Nanoneedle-electrode array packaged with amplifiers for recording biological-signals with a high voltage gain

Shuhei Tsuruhara[1], Yoshihiro Kubota[1], Hiroshi Kubo[1], Hirohito Sawahata[1,2], Shota Yamagiwa[1], Shinnosuke Idogawa[1] , and Takeshi Kawano[1]
[1]Toyohashi University of Technology, JAPAN. [2]National Institute of Advanced Industrial Science and Technology, JAPAN.

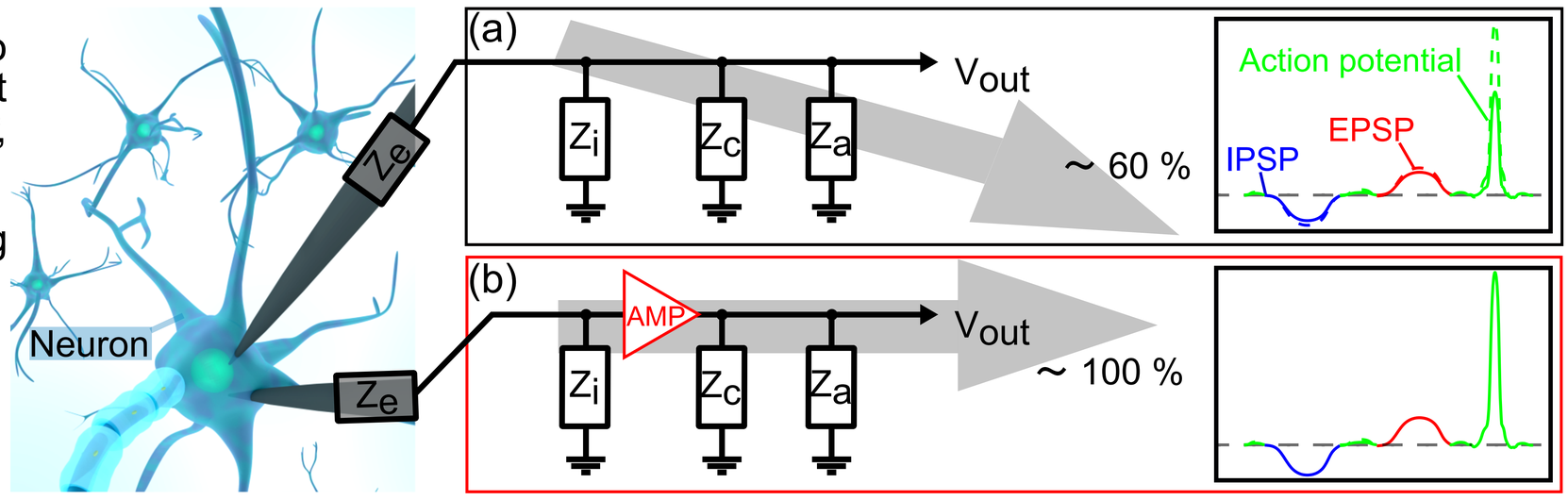
Background

The intracellular recording enables to record not only the action potentials but also the postsynaptic potentials (EPSP, IPSP), which reflect the synapse input.

Requirements for the intracellular recording include :

i) Sharpe needle tip, below 1 μm, and
ii) a high voltage gain.

Herein, we proposed a nanoneedle-electrode array, which is packaged with buffer amplifiers for a high voltage gain. As the buffer amplifier, source follower was fabricated within 1×1 mm^2 Si-block.

