A novel microwave humidity sensor based on a defected ground structure and its application

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Keywords: Defected ground structure; Microwave detection; Moisture sensor; Moisture-sensitive materials

In this study, a microwave humidity sensor based on a defected ground structure was investigated for detecting humidity and facilitating simple applications via microwave technology. The introduction of the DGS allowed for a reduction in the device's size, meeting the demand for device miniaturization. A polyacrylamide/chitosan hybrid gel, serving as the humidity-sensitive material, was coated on the surface of the DGS. It was revealed that this arrangement enabled the detection over a wide humidity range with minimal humidity hysteresis. Notably, the sensor exhibited a frequency shift of 440 kHz/%RH with a minimal loss variation of 0.02 dB/%RH across a humidity range of 11% to 90% RH. Additionally, the humidity hysteresis was maintained below 5% within this range,

accompanied by response and recovery times of 26.4s/12s, respectively. This work provides a promising pathway toward the development of miniaturized microwave humidity sensors characterized by extensive humidity detection capabilities and low humidity hysteresis.

Acoustofluidics Olympics: Piezoelectric thin films can be amazing

by Richard Fu | Northumbria University

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Keywords: Acoustic wave, actuator, film, microfluidics., piezoelectric

This talk will foucs on one exciting application using piezoelectric films for acoustofludics platform and lab-on-chip applications. Integrated acoustic wave sensing/microfluidic devices have been fabricated by depositing these piezoelectric films onto a number of substrates such as silicon, ceramics, diamond, quartz, glass, and more recently also polymer, metallic foils and bendable glass/silicon for making flexible devices. Such thin film acoustic wave devices have great potentials for implementing integrated, disposable, or bendable/flexible devices into various sensing and actuating applications, using portable, wireless, flexible and remotely controlled acoustic wave devices. This provides exciting opportunities to achieve some exciting phenomena and mechanisms. The challenges in material selections and structural designs for high-performance thin film based acoustic wave devices are discussed. The strategies for achieving high power operation and higher temperature, most efficient liquid pumping, jetting and nebulization, as well as acoustofluidics and sensors used in extremely environmental conditions have been discussed.

Activating morphotropic phase boundary behavior in porous ferroelectric polymer films toward high performance self-powered sensing

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Keywords: Poly(vinylidene fluoride-co-trifluoroethylene (P(VDF-TrFE); Thin film; Interface effect; Piezoelectric nanogenerator; Self-powered sensing

Piezoelectric polyvinylidene fluoride (PVDF) and its copolymer, poly(vinylidene fluoride-co-trifluoroethylene) (P(VDF-TrFE)), have attracted considerable attention due to their potential in flexible, biocompatible energy harvesting and sensing devices. However, their limited piezoelectric performance hinders widespread application. Inspired by the concept of morphotropic phase boundary (MPB) prevalent in high-performance piezoelectric ceramics, we successfully constructed "MPB" in the piezoelectric polymer P(VDF-TrFE) through size-dependent interface effect. The emergence of "MPB" is attributed to the interface effect induced by electrostatic interactions between ZnO fillers and the -CH_2, -CF_2, and -CHF groups in P(VDF-TrFE). This interaction drives a concomitant competition between the *all-trans* β phase (normal ferroelectric) and the 3/1 helical phase (relaxor), resulting in enhanced piezoelectric responses in the transition region. By coupling the "MPB" effect with a porous structure, we developed a piezoelectric nanogenerator (PENG) that surpasses the electrical output limitation of current P(VDF-TrFE)-based PENGs. The fabricated PENG exhibits superior piezoelectric outputs (6.9 μW/cm^2), impressive pressure sensitivity (2.3038 V/kPa), ultrafast response time (4.3 ms), and recovery time (46.4 ms) — notably, without the need for additional poling treatment. In practical applications, the constructed PENG can efficiently generate characteristic signals in response to various human movements and harvest biomechanical energy. This work offers insight into utilizing interface-induced "MPB" and proposes a simple, scalable approach for developing high-performance self-polarized piezoelectric polymer films for self-powered sensing systems toward human-machine interaction.

An integrated vertical force transmission structure of MEMS piezoresistive tactile sensor for sensitivity enhancement

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Keywords: tactile force sensor; sensitivity; force transmission structure; flexible buffer layer

In the design of the tactile sensor, the force transmission structure is a key component for the effective transfer of external load to the sensor. To enhance the sensitivity of a MEMS-based 4 × 4 array piezoresistive tactile force sensor, a novel force transmission structure which is composed of a rigid rectangular microcolumn array structure made of silicon and a flexible buffer layer made of PDMS is designed in this paper. The sensing unit of a MEMS-based 4 × 4 array piezoresistive tactile force sensor is in the middle of the force transmission structure and the glass substrate, forming a sandwich-type tactile sensor. This configuration achieves two main functions of the force transmission structure: effectively transmitting force and protecting the sensing unit of the sensor. Besides, the influences of geometrical parameters of the rectangular microcolumn and the buffer layer on sensor performance were analyzed through simulation. Subsequently, based on the simulation results, the force transmission structure was optimized, ultimately enhancing the sensitivity of the tactile sensor. Simulation results show that the sensor with the proposed force transmission structure has a sensitivity of 0.0012/□ (sensing range: 0~1.8□), compared to the referenced sensor, the sensitivity has increased by 1.5 times.

