The 18th U.S.-Korea Forum on Nanotechnology

Electrocorticography Display for High Precision Intraoperative Brain Mapping

Youngbin Tchoe
Biomedical Engineering, UNIST

Sep 23, 2024

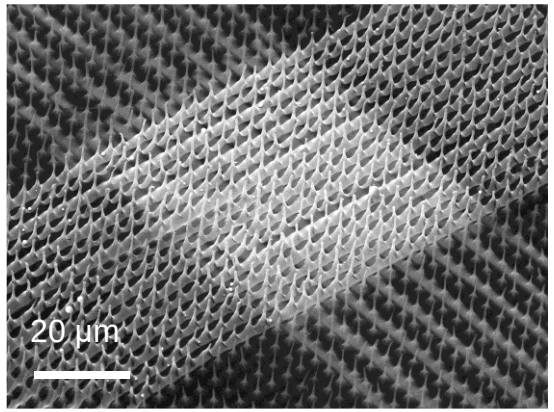
US-Korea nanotechnology collaboration in my research

Nanoscale Optoelectronics

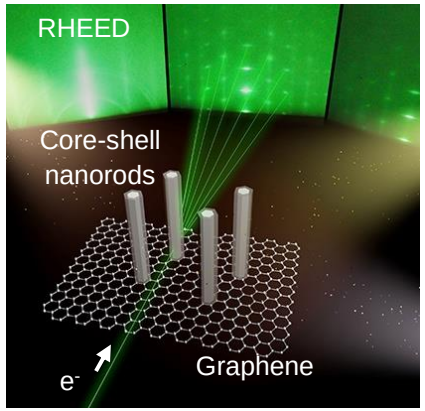
Advisor: Prof. Gyu-Chul Yi (SNU)

Ph.D. 2011-2018

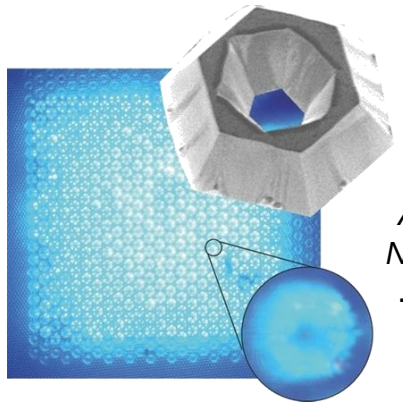
Semiconductor Nanodevices



MBE growth of nanomaterials



GaN nanostructured LEDs



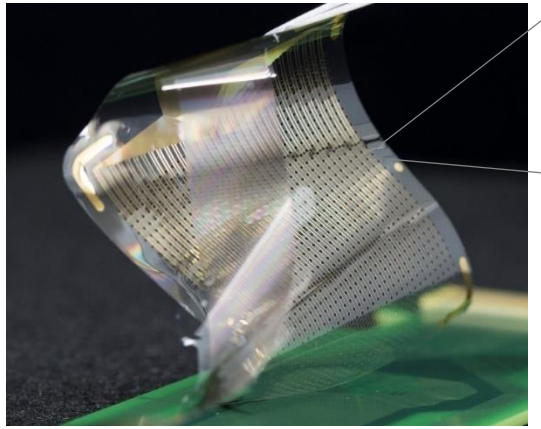
Y. Tchoe, et al. *Adv. Mater.* (2014) *Nano Energy* (2018) . *NPG Asia. Mater.* (2015)

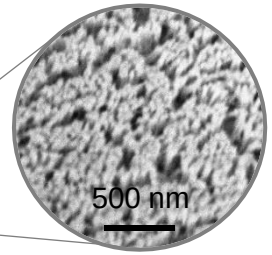
Neural Interface Devices

Advisor: Prof. Shadi Dayeh (UCSD)

Post doc 2018-2023

Brain interface electrodes (μECoG)





Platinum nanorods

Introduced on 'The 16th U.S.-Korea Forum on Nanotechnology' @ San Diego (2019) by Prof. Shadi Dayeh

Y. Tchoe, et al. *Sci. Trans. Med* (2022)

★ μLED+μECoG for cortical activity display

Y. Tchoe, et al. *Sci. Trans. Med* (2024)

Brain pathology that requires open brain surgery (craniotomy)

