



## Marine biology requires new line of inquiry in materials research

By Zhen Zhang, Bruce H. Robison, and Shriram Ramanathan

Although oceans cover nearly 70% of the planet, they comprise the least understood of Earth's major ecosystems. Oceans have been an important sustainer of life on Earth and promise vast future potential for overcoming current grand challenges in energy, food, global climate, and sustainability. However, current knowledge of oceanic ecosystems is limited by the complexity involved in exploring and sensing harsh marine environments.

Historically, the needs of the military to monitor surface and undersea vessels drove early developments in acoustic and magnetic field sensors,<sup>1,2</sup> and sonar has long supported the commercial fishing industry. Oceanographers require information on physical and chemical properties such as temperature, salinity, oxygen concentration, acidity, and pressure to understand climate change effects. There is also great interest among marine biologists to assess and understand different

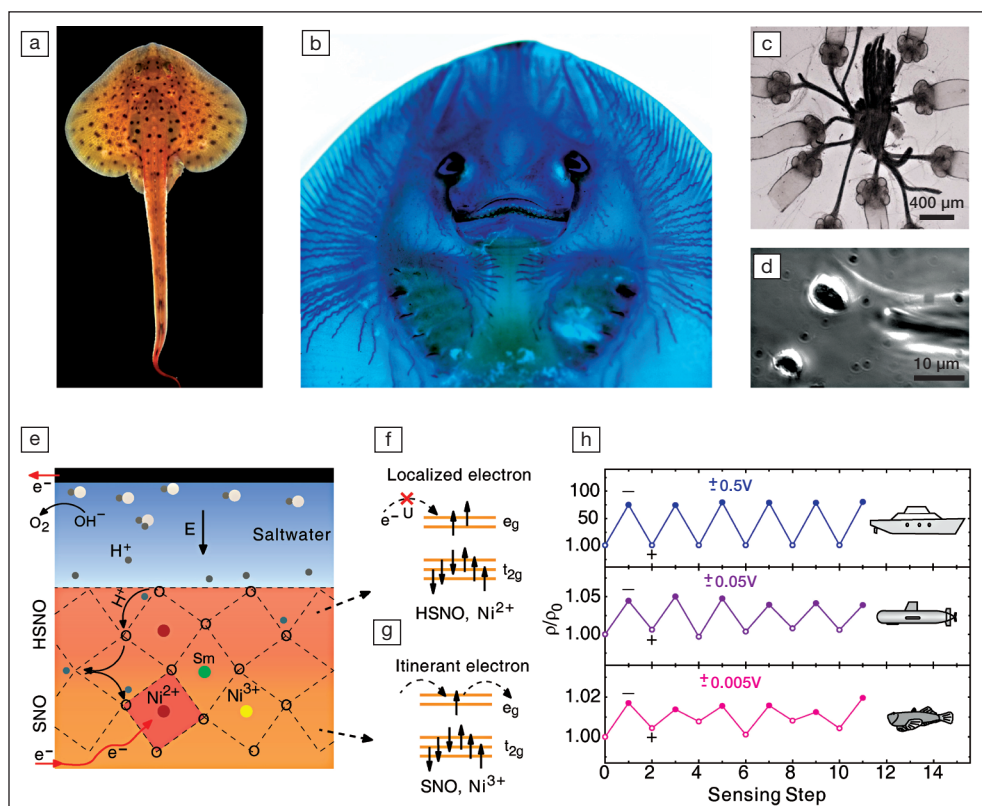
forms of life at various depths of the ocean and how the local populations interact and change over time.

Sampling even a small fraction of the planet's vast oceans requires the design of sensors that can be deployed from ships and robots and on autonomous vehicles or submersible floats that operate long-term. They also have the ability to transmit data directly or by satellite. For example, the Argo project—a global array of 3800 free-drifting profil-

ing floats—has successfully collected basic information such as ocean temperature and salinity over the past two decades by deploying thousands of sensors in various oceans across the planet.<sup>3</sup>

Designing functional materials to operate in ocean environments, such as for sensing applications, presents a formidable challenge. The materials have to be corrosion-resistant, but should not form passive layers that inhibit information transfer or sensing capability. Sensors must be pressure-tolerant and resistant to bio-fouling, as well as use low levels of power. Preferably, they should be calibration-stable over extended periods of time to be deployable on autonomous platforms.