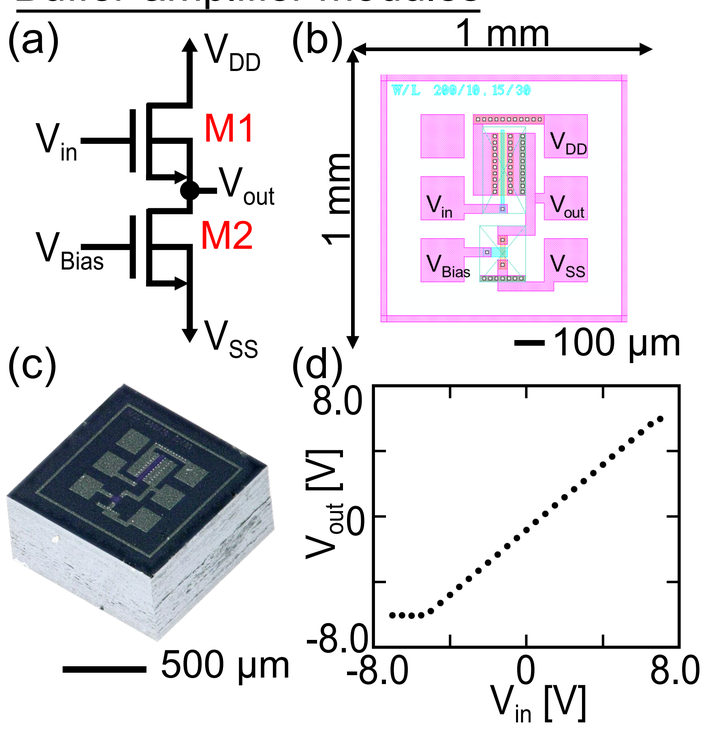


[Z_e:needle-electrode Z_i:device interconnection Z_c:cable Z_a:input impedance of recording system]

Schematic of intracellular recording using nanoelectrode. (a) Conventional electrode attenuates the voltage gain due to the high electrode's impedance and parasitic impedance characteristics. (b) Proposed amplifier package to solve the voltage attenuation of the nanoelectrode.