Brain tumor

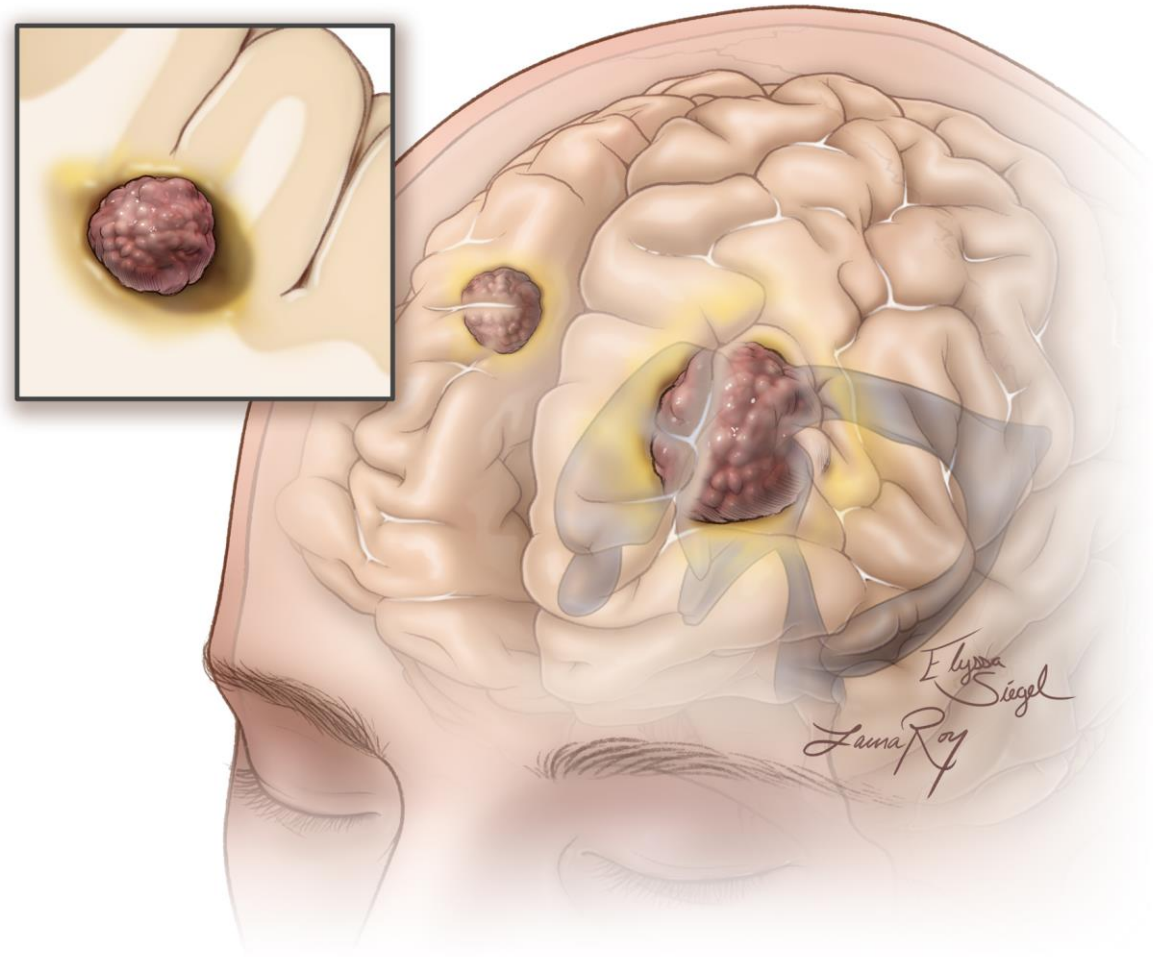


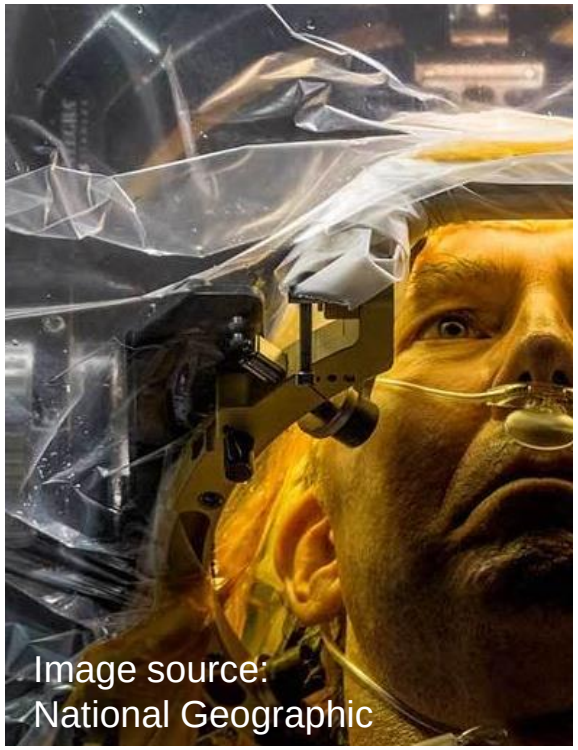
Image source: The Neurosurgical Atlas

