crystals

Editorial

Piezoelectric Materials Design for High-Performance Sensing

Weili Deng [1], Long Jin [1] and Weiqing Yang [1,2,*]

1 Key Laboratory of Advanced Technologies of Materials, Ministry of Education, School of Materials Science and Engineering, Southwest Jiaotong University, Chengdu 610031, China
2 Research Institute of Frontier Science, Southwest Jiaotong University, Chengdu 610031, China
* Correspondence: wqyang@swjtu.edu.cn

Piezoelectric materials can realize the mutual conversion of electrical energy and mechanical energy, and are widely used in electronic devices such as piezoelectric filters, micro-displacers, actuators, and sensors, which have crucial uses in the fields of information and communication, biomedicine, military defense, etc. [1]. Piezoelectric materials with excellent performance are some of the most important new materials in this century, and are one of the focal points of the international scientific frontier of functional materials. With the rapid development of science and technology, piezoelectric materials are developing in the direction of material compounding, function specialization, performance enhancement, and structure miniaturization [2]. Therefore, the study of piezoelectric materials and the development of their applications are of great importance in the current information age.

Piezoelectric sensors based on the piezoelectric effect can operate from lateral, longitudinal, or shear forces, and are insensitive to electric fields as well as electromagnetic radiation. Their response remains linear over a wide temperature range, making them an ideal sensor for harsh environments. In addition, piezoelectric sensors have a high-frequency response, meaning that they can sense rapidly changing parameters. Additionally, with a large transient response, they are able to detect microsecond-long events and provide a linear output. In the past decade, piezoelectric sensors have experienced rapid progress and attracted widespread interest. To facilitate such technologies to revolutionize high-performance sensing and drive applications in new fields, this Special Issue provides a panoramic view on the latest developments in piezoelectric materials for sensing.

The preparation of high-quality piezoelectric materials is the cornerstone for the development of high-performance sensors and novel applications. The phase structure engineering of piezoelectric materials, including the morphotropic phase boundary (MPB) of piezoelectric ceramics and the active phase of piezoelectric polymers, is an effective way to modulate piezoelectric properties [3]. With regard to preparation and performance tuning, Kang et al. [4] developed composition ceramics of $Pb(Ni,Nb_{2/3})O_3$-$Pb(Zr,Ti)O_3$-$Pb(Mg,W)O_3$ [PNN-PZT-PMW] to prepare acoustic emission sensors for nondestructive testing. The PNN-PZT-PMW was manufactured via a conventional mixed-oxide method, using Li_2CO_3 and $CaCO_3$ as sintering aids. After doping with Sm, the as-prepared ceramics exhibited excellent piezoelectric properties, including a dielectric constant of 2824, a piezoelectric coefficient d_{33} of 630 pC/N, and a planar electromechanical coupling coefficient k_p of 0.665. In addition, Yoo and coworkers [5] modulated the piezoelectric properties and temperature stability of $(Na,K)NbO_3$ system ceramics by using sintering aids of CuO, B_2O_3, and ZnO as a function of antimony substitution. They prepared $0.965(Li_{0.03}(Na_{0.5}K_{0.5})_{0.97})(Nb_{1-x}Sb_x)O_3$-$0.035(Bi_{0.5}Na_{0.5})_{0.9}(Sr)_{0.1}ZrO_3$ ceramics and analyzed their crystal structures and electrical characteristics. As a result of the addition of antimony substitution, the grain of the ceramic was refined, and the coexistence of tetragonal and rhombohedral phases occurred, resulting in an increased dielectric constant and a lowered Curie temperature. The optimization of the piezoelectric properties of the above materials facilitates the development of devices such as acoustic emission sensors and ultrasonic transducers.