Researchers can look at nature to better guide materials design. Over millions of years, in order to adapt to challenging marine environments, marine animals have evolved remarkable sensory systems such as echolocation in toothed whales



The electroreception organ of the elasmobranch species and its emulation by oxide quantum materials. (a) A skate's dorsal profile. (b) Ampullary organ canals stained by Alcian blue. (c) Ampullary organs with nerve fibers attached. (d) Image of electrosensory cells. (e) Electric-field-induced hydrogenation of SmNiO<sub>3</sub>. (f-g) Electronic structure of Ni 3d orbital of SmNiO<sub>3</sub> in (g) pristine and (f) hydrogenated states where electrons become localized. (h) Modulation of electrical resistivity of SmNiO<sub>3</sub> in saltwater after applying bias potential (±0.5~±0.005 V) over several cycles. (a-d) Images are reprinted with permission from Reference 5. (e-h) Images are reprinted with permission from Reference 7.

Zhen Zhang, Purdue University, USA; Bruce H. Robison, Monterey Bay Aquarium Research Institute, USA; Shriram Ramanathan, Purdue University, USA



(i.e., odontocetes), low-light vision in deep-sea fish, and mechanoreceptors in lateral lines of aquatic vertebrates. This naturally presents a great source of inspiration for materials researchers concerned with water interfaces.

Marine organisms such as elasmobranchii (sharks, skates, and rays) have evolved sensors to recognize the electrical and chemical nature of their environment by an electroreception organ, commonly known as *ampullae of Lorenzini* (AoL).<sup>4</sup> The AoL is typically arrayed on the head of elasmobranch species (see **Figures a–d**),<sup>5</sup> and this organ enables detection of weak electrical signals emitted by prey fish or generated by ocean currents. Weak electrical signals transmit through highly conductive gel-filled canals (**Figure b**) to electrosensory cells at the bottom membrane of the AoL (**Figures c–d**). Electric-bias-induced ion exchange through these sensing cells trigger neuronal activity for information transmission concerning the immediate environment.<sup>4,6</sup> Recent research on perovskite nickelates (e.g., SmNiO<sub>3</sub>) suggests a synthetic analogue to emulate

both the microscopic mechanism as well as functionality of AoL.<sup>7</sup> SmNiO<sub>3</sub> (SNO) detects electrical signals amplified by a phase transition caused by electric-field-induced hydrogenation from water (**Figures e–h**).

Besides this example, several areas in the marine sciences can benefit from advanced materials. For instance, identifying species-specific chemical or biological fingerprints of marine animals *in situ* would greatly enhance understanding their presence, passage, and ecological interactions. This can also help biologists understand how climate change and excessive fishing by humans affect the oceanic food web. Changing ocean ecosystems have both immediate and long-term repercussions on the quality of life for those reliant on fisheries to supply their food or livelihood.

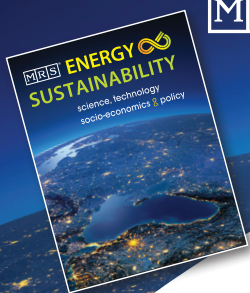
Materials that are stable in water and can exchange information between fluidic media and an external circuit through sensory interfaces can be game-changing for understanding the oceans. This requires fundamental research on interface science that bridges soft–hard materials systems,


ionic-electronic current transduction, and sensitivity to bio-matter, long-term stability, and preferably the read-out of signals in a noncontact manner (e.g., optical signaling). Multidisciplinary research is necessary to tackle the important societal problems for which advanced materials are a key ingredient.