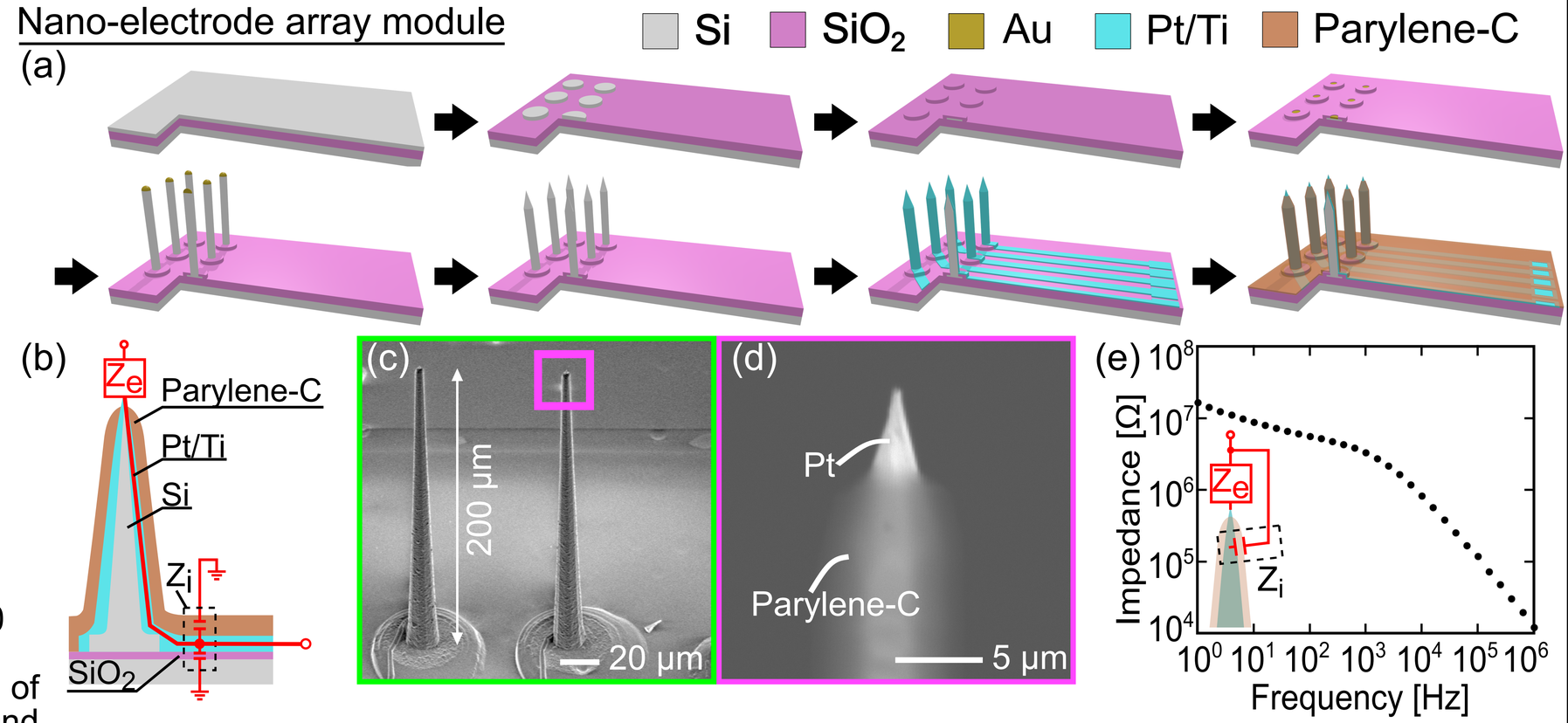
Fabrication of device modules

Buffer-amplifier modules



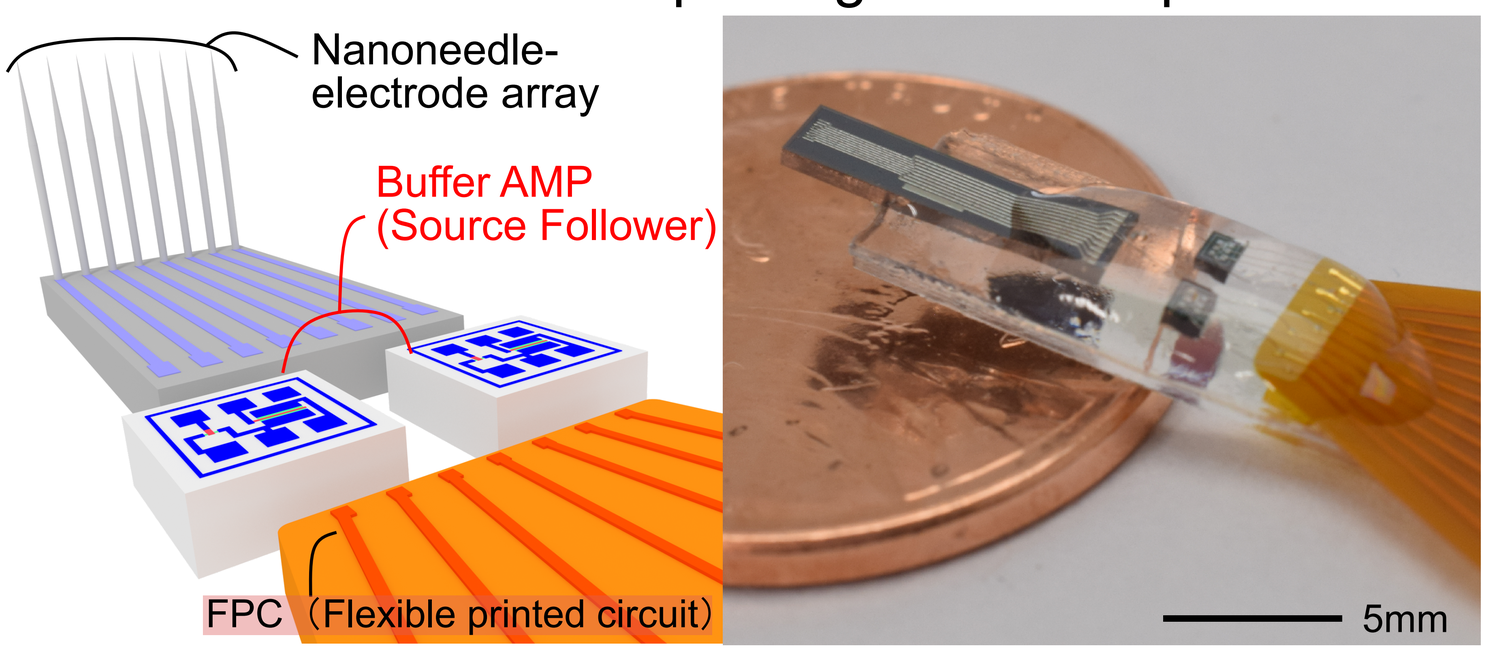
Amplifier module. (a) Equivalent circuit of source follower. (b, c) Layout and photograph of the fabricated module. (d) V_{out}-V_{in} characteristics of the fabricated amplifier module.

