryogenic condition.

We have fabricated and evaluated the proposed type of transducer. The prototype is a longitudinal vibrator and has a length of 40 mm. PZT elements and copper electrodes are fixed by titanium blocks and a frame-like part made of stainless steel. The fabricated transducer was installed in the chamber filled with helium gas. The chamber was cooled by a cryogenic refrigerator. The chamber has an optical window for the measuring using laser instruments. The relationship between admittance gain, phase and frequency has been measured under the room temperature, 300 K, and cryogenic condition, 4.5 K. Additionally, the vibration velocity at the tip of the transducer has been measured by using a laser Doppler vibrometer. Those experimental results show that preload by the thermal stress has been applied successfully by the proposed structure.



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Fabrication and Performance Improvement of Submillimeter-Scale Ultrasonic Motor

(Day 2, Presentation 6)

Abstract:

Micromotors have contributed significantly to the development of many of today's devices such as electronics, aerospace, and medical devices. Then, further miniaturization of motors and higher powers could lead to the advancement of new devices. Against this background, micro motors with various driving principles are developed. However, the scaling of the physical effects and the limitations of manufacturing and assembly limit their deployment in the sub-millimeter scale. The high torque density of ultrasonic motors has a characteristic that gives them an advantage when miniaturized. In addition, the very simple structure has the potential for further miniaturization. In this paper, to enable microfabrication and the design in the next generation of micromachines, ultrasonic motors that can be miniaturized to sub-millimeter scale are being designed and experimentally evaluated. The prototype motor is cubic of a side length of 0.42[mm] and achieves a rotation speed of 700[rad/s].

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Design and Test of a Piezoelectric Actuator with Bimorph Film Based for Biological Cell Manipulation

(Day 2, Presentation 7)

Abstract:

In order to better meet the application requirements, such as positioning accuracy and stability in the application of ultra-precision manufacturing and biomedical engineering, a piezoelectric actuator was presented with two vibrators consisting of the bimorph film for the first time that can generate linear motion by inertial impact principle. The drive unit with the bimorph thick film made by the MEMS fabrication processes obtains the low stiffness of bimorph, which allows the actuator to use small tip mass to generate enough driving force. As a result, this simple structural design can effectively increase the motion stability, resolution, and displacement linearity for the actuator. Based on the superior performances above, cell manipulation is carried out with the designed prototype to simulate the process of cell drug injection. The experimental results show that the actuator has a good application prospect in the field of cell manipulation.



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Design Optimization of Traveling Wave Ultrasonic Motor Using Theoretical Contact Model

(Day 2, Presentation 8)

Abstract:

Traveling wave ultrasonic motor (TWUSM) relies on the friction to convert piezoelectric vibration to rotational motion. Meanwhile, the friction also causes energy loss and abrasion, which result in low efficiency and short lifetime. By overcoming these shortcomings, the application area of the TWUSM can be expanded. One promising approach to achieve this is modifying the design of TWUSM to optimize frictional contact. In this study, we examined the frictional contact distribution while changing the elasticity of the rotor using linear spring contact model. Using this simulation model, preload distribution, friction distribution, contact states (slip or stick), frictional loss and abrasion are analyzed with varying elasticity of rotor in normal and tangential direction.

With small load torque, the simulation results show that the driving efficiency is minimized with relatively low normal elasticity and high tangential elasticity. In contrast, with large load torque, the driving efficiency is minimized with high normal elasticity and low tangential elasticity. Therefore, it was found that the rotor should be designed according to the expected load torque.

Additionally, the structure of the rotor which realizes designed elasticity property was automatically generated using the optimization algorithm and finite element analysis software. These designed rotors are under manufacturing for future experiments.

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Investigations on the Mechanisms of Ultrasonic Wire Bonding via a Piezo-Based Sensor Array

(Day 2, Presentation 9)

Abstract:

Ultrasonic wire bonding is a widely applied interconnection technology. Despite its long-term and wide applications, the mechanisms are still not completely understood. The main reason is the enclosed bonding interface which is invisible. In the past, sensors have been applied to measure the force and temperature changes during the bonding process so that the underlying mechanisms can be deduced. However, these sensors can only measure the average force or temperature over the whole interface while the mechanisms take place differently at different locations of the interface.

In this work, a piezo-based sensor array was designed, manufactured, characterized and was then used to measure the tangential stress over the bonding interface during the bonding process. The sensor array consists of 12 piezo columns which were diced from a d15 shear plate. Epoxy was then used to fill the space so that the wire material will not get stuck in. The coupling effect among these columns was measured with a micro system analyzer. Finally, aluminum wire bonding was processed on the sensor array for the tangential stress measurement. The results show that substantial friction took place at all the 12 different locations and the friction force varied to a large extent. The change of the tangential stress indicated the change of friction status, oxide removal, microweld formation and breakage. The gained knowledge provides a potential to improve the bonding quality.



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Deep Reinforcement Learning Speed Control of Travelling Wave Ultrasonic Motor

(Day 2, Presentation 10)

Abstract:

Ultrasonic motors (USMs) possess superior features compared to their electromagnetic counterparts in terms of their high compactness, lightweight, high energy density, and high speed at low torque. However, due to the inherent nonlinearity of USMs, their modeling and control can be challenging. The nonlinearity of USMs is a result of the nonlinearity of the piezoelectric material, as well as the nonlinearity of the contact model between the rotor and the stator. As a result, USMs exhibit nonlinear speed response, speed hysteresis (change in speed response based on frequency sweep direction), and pull-out phenomena (sudden drop in speed after reaching maximum speed). The use of an off-the-shelf linear controller (i.e. Proportional Integral Derivative (PID) or Linear Quadratic Regulator (LQR)) can thus lead to suboptimal behavior in terms of response time and stability. Additionally, these controllers are tuned based on the linearized model of USM which is only accurate within a narrow operation region. As a result, they would lack robustness under changing operation conditions like temperature, torque, or preload. The nonlinearity can be compensated through nonlinear controllers (i.e. Model Predictive Control (MPC), Iterative LQR (ILQR), fuzzy controller, or neural networks). Designing these controllers requires a relatively accurate model of USM as in MPC or LQR and expert knowledge to develop fuzzy rules or to train a supervised neural network.

Thus, there is a need for a controller that can address the nonlinearity of USM without the need for a complicated model, expensive online calculation, costly controller design, or compromising on the optimal behavior. One possible candidate that meets these requirements is a Reinforcement Learning (RL) controller. RL can be used to design a model-free controller by simply interacting with the environment. To design an RL agent (controller), the following should be defined; the input state (s_t), the output action (a_t), and the reward (r). The objective of an RL agent is to find the policy that maximizes the expected reward. The policy ($\pi_{\theta}(a_t | s_t)$) is a mapping from a state to action. In the case of continuous state space and a continuous (or discrete) action space, a deep neural network parameterized by weights θ can represent the policy. Consequently, Deep Reinforcement Learning is empowered by the flexibility of neural networks without explicit supervised learning. Training the policy (π_{θ}) is carried out by collecting sample trajectories generated by interacting with the environment. At a given state (s_t), an action (a_t) is taken; as a result, a new state (s_{t+1}) is realized and a reward (r_t) is received. An experience buffer records these sequences, where a sequence is defined as (s_t, a_t, s_{t+1}, r_t) . A batch of these sequences is used to improve the policy through gradient ascent to maximize the expected reward. The improved policy is applied to generate new trajectories and reiterate the process until the policy converges to an optimal behavior.

(Continued on next page.)

Deep Reinforcement Learning Speed Control of Travelling Wave Ultrasonic Motor (Continued)

(Day 2, Presentation 10)

To validate the feasibility of DRL for USM speed control, a simplified equivalent circuit model (ECM) of USM was developed. The ECM captures the nonlinearity of speed response. The hysteresis and pull-out phenomena were hardcoded by setting the speed to zero after a threshold frequency. The simulation model isn't required to match the motor behavior quantitatively but qualitatively. To apply RL for speed control of USM, the input state (s_t) was defined as a vector of the current frequency (f_t), the current temperature (T_t), the current speed (V_t), and the target speed ($[V_{ref}]_t$). This state definition has a minimal number of states to satisfy the full observability of the system and thus satisfy the Markovian property. The output action (a_t) was defined as a continuous frequency step ($[(\Delta f)]_t$), and it was bounded between $-2/+2$ kHz. The reward (r_t) was defined as the negative of the absolute speed error ($-|V_{err}|$). A Soft Actor Critic (SAC) agent was trained due to its sample efficiency, learning stability and its robustness to measurement noise. The agent was trained for 500 episodes, each of which had 30 steps. The trained agent has a fast response due to its variable optimized step size, and it can track varying target speeds under continuous drift in temperature. The same approach was applied to a Shinsei USR60 motor where the frequency was controller through a function generator, and the speed was measured by an encoder. The communication between the controller (PC) and the environment (USM) was carried out using an RS232 connection. The trained agent in the simulation was used as an initial policy, and then it was further trained throughout the experiment. The final agent has a fast response with low tracking error and robustness towards the motor's nonlinearity.

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The Determination of Tilted Planes in a Sound Field with the Spec-Radiation Method

Co-Authors: J. Twiefel

(Day 2, Presentation 11)



Abstract:

In non-destructive testing with air-coupled ultrasound, the sound waves are often sent at an angle to a panel-shaped material. This serves to excite special types of waves in the panel material, or to avoid standing waves between the transmitter and the panel material. In most cases, the panel material is tilted. With a surface scan, a receiver is then used to measure a plane parallel to the transmitter. Starting from this measurement plane, the sound field parallel to the receiver plane can be determined using the methods of ultrasonic holography. The tilt of the panel material leads to inaccurate results when determining a parallel plane. By directly calculating the Rayleigh-Sommerfeld diffraction integral or by calculating many parallel planes and then picking them out, the information of the tilted plane can be determined better, but this results in a very high time expenditure. The extension of the spec-radiation method presented here allows the tilted plane to be determined by rotating the sound field in Fourier space. This procedure allows a fast determination of the tilted plane. In this presentation we show the influence of the rotation of the sound field in Fourier space on the Ewald sphere using the example of an ultrasonic transmitter. This method also allows solving a wide variety of problems where the sound field information on tilted planes is of interest.



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Study of the Mode Shapes of Ultrasonic Sonotrode with Quasi Phononic Crystal Structure

(Day 2, Presentation 12)

Abstract:

Hot embossing is widely used in the production of polymer optical components and microfluidic components due to its simple process and high embossing quality. In the last two decades, ultrasound has been increasingly used to assist in manufacturing. Ultrasonic assisted embossing has the advantages of less energy consumption, shorter processing time, and suitability for embossing structures with large aspect ratios compared to hot embossing.

Sonotrode is an important part of the ultrasonic vibration system. The uniformity of the vibration of the sonotrode at the working surface has a great influence on the embossing quality. Modal coupling is the main reason for the uneven vibration of the working surface. This means that the sonotrode resonates in other modes in addition to the longitudinal mode. In this study, we will use quasi-phononic crystals to design the sonotrode. From previous studies, it is known that the geometry can be adjusted as well as the structure of the phononic crystal for a generating band gap. The idea is to use a periodic structure (quasi-phononic crystal) to create a band gap for transverse vibration, while the longitudinal vibration frequency of the sonotrode falls within this band. Thus, the influence of other modes on the longitudinal vibration can be reduced to achieve a more uniformly vibrating working surface.