Color-changing Hydrogel in Response to Dual Temperature/pH Stimulation

by LIN | Shanghai Jiao Tong University

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Keywords: hydrogels; thermochromic; surfactants; phase change temperature; pH response

In this work, composite color-changing hydrogels （SPS） with dual-stimulation response of temperature and pH were successfully prepared by free radical polymerization using sodium dodecylbenzene sulfonate （SDBS） and N-isopropylacrylamide （NIPAm） as the raw materials. The SPS hydrogel has higher temperature sensitivity, and the visible light transmittance of the composite hydrogel shows a linear change with the ambient temperature when the temperature-variable interval is 10-40°C. linear change, and the solar modulation rate ΔTsol was higher than 85.78% before and after discoloration. The composite hydrogel also functions as a pH discoloration response due to the greatly reduced solubility of SDBS in acidic environments （pH ≤ 2）. In addition, the SPS hydrogel has higher solar modulation and visible light transmittance than the SPN hydrogel with the addition of other anionic surfactants such as sodium dodecyl sulfate （SDS）. Therefore, compared with the traditional PNIPAM hydrogels, SPS composite hydrogels have the advantages of high solar modulation rate, linear temperature response, and multi-stimulus color change, which provide a wider range of application scenarios for smart color-changing hydrogels.

Deep Learning Spatiotemporal Visualization of Label-free Single-Cell Fate through Vibration Microstreaming

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Precise target rotation; three-dimensional reconstruction, deep learning, single-cell

Precise 3D observation of cellular structures and their inherent information is paramount in modern cell biology. However, conventional methods often suffer from limited resolution, cumbersome labeling procedures, and low throughput, leading to incomplete uniform single-cell capturing with large amounts. Recently, acoustofluidic manipulation has emerged as a promising, non-invasive, and cost-effective technique for single-cell rotation, facilitating detailed 3D visualization. Furthermore, advancements in image-based deep learning methods have revolutionized 3D reconstruction capabilities. Building upon these advancements, we propose the integration of high-precision acoustofluidic single-cell rotation in both xy and xz planes with deep learning-based 3D reconstruction. This synergistic approach offers advantages such as superior accuracy and label-free 3D reconstruction, eliminating tedious labeling steps; long-term observation of dynamic cellular processes like proliferation and drug responses; and an efficient platform for spatiotemporal analysis of cell fate decisions. This novel setup holds immense potential for furthering our understanding of cellular function and fate in health and disease.

Droplet Transportation Behaviours of Various Hydrophobic Surfaces in Superstrate platforms Using Thin Film Acoustic Wave Technology

by Luke Haworth | Huiling Ong | Jikai Zhang | Prashant Agrawal | Richard Fu | Northumbria University | Northumbria University | Northumbria University | Northumbria University | Northumbria University

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Keywords: Nanoscale surfaces, droplet transport, freezing dynamics, hydrophobic polymer, low temperature, superstrate

This research is focused on enhancing droplet transportation efficiency through various surface hydrophobic treatments within superstrate system using thin film surface acoustic wave (SAW) technology. As it is well-known, droplet transportation holds significant importance across diverse applications, from biotechnology to energy harvesting, necessitating efficient and reliable methodologies. Traditional approaches employ superhydrophobic or lubricant-infused surfaces but encounter challenges such as liquid penetration and fragility. To overcome these limitations, novel surface treatments such as slippery omniphobic covalently attached liquid (SOCAL), nanoscale cyclic fluoropolymer (CYTOP) coating, and slippery liquid-infused porous surfaces (SLIPS) have commonly used.

In this work, experimental investigations involve fabricating SAW devices integrated with different surface treatments on glass coverslips, facilitating droplet transportation, via silicon oil between glass and SAW device as a medium for wave propagation. Results demonstrate the superior performance of SOCAL surfaces attributed to their flexible chain structure and low surface energy, offering promising advancements in droplet manipulation efficiency. Temperature-dependent studies reveal the impact of temperature variations on droplet behaviour, with SOCAL and SLIPS maintaining high efficiencies even at freezing temperatures. Moreover, higher temperatures are found to facilitate increased droplet velocities. The study also elucidates the deicing mechanism of frozen droplets on CYTOP surfaces under different SAW powers, providing insights into temperature-dependent droplet dynamics and surface interactions.

The potential of integrating innovative surface treatments with SAW technology contribute to the optimization of droplet-based applications across various fields, addressing challenges associated with droplet manipulation and transport while paving the way for future advancements in thin films and surface coatings.

Exploring The Propagation Characteristics and Acoustic Streaming Velocity in Water Caused by Symmetric and Anti-Symmetric Lamb Waves

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Abstract ID: 10564
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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Acoustic streaming velocity, Anti-symmetric Lamb waves, Propagation characteristics, Symmetric Lamb waves

The utilization of Lamb waves in microfluidics, which is instrumental in sensing, droplet transfer, and chemical analysis, among other applications, necessitates a comprehensive understanding of their propagation characteristics in liquids. This is particularly crucial when symmetric or anti-symmetric Lamb waves spread into water. Our study initially involved conducting experiments and employing COMSOL simulations to ascertain the frequency and phase velocity of symmetric and anti-symmetric Lamb waves when they were excited on the surface of 128 Y-X LiNbO3. Subsequently, we utilized a Laser Doppler Vibrometer (LDV) to analyze the amplitude of both types of Lamb waves. In addition, we investigated the acoustic streaming velocity under high input power by recording the motion of 5-um polystyrene particles using Micro-PIV. This was achieved by placing the Lamb wave devices in a water reservoir enclosed by a transparent shell. Our findings suggest that anti-symmetric Lamb waves can attain a higher acoustic streaming velocity compared to symmetric Lamb waves. This research contributes to the ongoing efforts to harness the potential of Lamb waves in various scientific and technological domains.

