Check for updates

MATERIALS SCIENCE

A more biofriendly piezoelectric material

A ferroelectric molecular crystal displays characteristics required for implantation

By **Linping Wang**[1,2] *and* **Run-Wei Li**[1,2,3]

Devices implanted in the human body for sensing conditions and delivering treatments must be biosafe, biocompatible, and biodegradable. These requirements make piezoelectric materials attractive for their design because they convert mechanical force into electricity and vice versa (*1*). However, traditional piezoelectrics such as lead zirconate titanate are permanent, rather than transient, in nature (*2*, *3*). Although biodegradable piezoelectrics—such as those including amino acids, collagen, and chitin constituents—have the desired properties for implantation and are immune to infection and inflammation risks (*4*), they suffer from weak piezoelectric performance (*5*). On page 1492 of this issue, Zhang *et al.* (*6*) report a simple ferroelectric molecular crystal that exhibits piezoelectricity performance that is more than 13 times greater than that of amino acid–based piezoelectric materials (*7*). When composited with polyvinyl alcohol (PVA), the material demonstrates high flexibility and biodegradation and biosafety in physiological environments. The finding should advance piezoelectric materials further into transplant applications.

Inorganic piezoelectrics (piezoelectric ionic crystals) are known for their large piezoelectric response, but their brittle nature and resistance to sound wave propagation hinder their use in medical and biological applications (*8*). Conversely, piezoelectric polymers (piezoelectric molecular semicrystals) offer flexibility and low acoustical impedance but only a modest piezoelectric performance. For both materials, the absence of biodegradability limits their use as transient implantable devices.

A substantial advance in piezoelectric material design is ferroelectrochemistry, which centers on the strategic use of chemical design methodologies to tailor specific molecular ferroelectrics (*9*). Ferroelectric molecular crystals composed of organic single-component compounds have good solubility, potential biocompatibility, and biodegradability (*10*). However, despite these promising attributes, the piezoelectric performance of these molecular crystals falls substantially short, with low piezoelectric coefficients (d_{33}) of ≤40 pC/N (*11*). A desirable coefficient would be >100 pC/N.

Zhang *et al.* report that the piezoelectric molecular crystal $HOCH_2(CF_2)_3CH_2OH$ [2,2,3,3,4,4-hexafluoropentane-1,5-diol (HFPD)] exhibits a high piezoelectric response of ~138 pC/N under no poling condition (that is, without applying a strong electric field across piezoelectric materials to align the electric dipoles in a specific direction). It also displays an exceptional voltage constant (g_{33}) of ~2450 × 10^{-3} Vm/N under no poling condition, indicating a large voltage output when the material is subjected to mechanical stress or strain in the same direction. Achieving such properties in a ferroelectric molecular crystal is a milestone in piezoelectric material development.

> **"The exceptional performance… points to their suitability as carriers for drug delivery, as well as for…self-powered transient energy-harvesting devices…"**

The underlying mechanism of this biodegradable ferroelectric molecular crystal centers on a two-dimensional (2D) hydrogen bond network that is facilitated by $O-H\cdots O$ interactions of the terminal hydroxyl in the HFPD molecule. This interaction plays a pivotal role in solubility across various solvents. As well, this structural feature contributes to the biodegradability of the crystal, a crucial aspect of its potential biomedical application. Furthermore, Zhang *et al.* attribute the material's exceptional piezoelectric response to the anisotropy of Young's modulus, which comes from the ordered arrangement of the 2D hydrogen bond network and fluorine atoms along the chain in the crystal structure.

Zhang *et al.* also made HFPD-PVA film, a composite that could be used in biomedical device design. It exhibits an array of attributes that are essential for biomedical applications. Beyond high flexibility and biocompatibility, as demonstrated by culturing the film with multiple types of cells, these films also had no discernible toxicity to cultured cells and exhibited exceptional biodegradation and biosafety in physiological environments, which was confirmed through in vivo assessment in rats, including implantation tests beneath the skin. Moreover, the HFPD-PVA (2:1) composited films boasted strong piezoelectricity, with a d_{33} measuring 34.3 pC/N—eclipsing other organic piezoelectric composites formed by biofriendly molecular crystals such as γ-glycine (5.3 pC/N).

The exceptional performance of HFPD-PVA films points to their suitability as carriers for drug delivery, as well as for the development of self-powered transient energy-harvesting devices for therapeutic interventions. Furthermore, these films hold promise for regenerative medicine as scaffolds that support tissue repair and regeneration. Further research can focus on exploring elastification techniques for this advanced piezoelectric material because elastic ferroelectrics offer promising potential to expand implantable device applications (*11*). The findings of Zhang *et al.* are poised to transform the field of biomedical engineering. ■

---

[1]CAS Key Laboratory of Magnetic Materials and Devices, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, Ningbo, China. [2]Zhejiang Province Key Laboratory of Magnetic Materials and Application Technology, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences, Ningbo, China. [3]College of Materials Science and Optoelectronic Technology, University of Chinese Academy of Sciences, Beijing, China. Email: runweili@nimte.ac.cn

REFERENCES AND NOTES

1. S. Chen *et al.*, *Adv. Mater.* **35**, 2208256 (2023).
2. S. Selvarajan, A. Kim, S. H. Song, *IEEE Access* **8**, 68219 (2020).
3. K. Kapat, Q. T. H. Shubhra, M. Zhou, S. Leeuwenburgh, *Adv. Funct. Mater.* **30**, 1909045 (2020).
4. T. Liu *et al.*, *Nano Today* **52**, 101945 (2023).
5. F. Yang *et al.*, *Science* **373**, 337 (2021).
6. H.-Y. Zhang *et al.*, *Science* **383**, 1492 (2024).
7. D. Kim *et al.*, *Adv. Mater.* **32**, 1906989 (2020).
8. S. Gupta, G. Haiat, C. Laporte, P. Belanger, *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* **68**, 1653 (2021).
9. H.-Y. Liu, H.-Y. Zhang, X.-G. Chen, R.-G. Xiong, *J. Am. Chem. Soc.* **142**, 15205 (2020).
10. S. Guerin *et al.*, *Nat. Mater.* **17**, 180 (2018).
11. L. Gao *et al.*, *Science* **381**, 540 (2023).

10.1126/science.ado5706

Downloaded from https://www.science.org at Ningbo Institute of Material Technology & Engineering, CAS on March 29, 2024