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Development of High Precision Piezoelectrics Locomotion Robot for Optical Systems

Invited Speaker (Day 2, Presentation 13)

Abstract:

The paper represents numerical and experimental investigations on a piezoelectric robot that can provide rotary and planar motion of the payload. The design of the robot is based on a single PZT-8 piezoelectric ring and a triangular-shaped passive layer made from stainless steel. Both parts are glued together to form a bimorph structure. Three alumina balls are placed on the top of the piezoelectric ring and arranged by an angle of 120 degrees. Balls are in contact with the spherical payload and rotate it about three axes. Similarly, the other three alumina balls are glued to the bottom of the passive layer plate and allow the hole structure itself to move in the plane. Finally, the top electrode of the ring was divided into six equal sections in order to have the possibility to control the rotation of the spherical payload and locomotion in the plane. A single harmonic signal is used for the excitation of the piezoelectric robot, and the third radial vibrations mode of the piezoelectric ring is employed to generate rotary and planar motion. Motion control is performed by switching electric signal to the particular electrode of the piezoelectric ring.

A numerical investigation was performed to validate the operation principle of the robot as well as analyze electromechanical characteristics. Modal-frequency analysis showed that the modal shape with the dominant third radial vibration mode of the piezoelectric ring is obtained at the frequency of 47.18 kHz. The time-domain study showed that displacement amplitudes and motion trajectories of contact points are suitable for planar – rotary motions generation at different mechanical loads. Prototype of the piezoelectric robot was made, and an experimental study was performed to validate the operating principle and results of numerical modeling. Moreover, the investigation showed that the robot's maximum planar velocity is 5.63 mm/s while the maximum angular speed is 15.21 RPM. Resolution measurement showed that the robot can achieve an angular resolution of 28.25 μ rad and a linear resolution of 17.87 μ m.



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Investigations Regarding the Correlation Between the Driving Signals of an Ultrasonic Transducer and the Process Data During Ultrasonic-Assisted Laser Beam Welding

Co-Authors: C. Nowroth, J. Grajczak, S. Nothdurft, J. Hermsdorf, J. Twiefel, S. Kaierlek, J. Wallaschek

(Day 2, Presentation 14)

Abstract:

The quality of welds can be improved if the welding process is superimposed with vibration. Previous investigations have been carried out at frequencies from a few hundred hertz up to 20 kilohertz. The advantages consist in the better mixing of the melt pool, the breaking of dendrites and thus a finer grain structure.

This submission describes investigations made on circumferential welds on round bars as part of the Special Research Project 1153 (Tailored Forming) of the German Research Foundation. The laser beam welding process is superimposed with a longitudinal vibration of nearly 20 kHz. The focus is on the information that can be drawn from the operating signals of the ultrasonic transducer.

The impedance, which is formed from the current and the voltage signal of the transducer, shows a correlation with the laser power. The assumption is that with the laser power, the size of the melt pool increases and the impedance also increases due to the amount of liquid metal. For this purpose, investigations were carried out under different parameter configurations. The correlation between the impedance and the process data during laser beam welding provides a possibility for process monitoring. Here the concept is discussed and first results are presented.



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Vibrational Energy Harvesting Using Highly Coupled LiNbO₃ Unimorphs

(Day 2, Presentation 15)

Abstract:

Recently the implementation of piezoelectric materials for vibrational energy harvesting has become more prominent, as well as the need of finding an alternative to Pb-based ceramics for industrial upscaling. Among lead-free materials, the well-known LiNbO₃ has not been consistently explored for energy harvesting, although it is a cheap piezoelectric material without toxic elements, and it benefits of technological maturity in single crystal fabrication for optical and acoustic applications. In this paper, we propose to investigate a (YXlt)/128°/90° LiNbO₃ crystal orientation as it offers an improved piezoelectric coupling comparable to that of commonly used PZT ceramics. A unimorph cantilever with tip mass was fabricated using a commercial 500 μm thick LiNbO₃ wafer on silicon. LiNbO₃ and Si wafers were bonded by means of mechanical thermo-compression of Cr/Au layers. The LiNbO₃ wafer was subsequently thinned by polishing and lapping steps to an overall thickness of 30 μm. The harvester was studied under 0.1 g sinusoidal acceleration and presented an open-circuit resonance frequency of 105.9 Hz. In the frame of single degree of freedom lumped model with rectifying bridge, the electromechanical coupling of the device (k^2), the figure of merit $k^2 Q$ and the normalized average power density were compared to both Pb-based and Pb-free current devices. The generated power density by our device was 965 μW/cm²/g², which is among the highest reported values compared to both Pb- and Pb-free vibrational harvesting devices.

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An Approach to Design High Power Magnetolectric Transducers for Wireless Power Transfer Applications

Co-Authors: Rammohan Sriramdas, Sujay Hosur, Na
Liu, Mehdi Kiani, and Shashank Priya

(Day 2, Presentation 16)

Abstract:

At the present time Internet of Things (IoT) is driving the development of new generation of sensors, communication components, and power sources. Magnetolectric transducers (ME) are more efficient in converting low-frequency magnetic fields into electric fields for wireless biomedical implantable applications. The low-frequency magnetic fields are less harmful to the human body and can penetrate easily through different lossy media. The fabricated transducer comprised layers of amorphous magnetostrictive material and piezoelectric material interacts with an external magnetic field to generate electrical energy. A comprehensive analytical model of the transducer, operating in the longitudinal-transverse mode, is presented, describing both temporal and spatial deformations. The smallest fabricated device (75 mm³) generated ~0.37 mW power at 11 k Ω external resistance at 100.2 kHz frequency can be used for wireless power transfer applications.

Day 3 Abstracts



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Autonomous Self-healing of Fracture in Piezoelectric Organic Crystals: Crystal Engineering

(Day 3, Presentation 1)

Abstract:

Stress-accumulated electrical charges close wounds in living tissue, yet to-date this piezoelectric effect has not been realised in self-repairing synthetic materials which are typically soft amorphous materials requiring external stimuli, prolonged physical contact and long healing times (often >24h). Here we overcome many of these challenges using piezoelectric organic crystals, which upon mechanical fracture, instantly recombine without any external direction, autonomously self-healing in milliseconds with remarkable crystallographic precision (Figure 1). Atomic-resolution structural studies reveal that a 3D hydrogen bonding network, with ability to store stress, facilitates generation of stress-induced electrical charges on the fractured crystals, creating an electrostatically-driven precise recombination of the pieces via a diffusionless instant self-healing, as supported by spatially-resolved birefringence experiments. Perfect, instant self-healing creates new opportunities for deployment of molecular crystals using crystal engineering principles in robust miniaturised devices, and may also spur development of new molecular level repair mechanisms in complex biomaterials [1].

[1] Bhunia S, Chandel, S., Karan, SK., Dey, S., Tiwari, A., Das, S., Kumar, N., Chowdhury, R., Mondal, S., Ghosh, I., Mondal, A., Khatua, BB., Ghosh, N., Reddy, C. M. Autonomous self-repair in piezoelectric molecular crystals. (2021) *Science*. 373 , 321-327
Keywords: Self-healing in Piezoelectric, Crystal Engineering, Mechanical Property, Fracture Mechanics

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Bubble-Driven Micromotors: Working Principles and Fabrications

Invited Speaker (Day 3, Presentation 2)

Abstract:

Microrobots that could perform precise manipulations in micro/nano scale have attracted tremendous attention in past decades for helping human beings to explore the unknown nanoworld. Among several representative geometries of micromotors, tubular micromotors have aroused scientific concerns for their unique structural asymmetry featured with different inner and outer surfaces, therefore hold considerable promise for diverse applications. However, the interactions among individual tubular micromotor and the collective behavior of such assembled group have been rarely exploited because of the comparatively fast motions coupled with immense disturbance flow around bubbles. Here, we report an acoustically-powered superfast locomotion methodology for tubular micromotor swarms assembled by the ultrasound (US) oscillation of self-generated bubbles. With the applied ultrasound, micromotor individuals are headed by the attached oxygen bubbles to swim towards high pressure spots by the primary Bjerknes force. Subsequently, the bubble heads interact with each other by the secondary Bjerknes force to rapidly fuse into a big bubble core, serving as the collection center for attracting more micromotor individuals to join a dandelion-like swarming. The ultrafast microswarm growth and locomotion strategy offers a new paradigm for constructing distinct dynamic assemblies and rapid transmission of artificial microrobots, paving the way to a myriad of promising applications.



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Bonding and Debonding of Hybrid Engineering Materials and Structures by Power Ultrasonics

Plenary Lecturer (Day 3, Presentation 3)

Abstract:

Hybrid material systems consist either of different material groups like metals, alloys or reinforced polymers, which were produced by a material-specific joining process. The second option to engineer hybrid materials are composite materials which were directly manufactured in a one-shot process. Such hybrids result in excellent joint or composite properties for future engineering applications, most of which cannot be achieved by monolithic concepts. In a somewhat extended definition, multi-material systems are also still classified as hybrids, such as multi-metal structures, which show interesting properties for modern lightweight as well as functional applications. In addition to the initial production of hybrid structures, repair and separation processes are increasingly becoming important in order to achieve circular value creation or value retention. In this talk, selected joining options are presented by means of power ultrasonics including questions of achievable joint properties as well as interfacial formation related to the process characteristics. For this purpose, the latest ultrasonic welding variants were studied and also new processes such as orbital ultrasonic welding for tubular components were developed. In a second part, questions concerning the separation of composites or better the fatigue-induced damage mechanisms of reinforced thermoplastics at ultrasonic frequencies are also discussed. So novel testing or process options are introduced, which enable high-quality separation of individual layers of the composites and were also applied to determine longevity in an accelerated manner.

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Proposed Design and Development of an Automated System for Ultrasonic Velocity and Attenuation Measurement Using Pulse Transmission Technique

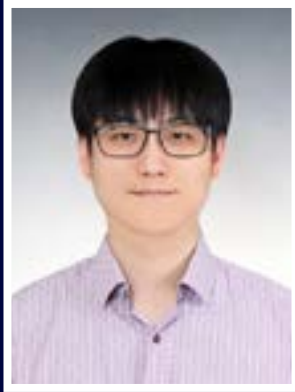
(Day 3, Presentation 4)

Abstract:

Measurements and interpretation of ultrasonic velocities and attenuation in complex media place requirements upon the measurements techniques which cannot be met by conventional ultrasonic equipment. A new high time resolution setup based upon the pulse transmission technique is being designed to meet these applications. This approach is well suited to the measurement of ultrasonic velocities and attenuation in media which are highly dispersive and/or highly attenuating. Here, we have proposed a simple and low-cost design of the sample holder and integrating it into a fully automated precise system for measuring the ultrasonic velocity and attenuation in solid with a wide range of temperature i.e. 300 K to liquid helium temperature (2 K) and magnetic field \square 14 Tesla. The temperature and magnetic field across the samples can be controlled through any commercial cryostat interfaced with automation software such as LabVIEW or python based code.

