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PRESS RELEASE

Source: Toyohashi University of Technology, Japan, Committee for Public Relations

Release Title: Goodbye large neural probes

Release Subtitle: Changing electrophysiology methods with an ultrasmall needle technology

Overview

A research team at the Department of Electrical and Electronic Information Engineering, Department of Computer Science and Engineering, Department of Applied Chemistry and Life Science, and the Electronics-Inspired Interdisciplinary Research Institute (EIIRIS) at Toyohashi University of Technology, and the National Institute of Technology, Ibaraki College, has developed a <3-µm-diameter ultrasmall needle-electrode with an amplifier for extracellular recordings. The team proposed an assembly technique via a single needle-electrode topped amplifier package, called 'STACK', within a device geometry of approximately 1×1 mm^2. The STACK device enabled the recording of neuronal activity from the mouse's brain *in vivo*, with a high signal-to-noise ratio (SNR). Because of the great advantage of the small needle geometry compared to conventional electrodes, the STACK device offers high biocompatibility and minimized tissue damage during the recording, as well as further long-term and safe chronic recordings, toward the next generation of electrode technology in electrophysiology.

Details

A research team at the Department of Electrical and Electronic Information Engineering, Department of Computer Science and Engineering, Department of Applied Chemistry and Life Science, and the Electronics-Inspired Interdisciplinary Research Institute (EIIRIS) at Toyohashi University of Technology, and the National Institute of Technology, Ibaraki College, has developed a <3-µm-diameter ultrasmall needle-electrode with an amplifier for extracellular recordings. The team proposed an assembly technique via a single needle-electrode topped amplifier package, called 'STACK', within a device geometry of approximately 1×1 mm^2. The STACK device enabled the recording of neuronal activity from a mouse's brain *in vivo*, with a high signal-to-noise ratio (SNR). Because of the significant advantage of the small needle geometry compared to conventional electrodes, the STACK device offers high biocompatibility and minimized tissue damage during recording, as well as further long-term and safe chronic recordings, toward the next generation of electrode technology in electrophysiology.

Microneedle electrode devices have been used as a powerful means of understanding how the brain works, thereby making significant contributions. However, the needle's geometry should be further miniaturized in terms of biocompatibility and chronic application to avoid tissue damage: i) Geometry of

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approximately 50 µm enhances the blood-brain barrier breach; ii) > 20 µm causes a distribution of the local communication between glia; and iii) < 10 µm offers no major traumatic tissue injury. Although advantages in micro/nano-scale fabrication technologies enable the formation of an approximately 10 µm needle-electrode, a smaller needle electrode causes electrical property degradation, making it impossible to record neuronal signals.

The research team has overcome these limitations by using an assembly technique, in which a module with a <3-µm-diameter needle-electrode is stacked on an amplifier module, called the single needle-topped amplifier package (STACK) device.

"To improve the electrical properties of our microscale silicon-needle electrode with a less-than 10 µm diameter, we had proposed additional deposition process of low-impedance material to the needle's tip, and demonstrated the neuronal recordings from rats with a 7-µm-diameter needle and from mice with a 5-µm-diameter needle. However, the deposition process enhances needle size, limiting the needle's miniaturization. To tackle this challenge, we used a different approach, in which a small amplifier (source follower) was embedded at the end of a small needle electrode. Clearly, we confirmed the amplification effect in the neuronal recording, as neuronal signals were detected with the amplifier, but no signal was detected without. This result leads us to further needle miniaturization," explains the first author of the article, master student Yuto Kita.

Development Background

The leader of the research team, Associate Professor Takeshi Kawano, said, "Before this device concept, we first tried another fabrication method in which the silicon-needle electrode was integrated with the amplifier on the same silicon substrate. However, the fabrication technology did not work well because of the process mismatch between the silicon needle fabricated with high-temperature silicon growth (vapor-liquid-solid growth) on the (1×1)-silicon substrate and the MOSFET on (100)-silicon. The device package technology reported in this manuscript first appeared in our weekly group meeting, where I discussed it with students and postdoc members. Immediately after, we named the device technology 'STACK', which became our project code to pursue it."