Fabrication of Conductive Film via Alternating Coating of Carbon Nanotubes and Adhesive

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: adhesive, carbon nanotube, flexible/wearable electrode, human body signal detection sensor

Conductive films play a significant role in various industrial and application fields, especially in the domain of biomedical applications where they are utilized for diverse purposes such as biosensors and biocompatible attachments. However, traditional methods for producing conductive films often require expensive equipment or involve complex processes, making the manufacturing process costly or restrictive. Additionally, some films may exhibit low biocompatibility, rendering them unsuitable for use within the biological environment. Therefore, there is a demand for the development of new, cost-effective, and highly biocompatible methods for producing conductive films.

In this study, we aimed to produce thin conductive films by utilizing spray coating technology, alternating between carbon nanotubes (CNTs) and adhesive coatings. Spray coating offers advantages such as simplicity and low cost, making it applicable to a wide range of surfaces. By employing this method and alternating between CNTs and adhesive coatings, we sought to improve the electrical properties and biocompatibility of the films.

Through our research, we demonstrated that the conductive films produced using the proposed spray coating method exhibit excellent electrical properties and biocompatibility. Particularly, by investigating the electrical characteristics and durability of the films according to their thickness, we derived optimal conditions. Furthermore, we validated the applicability of these films for measuring biological signals. These findings are expected to contribute to the advancement of knowledge and technology in the field of conductive film production and applications.

Flexible Electronic Skins and its Application in Human-Robot Collaboration

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: flexible electronics, human-robot Collaboration, muti-information detection

Nowadays, intelligentization is one of significant trends for the developing of robotics. The key of this trend lies in the sensors for feeling and interaction with external environment. Among then, the vision sensing is the most mature, but there is still difficult to deal with various complex conditions involving human-machine interaction and cooperation alone. Therefore, it is urgent to develop tactile sensors for robotics. Flexible electronic device with their high performance, flexible, bending and other advantages, will play an important role in the robotics sensing. The report will reveal the needs of robot intelligent perception, analyze the key technologies in the design and manufacturing of several typical sensors, and review the recent research work of the research group.

Flexible thin film surface acoustic wave technology for transdermal drug delivery

by Jikai Zhang | Northumbria University

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Drug delivery, Surface acoustic wave, Wearable transdermal drug delivery

Transdermal drug delivery, as an alternative to oral and intravenous subcutaneous injection drug delivery, allows painless delivery of drugs or macromolecules through the skin into the body [1]. Unlike needle injection, transdermal drug delivery method offers minimally invasive delivery [2] in addition to avoidance of drug degradation in the stomach [3], and potentially controlled release of drugs [4]. Various technologies have been evaluated as means to enhance drug delivery through the relatively impervious epidermal layer of the skin, however precise delivery of large hydrophilic molecules is still a challenge even with microneedles or other energized (electrical, thermal or ultrasonic) patches, which are often difficult to integrate into small wearable devices. This study developed a flexible thin film surface acoustic wave (SAW) platform to facilitate transdermal delivery of macromolecules with fluorescein isothiocyanate up to 2000 kDa. ZnO thin films were deposited onto alumnium substrates and flexible thin film SAW devices were prepared. Two surrogates for human skin have been used to evaluate SAW energized devices, i.e., delivering dextran through agarose gel and also across stratum corneum of pig skin into the epidermis. Mechanical agitation, acoustothermal effect, and microscale acoustic cavitation induced by SAWs activated on the skin surface were identified as the main mechanisms for promoting drug transdermal transmission. Our studies showed that SAW based transdermal drug delivery is dependent on the combined effects of wave frequency and intensity, duration of applied acoustic waves, temperature, and drug molecules molecular weights.

Freeze-drying induced gradient microporous composite film with high ionic conductivity for ultrasensitive wearable iontronic pressure sensor

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Abstract ID: 10568
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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: flexible sensors, freeze-drying, ionic film, molecular dynamics simulation, ultrahigh sensitivity

Flexible pressure sensors are essential and key components for wearable electronics, but they have many limitations. The requests for a simple, fast, and low-cost fabrication method for ultrasensitive sensors hold practical significance. In this paper, we introduce an innovative ionic film with gradient porous structures, synthesized using a casting and freeze-drying method, to fabricate flexible iontronic pressure sensors. We demonstrate that low synthesis temperatures markedly enhance hydrogen bonds number of the ionic films, as revealed by Molecular Dynamics simulation, thereby significantly increasing the ionic conductivity of the film to an impressive value of 6.62 mS/cm. The films exhibit a composite structure comprising layered pores and a rough surface. Leveraging these properties, this film-based iontronic capacitive pressure sensor achieves an unprecedented sensitivity of 13786.2 kPa^{-1} and a broad pressure sensing range of 300 kPa, and is capable of distinguishing subtle pressures as low as 0.1 Pa, featuring a remarkably swift response time of 8 ms. We demonstrate that the sensor and its array could perform sensitive and accurate monitoring of physiological information and physical activities, and act as an excellent human-computer interface. This study offers an innovative and scalable approach to dramatically enhance sensor performance for various applications.