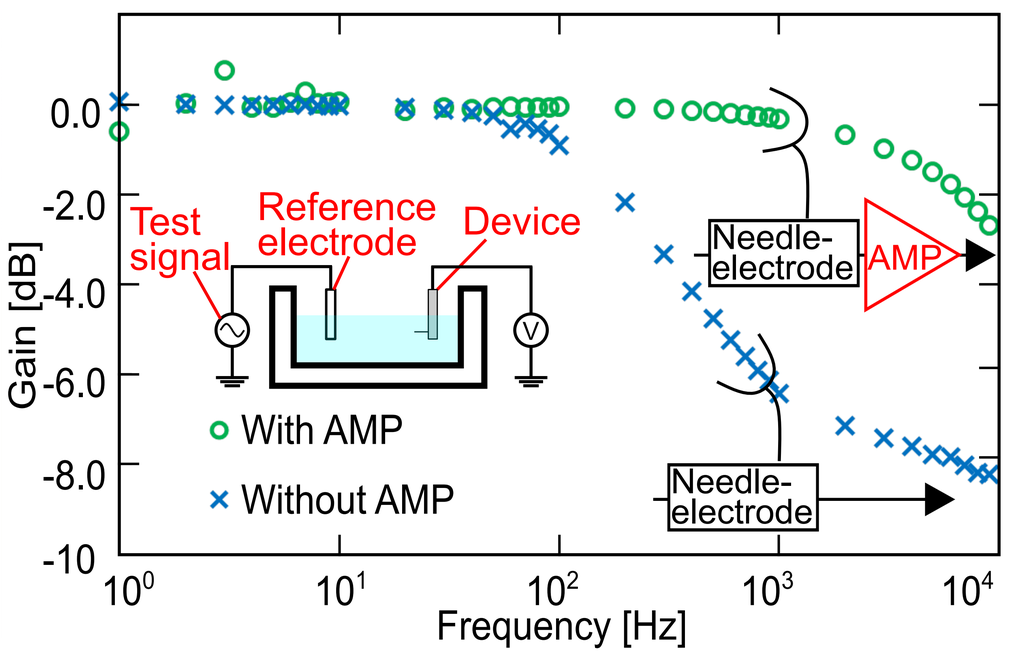
Nano-electrode array module



Nanoneedle-electrode array module. (a) Fabrication process steps. (b) Cross section of the nanoneedle. (c,d) SEM images of some needles and a needle-tip. Section. (e) Impedance characteristics of nanoneelde measured in saline solution.

Nanoneedle-electrode packaged with amplifier module





Nanoneedle-electrode packaged with amplifier modules. (a, b) Photograph and schematic of the packaged device. (c) Voltage gain characteristics of the device measured in saline solution. The graph also includes the data of nanoneedle without amplifier module for comparison.

Conclusion

We have proposed a nanoneedle-electrode device packaged with the buffer amplifier module for the application to intracellular recording with a high voltage gain. By packaging the buffer amplifier with the nanoneedle array device. This result indicates that the proposed nanoneedle-electrode array device will offer high-quality recording of intracellular signals, not only action potentials of the neuron but also the postsynaptic potentials.