Drug-resistant Epilepsy

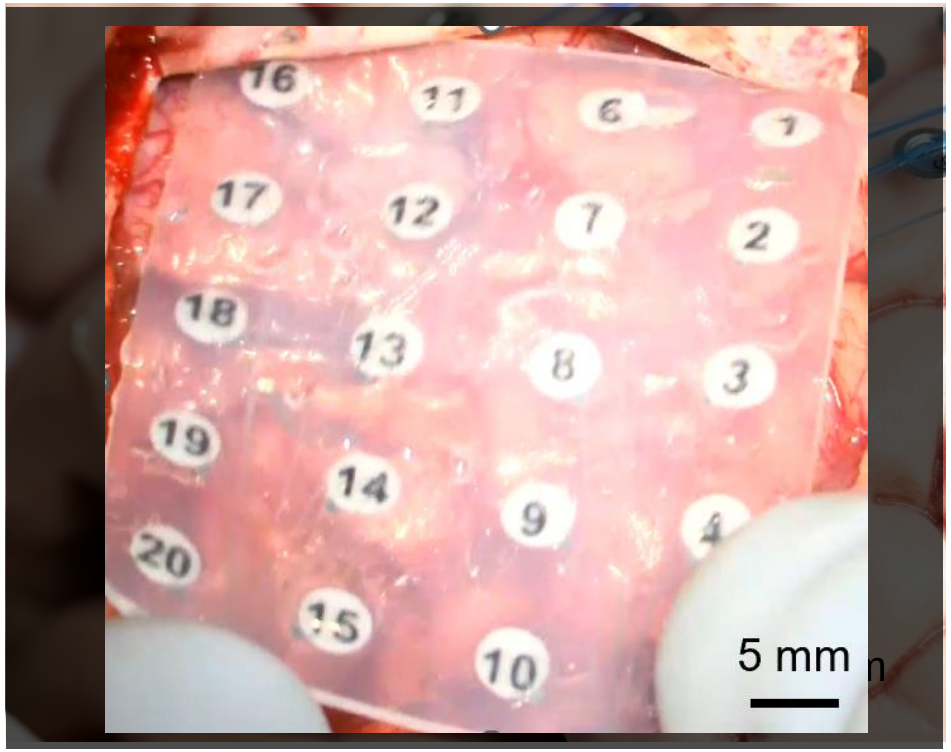
Image source: Kateryna Kon / Science Photo Library