The main interest of such technique is to probe the mechanical properties; structural and magnetic transition, and charge ordering in various systems like colossal magnetoresistance (CMR), manganite, multiferroic, and elastic behaviour in single-phase and composites thermoelectric, piezoelectric materials using this non-destructive technique. In principle, any solid-state materials can be characterized for understanding the sound velocity propagation behaviour to reveal an insight into the mechanical properties. From the fundamental physics point of view, as a sensitive probe, such measurements can provide the information to explore the electron-phonon and spin-phonon coupling in many perovskite materials. Measuring the ultrasonic velocity and attenuation in presence of the magnetic field will give the exact mechanism of magneto-elastic coupling in the multiferroic materials.

In this international workshop on piezoelectric materials and applications in actuators, more detail about the design and development of ultrasonic velocity measurement systems, and their application in the investigation of several physical properties will be discussed in more detail.



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**Ferroelectrically Enhanced Contact
Electrification Enables Efficient Elastic Wave
Energy Transfer Through Various Media**

(Day 3, Presentation 5)

Abstract:

As demands for portable electronic devices grow, wireless energy transfer (WET) has started to become readily available. Until now, studies on WET have been mainly based on the electromagnetic (EM) induction method using EM waves. However, it is still challenging to utilize current EM wave mediated WET in those areas where it is most needed: underwater, body-implant, and EM-shielded cases (liquid/metals). Acoustic energy transfer (AET) can be an alternative to EM-wave based WET. Here, we present a simple but powerful triboelectric AET module by tuning the contact potential difference (CPD) of the triboelectric layer via the large polarization of the embedded relaxor single crystal. Additionally, uniform displacement, a quasi-mode oscillation, across the flexible electrode surface in response to the square wave has improved energy transfer efficiency. A systematic investigation was conducted for energy transferring conditions of receiving angle and ferroelectric polarization. We successfully demonstrated the transmission of 8 mW electric power at a distance of 6 cm underwater, which is sufficient to use in most demanding but inaccessible areas. In addition, AET is demonstrated and discussed in both liquids (underwater and in-body), and solids (metal, wood, and plastic). We anticipate that our approach will enable current next-level AET technology to be utilized in the actual field.

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Minimize Temperature Influence on Micro-Ultrasonic Motors

Co-Authors: Tomoaki Mashimo

(Day 3, Presentation 6)

Abstract:

In this paper, we study the temperature problem in piezoelectric actuators, and we propose a solution to enhance the performance of these actuators under such conditions. The problem was investigated in this paper for micro-ultrasonic motors where their theory of operation depends mainly on friction to transmit power between stator and rotor. Recent micro-ultrasonic motors run at high speed which generates high friction, that friction increases the temperature of the stator and changes the properties of piezoelectric elements mounted on it. That phenomena cause the performance of micro-ultrasonic motors to drop after running for some time. A new theory of changing the driving frequency based on stator temperature is proposed in this paper. The theory was applied and tested through a PID controller, and the results were compared to original motor data.



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An Ultrasonic Linear Motor Control Method Considering the Driving Trajectory

(Day 3, Presentation 7)

Abstract:

Ultrasonic linear motor (USLM) converts the piezoelectric vibration to straight motion of a slider using the frictional force. Our laboratory has proposed the ultrasonic linear motor with a stator quadruped four legs, which are used for the inchworm motion. For this motor, the first longitudinal (L1) mode and the first-second bending (B1-2) modes are excited and combined with a piezoelectric plate. An elliptical trajectory is excited on the driving leg of stator, then a cylindrical slider is driven in the straight direction. The length, width and height of the stator are 20mm, 10mm and 6.7mm. The diameter of the slider is 5mm and the length is 100mm.

For the conventional USLM speed control method, the vibration amplitudes of longitudinal mode and bending mode are modified keeping a fixed ratio. When we want to drive the slider at low speed with this conventional control method, the speed dead-zone becomes a serious problem, and we cannot control the slider speed less than 20mm/s using our motor. To apply this motor to wide applications, a new speed control method for this motor is needed. Firstly, we built a closed-loop speed control system for this motor. Since the slider speed can be controlled by changing phase difference, amplitude of input voltage and driving frequency, we used these different parameters to control slider speed, and compared the motor performances. According to the experimental results, amplitude of input voltage was finally used to realize a closed-loop speed control system.

Different from other ultrasonic linear motors, two vibration modes can be controlled independently for this motor, that means it is possible to control the trajectory of driving legs. The influence of driving trajectory on the slider motion was analyzed by a simple model. Based on the simulation and experimental results, we improved the control method, which can change the driving trajectory. With the proposed system, the speed dead-zone was narrowed down and the slider could be driven at a lower speed as 7mm/s successfully.

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Research on Low Speed Driving Model of Ultrasonic Motor Based on Beat Traveling Wave Theory

(Day 3, Presentation 8)

Abstract:

This paper proposes a driving method — — superimposed pulse driving method that can make ultrasonic motor run at low speed. Although this method solves the problem of periodic oscillation of speed in the traditional method of low speed driving motor, it still has a small periodic fluctuation, which affects the stability of the speed. In order to reduce the fluctuation rate of motor speed, the structure model and driving model of motor are established based on the theory of beat traveling wave, and the motion characteristics of particle point are analyzed in this paper. The simulation curve of motor speed is obtained according to the theory of stator and rotor contact model and transfer model. The research shows that the driving method introduced in this paper causes the stator surface to generate traveling beat wave, and the driving end of stator generate intermittent reciprocating vibration and drives the rotor rotation, which is not only the mechanism of low speed operation when the driving method is used to drive the motor, but also the reason for the periodic fluctuation of the motor speed. In order to improve the speed stability, this paper controlled the output performance of the motor by changing the two control variables of pre-pressure and frequency difference, and finally got the conclusion that the variation trend of the average speed and speed volatility were consistent with the variation trend of the motor average speed determinant and speed volatility determinant respectively, which is verified by velocity measurement experiment and vibration measurement experiment and lays theoretical foundation for velocity adjustment and stability optimization, finally, the application of the new driving method is prospected.



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Temperature Compensation for Multimodal Ultrasonic Transducer's Frequency Ratio

(Day 3, Presentation 9)

Abstract:

Multimodal ultrasonic transducers can output specific motions by coupling different vibration modes, and the frequency ratio should be a constraint for such operation. However, the temperature rise of the transducer caused by internal friction and boundary condition is inevitable. Meanwhile, when operating in resonance, the high mechanical quality factor makes the resonant frequency shift easily by the temperature change, ensuing dramatic performance degradation.

In this study, temperature compensation for the frequency ratio of multimodal ultrasonic transducer through a dynamic resonant frequency control method is realized. A step-shaped bolted Langevin transducer was designed to realize non-sinusoidal excitation. It works in both the first and third longitudinal modes, and the resonant frequency ratio of these modes is close to two. A group of passive PZT parts were deployed at the third mode's antinode position and controlled by a MOSFET switch. Due to the electrical boundary condition change of the passive PZT part, the first mode resonant frequency can be changed with a slight shift of the third mode's frequency, and the frequency ratio control becomes possible.

Experiment results verified this temperature compensation method. A constant temperature oven changed the transducer's temperature to shift its resonant frequencies. After resonant frequency ratio controlling, a quasi-sawtooth wave composed of two sin waves was generated and maintained even with the temperature increasing from 30 to 70°. In future work, we will optimize the control parameters to shorten the adjusting time and apply this method to piezoelectric devices operating in more complicated modes.

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Experimental Investigation of the Influence of Different Bond Tool Grooves on the Bond Quality for Ultrasonic Thick Wire Bonding

(Day 3, Presentation 10)

Abstract:

Ultrasonic wire bonding is the mainly used interconnection technology in microelectronic packaging industry. Different wire materials are used, depending on the bonding method and wire diameter. Aluminium and copper are present state of the art materials for thick wire wedge-wedge bonding. Due to its mechanical and electrical properties, copper wire has multiple advantages over aluminium wire. The disadvantage using copper wire are the higher normal forces in combination with higher ultrasonic amplitudes needed to produce an acceptable interconnection of wire and substrate. Thus, bonding copper wire on sensitive substrates gets delicate, as stresses increase with normal load and ultrasonic amplitude.

One possibility to reduce the risk of fails are softer bonding parameters, for example lower ultrasonic voltages resulting in lower tool vibration amplitudes. Unfortunately, this is most often accompanied by a reduction of bond quality and thus not beneficial for lifetime. To overcome this dilemma, new approaches must be found. One of them might be a redesign of the bond tool in such a way that maximum bond quality is achieved at reduced bonding parameters.

Therefore, bond experiments with different bond tool groove geometries have been done for copper and aluminium wire on DCB substrates to investigate the impact of geometric parameters on bond formation and bond quality.

Evaluating the experimental results leads to the conclusion, that the bond formation and deformation is influenced by the groove geometry. For aluminium wire the influence on the bond formation over time is found to be less than compared to copper wire. This leads to the conclusion, that the optimization of the groove geometry has higher potential for copper wire than for aluminium wire. Additionally, a bonding parameter design of experiments (DOE) has been conducted for the reference and the most promising groove geometry. Shear values and vertical tool displacement of the chosen geometry show for nearly all bonding parameter combinations better performance, than the reference tool. This validates the hypothesis that the bond quality (regarding shear values and vertical tool displacement) can be improved by optimizing the groove geometry.



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Integrated Composite Transducer Design for Impacts Estimation in Thin Plates

Co-Authors: *Mickaël Lallart, Pierre-Jean Cottinet, Claude Richard, Jean-Fabien Capsal*

(Day 3, Presentation 11)

Abstract:

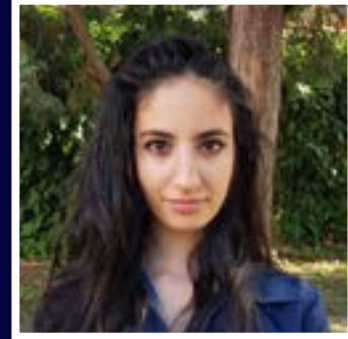
The estimation of impact location and associated energy in composite structures is of great importance in structural health monitoring. Most existing solutions are either limited by experimental conditions such as anisotropy or have a large power consumption. Additionally, the integration of the transducer may be a significant issue, especially considering the necessity of lightweight structures as well as the implementation on curved shapes. In this work, a piezoelectric composite material made of polyurethane (for the matrix) and barium titanate (for the ferroelectric colloids) is used as a flexible transducer that adapts to the structure while staying lightweight and low cost. This material is also easily integrable thanks to its mechanical properties. Experimental sensors have been made both by 3D printing and using spray gun to apply the piezoelectric material on an anisotropic composite plate. The obtained device was then used as in an impact detection system that exploits simple and energy-efficient energy flow estimator over a monitored area, leading to a positive criterion if the impact occurred in the monitored area, that is negative otherwise.