Acknowledgements

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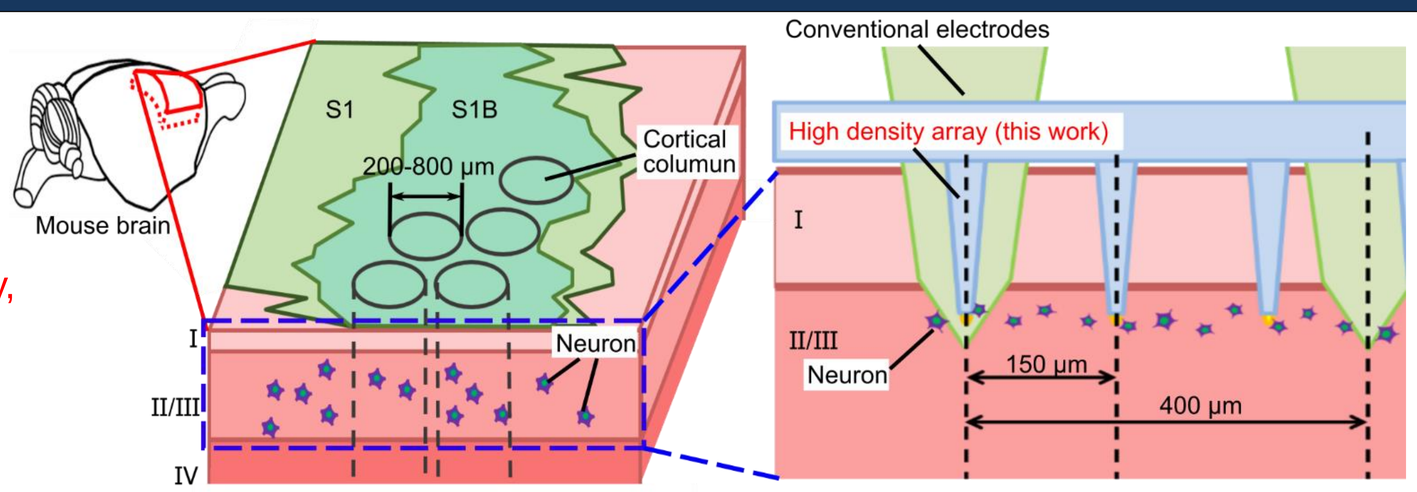
A HIGH-DENSITY ARRAY OF 3D MICRONEEDLE-ELECTRODES FOR EVALUATION OF SPATIAL RESOLUTION OF NEURONAL ACTIVITY

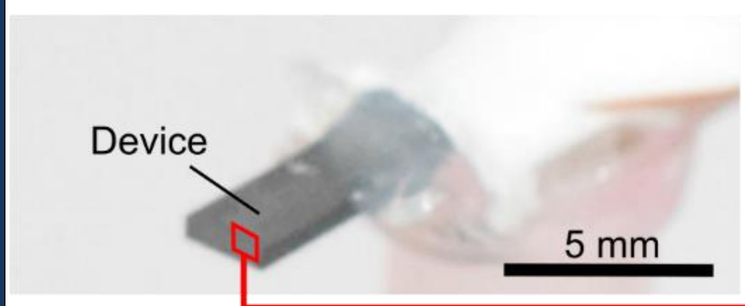
Yuta Kotani[1], Hirohito Sawahata[2], Shota Yamagiwa[1], Rika Numano[1], Kowa Koida[1], and Takeshi Kawano[1]
[1]Toyohashi University of Technology, JAPAN and [2]National Institute of Advanced Industrial Science and Technology, JAPAN