Comparison of conventional ECoG grid with micro-ECoG grid

Awake Craniotomy

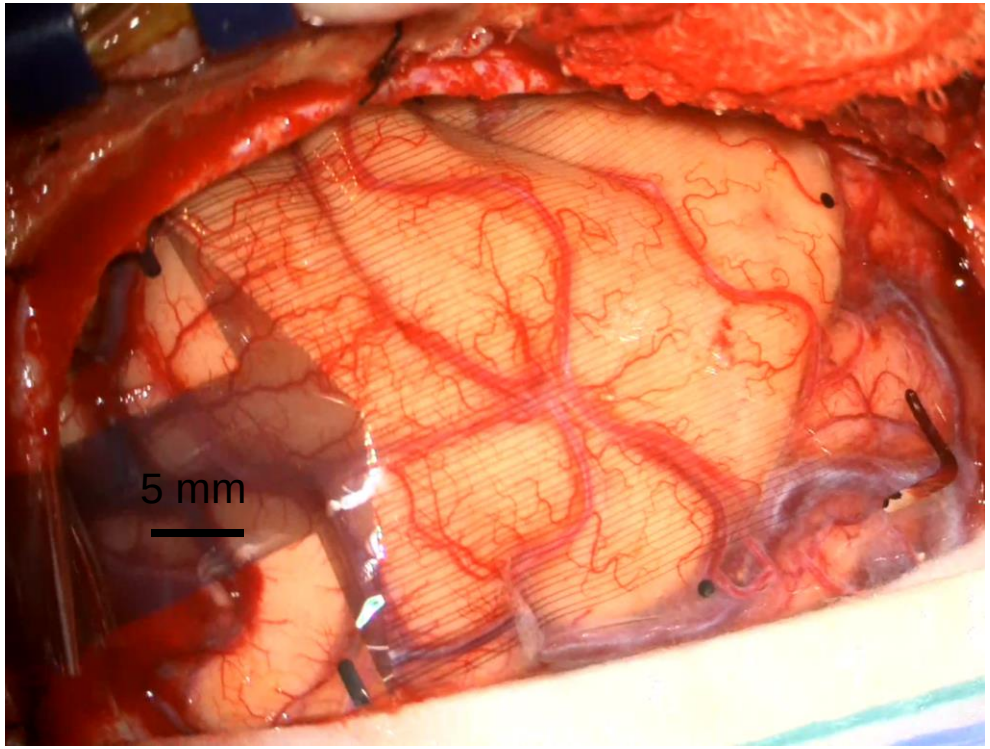


Conventional ECoG grid



→ Low resolution compared to the complexity of the brain
→ Thick and stiff, hard to achieve good contact

Thousand Channels micro-ECoG grid



→ High resolution brain mapping
→ Conformal and compliant to the constantly moving brain curvatures