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Combination of a Static Finite Elements Approach and Dynamic Lumped Model for Bistable Vibration Energy Harvester Modeling

Co-Authors: Thomas Huguet, David Gibus, Camille Saint-Martin, Emile Roux, Ludovic Charleux, Adrien Badel

(Day 3, Presentation 12)

Abstract:

Bistability has widely been used to develop broadband vibration energy harvesters. Bistable mechanical oscillators offer larger frequency bandwidths than their linear monostable counterparts. They are however more complex to design, model and optimize, due to their complex vibratory behavior. Bistability is usually achieved through magnetic interactions or through the buckling of mechanical beams. Compared to magnetic interactions, the use of buckled beams offers compactness, but the inherent elastic energy in the beams affects the electromechanical coupling of the energy harvesting device and its behavior. In this paper, we consider an original vibration energy harvester design that includes a bistable mechanical oscillator, made of buckled beams, and a dynamic mass. This oscillator drives an amplified piezoelectric actuator used as a mechanical-to-electrical transducer. We investigate a simple but accurate model of such harvesters, which includes the effect of the elastic energy in the buckled beams. Elastic energy in post-buckling beams is computed by static finite element analysis. Its effect on the dynamical behavior of the harvester is considered in a lumped model which allows transient simulations of the generator subjected to ambient vibration. Finally, the combination of static finite element analysis and dynamic simulations constitutes an efficient approach to optimize the design of a bistable vibration energy harvester by including the dimensions and shapes of the buckled beams as optimization parameters.



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Effects of Design Parameters on Compression Type Piezoelectric Acceleration Sensor Co-Authors: Murat Karaer, Cagdas M. Unal, Aydin Dogan

Invited Speaker (Day 3, Presentation 13)

Abstract:

Piezoelectric Acceleration Sensors used in many areas while vibration occurs. Important parameters of the design are piezoelectric ceramic and mechanical design. In this investigation, piezoelectric ceramics were fixed between Bellevue washer based spring and seismic mass. Finite Element Analysis were carried out by using COMSOL Software. Metallic and piezoelectric parts of the design were manufactured and assembled in accordance with the design and the first prototype sensor with voltage output was obtained. For experimental study PZT-5A type ceramics were used. The experimental vibration setup was set using a shaker device to measure 0-10 kHz. Experimental results of prototype accelerometer and COMSOL analyzes were compared. It was observed that the voltage output of the prototype sensor were in accordance with FEA analysis. The obtained voltage output was the 4.11 mV/g when the seismic mass value was 3 grams. When seismic mass value was increased to 10 grams, 12.47 mV/g voltage output has been obtained. It has been observed that the Bellevue washer type spring thickness does not have a significant effect on the sensitivity for the specified model. In compression type design, as the seismic mass increases, the sensitivity increases almost linearly. The designed system provides more consistent outputs in the 0-5kHz frequency range.

In the real environment measurements made simultaneously with the industrial acceleration sensor in the drivetrain of heavy commercial vehicles, it has been observed that the measured acceleration changes and the voltage changes obtained from the primitive design overlap by 97%. All vibration peaks could be detected with both sensors.

Results from experimental studies with the COMSOL finite element analysis software are largely consistent. The number of experiments can be reduced by using the COMSOL software in piezosensor design and similar studies.

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Nonlinear Modelling of Piezoelectric 31 and 33 Effect Vibration Considering Higher Order Elasticity

Co-Author: Takeshi Morita

Invited Speaker (Day 3, Presentation 14)

Abstract:

Piezoelectric transducers are used in various ultrasonic devices and they are driven under high power condition. Nonlinear effects such as “jumping phenomena” in current, hysteresis of admittance curve and saturation of the vibration velocity of piezoelectric transducer under high power driving are well-known. It is originated from the mechanical nonlinearity rather than the dielectric and piezoelectric nonlinearities. It indicates that the influence of the higher order elasticity becomes significant because of large inner strain and stress. Performance of piezoelectric transducer is usually evaluated using the piezoelectric constant, electromechanical coupling factor and mechanical quality factor; however, they are based on the linear piezoelectric effect. Therefore, piezoelectric transducers used in the ultrasonic devices are not evaluated and selected properly. In addition, ultrasonic devices are not designed based on consideration of the higher order elasticity. Especially for resonant type ultrasonic devices, large stress can easily oscillated under relatively low voltage. To realize high power ultrasonic devices having high maximum output power and efficiency, it is necessary to evaluate higher order elastic constant of piezoelectric transducer.

To analyze piezoelectric nonlinear vibration, higher order terms were introduced into piezoelectric constant. In this research, 3rd and 5th order terms of strain were introduced. 3rd and 5th order elastic constant are the material constant which represents higher order elasticity of the piezoelectric transducer. Using this nonlinear piezoelectric equation, we developed the nonlinear vibration model of piezoelectric 31 effect and 33 effect transducer as nonlinear LCR equivalent circuit and nonlinear transfer matrix, respectively. For 31 effect transducer, nonlinear LCR equivalent circuit which includes nonlinear equivalent stiffness C and nonlinear mechanical loss R was used. On the other hand, LCR equivalent circuit is not suitable for analyzing nonlinear 33 effect vibration because vibration mode becomes complex to represent by single LCR branch. It is caused by the inner electric field in the transducer by piezoelectric effect. Accordingly, nonlinear transfer matrix method was developed to analyze 33 effect vibration.

In this research, admittance curve was measured and used to obtain higher order elastic constant. Hard-type PZT (Fuji-ceramics C203) transducers were measured. The dimensions of the 33 effect transducer was 2 mm×3 mm×10 mm and polarization direction was aligned to 10 mm direction and 31 effect transducer's dimension was 7 mm×2 mm×44 mm, which was polarized along 2 mm direction. Frequency response analyzer (NF FRA5097) and power amplifier (NF 4010) were used to measure the admittance curve under various voltages, which are 0.25 Vpp, 10 Vpp, 40 Vpp, 70 Vpp, 100 Vpp, 200 Vpp and 300 Vpp, to measure the stress dependency of 3rd and 5th order elastic constant. Conducting the curve fitting to the admittance curve, 3rd and 5th order elastic constant was obtained under various inner stress.

(Continued on next page.)

Nonlinear Modelling of Piezoelectric 31 and 33 Effect Vibration Considering Higher Order Elasticity (Continued)

Co-Author: Takeshi Morita

Invited Speaker (Day 3, Presentation 14)

From the relationship between real and imaginary part of 3rd order elastic constant and maximum stress obtained from 31 effect measurement, real part of 3rd order elastic constant increase and imaginary part of 3rd order elastic constant decrease with increasing inner stress. In the fitting process of 33 effect measurement result, we used two calculation models. One was the model including 3rd and 5th order terms and the another was the model with only 3rd order term. Using 3rd order model, imaginary part of 3rd order elastic constant had negative value and 5th order model calculation couldn't converge under 20.4 MPa. It is because of insufficient stress to evaluate higher order elasticity. In the range over 30 MPa, with 3rd order model, the change rate of real part and imaginary part of 3rd order elastic constant were 21% and 66%, respectively. On the other hand, with 5th order model, the change rate were only 0.5% and 39 %. About 5th order term, real part increase and imaginary part decrease with increase of maximum stress. These results indicate the influence of 5th order elasticity becomes significant in high stress condition. In addition, 7th and greater order elasticity can affect under larger stress range.



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VIBRO3 (Vibro-supply, Vibro-Communication and Vibro-Inspection): a Global Multifunctional System for Wireless Supply, Communication and Sensing

Co-Authors: Fabien Mieyeville, Olivier Bareille, David Navarro and Stéphane Ndogna

Invited Speaker (Day 3, Presentation 15)

Abstract:

In the context of autonomous communicating devices, the advent of IoT (“Internet of Things”) opens up tremendous opportunities such as autonomous in-situ inspection, allowing the assessment of structural integrity (e.g., leaks in a pipeline) for the safety of goods and people. However, IoT faces challenging stakes, including integration and energy supply. In this context, the ability of using ambient energy sources have been of significant interest for providing energy supply. Apart from energy harvesting which consists in opportunistically converting energy of an uncontrolled energy source (vibrations, thermal and so on) that would otherwise be wasted, wireless power transfer has also been of significant interest over the last few years. In this case, the energy source is fully controlled allowing a significant optimization of the coupling and transfer process.

Still, the large majority of autonomous sensors decouple power supply (battery, having a limited lifetime), detection (vibration sensors, temperature and so on) and communication (RF device). Vibro3 proposes a shift of paradigm by unifying these three components using the acoustic vector for their achievements. Furthermore, thanks to this approach, all of the considered functions may be ultimately achieved using a single material as a multifunctional element. This innovative perspective thus makes it possible to ensure both integration (same kind of transducer for all three aspects) and energy sustainability (remote power supply).

This presentation thus exposes the first steps towards this threefold unified concept, through the development of acoustic power transfer, communication through acoustic medium and inspection using acoustic waves. First experimental implementation, with emphasize on energy-efficient design, will be exposed, as well as initial results in terms of sensing performances. Hence, the present study providing an alternative way for unified power transfer, communication and associated use for sensing and inspection, is a first step towards a more complex device taking into advantage structural modes or self-synchronization for instance, while raising interesting scientific questions regarding multifunctionality and energy-efficient approaches.

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Statistical Performance Assessment of a Bistable Vibration Energy Harvester

(Day 3, Presentation 16)

Abstract:

Vibration energy harvesters allow the extraction of the ambient mechanical energy. Our analysis focuses on a bistable generator with Duffing nonlinearity. Bistable generators exhibit larger frequency bandwidth than linear monostable generators, but they exhibit complex behaviors (multiple periodic orbits and chaos), making their evaluation challenging. To assess the quality of a vibration energy harvester, it is necessary to evaluate its energy performance in a generic way. In this presentation, we describe a numerical approach to predict the probability of occurrence of each orbit regarding the initial conditions of the dynamical system. The estimation of the orbit probabilities and powers allowed us to calculate an expected power for each vibration frequency. This approach has been used to demonstrate that our generator has a constant expected harvested power for a driving frequency between 23 Hz and 55 Hz. Moreover, the choice of the initial conditions grid is fundamental since it affects the capture rate of the orbits and thus their probability of occurrence. Thanks to numerical simulations, we show that the initial conditions grid must be precise enough to ensure the reliability of the orbit probabilities derived with the proposed method.



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**Multi-dimensional Constrained Energy
Optimisation applied to Piezoelectric Harvesters**

(Day 3, Presentation 17)

Abstract:

This work presents a methodology for the design optimisation of piezoelectric energy harvesters within a constrained environment. The optimisation procedure accounts for the physical size of the device, the physical, geometrical and electrical properties of the piezoelectric beams, and a power management circuit to increase the device's efficiency. The device is operated gravity-based as it is rotated around its out-of-plane axis, allowing a carriage mass to pluck the beams through plectra attached to it. The plucking mechanism proposed is inspired by the frequency up conversion technique and allows increasing the total number of excitations multiple times, which yields a considerable higher energy output when compared to the most common techniques. The established numerical model is validated first using a set of experimental data. The obtained numerical results demonstrate that a 10.2" size device produces 55 mJ in half-period when inclined at 45°, which is equivalent to generating 0.3 W.

