

Metabolite-induced in vivo fabrication of substrate-free organic bioelectronics

XENOFON STRAKOSAS , HANNE BIESMANS , TOBIAS ABRAHAMSSON , KARIN HELLMAN , [...] AND MAGNUS BERGGREN +13 authors [Authors Info & Affiliations](#)

SCIENCE 23 Feb 2023 Vol 379, Issue 6634 pp. 795-802

327



"



CHECK ACCESS



A recipe for in situ bioelectronic materials

There are challenges in making materials that are soft enough to be interfaced with living tissue but firm enough to be inserted into the body. Strakosas *et al.* bypassed this challenge by developing a route to the polymer in vivo (see the Perspective by Inal). They introduced a complex precursor system including an oxidase to generate hydrogen peroxide in situ, a peroxidase to catalyze oxidative polymerization, a water-soluble conjugated monomer, a polyelectrolyte with counterions for covalent cross linking, and a surfactant for stabilization. With this cocktail, the authors were able to induce polymerization and subsequent gelation in different tissue environments. Demonstrations include the ex situ fabrication of this conducting gel in zebrafish (brain, fin, and heart), in food samples (beef, pork, chicken, and tofu), and a proof of concept of in vivo stimulation of a leech nerve. —MSL

Abstract

Interfacing electronics with neural tissue is crucial for understanding complex biological functions, but conventional bioelectronics consist of rigid electrodes fundamentally incompatible with living systems. The difference between static solid-state electronics and dynamic biological matter makes seamless integration of the two challenging. To address this incompatibility, we developed a method to dynamically create soft substrate-free conducting materials within the biological environment. We demonstrate in vivo electrode formation in zebrafish and leech models, using endogenous metabolites to trigger enzymatic polymerization of organic precursors within an injectable gel, thereby forming conducting polymer gels with long-range conductivity. This approach can be used to target specific biological substructures and is suitable for nerve stimulation, paving the way for fully integrated, in vivo-fabricated electronics within the nervous system.

RELATED PERSPECTIVE

Turning tissues into conducting matter

BY SAHIKA INAL

Get full access to this article

View all available purchase options and get full access to this article.

CHECK ACCESS

Supplementary Materials

This PDF file includes:

Materials and Methods

Supplementary Text

Figs. S1 to S20

Table S1

References (34–45)

[DOWNLOAD](#)

2.48 MB

Other Supplementary Material for this manuscript includes the following:

MDAR Reproducibility Checklist

[DOWNLOAD](#)

464.99 KB

Movies S1 to S6

[DOWNLOAD](#)

58.56 MB

References and Notes

- 1 J. W. Salatino, K. A. Ludwig, T. D. Y. Kozai, E. K. Purcell, Glial responses to implanted electrodes in the brain. *Nat. Biomed. Eng.* **1**, 862–877 (2017).

[CROSSREF](#) • [PUBMED](#) • [GOOGLE SCHOLAR](#)

- 2 M. Aizawa, Design and fabrication of biomolecular electronic devices and neuro devices. *Proc. Annu. Int. Conf. IEE Eng. Med. Biol. Soc.* **13**, 1792–1793 (1991).

[CROSSREF](#) • [GOOGLE SCHOLAR](#)

- 3 C. Boehler, S. Carli, L. Fadiga, T. Stieglitz, M. Asplund, Tutorial: Guidelines for standardized performance tests for electrodes in-

[SHOW ALL REFERENCES](#)

eLetters (0)

eLetters is an online forum for ongoing peer review. Submission of eLetters are open to all. eLetters are not edited, proofread, or indexed. Please read our [Terms of Service](#) before submitting your own eLetter.

[LOG IN TO SUBMIT A RESPONSE](#)

No eLetters have been published for this article yet.

CURRENT ISSUE



Samples returned from the asteroid Ryugu are similar to Ivuna-type carbonaceous meteorites

BY TETSUYA YOKOYAMA, KAZUHIDE NAGASHIMA, ET AL.

Formation and evolution of carbonaceous asteroid Ryugu: Direct evidence from returned samples

BY T. NAKAMURA, M. MATSUMOTO, ET AL.

Soluble organic molecules in samples of the carbonaceous asteroid (162173) Ryugu

BY HIROSHI NARAOKA, YOSHINORI TAKANO, ET AL.

TABLE OF CONTENTS >

LATEST NEWS

SCIENCEINSIDER | 24 FEB 2023

['Unfair' medical screening plagues polar research](#)

SCIENCEINSIDER | 23 FEB 2023

[After uproar, society backpedals from actions against scientists who staged climate protest at meeting](#)

NEWS | 23 FEB 2023

[News at a glance: New asteroid hunter, shark hatchery, and a telescope disrupted](#)

NEWS | 23 FEB 2023

[Iron shortage threatens microbes key to food chain in Southern Ocean](#)

NEWS FEATURE | 23 FEB 2023

[MRI for all: Cheap portable scanners aim to revolutionize medical imaging](#)

SCIENCEINSIDER | 23 FEB 2023

[How to fold Indigenous ethics into psychedelics studies](#)

RECOMMENDED

REPORTS | MARCH 2022

[Topological supramolecular network enabled high-conductivity, stretchable organic bioelectronics](#)

RESEARCH ARTICLES | FEBRUARY 2019

[Internal ion-gated organic electrochemical transistor: A building block for integrated bioelectronics](#)

RESEARCH ARTICLES | MAY 2015

[Therapy using implanted organic bioelectronics](#)

RESEARCH ARTICLES | JUNE 2018

[Direct metabolite detection with an n-type accumulation mode organic electrochemical transistor](#)

[View full text](#) · [Download PDF](#)

Science

Science
Advances

Science
Immunology

Science
Robotics

Science
Signaling

Science
Transla
Medic

FOLLOW US



NEWS

All News

ScienceInsider

CAREERS

Careers Articles

Find Jobs

COMMENTARY

Opinion

Analysis

JOURNALS

Science

Science Advances

AUTHORS & REVIEWERS

Information for Authors

Information for Reviewers

[News Features](#)[Employer Profiles](#)[Blogs](#)[Science Immunology](#)[Science Robotics](#)[Science Signaling](#)[Science Translational Medicine](#)[Science Partner Journals](#)[Subscribe to News from Science](#)[News from Science FAQ](#)[About News from Science](#)**LIBRARIANS****ADVERTISERS****RELATED SITES****ABOUT US****HELP**[Manage Your Institutional](#)[Advertising Kits](#)[AAAS.org](#)[Leadership](#)[FAQs](#)[Subscription](#)[Custom Publishing Info](#)[AAAS Communities](#)[Work at AAAS](#)[Access and Subscriptions](#)[Library Admin Portal](#)[Post a Job](#)[EurekAlert!](#)[Prizes and Awards](#)[Order a Single Issue](#)[Request a Quote](#)[Science in the Classroom](#)[Reprints and Permissions](#)[Librarian FAQs](#)[TOC Alerts and RSS Feeds](#)[Contact Us](#)

© 2023 American Association for the Advancement of Science. All rights reserved. AAAS is a partner of HINARI, AGORA, OARE, CHORUS, CLOCKSS, CrossRef and COUNTER. *Science* ISSN 0036-8075.

[Terms of Service](#) | [Privacy Policy](#) | [Accessibility](#)