Improving Infrared Photodetection Performance by Ultraviolet-Ozone Treatment in Lead Sulfide Films

by Jing Sun | Zihao Liu | Junhui Ran | Bin Yang | Hunan University | Hunan University | Hunan University | Hunan University

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Defect passivation, Infrared photodetectors, Lead sulfide, Ultraviolet-ozone treatment

Lead sulfide (PbS) films are important infraredactive materials, and they are generally made by physical vapor deposition techniques such as magnetron sputtering. However, these deposition techniques are costly, and the PbS films need high-temperature oxygen-treatment to passivate sulfide vacancies and lead ion cluster defects. In this work, we report a facile chemical water bath to fabricate highly crystalline PbS films, where their defects were passivated by a controllable low-temperature ultraviolet-ozone (UVO) treatment, leading to a significantly reduced dark current and thus an improved room-temperature photodetectivity. The PbS photodetectors exhibited a specific detectivity increasing from 1.94 × 10^10 to 4.40 × 10^10 Jones under the reverse biased condition of −0.8 V after the UVO treatment. This work has demonstrated a low-cost production of high-quality PbS films and a low-temperature defect-passivation approach to improve infrared photodetection performance.

Integration of acoustofluidics, sensing and printing circuit board technologies

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: PCB, Surface acoustic wave, ZnO, acoustofluidics, sensing, thin film

In this study, we integrated acoustofluidics, acoustic wave sensing and electronics functions with widely used prototyping printing circuit boards (PCB) technologies for lab-on-a-chip applications. Such PCB board consisted of sandwich structure of epoxy glass core with copper layers, where we have fabricated surface acoustic wave (SAW) devices with sputtered thin film piezoelectric material (zinc oxide) directly on one side of the PCB. With a thin copper layer of 32 µm of PCB, we have achieved SAW sensing functions. We further demonstrated that such a copper thickness plays a key role in achieving actuation and acoustofluidics functionalities, i.e., as the thickness of the copper layer was increased up to 135 µm, acoustofluidics actuation can be efficiently achieved on such PCB configuration. This study paves the way for low-cost combination of electronics, SAW sensing and acoustofluidics in the same physical substrate.

Interface modulation and structure design of lead-free piezoelectric composite films for enhanced energy harvesting and self-powered sensing

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: piezoelectric materials; Piezoelectric nanogenerator; Interface modulation; Self powered sensing; Composite films

Piezoelectric composite thin films have been widely used in the fields of energy collection and self-powered sensing due to their high-voltage electrical properties, mechanical flexibility, and simple and efficient preparation methods. However, designing and preparing lead-free piezoelectric composite films for high-voltage output remains a huge challenge. Here, from the viewpoints of interface modulation and structure design, serval piezoelectric composite films such as BT@C-P(VDF-TrFE), Ag/BCZT-PVDF, and porous structure P(VDF-TrFE) were constructed, and their output performance of piezoelectric generators were systematically studied. The results indicated that these special structure composite films can lead to the formation of more polar β phase, resulting in the enhanced piezoelectricity of composites and the boosted output performances of lead-free PENGs. Additionally, the potential applications of lead-free piezoelectric composite films in energy harvesting (including harvesting energy from environmental vibration and human motions), self-powered sensing (including detecting physical motions and physiological signals) and human-machine interfaces are also broadly exploited, which enrich the applications of lead-free PENGs.

Interplay of Structure and Properties in Piezoelectric Aluminum Nitride Thin Films

by Bin Yang | Huiqian Yang | Xueqian Yang | Langru Yuan | Jing Sun | Hunan University | Hunan University | Hunan University | Hunan University | Hunan University

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Aluminum nitride, Piezoelectric response, Wurtzite-structure

Aluminum nitride (AlN) piezoelectric film is an important candidate for developing resonators and sensors. However, this material suffers from poor piezoelectric response due to the local hexagonal symmetry of wurtzite crystal structure which makes polar bonds hard to rotate at room temperature. In this talk, I will present our recent progress in understanding the growth mechanism of oriented wurtzite-structure AlN films and strategies for manipulating crystalline orientations during the sputtering process. And then, I will discuss chemical doping mechanisms and how we tune the local hexagonal symmetry of wurtzite crystal structure for enhanced piezoelectric response.

Machine Learning Empowered New Applications of Thin-Film Flexible Surface Acoustic Wave Devices

by Zhangbin Ji | Yihao Guo | Jian Zhou | Hunan university | Hunan university | Hunan university

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: AlN, AlscN, Machine learning, Surface acoustic wave, sensor, strain.

Abstract: Surface Acoustic Wave (SAW) sensors are typical MEMS sensors that find wide applications in aerospace, intelligent industry, and other fields for sensing physical parameters such as stress, strain, temperature, and torque, as well as detecting trace amounts of chemical agents and high-precision biosensing. Compared to traditional SAW sensors, the newly developed AI-empowered flexible SAW devices enable intelligent SAW sensing and open up new applications. Specifically, the following advancements are achieved:

(1) AI-empowered flexible SAW devices enable simultaneous monitoring of strain magnitude and direction using a single device. Typically, monitoring both strain magnitude and direction requires multiple strain gauges distributed on the surface under test to achieve strain vector monitoring. Leveraging the fact that flexible SAW sensor signals inherently contain multiple pieces of information, such as frequency, phase, etc., we propose a method to extract key information (e.g., frequency, phase, amplitude) from scattering parameters. Machine learning is then employed to assist in signal analysis, enabling a single SAW device to simultaneously monitor strain magnitude and direction.