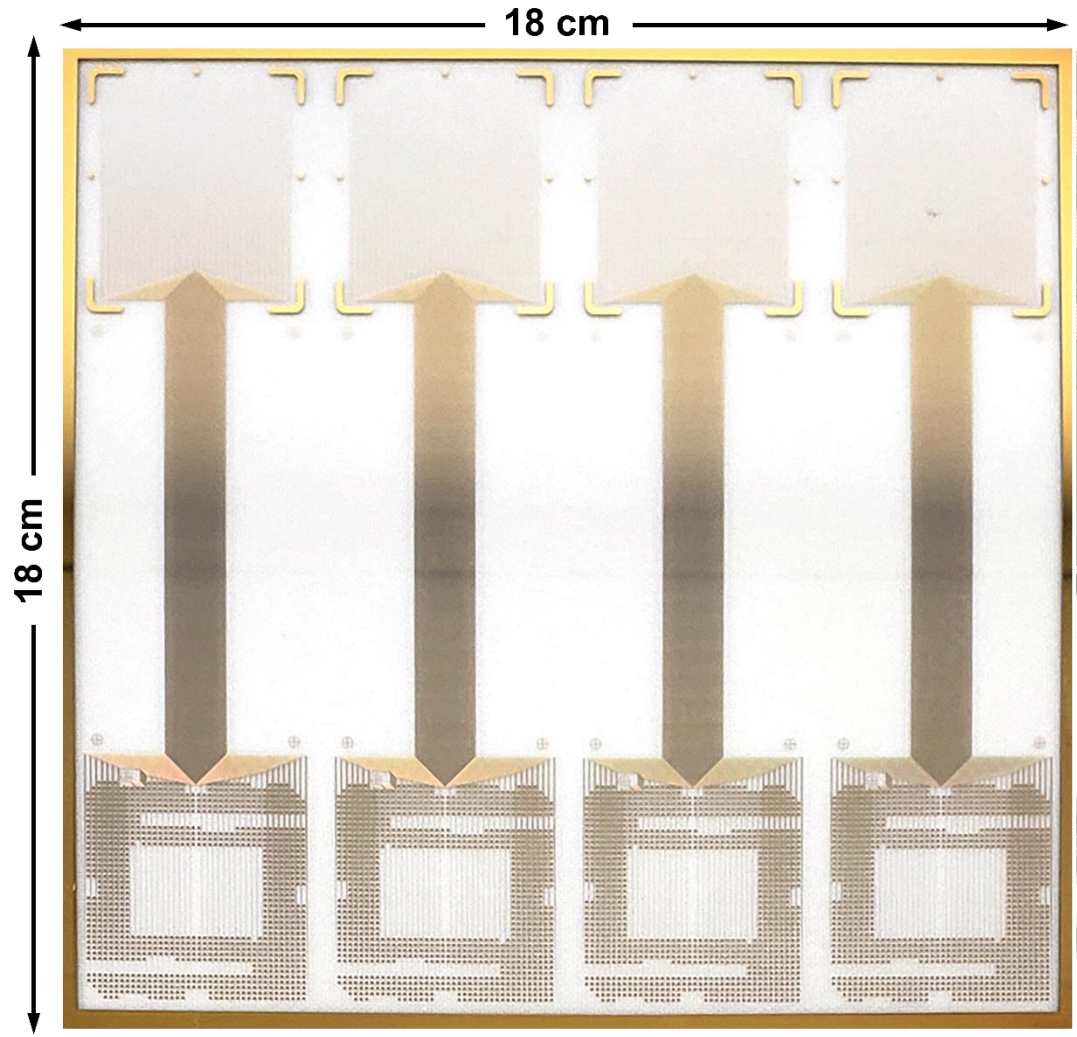
Video source: OHSU Dr. Admed Raslan

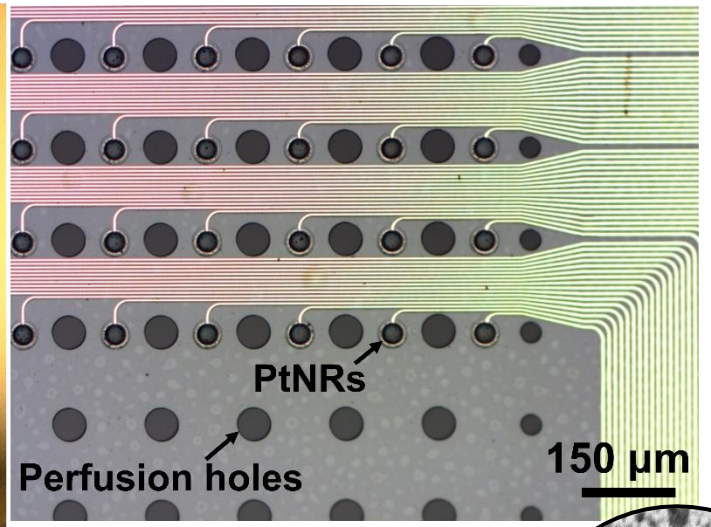
Y. Tchoe *et al.*, Sci. Transl. Med. 14(628), eabj1441 (2022)

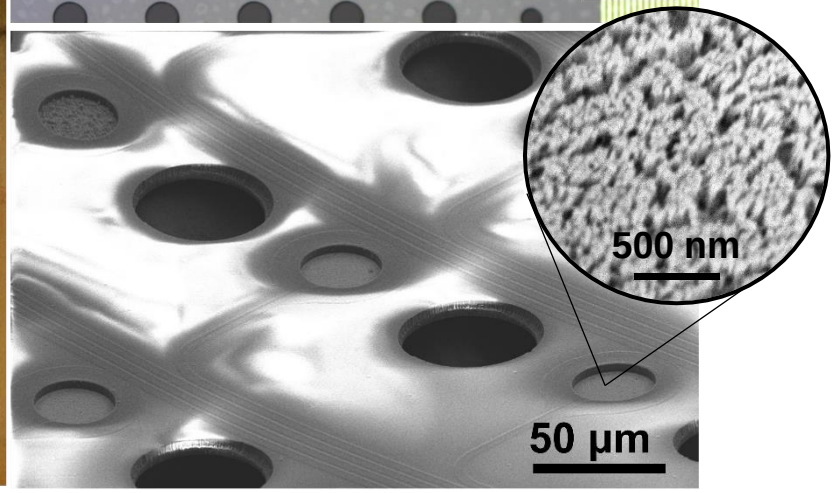
Reliable Electrode Technology for Human Brain

Large area manufacturing (scalable)