Citation: Deng, W.; Jin, L.; Yang, W. Piezoelectric Materials Design for High-Performance Sensing. *Crystals* **2023**, *13*, 1063. https://doi.org/10.3390/cryst13071063

Received: 21 June 2023
Revised: 29 June 2023
Accepted: 3 July 2023
Published: 5 July 2023

Due to the excellent piezoelectric properties of these materials, various sensors have been developed and many interesting applications have arisen. For instance, Govindarajan et al. [6] discussed the effect of different micro- and nanofillers in polyvinylidene fluoride (PVDF) polymer matrices on the structural, thermal, and electrical properties of surface acoustic wave (SAW) sensors. Results show that the addition of fillers to the polymer had a significant impact on the piezoelectric and structural properties of the piezocomposite. The maximum piezoelectric coefficient d_{33} of the composite reached 42 pC/N when the PVDF polymer was compounded with CNT nanofillers. In addition, they demonstrated a passive strain sensor based on SAWs, which can measure mechanical strains by examining the frequency shifts in the detected wave signals. Finally, Liu and his coworkers [7] proposed a method for corrosion depth assessment based on piezoelectric sensors. Since ultrasonic guided waves are reflected and transmitted at discontinuous boundaries in a medium, corrosion depth can be evaluated based on the reflected/transmitted signal amplitude ratio (RTAR) received by a piezoelectric sensor. With the aid of a depth assessment model, corrosion defects with a minimum depth of 0.2 mm can be quantitatively evaluated. This study provided an efficient way to apply piezoelectric sensors to the parametric estimation of corrosion growth and variation in defect depth with time.

With continuous innovation and development, especially the combination of scientific research and industrial applications, piezoelectric materials and devices present brighter and broader application prospects; therefore, this Special Issue focuses on the latest trends in piezoelectric materials and their applications. We hope that this collection of papers will meet the expectations of readers seeking the synthesis methods, enhanced properties, and applications of piezoelectric materials as well as devices. In addition, we also hope that this collection will inspire further research work on the related topics included in this Special Issue. We believe that there is the potential for booming growth in piezoelectricity and expect to witness more breakthroughs as well as applications that will lead to a more convenient, intelligent, and sustainable future for society.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mahapatra, S.D.; Mohapatra, P.C.; Aria, A.I.; Christie, G.; Mishra, Y.K.; Hofmann, S.; Thakur, V.K. Piezoelectric Materials for Energy Harvesting and Sensing Applications: Roadmap for Future Smart Materials. *Adv. Sci.* **2021**, *8*, 2100864. [CrossRef] [PubMed]
2. Deng, W.; Zhou, Y.; Libanori, A.; Chen, G.; Yang, W.; Chen, J. Piezoelectric Nanogenerators for Personalized Healthcare. *Chem. Soc. Rev.* **2022**, *51*, 3380–3435. [CrossRef] [PubMed]
3. Zhao, C.; Huang, Y.; Wu, J. Multifunctional Barium Titanate Ceramics via Chemical Modification Tuning Phase Structure. *InfoMat* **2020**, *2*, 1163–1190. [CrossRef]
4. Kang, S.; Lee, J.; Yoo, J.; Whang, S.A.; Lee, S.; Kee, S.; Im, I.; Oh, C. High-Performance Piezoelectric Characteristics of Sm Substituted $Pb(Ni,Nb)O_3$-$Pb(Zr,Ti)O_3$-$Pb(Mg,W)O_3$ System Ceramics for Ultrasonic Transducer Application. *Crystals* **2022**, *12*, 738. [CrossRef]
5. Yoo, J.; Kang, S. Crystal Structure and Electrical Characteristics of $(0.965)(Li_{0.03}(Na_{0.5}K_{0.5})0.97)(Nb_{1-x}Sb_x)O_{3-}0.035(Bi_{0.5}Na_{0.5})_{0.9}(Sr)_{0.1}ZrO_3$ Ceramics Doped with CuO, B_2O_3, and ZnO. *Crystals* **2021**, *11*, 859. [CrossRef]
6. Srinivasaraghavan Govindarajan, R.; Rojas-Nastrucci, E.; Kim, D. Surface Acoustic Wave-Based Flexible Piezocomposite Strain Sensor. *Crystals* **2021**, *11*, 1576. [CrossRef]
7. Liu, W.; Fan, J.; Yang, J. Characterization of Thickness Loss in a Storage Tank Plate with Piezoelectric Wafer Active Sensors. *Crystals* **2022**, *12*, 92. [CrossRef]