(2) AI-empowered flexible SAW devices achieve consistency in planar and curved surface monitoring. Based on AlScN/ultra-thin flexible glass-based SAW devices, we experimentally and theoretically investigate the response characteristics of flexible SAW devices to off-axis deformation. By employing machine learning algorithms, we establish the correlation between device response features and target parameters (e.g., temperature). The optimized model exhibits excellent temperature prediction performance under complex off-axis strain perturbations, with a normalized root mean square error of less than 1% and a coefficient of determination (R^2) greater than 0.997. Finally, under arbitrarily curved conditions on the surface of an aerospace turbine engine model, the flexible SAW sensors demonstrate highly consistent temperature sensing capabilities.

In summary, the AI-empowered flexible SAW devices enable intelligent strain monitoring and open up new possibilities for planar and curved surface sensing applications.

Magnetoelectric coupling in flexible magnetostrictive/piezoelectric nanocomposites

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Keywords: Clamping effect, Coaxial nanofibers, Magnetoelectric coupling, Nanocomposite films

Magnetoelectric coupling in flexible magnetostrictive/piezoelectric nanocomposites

One-dimensional coaxial multiferroic composite nanofibers promise much tighter coupling between ferroelectric and ferromagnetic phases, and offer additional degrees of freedom in size, interface and epitaxial strain to further enhance the magnetoelectric (ME) coupling. It could not only reveal interesting one-dimensional multiferroicity at nanoscale, but could also enable novel multiferroic devices, such as one-dimensional spintronic devices and RF/microwave signals filter. The large aspect ratio of the nanofibers also makes it possible to magnify the mechanical displacement due to the piezoelectric or magnetostrictive effect, and thus enhance the magnetoelectric coupling even further. However, most of the reported works focused on the magnetic-field-induced polarization ME coupling, seldom works have been done on the converse ME coupling. In this work, we synthesized $CoFe_2O_4$-$Pb(Zr_{0.2}Ti_{0.8})O_3$ (CFO-PZT) coaxial nanofibers by electrospinning, and estimated the magnetoelectric response by measuring localized changes in magnetization as a result of electrical poling using a systematic sequence of piezoresponse force microscopy and magnetic force microscopy techniques. A static, large converse ME coupling coefficient of 1×10^{-8} s m^{-1}, or an equivalent ME voltage coefficient of 24.4 V Oe^{-1} cm^{-1}, was obtained in a single CFO-PZT nanofiber. These findings indicate the one-dimensional coaxial nanofibers are favorable candidates for ME sensing and actuating applications in nanodevices. This work will be helpful for understanding the converse ME coupling in one-dimensional nanostructure at nanoscale and will also help us to make further progress for the application of the one-dimensional multiferroic composites.

Monitoring, Sensing, and Mitigation of Condensation, Frost, and Ice Formation on Glass in Cold Environments via Thin Film Surface Acoustic Waves

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: SAW sensing, Surface acoustic waves, frequency shift, ice monitoring, rime ice

There have been various concerns on the safety and hazardous issues due to fogging, ice/frost formation, moisture, and condensation conditions occurring on glass surfaces [1]–[4]. Such glass surfaces include glass structural surfaces such as on windshields, glass lenses, solar panels, and even the windows of transportational vehicles [1]–[3]. However, an integrated function of both sensing and actuation have not been widely reported. In this study, it was proposed that with SAW technology, integrated functions of sensing and actuation are realised by monitoring the frequency shifts when subjected to different conditions in cold environments and application of various RF powers to evaluate the effects of SAW powers on de-icing performance.

Various factors were studied such as various different frequencies of ZnO/glass SAW devices, humidity, temperature, moisture, and condensation while subjected to cold environments. The frequency shifts induced by these factors on the ZnO/glass SAW devices were analysed and evaluated. Results have shown that greater frequency shifts were observed at higher frequency ZnO/glass SAW devices due to the increased sensitivity and mass loading effect induced by the water molecules, condensation, and ice/frost formation.

The low frequency ZnO/glass SAW devices, on the other hand, are much more utilised for actuation studies such as de-icing. In this case, the effects and influences of RF powers and acousto-heating were evaluated. Results have shown that under SAW agitations at various different RF powers, de-icing was promoted due to the interfacial nanoscale vibration and localised heating effect.