Day 4 Abstracts

Dr. Susan Trolier-McKinstry

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Electrical Reliability of Lead Zirconate Titanate Piezoelectric Films

Co-Authors: Betul Akkopru-Akgun, Wanlin Zhu, Jung In Yang, Song Won Ko and Peter Mardilovich

Plenary Lecturer (Day 4, Presentation 1)

Abstract:

Failure of lead zirconate titanate under DC electric fields occurs by a coupled failure mode in donor-doped, acceptor-doped, and films with graded doping. Curiously, the median failure time of PZT films can be increased on doping with either donors or Mn as an acceptor. The lifetimes under DC fields are controlled by migration of oxygen vacancies, coupled with changes in the interface barrier heights for conduction in thin films. The defect chemistry of the film, including variations in this defect chemistry at interfaces strongly influences both the failure and the asymmetry of the failure as a function of the electrical polarity. It is possible to combine high piezoelectric responses with high lifetimes under DC electric fields through use of graded doping schemes through the film depth.



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Pb(Zr,Ti)O₃-based Transparent Piezoelectric Devices on Glass Substrates

(Day 4, Presentation 2)

Abstract:

Pb(Zr,Ti)O₃ (PZT) thin films have attracted considerable attention due to the versatility on advanced applications, as well as their excellent piezoelectric properties. In this context, they have been extensively studied for the usage in piezoelectric microelectromechanical systems (MEMS). However, PZT thin films are normally deposited on non-transparent silicon or metal substrates, which would restrict their applications on optical devices, such as touch panels and intelligent windows. In this study, we grew PZT thin films on glass substrates coated with transparent indium tin oxide (ITO) by RF magnetron sputtering method (PZT/ITO/Glass). Subsequently, ITO was deposited as top electrodes to form a lamination of ITO/PZT/ITO/Glass. After that, structural, optical, dielectric, ferroelectric and piezoelectric properties were evaluated for the prepared lamination.

For the applications in transparent piezoelectric devices, in particular, the biggest issues are to get a good transparency over a wide frequency range, and to obtain a useful range of piezoelectric coefficient. Optical properties are presented, in which the transparency of the lamination is demonstrated. Furthermore, converse piezoelectric coefficients ($|e_{31,f}|$) that were measured by the cantilever method are presented as well, from which the value of 3.5 C/m² was obtained. Such characteristics suggest the feasibility of our PZT for applications on transparent piezoelectric MEMS.

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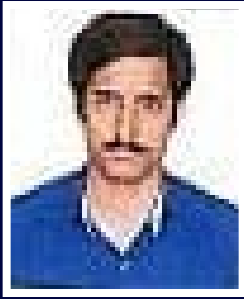
Templated Grain Growth of Mn-Doped PYN-PMN-PT Piezoelectric Ceramics for High Power Applications

Co-Authors: Sahn Nahm, Chong-Yun Kang and Hyun-Cheol Song

(Day 4, Presentation 3)

Abstract:

Piezoelectric materials exhibit the best electrical properties when they are single crystals. However, the single crystals have serious drawbacks of poor mechanical property and high cost due to a long growth time. As the alternative to single crystals, the grain-oriented polycrystal ceramics have been a great attention through Templated Grain Growth (TGG) which is a cost-effective and facile production method that allows piezoelectric ceramics to be oriented in a specific crystallographic orientation to bring their properties closer to single crystals. For high power applications, piezoelectric materials should have "hard" piezoelectric properties of high mechanical quality factor (Q_m) and low dielectric loss ($\tan \delta$) as well as "soft" properties of high strain coefficient (d) and high electromechanical coupling coefficient (k). However, these two characteristics are difficult to achieve at the same time because they are a trade-off relationship. In this study, we tried to improve soft properties while maintaining high hard properties through TGG of hard piezoelectric ceramics. Mn-doped $\text{Pb}(\text{Yb}_{1/2}\text{Nb}_{1/2})\text{O}_3\text{-Pb}(\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$ (PYN-PMN-PT) ternary hard ceramics were oriented in the direction employing BaTiO_3 platelet templates. Through the TGG process, the d_{33} property improved while maintaining the high Q_m properties of the matrix materials. Thus, we believe that the TGG method is an effective way to make high-power applications such as ultrasonic transducers by engineering the microstructure of hard piezoelectric ceramics.



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The Effects of Low Melting BAO Doping on the Structure, Microstructure, Ferroelectric and Piezoelectric Properties of BCTZ Ceramics for Actuator Application

Co-Author: Kumar Brajesh and Ashish Garg

(Day 4, Presentation 4)

Abstract:

In the last decade, environmental concerns have prompted a great surge in research interest in lead-free piezoceramics. One of the major breakthroughs was the discovery of the lead-free piezoelectric ceramic $(1-x)\text{Ba}(\text{Ti}_{0.8}\text{Zr}_{0.2})\text{O}_3-x\text{Ba}_{0.7}\text{Ca}_{0.3}\text{TiO}_3$ (BCTZ) by Liu and Ren [1] which exhibited excellent piezoelectric properties ($d_{33} \sim 600$ pC/N) near tetragonal composition in the vicinity of the tetragonal-orthorhombic polymorphic phase boundary[2,3]. The extraordinary piezoelectric response is however obtained only in specimens prepared by sintering at temperatures more than 1500°C, making its processing extremely energy-consuming. An alternative energy-saving processing route wherein the sintering temperature can be lowered without compromising on the piezoelectric response is highly desirable. We adopted the strategy of adding sintering aids BiAlO_3 and synthesized lead-free $(1-x)(\text{Ba}_{0.85}\text{Ca}_{0.15})(\text{Zr}_{0.1}\text{Ti}_{0.9})\text{O}_3-x\text{BiAlO}_3$ piezoelectric ceramics by a solid-state reaction method by fixing the sintering temperature at 1300°C. We found an optimum concentration of BiAlO_3 to give $d_{33} \sim 560$ pC/N, a value which was achieved while sintering without additive at 1550°C.

The effect of BiAlO_3 (BAO) content on the sintering temperature, crystal structure, microstructure, and piezoelectric behaviors of BCTZ ceramics was investigated. Rietveld fitting of diffraction data reveals a phase transition from tetragonal+orthorhombic phase coexistence to pure tetragonal phase with increasing BAO content in the BCZT matrix. The grain size gradually increases with increasing BAO content. It was observed that the introduction of BAO content not only decreased the sintering temperature from 1550 to 1300°C but also enhanced the piezoelectric properties. Interestingly, a slightly larger strain $\sim 0.16\%$ was observed at $x=0.06$, thereby suggesting that this system is a promising candidate for actuator application.

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Enhanced Energy Generation of Magneto-Mechano-Electric Harvester by Optimizing Its Design and Concepts

Co-Authors: Jungho Ryu

Invited Speaker (Day 4, Presentation 5)

Abstract:

The cantilever-structured magneto-mechano-electric (MME) energy generator comprises a piezoelectric material laminated on a magnetostrictive metal plate and permanent magnets (proof mass) exhibit excellent magnetic energy-harvesting performance. The MME generator is a newer concept than piezoelectric energy harvester (PEH) and which needs various optimization in its design and concepts such as geometry (size and shape) of the magnetostrictive and piezoelectric layers, weight and position of the proof mass, stress, mechanical properties of an elastic layer, clamping condition, driving condition, etc. to produce the optimum power. The selection of the adhesive layer is important because the magneto-electric coupling between the piezoelectric material and magnetostrictive metal layer highly depends upon the mechanical properties of the interfacial adhesive layer. Geometric optimization is also considered the most important factor for energy harvesters. In the case of MME generators, not only the geometry of the magnetostrictive plate but also the aspect ratio of piezoelectric single crystal fiber (SCF) plates affects their energy harvesting properties. It was found that the shape of the cantilever (magnetostrictive plate) affects the distribution of strain, elastic compliance, and resonance frequency of the MME generator. The effect of aspect ratio (length (L)/width (W)) of piezoelectric SCF plates on the energy harvesting performance of the MME generator is also investigated. PMN-PZT SCF's with different aspect ratios (0.59, 0.78, 1, 1.25, and 1.6), a magnetostrictive Ni plate and NdFeB permanent magnet proof mass were used to fabricate the MME generator. The MME harvester with a PMN-PZT SCF aspect ratio of 1.6 shows a ~440% increment in the RMS voltage and power and ~300% enhancement in the power density measured at an RL of 100 k Ω and a magnetic field of 10 Oe. The MME structure shows completely different results where the piezoelectric element with longer lengths ($L_{\text{piezo}} > W_{\text{piezo}}$; larger aspect ratio) shows the optimized output voltage (for PEH; $L < W$) due to the additional in-plane (longitudinal) magnetostrictive vibrations. The experimental results show good agreement with the results of the finite element analysis.

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Energy Harvesting Concept Based on the Two Phase Flow: Pressure and Temperature Variations

Co-Authors: Grzegorz Litak, Romuald Mosdorf, Hubert Grzybowski, Paweł Dzienis

Invited Speaker (Day 4, Presentation 6)

Abstract:

We present the results of flow boiling experiment in heat exchanger with mini channels for 3 different configurations: the channels covered with a 0.1 mm thick stainless steel plate (classical), the channel covered with stainless steel mesh: (b) Dutch weave, (c) plain weave presented in Fig. 1(b,c). The schematic diagram of experimental system is shown in Fig. 1d, distilled water was pumped by means of a gear pump (1) to the surge tank (2). The water flow rate was measured by the mass flow meter (3) (Bronkhorst mini CORI-FLOW™ M13 with accuracy of $\pm 0.2\%$ of rate), and the rectangular 0.5x0.25 mm mini channels were heated by cartridge heater. Pressure-driven air flow system consisted of compressor (12) and tank (10) that supplied air to the test section. The air pressure was controlled by a proportional pressure regulator (11) (Metal Work Regtronic). The air flow rate was measured by the mass flow meter (9).