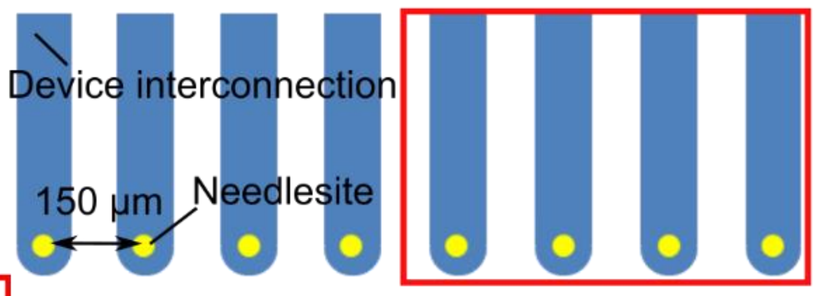
Background

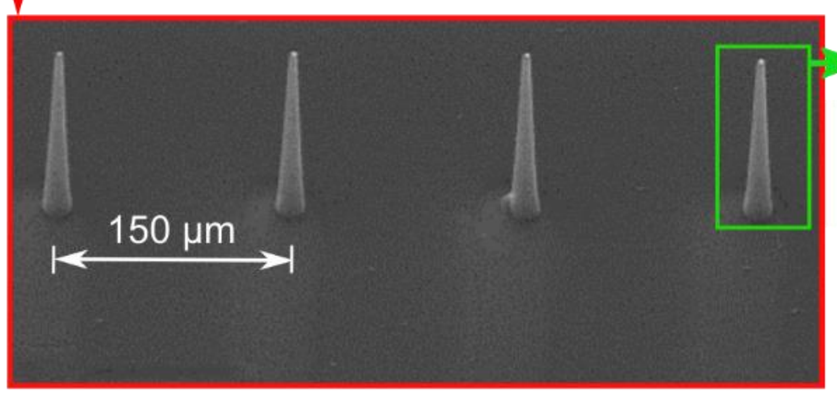
Exploring behavior of a micro-scale neural network of cortical column with a high spatiotemporal resolution is important to understand how the brain works. The query here is “how high spatial resolution of electrode array is necessary to detect different signals from neurons within the tissue”. For this query, however, needle’s pitch of conventional electrode devices has been limited by the fabrication process (e.g., 400 µm-pitch)

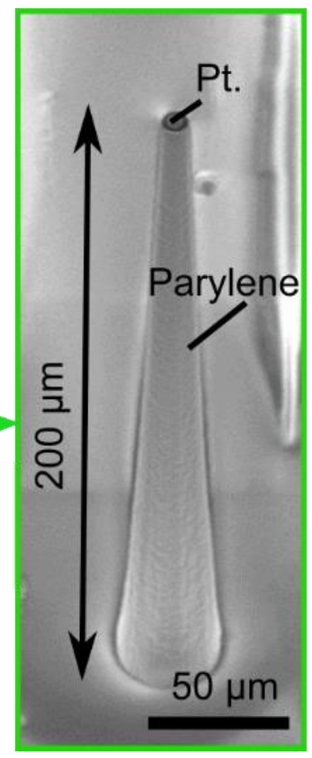


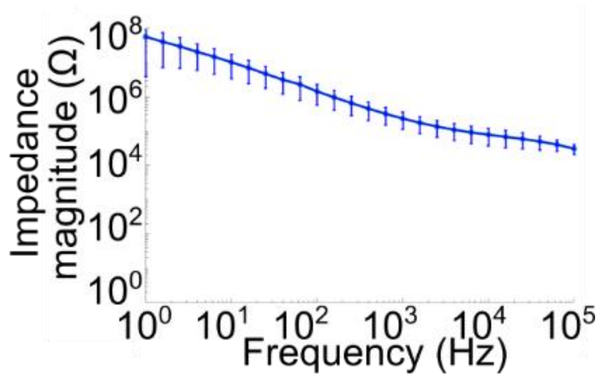
Fabricated high-density needle-electrode array