High electrochemical sensitivity







Platinum nanorods

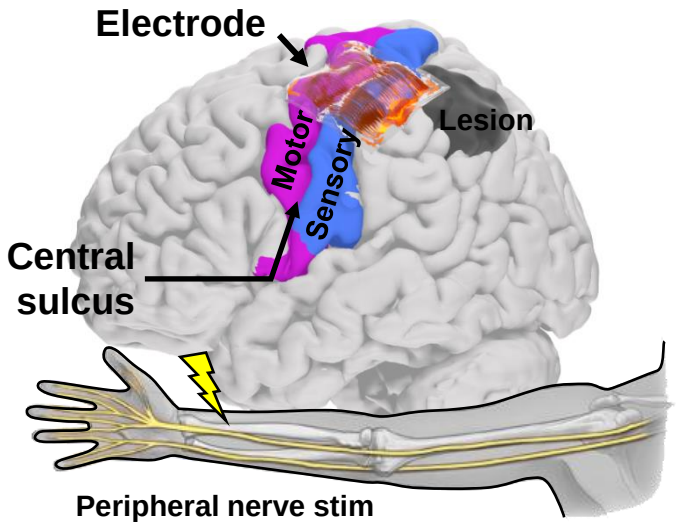
→ Large enough for intraoperative use

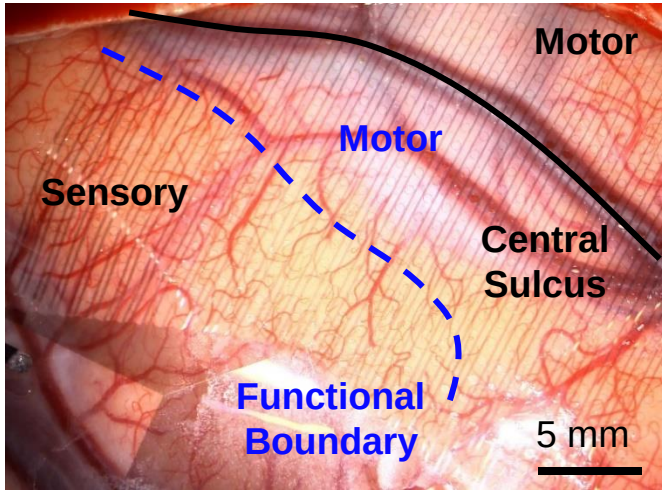
& Sophisticated enough to resolve individual cortical column

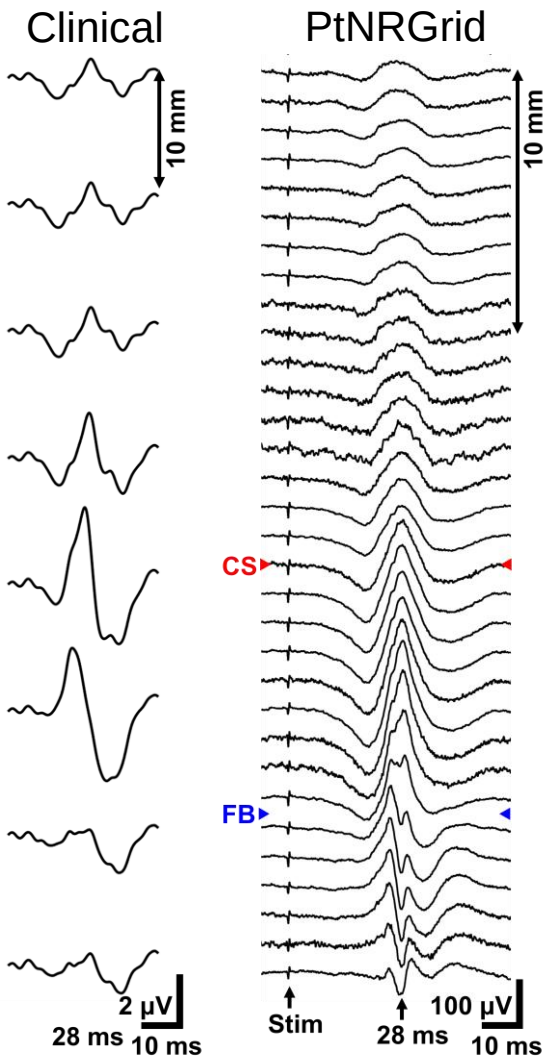
Y. Tchoe *et al.*, Sci. Transl. Med. 14(628), eabj1441 (2022)