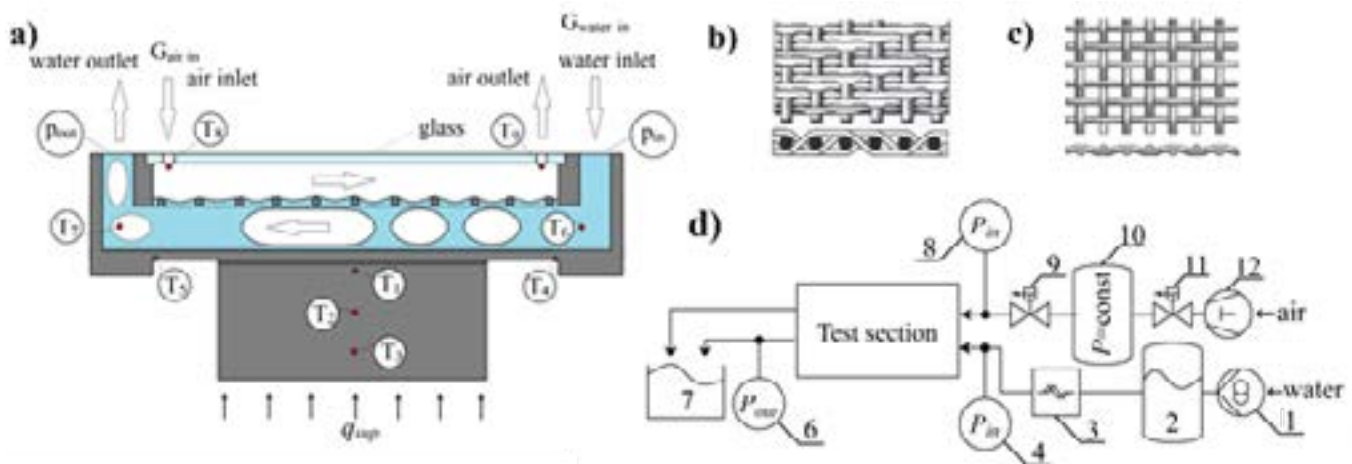


Figure 1: Experimental setup:(a) test section cross section, (b) Dutch weave wire mesh, (c) plain weave wire mesh, (d) water supply system, (e) schematic diagram of experimental system.

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Energy Harvesting Concept Based on the Two Phase Flow: Pressure and Temperature Variations (Continued)

Co-Authors: Grzegorz Litak, Romuald Mosdorf, Hubert Grzybowski, Paweł Dzienis

Invited Speaker (Day 4, Presentation 6)

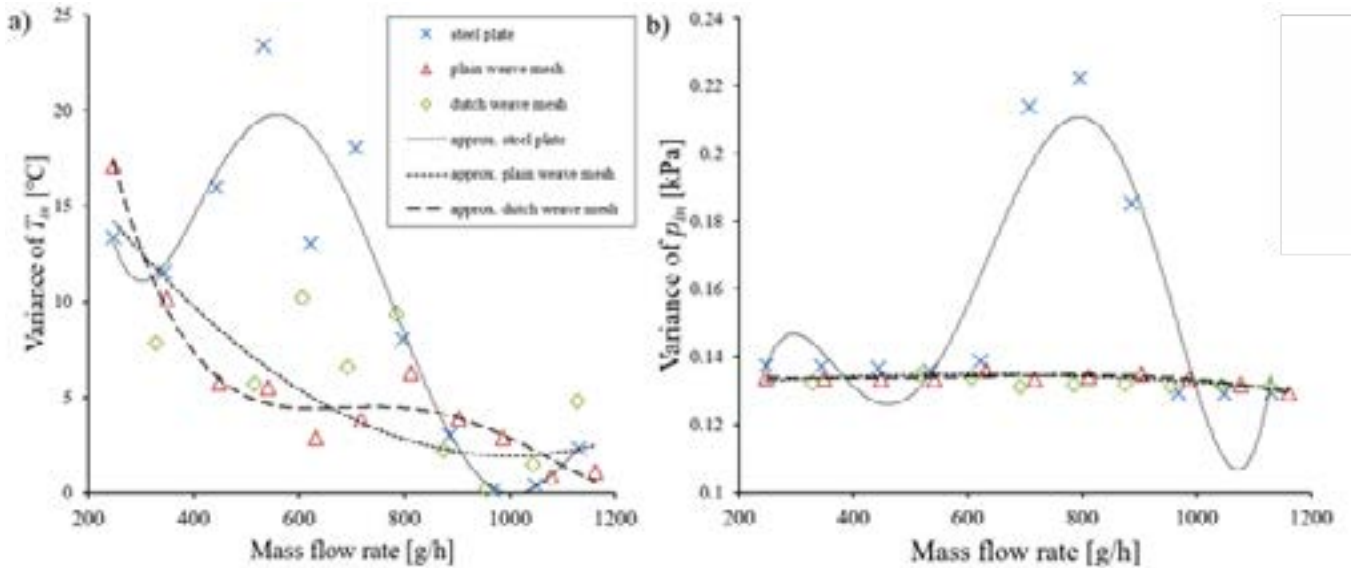


Figure 2: Variances of water temperature and pressure versus mass water flow rate.

Variances of inlet water temperature and pressure are presented in Fig. 2. Note that in case of the classical heat exchanger (case (a)) the variations have a significant peak. As a result, novel energy harvesting solutions system such as piezoelectric (pressure variation) and pyroelectric (temperature variation) systems that utilize the latent heat of vaporization of a fluid are needed

Acknowledgments

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Low Temperature Sintering and Properties of $(1-x)\text{Pb}(\text{Zr},\text{Ti})\text{O}_3\text{-}0.05\text{Pb}(\text{Mn}_{1/3}\text{Sb}_{2/3})\text{O}_3\text{-}x\text{Pb}(\text{In}_{1/2}\text{Nb}_{1/2})\text{O}_3$ High-Power Piezoelectric Ceramics

Co-Authors: Jingjing Shia, Ying Yanga, Shuting Panga, Yiping Wanga

(Day 4, Presentation 7)

Abstract:

$\text{Pb}(\text{Zr},\text{Ti})\text{O}_3$ based high-power piezoelectric ceramics are usually with sintering temperature over 1200° . To realize the co-firing process with cheap metals such as silver and copper inner electrodes and to reduce the lead volatilization, it is crucial to achieve low temperature sintering for these ceramics. In this research, $(1-x)\text{Pb}(\text{Zr},\text{Ti})\text{O}_3\text{-}0.05\text{Pb}(\text{Mn}_{1/3}\text{Sb}_{2/3})\text{O}_3\text{-}x\text{Pb}(\text{In}_{1/2}\text{Nb}_{1/2})\text{O}_3$ system with excellent piezoelectric properties was synthesized by using traditional solid phase reaction, and CuO sintering aid was introduced to decrease the sintering temperature. The microstructure and electrical properties of piezoelectric ceramics were investigated by x-ray diffraction (XRD), scanning electron microscope (SEM) and electric measurements. The results verified that 1.0 wt% CuO addition could effectively realize a dense microstructure with uniform grain size at 900°C for the ceramics. To compensate the possible decreasing trend in piezoelectric properties induced by CuO doping, the addition of rare-earth element Yb^{3+} was adopted as a substitution. The enhanced high-power properties of the piezoelectric ceramic by Yb doping, as well as the sintering densification at low temperature, could be beneficial to the application of this high-power piezoelectric ceramic in multilayer devices.





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Epitaxial Growth of Lead-Free Piezoelectric KNbO₃ Thin Films Using Metal-Organic Chemical Vapour Deposition

Co-Authors: Nishant Peddagopu, Merieme Oubahaz, Samuel Margueron, Jean-Manuel Decams, Vincent Astié, Graziella Malandrino, Ausrine Bartasyte

(Day 4, Presentation 8)

Abstract:

The demand for lead-free piezoelectric materials is increasing over the concerns of lead toxicity and related environmental issues. Among the large family of ferroelectrics, the perovskite-type KNbO₃ has attracted considerable interest in the field of agile and high-frequency RF filters thanks to its excellent piezoelectric properties and can be an alternative for traditional lead-based piezoelectric materials. However, the synthesis of KNbO₃ single crystals is very challenging and only very expensive single crystals with small sizes are available at present. To bring this material towards industrial applications, the only remaining possibility is to use the grown KNbO₃ thin films. Nevertheless, the growth of KNbO₃ is far from being a routine process due to the high volatility and reactivity of K₂O. The chemical deposition methods, enabling better control of volatile element composition, face difficulty in finding a reliable K precursor. The industrially available K precursors present low volatility or high instability at ambient conditions.

In this paper, we report the growth of dense epitaxial thin films of KNbO₃ by pulsed injection metal-organic chemical vapour deposition (MOCVD). An advanced K precursor, the K₄(hfa)₄tetraglyme adduct is used instead of industrially available K(thd) precursor, enabling better control of K stoichiometry in KNbO₃ films. The epitaxy of the KNbO₃ films was studied on C-sapphire, R-sapphire, and 36°Y-LiNbO₃ (36°Y-LN) substrates utilizing X-ray diffraction.

KN films on C-sapphire, R-sapphire and 36°Y-LiNbO₃ substrates (supplied by Roditi) were deposited by pulsed-injection metalorganic chemical vapour deposition (MOCVD)—a method providing digital control of the film deposition. Mixtures of K₄(hfa)₄tetraglyme and Nb(thd)₄, dissolved in 1,2-dimethoxyethane were used for the growth of KNbO₃ films, where thd = 2,2,6,6-tetramethyl-3,5-heptanedionate and hfa = hexafluoroacetylacetonate. Micro-doses of the solution was injected into a hot evaporator with a frequency of 0.5 Hz, and the vapour was transported to a hot substrate by a mixture of Ar and O₂ (33%) gases. The deposition temperature was 700 °C. The phase composition and the texture have been analysed utilizing X-ray diffraction (XRD). The surface morphology and the elemental composition were studied employing surface scanning microscopy (SEM) and energy dispersive X-ray analysis (EDX). The stereographic projections have been visualized by using Winwulf software.

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Epitaxial Growth of Lead-Free Piezoelectric KNbO₃ Thin Films Using Metal-Organic Chemical Vapour Deposition (Continued)

Co-Authors: Nishant Peddagopu, Merieme Oubahaz, Samuel Margueron, Jean-Manuel Decams, Vincent Astié, Graziella Malandrino, Ausrine Bartasyte

Invited Speaker (Day 4, Presentation 8)

The KNbO₃ films, grown by using the advanced K₄(hfa)₄tetraglyme and the standard Nb(thd)₄ precursors, presented a K/Nb ratio close to 1 as indicated by EDX analysis. The film texture and morphology was heavily dependent on the substrate. In the case of R-sapphire substrates, a mixture of (110) & (001) with the presence of (111) orientation has been obtained. The morphology of these films consisted mainly of squares rotated by 90° and 45° in the substrate plane with respect to each other. In the case of C-sapphire, the dominating orientation was (201), which presents triangular growth symmetry, which can be identified in its stereographic projection as well. The purest growth texture was obtained on 36°Y-LN substrates, which is clearly identified from the homogeneously oriented squares in the morphology and XRD pattern. Epitaxial growth of KNbO₃ films is confirmed by pole figures measurements around the (110), (001) and (201) poles for 36°Y-LiNbO₃, R Sapphire, and C Sapphire substrates respectively.

In Summary, better control of K: Nb stoichiometry in KNbO₃ films has been demonstrated by using the K₄(hfa)₄tetraglyme precursor with respect to the industrially available K(thd) precursor. This enabled the achievement of nearly stoichiometric dense KNbO₃ films and their epitaxial growth on different substrates.

ACKNOWLEDGEMENTS

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Synthesis and Electrical Properties of Ex-Situ and In-Situ Sputtered BNT Thin Films

(Day 4, Presentation 9)

Abstract:

In this work, BNT thin films on LNO/Si substrate were deposited by ex-situ and in-situ RF magnetron sputtering from homemade targets. An original approach was developed to control the composition of BNT films based on the high sensibility of Bi sticking coefficient to the substrate temperature. It was found that two key parameters allow the control of film's composition: target's composition and substrate temperature.