**References**

1. J.E. Lenz, *Proc. IEEE* **78**, 973 (1990).
2. D.R. Dowling and K.G. Sabra, *Annu. Rev. Fluid Mech.* **47**, 221 (2015).
3. S.C. Riser, H.J. Freeland, D. Roemmich, S. Wijffels, A. Troisi, M. Belbéoch, D. Gilbert, J. Xu, S. Pouliquen, A. Thresher, P.-Y. Le Traon, G. Maze, B. Klein, M. Ravichandran, F. Grant, P.-M. Poulain, T. Suga, B. Lim, A. Sterl, P. Sutton, K.-A. Mork, P.J. Véléz-Belchí, I. Ansoorge, B. King, J. Turton, M. Baringer, S.R. Jayne, *Nat. Clim. Change* **6**, 145 (2016).
4. A.J. Kalmijn, *J. Exp. Biol.* **55**, 371 (1971).
5. N.W. Bellono, D.B. Leitch, D. Julius, *Nature* **543**, 391 (2017).
6. R.D. Fields, *Sci. Am.* **297**, 74 (2007).
7. Z. Zhang, D. Schwanz, B. Narayanan, M. Kotiuga, J.A. Dura, M. Cherukara, H. Zhou, J.W. Freeland, J. Li, R. Sutarto, F. He, C. Wu, J. Zhu, Y. Sun, K. Ramadoss, S.S. Nonnenmann, N. Yu, R. Comin, K.M. Rabe, S.K.R.S. Sankaranarayanan, S. Ramanathan, *Nature* **553**, 68 (2018). □

We welcome comments and feedback on Material Matters articles via email to [Bulletin@mrs.org](mailto:Bulletin@mrs.org).





# ENERGY & SUSTAINABILITY


science technology socio-economics policy

Set in an integrated context of scientific, technological and sociological complexities relating to energy, the environment and sustainability, topics featured in *MRS Energy & Sustainability* include: new R&D of both established and new areas; interdisciplinary systems integration; and objective application of economic, sociological and governmental models.

- ▶ View recent articles at [mrs.org/energy-sustainability-journal](https://mrs.org/energy-sustainability-journal).
- ▶ Sign up for content alerts at [cambridge.org/mre/alerts](https://cambridge.org/mre/alerts).

**RELATED RESOURCES**

- ▶ 2019 MRS Fall Meeting – [mrs.org/fall2019](https://mrs.org/fall2019)  
17 Symposia on Energy and Environment topics!
- ▶ Video Feature– [mrs.org/mre-video](https://mrs.org/mre-video)  
“Large-scale battery storage: Challenges and opportunities for technology and policy”  
Thomas A. Faunce, James Prest, Dawei Su, Sean J. Hearne, Francesca Iacopi  
Read the article: Volume 5, 2018 | <https://doi.org/10.1557/mre.2018.11>



**EDITOR-IN-CHIEF**  
**Y. Shirley Meng**  
University of California,  
San Diego

[mrs.org/energy-sustainability-journal](https://mrs.org/energy-sustainability-journal)



MATERIALS  
RESEARCH  
SOCIETY™





# CALL FOR PAPERS

**Abstract Submission Opens**  
September 26, 2019

**Abstract Submission Deadline**  
October 31, 2019

Spring Meeting registrations include MRS Membership July 1, 2020 – June 30, 2021

## CHARACTERIZATION AND THEORY

- CT01 Artificial Intelligence for Material Design, Processing and Characterizations
- CT02 Halide Perovskites—  
From Lead-Free Materials to Advanced Characterization and Deposition Approaches
- CT03 Expanding the Frontiers of Actinide Materials Science  
Through Experiment and Theory
- CT04 Tailored Interphases for High Strength and Functional Composites—  
Advances in Experiments, Simulations and AI-Based Design
- CT05 Defects, Order and Disorder in Structural and Functional Fluorite-Related Compounds
- CT06 Local and Global Fluctuations in Plasticity
- CT07 Micro-Assembly Technologies and Heterogeneous Integration—  
Fundamentals to Applications
- CT08 Crystallization via Nonclassical Pathways in Synthetic, Biogenic  
and Geologic Environments

## ELECTRONICS AND PHOTONICS

- EL01 Surfaces and Interfaces in Electronics and Photonics
- EL02 Advanced Manufacturing of Mixed Dimensional Heterostructures
- EL03 Novel Approaches and Material Platforms for Enhanced Light–Matter Interaction,  
Plasmonics and Metasurfaces
- EL04 Materials for Nonlinear and Nonreciprocal Photonics
- EL05 Scalable Photonic Material Platforms—Applications and Manufacturing Advances
- EL06 Photonic Materials for Information Processing and Computing
- EL07 Fundamental Mechanisms and Materials Discovery for Brain-Inspired Computing—  
Theory and Experiment
- EL08 Neuromorphic Materials and Devices for Bioinspired Computing  
and Artificial Intelligence
- EL09 Phase-Change Materials for Electronic and Photonic Nonvolatile Memory  
and Neuro-Inspired Computing
- EL10 Electroactive Ceramics for Information Technologies and Flexible Electronics
- EL11 Lead-Free Ferroelectrics and Their Emerging Applications
- EL12 Ferroc Materials and Heterostructures for Electronics and Data Storage
- EL13 Processing, Microstructure and Multifunctioning of Organic Semiconductors
- EL14 New Materials Design for Organic Semiconductors Through Multimodal  
Characterization and Computational Techniques
- EL15 Ultra-Wide Bandgap Materials, Devices and Systems