Optimization of LiNbO3/SiC Layered Structure for High-performance RF MEMS SAW devices

by Qiaozhen Zhang | Huiling Liu | Yang Yang | Sulei Fu | Shanghai Normal University | Shanghai University | Shanghai Normal University | Tsinghua University,

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: high-performance, layered structure, piezoelectric thin film, surface acoustic wave

Layered structures consisting of high coupling lithium niobate ($LiNbO_3$) piezoelectric thin film combined with high velocity SiC substrates have attracted much attention in RF MEMS surface acoustic wave (SAW) devices. However, such layered structures exist severe spurious responses that degrade the performances of SAW devices. This talk presents the analysis of generation mechanism of spurious modes in SAW resonators on layered structure, and proposes an optimized $LiNbO_3$/SiC layered structure with suppressed Rayleigh spurious modes. The Euler angle range of $LiNbO_3$ is derived by analyzing the slowness surface of $LiNbO_3$ and SiC, which provided a good energy confinement to suppress bulk wave spurs and improved Quality(Q) factor value. The results show that the bulk waves of SiC have higher velocities than $LiNbO_3$. It is expected to suppress the leakage of the bulk waves energy in the $LiNbO_3$. Meanwhile, the Rayleigh spurious mode could be effectively suppressed by controlling the $LiNbO_3$ Euler angle range. Simulation results of the rotated $LiNbO_3$/SiC layered structure are compared with various LT/LN thin plate layered structures. It is proved that the optimization structure offering larger K^2, higher velocity and improved Q values and Rayleigh spurious mode suppression, which is favorable for development of high-performance SAW devices for high frequency and wideband applications.

Performance analysis of TSV and MEMS capacitive sensor integration based on COMSOL

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Keywords: COMSOL, integration, performance analysis, reliability, through-silicon-via

At present, the integration technology of through-silicon vias (TSVs) and micro-electro-mechanical systems (MEMS) reached a certain level of development, which can address the issue of area cost of the entire system, but the impact on the performance of the two integrations is not too much discussion. Since the parasitic effect of TSV may affect some aspects of the performance of MEMS sensors, this paper analyzes the integrated performance of TSV and MEMS capacitive sensors through theoretical derivation and finite element method (FEM) of COMSOL simulation. Firstly, the derivation and simulation verification of TSV parasitic parameters and variation trends are made, and a suitable TSV model and MEMS capacitive sensor model are obtained. Secondly, theoretical derivation is made on the influence of the parasitic effect on the system output and the influence of the excitation signal on the system reliability. Finally, the simulation of the integrated model by COMSOL verifies the trend consistency of the theoretical results. This article confirms that TSV parasitic effects affect sensors of different sizes to varying degrees. A through hole with a diameter of 10μm (aspect ratio 2:1) can increase the sensitivity of a small cavity model by up to 2.63% (19.96fF/N). Additionally, it improves the stable equilibrium range and recovery rate of the system.

Performance improvement of a shear horizontal surface acoustic wave biosensor integrated with Rayleigh wave streaming

by Chen Fu | Shenzhen University

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Keywords: Acoustic Streaming, Biosensors, Rayleigh wave, SAw, Sensitivity

Surface acoustic wave (SAW) is capable of effectively controlling fluids and particles in lab-on-a-chip devices and has promising advantages as biosensors, including label-free, fast, real time, high specific and sensitive detection. We present here Shear horizontal surface acoustic wave (SH-SAW) biosensor accompanied by a unique Rayleigh wave-based actuator to overcome the sensitivity limits imposed by the mass transport and probe-target affinity. The platform assembled on an ST-quartz substrate consists of dual-channel SH-SAW delay lines fabricated along a 90°-rotated direction, whilst another interdigital electrode (IDT) is orthogonally placed to generate Rayleigh waves so as to induce favourable streaming in the bio-chamber, enhancing the binding efficiency of the bio-target. Simulation has shown that Rayleigh acoustic streaming generates a level of agitation that accelerates the mass transport of the biomolecules to the surface. A fourfold improvement in sensitivity is achieved compared with conventional SH-SAW biosensors by means of complementary DNA hybridization with the aid of the Rayleigh wave device. This suggests that the proposed scheme could improve the sensitivity of SAW biosensors in real-time detection.

PVTF-ZNR composite film with controllable embedding degree and its modulation of macrophages polarization

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Keywords: Controllable embedding, Macrophage, PVTF-ZNR composite film, Photoresponse, Polarization

Piezoelectric poly(vinylidene fluoride-trifluoroethylene) (PVTF) is a kind of electroactive biomaterial, which is promising in tissue repair. In this study, PVTF and zinc oxide nanorods (ZNR) were combined to obtain a controllable wettability surface based on a controllable embedded ZNR array with photoinduced hydrophilic property, and the modulation effects of the composite film on the immune activity and M1/M2 polarization ratio of macrophage were studied.

Firstly, PVTF film with ZnO crystal seed was prepared by casting method. Subsequently, the ZNR were in situ grown on the surface of PVTF by hydrothermal method and embedded in the PVTF by heat treatment according to high temperature capillarity, obtaining the PVTF-ZNR composite film with adjustable ZNR embedding degree, which depends on the C-axis orientation of ZNR array. Then the surface potential of the composite film is modulated by contact polarization.

With the deepening of ZNR embedding in PVTF, the wettability of the composite film changed from the hydrophobic property of ZNR array to the wettability closer to PVTF, and the range of photoinduced hydrophilicity changes gradually decreased under the UV-light, so that the wettability changes could be adjusted. Besides, the surface crystallization of PVTF in contact with ZNR was improved by embedding, and the presence of ZNR improved the piezoelectric sensitivity of PVTF.

The results of biological evaluation showed that the highly embedded composite film had the best biocompatibility. Compared with pure PVTF, it activated macrophages, significantly enhanced the immune activity, and adjusted the M1/M2 polarization ratio of macrophages according to the modulated surface potential.

In addition, by modulating the degree of embedding, the composite film can design ideal surface wetting behavior before and after photoresponse for the wettability requirements in a specific biological application context. It also has potential in different types of tissue engineering due to its electroactive properties for tissue repair and immunomodulatory effects.