Human Brain Functional Mapping

Motor/Sensory Boundary Mapping

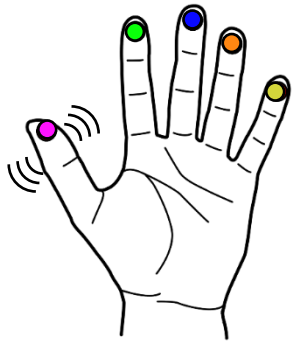


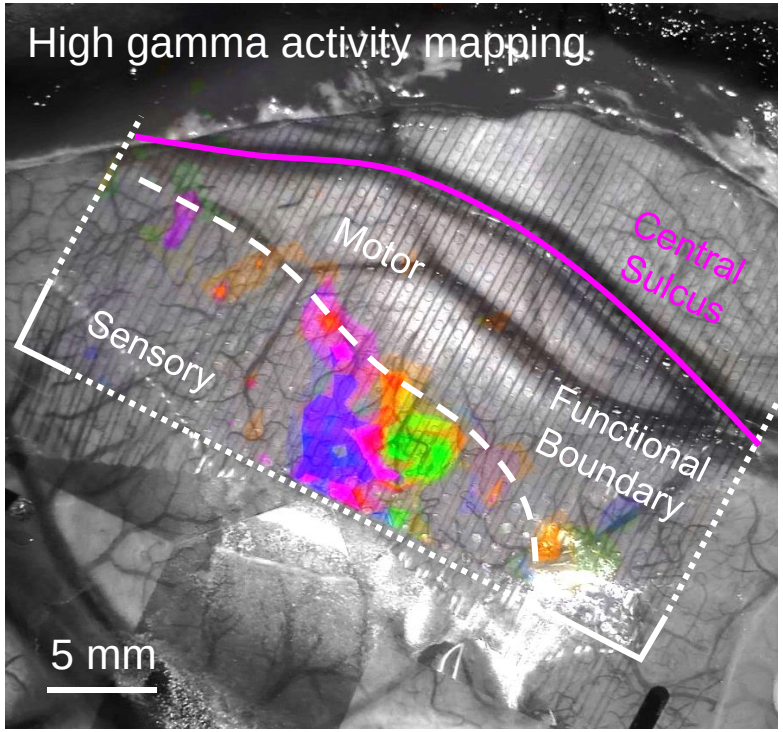




→ Mapping the true curvilinear nature of the motor/sensory functional boundary for the first time

Individual Fingertip Mapping



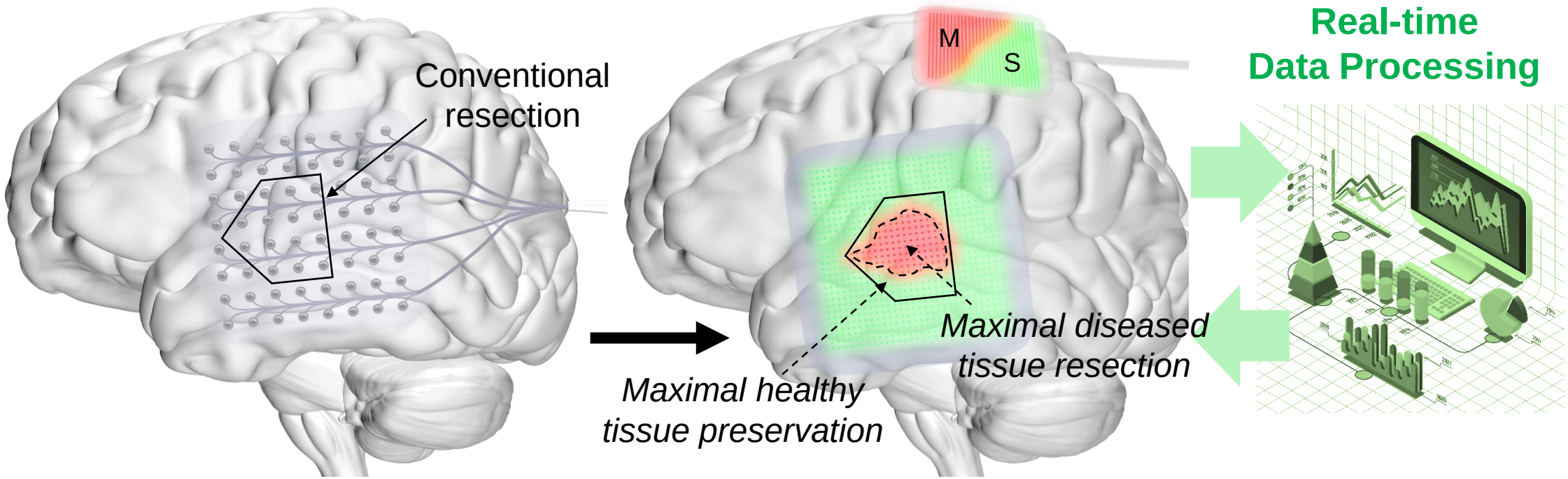


→ Vibrotactile stimulation of each fingertip evoked spatially distinctive HGA patterns