At first, using a stoichiometric target, a bismuth excess was obtained when films are deposited without heating (150°C due to the plasma heating). However by a slight heating of the substrate temperature until 200°C, it was found that the obtained film is stoichiometric. Despite the heating, the obtained film was amorphous and a post annealing at 650°C was realized in air to crystallize the BNT film. With the same approach, it was also possible to find a compromise between the target's composition and the substrate temperature to reach an in-situ growth of the film, i.e. BNT films crystallize in the desired composition directly during the deposition. An excess of Bi of 60% was introduced into the target to shift the deposition temperature until 550°C to reach stoichiometric BNT films crystallized in a pure perovskite structure.

In this presentation, the impact of target's composition and the substrate temperature on the film's properties will be discussed. A comparative of electrical properties of ex-situ and in-situ films will be also presented.



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Auxetic Partially 3D Printed Piezoelectric Structures

Invited Speaker (Day 4, Presentation 10)

Abstract:

In this communication, we report the recent work performed on piezoelectric composite samples manufactured by using additive manufacturing process in a standard Fablab environment. The auxetic and square meshed matrix structures were printed with a UV polymerized resin by using conventional 3D printer. Then, the piezoelectric Rochelle salt (RS) crystals were grown in the meshes of resin matrix by using liquid phase epitaxial growth method. Piezoelectric resonators with enhanced high quality factors were successfully fabricated using this process. Production yield and difficulties were also discussed in order to improve the piezoelectric response of these samples. These composite transducers made by commercial UV curable polymer resin and Rochelle Salt are promising for fablab ready process and ecologic circular production.

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Phase Field Modeling and Computational Study of Piezoelectric Materials and Magnetolectric Composites

Co-Authors: *Jie Zhou, Liwei Geng, Yongke Yan, Shashank Priya*

Invited Speaker (Day 4, Presentation 11)

Abstract:

Phase field model has been developed and employed to perform computer simulation study of ferroic (e.g., ferromagnetic, ferroelectric, ferroelastic) and multiferroic (e.g., magnetoelectric) materials. The modeling characterizes realistic material microstructures (e.g., multi-phase morphology, polycrystalline grain structure, crystallographic texture -- single-phase single crystal being treated as a special case), considers multiple physical processes (e.g., magnetization, polarization, magnetostriction, elastostriction, electric current), describes coupled domain evolutions, and predict material properties. The simulations correlate the material properties to the material microstructures and domain processes, identify the underlying mechanisms responsible for the relationships, and gain insights into material design strategy. The phase field modeling is discussed through two application examples, namely, textured piezoelectric materials, and multiferroic magnetoelectric composites. In both cases, close collaboration and comparison with experiments are presented.

Textured polycrystalline ceramics of piezoelectric materials can achieve properties and performance comparable to that of single crystals but at much lower cost. In this computational study, relationships between templated grain growth processing, polycrystal microstructure, and dielectric and piezoelectric properties in textured ferroelectric polycrystals and the underlying responsible mechanisms are investigated by phase field modeling. It focuses on three important aspects of textured ferroelectric ceramics: (i) grain microstructure evolution during templated grain growth processing, (ii) crystallographic texture development as a function of volume fraction and seed size of the templates, and (iii) dielectric and piezoelectric properties of the obtained template-matrix composites of textured polycrystals. Grain structure evolution during templated grain growth is simulated, and evolution of X-ray diffraction peak intensities is computed. Texture development is characterized by the evolution of Lotgering factor. The effects of template seed volume fraction and template dimensions on the final grain structure and texture are investigated. It is found that, while the degree of crystallographic texture increases with increasing template volume fraction until approaching maximum uniaxial texture, the average template seed distance also plays an important role. Reducing the template size and shortening the seed distance is an effective way to achieve higher texture at lower template volume fraction. Subsequently, the competing effects of crystallographic texture and template seed volume fraction on the dielectric and piezoelectric properties of ferroelectric polycrystals are investigated. Domain evolution, polarization-electric field and strain-electric field hysteresis loops are simulated in the ferroelectric composites consisting of template seeds embedded in matrix grains.

(Continued on next page.)

Phase Field Modeling and Computational Study of Piezoelectric Materials and Magnetoelectric Composites (Continued)

Co-Authors: *Jie Zhou, Liwei Geng, Yongke Yan, Shashank Priya*

Invited Speaker (Day 4, Presentation 11)

The coercive field, remnant polarization, dielectric permittivity, piezoelectric coefficient, and dissipation factor are studied as function of grain texture and template seed volume fraction. It is found that, while crystallographic texture significantly improves the polycrystal properties towards that of single crystals, a higher volume fraction of template seeds tends to decrease the electromechanical properties, thus canceling the advantage of ferroelectric polycrystals textured by templated grain growth processing. This competing detrimental effect is shown to arise from the composite effect, where the template phase possesses material properties inferior to the matrix phase, causing mechanical clamping and charge accumulation at inter-phase interfaces between matrix and template inclusions. Finally, a giant piezoelectric voltage coefficient is demonstrated in textured piezoelectric material, originating from maximized piezoelectric strain coefficient and minimized dielectric permittivity in [001]-textured ceramic.

Multiferroic magnetoelectric composites composed of magnetostrictive and piezoelectric materials offer unique properties and functionalities that cannot be obtained in individual constituent materials, thus enabling development of new devices and technology. In particular, electric field control of magnetic permeability via magnetization-polarization coupling promises to create a novel electronic component, i.e., magnetoelectric voltage tunable inductor. Phase field modeling is employed to perform computational study of strain-mediated domain-level magnetization-polarization coupling mechanisms in the composites. Phase morphology, grain microstructure, internal stress distribution, and magnetization and polarization domain processes are simulated. The interplays among magnetocrystalline anisotropy, stress-induced anisotropy, and internal residual bias stress are studied. Various magnetostrictive constituents (Metglas, Terfenol-D, ferrite) are considered for their distinct properties: amorphous Metglas with low material magnetic anisotropy and small magnetostriction, polycrystalline Terfenol-D with high magnetocrystalline anisotropy and large magnetostriction, and ferrite in between. Magnetoelectric coefficients and voltage-tunable magnetic susceptibility are simulated. Different regimes of the voltage tunable inductor behaviors are found to arise from the stress-induced anisotropy and the resultant ground-state magnetization domains in the composites.



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Screen-Printed Low Temperature BaTiO₃ Piezoelectrics for Integration on Eco-Friendly Substrates

(Day 4, Presentation 12)

Abstract:

Barium Titanate (BaTiO₃) has, for many years, been a piezoelectric material of interest, with great potential as an eco-friendly lead-free alternative to the industry-leading lead zirconate titanate (PZT). Recent advances in materials processing have shown the potential for integration of BaTiO₃ with printed technologies such as screen, inkjet, and 3D printing. Printing is a greener alternative to cleanroom processes in that it is highly scalable, minimizes material waste, and is significantly more energy efficient than conventional cleanroom processes.

However, little effort has been placed on the development of low-temperature processed printed BaTiO₃, with the focus instead being on the additive assembly of green bodies that are later sintered at traditional temperatures upwards of 800°C. This method optimizes piezoelectric performance, but limits the integrability of BaTiO₃ piezoelectrics with green electronic components, which are typically limited by temperature thresholds of below 200°C. Developing low-temperature printing processes for piezoelectric BaTiO₃ can open the door to greener, more eco-friendly electronics with degradable components.

In this contribution, we demonstrate printed piezoelectric BaTiO₃ structures produced entirely at temperatures below 130°C and their integration on biodegradable substrates such as cellulose.

First, a screen-printable ink was developed composed of BaTiO₃ microparticles (1-3µm diameter) in a solvent milled together with a cellulose-derivative binding agent. Piezoelectric capacitors are then fabricated by screen-printing the ink onto gold-coated cellulose substrates. Printed layers are cured in room air for 30 min, and top electrodes are integrated into the system. Once fabrication is complete, samples are poled using a direct poling method.

In this communication, we will show the dielectric and piezoelectric behavior of these low-temperature piezoelectric devices. These initial devices and measurements can be utilized to develop eco-friendly, low-temperature replacements for PZT materials, particularly in single- or short-term usage applications. The printed low-temperature lead-free films and their patterning on biodegradable substrates pave the way towards eco-friendly printed piezoelectrics.

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Enhanced Piezoelectric Properties of Grain Oriented (K,Na)NbO₃-Based Piezoceramic

(Day 4, Presentation 13)

Abstract:

The significant development of lead-free piezoelectric ceramics has raised the concerns for high performance materials. Despite being the most promising lead-free piezoceramic, Potassium Sodium Niobate (KNN) necessitates its figure-of-merit to exhibit large piezoelectric characteristics. In this work, we report the multi-element doped KNN, $0.96(\text{K}_{0.5}\text{Na}_{0.5})(\text{Nb}_{0.965}\text{Sb}_{0.035})\text{O}_3-0.01\text{CaZrO}_3-0.03(\text{Bi}_{0.5}\text{K}_{0.5})\text{HfO}_3$ (KNNS-CZ-BKH), prepared using Sodium Niobate, NaNbO_3 (NN), assisted texturing technique. Here, we combine the influence of sintering temperature on NN textured KNNS-CZ-BKH to establish the dependent behaviors of proper densification to piezoelectric properties. The results indicate the textured KNNS-CZ-BKH to exhibit higher piezoelectric coefficient (d_{33}) than random/ non-textured KNNS-CZ-BKH and the enhancement through tailoring the sintering profile with 10 °C variation. With the improved piezoelectric nature of textured KNN, we further demonstrate the effective approach to design and develop devices/sensors which are expected to draw attention towards high-performance energy harvesting applications.



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Design and Development of High-Power Piezoelectric Ceramics Through Integration of Crystallographic Texturing and Acceptor-Doping

Co-Authors: Yongke Yan, Shashanke Priya

(Day 4, Presentation 14)

Abstract:

For high-power piezoelectric ceramics, the combined soft (high d_{33} , high k) and hard (high Q_m , high E_c , and low $\tan \delta$) piezoelectric properties are required to generate high mechanical power. This study demonstrates an integrated approach based upon crystallographic texturing and acceptor doping for realizing a high-power piezoelectric ceramic with combined soft and hard properties. The textured MnO₂-doped $0.24\text{Pb}(\text{In}_{1/2}\text{Nb}_{1/2})\text{O}_3\text{-}0.42\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-}0.34\text{PbTiO}_3$ (PIN-PMN-PT) ceramic can exhibit enhanced piezoelectric coefficient d_{33} and electromechanical coupling factor k_{31} in comparison with random counterpart. The enhanced piezoelectric response originates from the combined intrinsic high piezoelectric properties of oriented grains, and reduced energy barrier for polarization rotation in textured ceramics. In addition, the BaTiO₃ (BT) template in textured ceramics increases the tetragonality degree, resulting in improved coercive field E_c but decreased mechanical quality factor Q_m in comparison with random counterpart. The decreased Q_m values of textured ceramics are related to the crystallographic dependence of Q_m and the enhanced domain mobility due to the existence of small size domains. Finally, the textured ceramic with 2 vol.% BT content exhibited an excellent combination of soft and hard piezoelectric properties, measured to be: $d_{33} = 517$ pC/N, $Q_m = 1147$, $E_c = 10.0$ kV/cm, and $\tan \delta = 0.49\%$, which is highly promising for high power piezoelectric applications.

