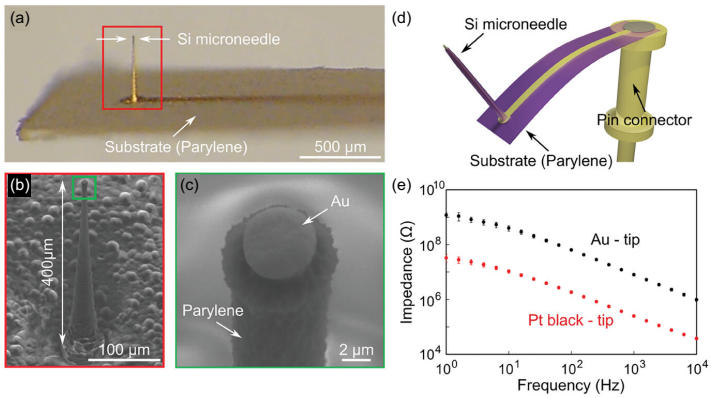
IRES²プロジェクト研究

A Flexible-Substrate 5-µm-Diameter Needle Electrode: Minimizing Neuronal Death and Enabling Year-Long Neural Recording

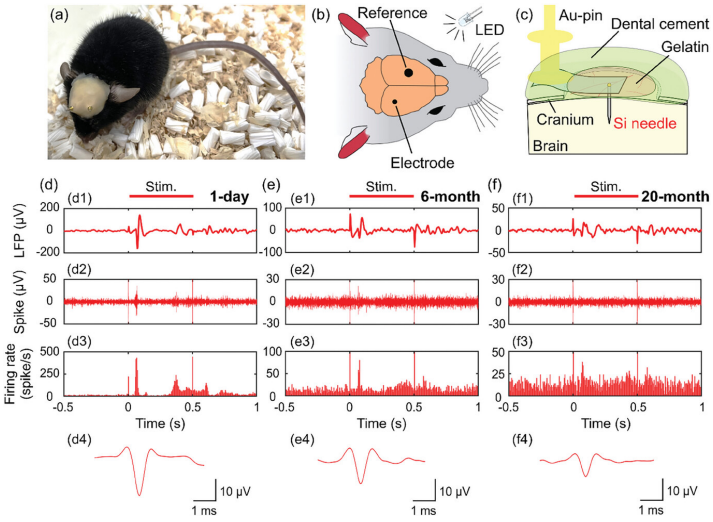
Hinata Sasaki, Koji Yamashita, Sayaki Shimizu, Kensei Sakamoto, Rika Numano, Kowa Koida, and Takeshi Kawano

Department of Electrical and Electronic Information Engineering,
Institute for Research on Next-generation Semiconductor and Sensing Science (IRES2), Toyohashi University of Technology
Department of Applied Chemistry and Life Science, Toyohashi University of Technology
Department of Computer Science and Engineering, Toyohashi University of Technology

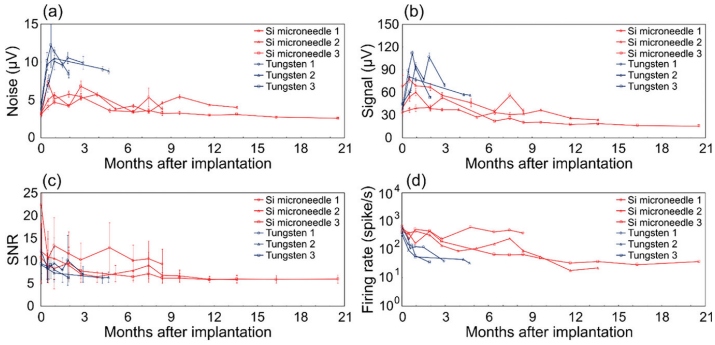
Abstract Long-term quantitative observations of the physiological state of the brain are essential technologies in various fields. In vivo electrophysiology with microelectrodes enables high spatiotemporal recordings of neuronal activities; however, tissue damage occurs due to electrode penetration, which limits the recording period. We introduce a neural recording technology that uses a 5-µm-diameter microneedle electrode device. The electrode implanted in the mouse cortex shows in vivo recording capabilities one day after implantation, which exceeds the year-long duration. The electrode does not significantly increase neuronal death compared with tissue without electrode implantation.