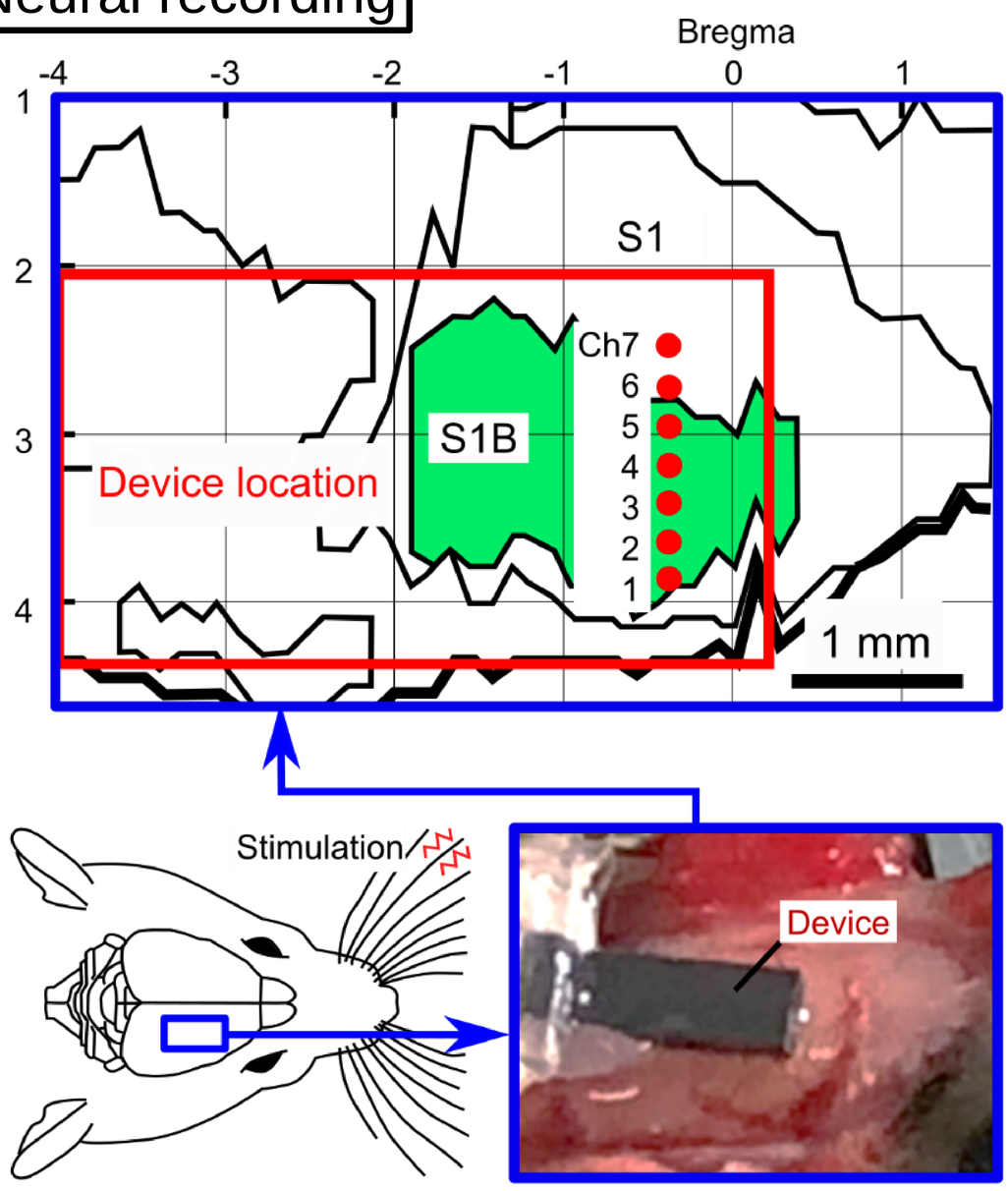


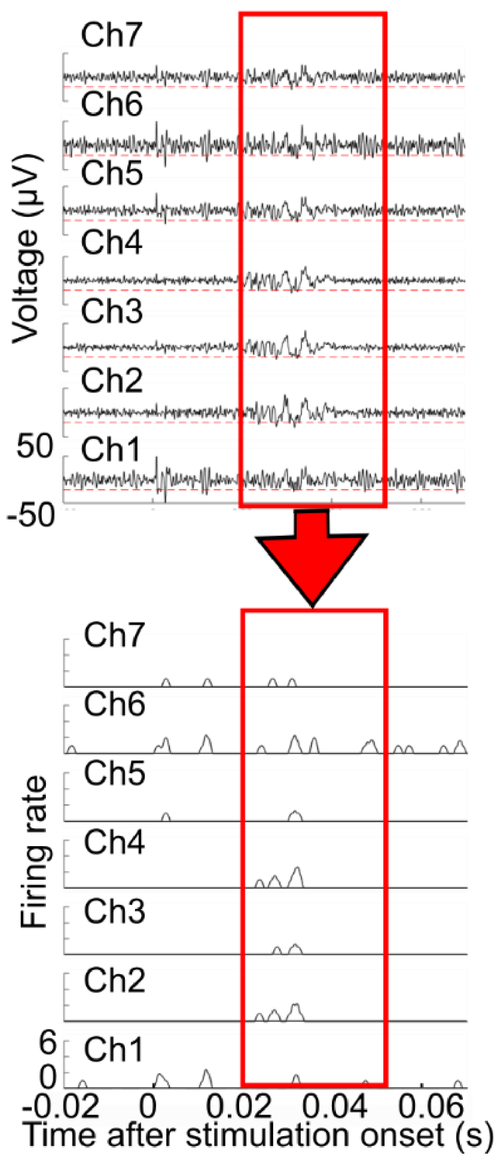


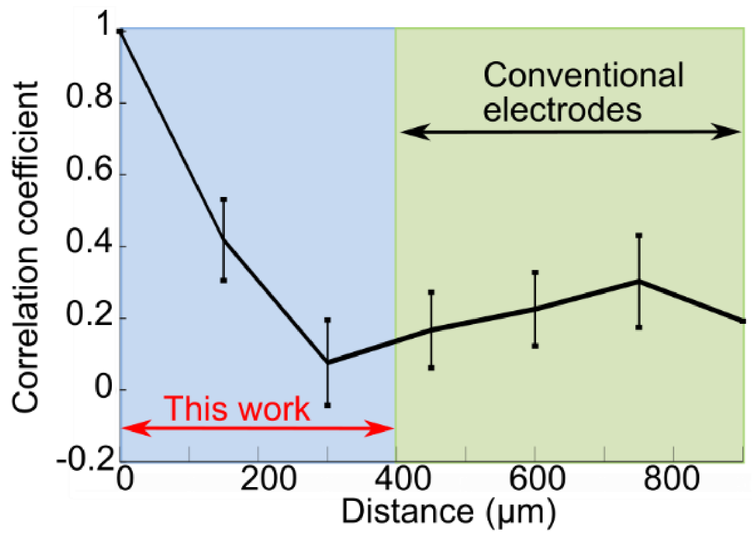
The microneedle-electrode array device is fabricated by vapor-liquid-solid (VLS) growth. The VLS growth employed an array of 5-µm-diameter and 200-µm-long Si-microneedles. Each Si-microneedle is then metalized with 200-nm-thick platinum (Pt) and insulated with 1-µm-thick parylene for multichannel recording of neuronal activities in the tissue.

The tip section was modified with a low impedance material of Pt black for the electrode’s impedance reduction (tip diameter of Pt black = 9.2 µm). The impedance of needle measured in saline at 1 kHz shows 208.8 kΩ (average from 7 chs.), which is low enough to detect spike (~ 3,000 Hz) signals.

Neural recording







The needles penetrated the primary somatosensory barrel cortex (S1B:1-4 mm lateral, 0-3 mm caudal from bregma) of an anesthetized mouse. During the recording, mouse’s whiskers were physically stimulated to record the neuronal responses. The graph shows electrode’s interval (distance) dependent correlation coefficients of the spike firing rates, representing the independency of spike signals between electrode channels. At the electrode intervals of over 300 µm, the correlation coefficient ranges from 0-0.4 (average 0.2). Compared to these interval ranges, we obtained the correlation coefficient of 0.3-0.6 (average 0.4) with 150 µm interval electrodes of our device.

Conclusiton

In this work, we evaluated spatial resolution of neuronal activities in mouse’s cortex, using a high-density array of microneedle-electrodes. As the result, the spatial resolution is smaller than the interval of conventional electrode (e.g., ~400 µm) as well as smaller than the cortical column of the somatosensory barrel region (200 –800 µm in diameter). Moreover, these results suggest that the further study on microscale neural network in the cortex will be required by using higher needle’s density with the interval below 150 µm. As demonstrated here, our Si-growth based needle-electrode with the diameter of < 10 µm is applicable to this challenge.

Acknowledgements

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