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In Vitro Drug Release in Gastric Mucosa Under Safe Human Temperature

Co-Authors: Zhu Pancheng

(Day 4, Presentation 15)

Abstract:

I. Introduction

Recently, one of the most common methods of drug delivery control technology is sonophoresis technology [1]. For instance, Langer R. et al. [2] introduced the high effect of low-frequency ultrasound on drug permeability. In addition, Zhou Q. et al. introduced many kinds of ultrasonic transducers used in biomedical application [3]. We developed a piezoelectric single crystal ultrasonic transducer (the diameter was only 2.2 mm) to produce acoustic waves, which could promote the drug release in the designed position of the digestive tract through an endoscope [4]. However, it is worth noting that the safe temperature limit for human body is around 42°C [5] while the ultrasonic drug delivery system often leads to heat problems during operation. To predict and impede the overheating problems in sonophoresis, a finite element method (FEM) based on COMSOL Multiphysics software was proposed to achieve thermal analyses. Also, the temperature distribution and its rising curves in in vitro sonophoresis were obtained by the FEM method and experimental measurements. In addition, several potential thermal influence factors had been studied, which may be helpful in restraining the temperature increase to limit thermal damage.

II. MATERIAL

The pig gastric mucosa was stripped from fresh pig stomach and was sectioned into small strips before storing in phosphate buffer saline at 4 °C; Bovine Serum Albumin (BSA) with fluorescein isothiocyanate (FITC, a fluorescent indicator dye) was purchased from Bo Erxi Technology Co., Ltd., Beijing, China. The excitation and emission wavelengths of FITC were 495 nm and 525 nm, respectively. In addition, we designed and manufactured a 2.2-mm diameter piezoelectric single crystal ultrasonic transducer used in an endoscope in order to promote the drug penetration in the digestive tract lesion area.

III. EXPERIMENTAL METHOD

In order to get the thermal conductivity and sound velocity of the gastric mucosa, we set up two parameter measurement system of the gastric mucosa. Through in vitro sonophoresis and temperature rise experiment, we obtained the gastric mucosa permeability to Bovine Serum Albumin and temperature rise under different duty ratio and amplitude of the driving voltage, and liquid temperature in the donor, which proved that employment of this transducer could facilitate drug penetration in the gastric mucosa under safe human temperature.

(Continued on next page.)

In Vitro Drug Release in Gastric Mucosa Under Safe Human Temperature (Continued)

Co:Authors: Zhu Pancheng

(Day 4, Presentation 15)

IV. RESULTS & DISCUSSION

By using the parameter measurement system of the gastric mucosa, we obtained the thermal conductivity and sound velocity of gastric mucosa, which was $0.35 \text{ W/m}\cdot\text{K}$ and 1549 m/s , respectively. An up-trend in concentration was observed with increasing time. Also, it could be seen from the experimental results that as the duty ratio and amplitude of the driving voltage increased, the permeability and the maximum temperature in the donor also raised, but the time it took for them to reach temperature equilibrium was almost the same (15 minutes). The simulated and experimental maximum temperatures were less than the safety value (e.g., 42°C on human tissues) when the duty ratio of the driving voltage was less than 40 % at 20 Vpp. In addition, the duty ratio and amplitude of the driving voltage were sensitive to the rise in temperature, but a small scale of amplitude of the driving voltage increase could enhance the permeation of Bovine Serum Albumin without obvious temperature change. Moreover, the experiment found that the change in the temperature of the water bath was relatively small (2°C) and hardly affected the permeability. Furthermore, the results showed that the calculated temperature rising curves in in vitro sonophoresis corresponded to the experimental results, proving the effectiveness of this FEM method.

V. CONCLUSION

According to the calculated and experimental results, the duty ratio and amplitude of the driving voltage were sensitive to the rise in temperature, but a small scale of amplitude of the driving voltage increase could enhance the permeation of Bovine Serum Albumin without obvious temperature change. Moreover, we believed that the temperature of the water bath had little effect on the temperature rise of the system. Hence, the former two factors could be synthetically utilized to restrain the rise in temperature with little sacrifice of permeation ability. Hence this acoustic-flow-thermal FEM method could be applied to an optimized sonophoresis system design and simulating the thermal analyses of sonophoresis in healthy human gastrointestinal tract in terms of safe thermal limits.

ACKNOWLEDGMENT

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Session Chair/Guest Speaker Biographies

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Shashank Priya is currently Professor of Materials Science and Engineering at Pennsylvania State University, and serves as Associate Vice President for Research and Director of Strategic Initiatives. He also has adjunct Professor appointments in Department of Mechanical Engineering at Pennsylvania State University and Virginia Tech. His research is focused in the areas related to multifunctional materials, energy harvesting and bio-inspired systems. He has published over 450 peer-reviewed high impact journal papers / books chapters and more than 60 conference proceedings covering these topics. He has published ten US patents and edited ten books. His research group is interdisciplinary, consisting of materials scientists, physicists, mechanical engineers, roboticists, and electrical engineers. This allows the group to conduct integrated research addressing several aspects at the material, component, and system level. He is the founder and chair of the Annual Energy Harvesting Society Meeting. He is a member of the Honorary Chair Committee for the International Workshop on Piezoelectric Materials and Applications (IWPMMA). He is a fellow of the American Ceramic Society.



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Clive A. Randall is a Distinguished Professor of Materials Science and Engineering and Director of Materials Research Institute at The Pennsylvania State University. He has a B.Sc. (Honors) in Physics from University of East Anglia, UK (1983), and a Ph.D. in Experimental Physics from University of Essex, UK (1987). He was Director for the Center for Dielectric Studies 1997-2013, and Co-Director of the Center for Dielectrics and Piezoelectrics 2013-2015 (now Technical Advisor). Interests include discovery, processing, material physics, and compositional design of functional materials. Among his awards are Fellow of the American Ceramic Society, Academician of World Academy of Ceramics, IEEE Distinguished Lecturer, and Fellow of the European Ceramic Society. Prof. Randall has a Google h-factor of 85 and over 25,000 citations.



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Dr. Xiaoshi Qian is an associate professor and the founding director of the Research Center for Metamaterials and Intelligent Systems in the School of Mechanical Engineering at Shanghai Jiao Tong University. He obtained his Ph.D. in Electrical Engineering at Penn State University and later had his postdoc training in the department of material science and engineering at UCLA. He served as the CTO in Nascent Devices Inc. that aims to commercialize advanced electronic devices. His research focuses on smart dielectrics and related devices, especially on electrocaloric cooling technology for advanced thermal management.

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Jens Twiefel heads the research laboratory for piezo and ultrasound technology at the Institute of Dynamics and Vibration Research at Leibniz Universität Hannover. His research focuses on adapting high-power ultrasound technology to new challenges and applications and improving the fundamental understanding of the influence of ultrasound on various processes. A special focus is on the holistic view of the ultrasonic system from the electromechanical energy conversion via the mechanical vibration system to the process.

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Jörg Wallaschek is Director of the Institute of Dynamics and Vibration Research at Leibniz University Hannover, Germany. He has over 25 years of professional research experience in the field of mechatronics, dynamics and vibration in both academia and industry. His research is focussed on contact mechanics and friction, piezoelectric systems and ultrasonic engineering, and he has contributed to the continuous development of ultrasonic vibration motors.

During his academic career Jörg Wallaschek has supervised more than 80 successfully completed PhD projects. He has authored more than 150 scientific publications, including contributed chapters on sensors and actuators, modelling of electromechanical systems and energy harvesting technologies and textbooks on engineering mechanics.

Jörg Wallaschek teaches courses on engineering mechanics and structural dynamics at Leibniz University Hannover, Germany and gives expert seminars on vibration technologies at various institutions. He is member of editorial boards of scientific journals (including Archive of Applied Mechanics and International Journal of Vibroengineering) and steering committees of international conferences. He serves as reviewer for public organisations and consultant for small, medium and large enterprises. He was Fachkollegiat of the German National Research Council (DFG) in the expert panel on mechanics and is now elected member of the DFG Senate Committee for Graduate Schools.

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Dr. Hemsel studied mechanical engineering and got his PhD in 2001 for his work on piezoelectric ultrasonic linear motors. Since then he is engineering head at the chair for dynamics and mechatronics within the faculty of mechanical engineering at Paderborn university, Germany. His academic work focusses on sensors, actuators and ultrasonic systems.



Dr. Takeshi Morita

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Takeshi Morita received B. Eng., M. Eng. and Dr. Eng. degrees in precision machinery engineering from the University of Tokyo in 1994, 1996, and 1999, respectively. After being a postdoctoral researcher at RIKEN (the Institute of Physical and Chemical Research) and at EPFL (Swiss Federal Institute of Technology), he became a research associate at Tohoku University in 2002. He obtained a position at the University of Tokyo as an associate professor in 2005 and has been a full professor since 2018. His research interests include piezoelectric actuators and sensors, their fabrication processes and control systems.

Prof. Mickaël Lallart

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Mickaël Lallart was born in 1983. He graduated from Institut National des Sciences Appliquées de Lyon (INSA-Lyon), Lyon, France, in electrical engineering in 2006, and received his Ph.D. in electronics, electrotechnics, and automatics from the same university in 2008, where he worked for the Laboratoire de Génie Electrique et Ferroélectricité (LGEF). After completing a post-doctoral fellowship in the Center for Intelligent Material Systems and Structures (CIMSS) in Virginia Tech, Blacksburg, VA, USA in 2009, Dr. Lallart has been hired as an Associate Professor in the Laboratoire de Génie Electrique et Ferroélectricité, and has been appointed full-time Professor in 2019. Dr. Lallart was the recipient of an invited JSPS research fellowship in Tohoku University, Sendai, Japan in 2019-2020 and held an invited adjunct researcher position in NorthWestern Polytechnical University (NPU), Xi'An, China in 2018-2020. His current field of interest focuses on electroactive conversion and its application to vibration damping and energy harvesting, as well as autonomous, self-powered wireless systems. Since 2006, Dr. Lallart published more than 100 papers in international peer-reviewed journals and authored more than 90 conference papers including 9 personally invited talks and 3 plenary talks. He edited 6 books and participated to 9 book chapters and reviewed more than 250 manuscripts for various journals. Dr. Lallart was also recipient as PI or key partner of national and international academic projects funded by French National Research Agency or European Union for instance, and participated to several industrial collaborations as well.



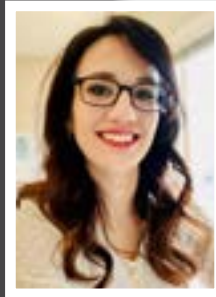
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