## ENERGY, STORAGE AND CONVERSION

- EN01 Next Steps for Perovskite Photovoltaics and Beyond
- EN02 Caloric Materials for Sustainable Cooling Applications
- EN03 Solar-Energy Conversion for Sustainable Water-Energy-Environmental Nexus
- EN04 Dual-Ion Batteries as an Emerging Technology for Sustainable Energy Storage—  
Anion Storage Materials and Full Dual-Ion Battery Devices
- EN05 Low-Cost Aqueous Rechargeable Battery Technologies
- EN06 Rational Designed Hierarchical Nanostructures for Photocatalytic System
- EN07 Next-Generation Electrical Energy Storage—Beyond Intercalation-Type Lithium Ion
- EN08 Multivalent-Based Electrochemical Energy Storage
- EN09 Flow-Based Open Electrochemical Systems
- EN10 Emerging Inorganic Semiconductors for Solar-Energy Conversion
- EN11 Materials, Modeling and Technoeconomic Impacts for Large-Scale  
Hydrogen and Energy Applications
- EN12 Materials for Safe and Sustainable Electrochemical Energy Storage

## NANOSCALE AND QUANTUM MATERIALS

- NM01 Nanodiamonds—Synthesis, Properties and Applications
- NM02 Colloidal Nanoparticles—From Synthesis to Applications
- NM03 Nanomanipulation of Materials
- NM04 Nanosafety
- NM05 1D Carbon Electronics—From Synthesis to Applications
- NM06 Theory and Characterization of 2D Materials—  
Bridging Atomic Structure and Device Performance
- NM07 Two-Dimensional Quantum Materials Out of Equilibrium
- NM08 2D Atomic and Molecular Sheets—  
Electronic and Photonic Properties and Device Applications
- NM09 Layered van der Waals Heterostructures—  
Synthesis, Physical Phenomena and Devices
- NM10 Synthesis, Properties and Applications of 2D MXenes
- NM11 Topological and Quantum Phenomena in Oxides and Oxide Heterostructures
- NM12 Synthesis and Control of Dirac or Topological Materials

## SOFT MATERIALS AND BIOMATERIALS

- SM01 Organ-on-a-Chip—Toward Personalized Precision Medicine
- SM02 Progress in Open-Space Microfluidics—  
From Nanoscience, Manufacturing to Biomedicine
- SM03 Flexible, Stretchable Biointegrated Materials, Devices and Related Mechanics
- SM04 Fundamental Materials, Devices and Fabrication Innovations for  
Biointegrated and Bioinspired Electronics
- SM05 Engineered Functional Multicellular Circuits, Devices and Systems
- SM06 Soft Organic and Hybrid Materials for Biointerfacing—  
Materials, Processes and Applications
- SM07 Bioinspired Synthesis and Manufacturing of Materials
- SM08 Emerging Strategies and Applications in Drug Delivery
- SM09 Advances in 3D Printing for Medical Applications

### Meeting Chairs

- Qing Cao** University of Illinois at Urbana-Champaign
- Miyoung Kim** Seoul National University
- Rajesh Naik** Air Force Research Laboratory
- James M. Rondinelli** Northwestern University
- Hong Wang** Southern University of Science and Technology

### Don't Miss These Future MRS Meetings!

**2020 MRS Fall Meeting & Exhibit**  
November 29–December 4, 2020, Boston, Massachusetts

**2021 MRS Spring Meeting & Exhibit**  
April 19–23, 2021, Seattle, Washington

### FOLLOW THE MEETING!

#S20MRS  

**MRS MATERIALS RESEARCH SOCIETY®**  
*Advancing materials. Improving the quality of life.*

[mrs.org/spring2020](https://mrs.org/spring2020)