Future Outlook

He continued, "Although we demonstrated the device technology using a single channel electrode, the number of electrodes can be increased using the same technology. Because the amplifier embedment achieves approximately 500 times less electrode impedance (>5 MΩ at 1 kHz), the needle geometry can be further miniaturized, probably to nanoscale, which will open a new class of electrophysiology." The research team also pointed out other device issue of the thick substrate (>1 mm); the team has been exploring the fabrication process to make the device substrate thin and flexible, to realize further minimization of tissue damage for long-term and safe neuronal recordings.

Funding agency

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Reference

Yuto Kita, Shuhei Tsuruhara, Hiroshi Kubo, Hirohito Sawahata, Shota Yamagiwa, Koji Yamashita, Shinnosuke Idogawa, Yu Seikoba, Xian Long Angela Leong, Rika Numano, Kowa Koida, and Takeshi Kawano (2021). "Three-micrometer-diameter needle electrode with an amplifier for extracellular *in vivo* recordings," *Proceedings of the National Academy of Sciences*, 10.1073/pnas.2008233118.

Further information

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Toyohashi University of Technology founded in 1976 as a National University of Japan is a research institute in the fields of mechanical engineering, advanced electronics, information sciences, life sciences, and architecture.

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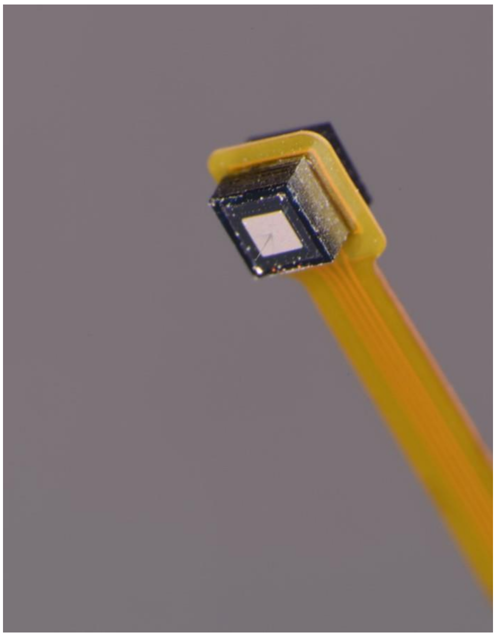
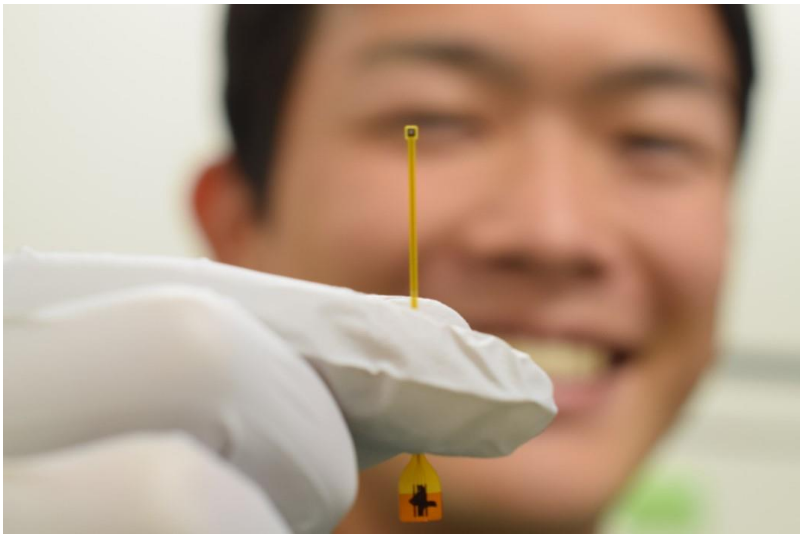
Figure1:



Caption: A block module of a 3-µm-diameter and 400-µm-length needle-electrode (frontside block, 1 × 1 mm^2) is stacked on an amplifier module (backside block) via a flexible interposer.

Figure2:



Caption: Photograph of the overall STACK device, which enabled neuronal activity recording in a mouse brain.

Keywords: BIOMEDICAL/ENVIRONMENTAL/CHEMICAL ENGINEERING, ELECTRICAL ENGINEERING/ELECTRONICS, NANOTECHNOLOGY/MICROMACHINES, TECHNOLOGY/ENGINEERING/COMPUTER SCIENCE