Sandwiched Structure for Temperature Compensated Laterally-excited Bulk Wave Resonators Based on Lithium Niobate Film

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Keywords: bulk wave resonators, electromechanical coupling, sandwiched structure, temperature compensation

Recently, lithium niobate (LN) thin film laterally-excited bulk wave resonators (XBARs) have attracted much attention because of its advantage in high frequency and outstanding electromechanical coupling factor (K2) enabling ultra-wide band filter. This can satisfy the developing 5G communication demand. However, its large temperature coefficient limits its development to some extent. To improve its temperature stability with little K2 reduction, this paper has proposed a sandwiched structure for temperature compensated XBARs (TC XBARs). This structure includes the top silicon dioxide(SiO2) layer and the bottom SiO2 layer. One layer can improve temperature stability and the other layer can increase the K2. The optimized XBAR have a temperature coefficient of frequency (TCF) of -90.77 ppm/℃. The common two layers TC XBAR can achieve the TCF of -22 ppm/℃ with sacrificing K2 to 8%. However, the proposed sandwiched TC XBARs can achieve K2 of 11.9 and TCF of -28ppm/℃ simultaneously, with a high . Meanwhile, spurious modes can be suppressed in the sandwiched structure. Thus, this sandwiched structure can provide a good solution for the high performance of XBARs.

Self-Powered TENG with High Humidity Sensitivity Based on PVA Film modified by the synergistic effect of LiCl and MXene

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Keywords: MXene, composite film, energy harvesting, high humidity sensitivity, self-powered triboelectric nanogenerator

Triboelectric nanogenerators (TENGs) show great promise for a wide range of applications that require reliable output performance and stability. The present study focuses on the development of humidity-sensitive poly(vinyl alcohol) (PVA) based composite films, which exhibit enhanced output performance under high humidity conditions, by harnessing the synergistic effect of lithium chloride (LiCl) and MXene. These films, when used as a friction layer, enable the creation of self-powered TENGs with significantly enhanced output capabilities in high humidity environments. The composite material exhibits exceptional and stable output performance across a wide range of humidity levels from 30% to 95%, demonstrating a clear linear relationship with increasing relative humidity (RH). Notably, at 95% RH, the short-circuit current reaches an impressive value of 31.91 μA, which is three times higher than TENGs fabricated using PVA and PTFE (P-TENGs). The presence of rich hydroxyl groups in PVA, combined with the strong hygroscopicity of LiCl and the microcapacitor network formed by MXene nanosheets, greatly enhance water retention and surface texture within the composite, resulting in an excellent triboelectric output of TENG. The short-circuit current of the TENG shows excellent responsiveness to changes in ambient humidity within the range of 50% to 98%, indicating superior adsorption-desorption capabilities as humidity levels fluctuate. Furthermore, when employed as a power source in high humidity conditions, the TENG successfully instantaneously illuminates 240 LEDs with the transfer charge density of TENG reaching 194.37 μC·m−2. This breakthrough technology offers a viable and effective approach for stable energy harvesting and self-powered sensing in foggy environments, oceanic settings, and other high-humidity conditions.

Self-powered wearable electrical stimulation patch with integrated triboelectric nanogenerator for tendinopathy treatment

by Kaihang Zhang | Zhejiang University

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Keywords: Self-powered wearable patch; Triboelectric nanogenerator; Bionic; Mitochondrial function; Tendinopathy.

Tendinopathy is a common musculoskeletal disease for which researchers have proposed various treatments but with limited efficacy. Here, we propose a self-powered wearable electrical stimulation (ES) patch with an integrated triboelectric nanogenerator (TENG) for tendinopathy treatment. The ES patch comprises a freeze-dried PVDF-TrFE/PA6 TENG and a pair of interdigital electrodes (IDTs). The bionically designed ES patch is attached directly to affected tendons. It undergoes deformation and friction during movement and generates pulsed electric output, which is then converted into an electric field via the IDTs to treat tendinopathy. In vitro experiments showed that the self-powered ES patch greatly increased mitochondrial function in degenerative tendon stem/progenitor cells (TSPCs) and promoted tenogenesis. In vivo experiments revealed that the ES patch significantly improved the gait motor function of tendinopathy rats, boosted collagen regeneration, and drastically reduced the degree of tissue inflammatory infiltration and recovery time. Our study demonstrated the great potential of wearable electrical stimulation patches for effectively treating tendinopathy.

SiBCN-based ceramic films for high temperature electrode of SAW sensors

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Keywords: CVD, PDC, SAW sensor, SiBCN ceramics, electrode

High-temperature surface acoustic wave (SAW) sensors for multi-parameter simultaneous measurement are widely needed in the fields of aerospace and energy. For the SAW sensors that can be operated up to 1200 C, high temperature conductive coatings are required to match with the YCa4 O(BO3) 3 (YCOB) single crystal, which is the only available piezoelectric ceramics now for use at 1200 C. Promising high temperature conductive films comprised of SiBCN ceramics were coated via chemical vapor deposition (CVD), polymer-derived ceramic (PDC) route and PDC plus CVD method, respectively. Several ways including physical doping and chemical modification were tried to lower the electrical resistivity of SiBCN-based ceramic films to meet the requirement of SAW sensor's electrode. The microstructure,morphology and electrical properties of the films were characterized in detail. It was found that a film with few defects and good conductivity can be obtained at 1000℃ by PDC plus CVD route. However,a BN film has to e deposited on YCOB wafer first to suppress its decomposition in inert atmospheres around 1000℃ in the case of using CVD method. The overall conductivity change is primarily due to the increase in graphitization degree of free carbon and number of condutive nano crystal in SiBCN-based ceramic films.