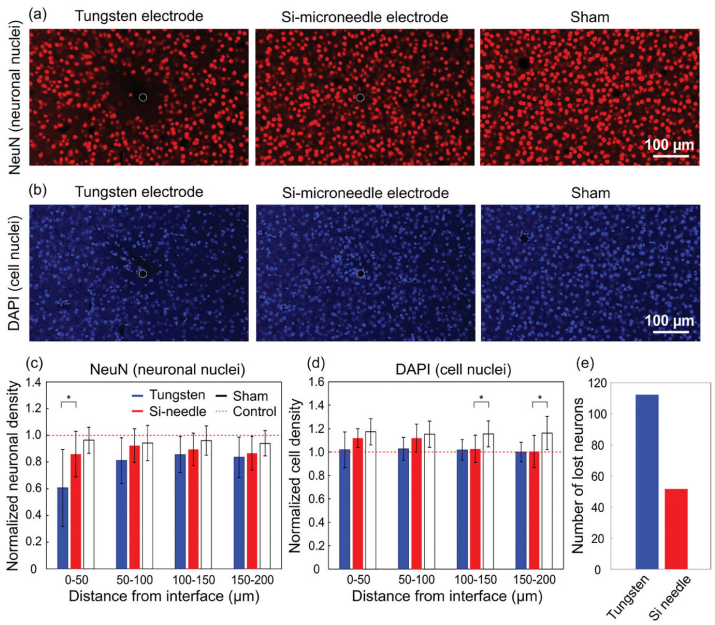
Si microneedle electrode device. a) Photograph of the overall view of a fabricated device. b, c) SEM images of the Si microneedle and the tip portion, with a length of 400 µm and a tip diameter of <5 µm, respectively. d) Schematic of the Si microneedle device assembled on a pin connector. e) Electrical impedance characteristics of Si microneedle electrode measured in saline (n = 5 devices).



Long-term neural recordings from the cortex of a mouse using a Si microneedle electrode device. a) Photograph of a mouse implanted with the Si microneedle. b, c) Schematic showing the position of the electrode implanted in the primary visual cortex (V1). d) Recorded signals 1 day after implantation: d1) average waveform of low-frequency band signals (10–100 Hz), d2) a typical high-frequency band signal (500–1,500 Hz), d3) PSTHs taken from these high-frequency signals, and d4) the averaged waveform of high-frequency signals. e) Recorded signals 6 months after implantation. f) Recorded signals 20 months after implantation.



Long-term neural recording stability of Si-microneedle electrode and tungsten-microelectrode implanted in mice (n = 3 mice for each electrode). a) Voltage noise of the recording system using each electrode (500–1,500 Hz). b) Signal amplitude. c) SNR. d) Firing rate (mean ± SD, n = 100 trials for each recording period).



Histological comparison of the brain tissue in the mouse a month after implantation of a tungsten microelectrode and a Si microneedle electrode. a, b) CMI of brain tissues implanted with the tungsten electrode, the Si microneedle, and the tissue with craniotomy alone ("sham"). c, d) Quantitative comparisons of each cell type in the tissue between the tungsten electrode, the Si microneedle, and the sham. Asterisks denote a significant difference in cell density; *p < 0.05 (mean ± standard deviation) (Welch t-test). e) Comparison of the number of lost neurons between the tungsten and Si microneedle electrodes.

Conclusion We present an electrophysiological recording technology that uses a 5-µm-diameter microneedle electrode device. The microneedle electrode was fabricated on a flexible parylene substrate by the VLS growth of Si and subsequent microfabrication processes. We demonstrated its capabilities for year-long neural recording using mice, indicating a promising technology for long-term quantitative observations of the physiological state in the brain in vivo. Chronic neuronal recording and immunohistochemical evaluations revealed the advantages of the Si microneedle electrode. Challenges of the device technology will include achieving multisite recording through electrode arraying, enabling a large-scale brain mapping with the device's advantages. Although we confirmed the capabilities of the electrode device using mice in this study, our newly developed technology will be extended to neural recording in other animals, including primates requiring long-term recording.

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Hinata Sasaki
(sasaki.hinata.wc@tut.jp)
Takeshi Kawano
(kawano@ee.tut.ac.jp)

技術を究め、技術を創る

国立大学法人 豊橋技術科学大学