Ultra-sensitive humidity sensing based on Coherent perfect absorber-lasing system

by Jianhui Wu | Jikui Luo | Zhejiang university | Zhejiang university

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: humidity sensor, parity-time symmetry, ultrasensitive sensing

As a singularity in non-Hermitian physics, coherent perfect absorber-lasing (CPAL) point theoretically has an infinite quality factor and can detect small perturbations, so it has potential applications in ultra-sensitive sensors. However, in the radio frequency field, due to deviations in actual components, the system will deviate from the CPAL point and the performance will degrade significantly (the output coefficient amplitude is only 30 dB). At the same time, actual sensing research is also very lacking. Based on these, we demonstrate a CPAL-based sensor system that increases its output coefficient amplitude to 60dB. When using the lasing state as the sensing mode, it has a capacitance detection accuracy of 10 fF. Then a high-frequency capacitive humidity sensor based on polyaniline/graphene oxide/titanium dioxide film is designed. The heterojunction formed between these materials increases the number of active sites for adsorbing water molecules. With the ultra-high capacitance detection accuracy of the CPAL sensor system, it is finally able to distinguish a 1% relative humidity change at 20%RH (corresponding to a 20 fF capacitance change, or a 1.63 dB output coefficient change), showing potential sensing application prospects.

Using diamond to fight fungi in space

by Haitao Ye | University of Leicester

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: antibacterial, diamond, fungi, surface modification

Most school children are familiar with a picture or model of the space station and spacecraft, some of which are on exhibit at Leicester's National Space Centre. However, potentially dangerous fungi currently reside on the space stations and in spacecraft. Fungi are highly adaptable and can corrode and degrade many materials that make up the space station, leading to equipment failure and sealing decline, and even eventually platform failure. Additionally, some of these fungi may be harmful for astronauts, especially during long-term exposure or as they change in the hostile environment of space. Although scientists have conducted extensive research on bacteria in space, fungi remain relatively poorly understood. The talk will focus on using the disruptive innovation of surface functionalized diamonds through plamsa process and ion implantation to address the problem of fungal growth in space environment, including on surfaces and critical components in manned satellites. Diamonds are corrosion-resistant and radiation hard materials that can withstand in harsh environments. Surface functionalized diamonds have the potential to add antifungal properties to the well-known hardness and wear resistant qualities of diamond coatings.

Wideband and ultrahigh steep skirts heterogeneous integration filter for 5G N77 applications

by Weipeng Xuan | Hong Jiang | Rui Ding | Jikui Luo | Shurong Dong | Hangzhou Dianzi University | Hangzhou Dianzi University | Zhejiang University | Zhejiang University | Zhejiang University

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: Acoustic wave, Filter, IPD, Zhejiang University

Filters has played a key important role in the communication systems. For 5G New Radio (NR) application, such as N77 band or N79 band, the full bandwidth is 900MHz and 600 MHz, respectively. Through the piezoelectric acoustic wave devices-based filters are well known have very high Q factors (>1000) and small size, its bandwidth is limited. lumped-LC Integrated Passive Device (IPD) devices-based filters have a wide bandwidth; however, their Q factor is low, which induced a low steep skirt. In this work, we present a novel filter structure with the acoustic wave-based devices heterogeneous integrated with IPD devices. And a wide bandwidth filter with high steep skirts was achieved. As a proof of concept, the N77 band filter with a 900 MHz bandwidth and 200 MHz roll-off band down to -28dB was designed.

Influence of amplitude modulation and substrate hydrophilicity treatment on surface acoustic wave atomization

by Qingyun Huang | Shenzhen Polytechnic University

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Symposium: 10. Smart Materials and Microsystems (SMM)
Keywords: SAW atomization; Amplitude modulation; Substrate hydrophilic treatment

Maintaining high atomization rates while reducing thermal effects remains a challenge in using surface acoustic wave (SAW) atomization for single- or multiple-inhalation drug delivery. The miniaturization and portability of atomization platforms also limit the commercialization of the SAW atomization technology. This paper presents a method for reducing the thermal effects while maintaining high input power efficiency. The method combines amplitude modulation and hydrophilic treatment of SAW substrates. Amplitude modulation was used to increase the power efficiency of the SAW atomization device, and its effects on key atomization parameters were investigated. We found that continuous operation at 1 kHz amplitude modulation can achieve a water atomization rate of 850 μL/min at 3.31 W input power. The hydrophilicity of the substrate surface was modified, and the effects of different hydrophilic conditions on the relevant characteristics of the atomization process were studied. Hydrophilic treatment of the substrate surface can effectively reduce the significant droplet ejection phenomenon and average aerosol diameter during the atomization process. Finally, we combined these two strategies to determine the optimal conditions for obtaining low-temperature distributions, high atomization rates, and small particle sizes. By setting a contact angle of 12° and 1 kHz amplitude modulation, we concluded that using the combined method can effectively improve the atomization rate, meeting the application requirements of pulmonary drug delivery and other fields, while also keeping the atomization temperature at an acceptable level.