Bringing Light into Resective Neurosurgery

Manual marking based on
the ephys waveforms

Direct Visual Feedback
to the Neurosurgeon



→ Fine delineation of functional/pathological regions

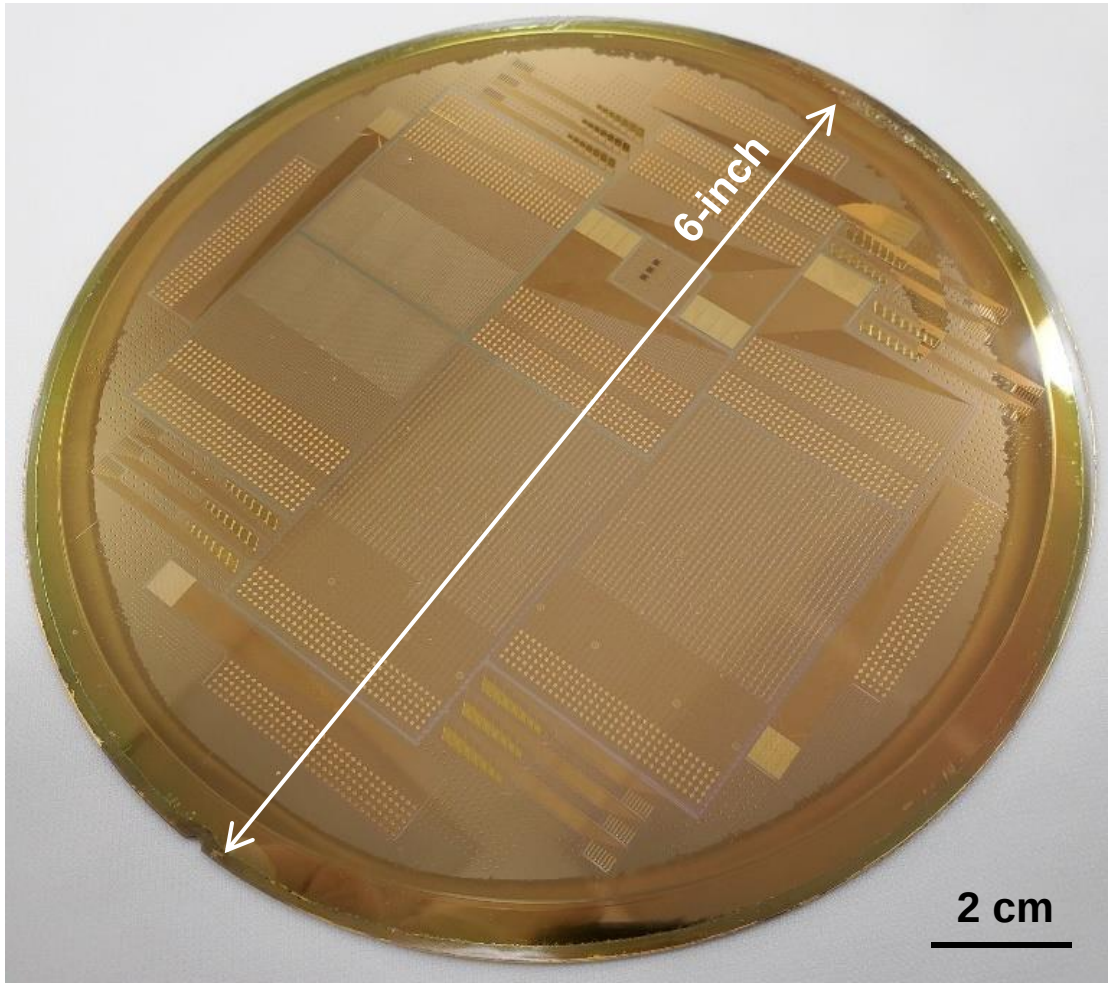
→ Directly **displaying** the resection boundary **on the 3D brain surface**

→ High precision neurosurgery

Y. Tchoe *et al.*, Sci. Trans. Med. (2024)

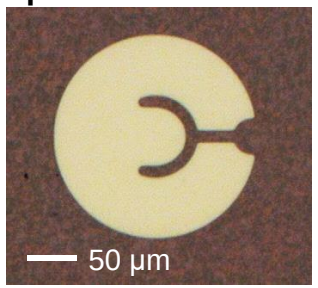
Microfabrication of micro-LED arrays

Micro-LED arrays on 6-inch substrate

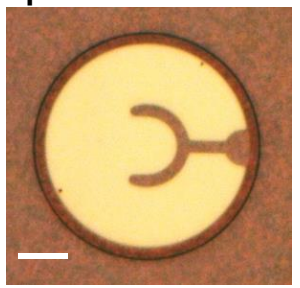


How single micro-LED pixel was built:

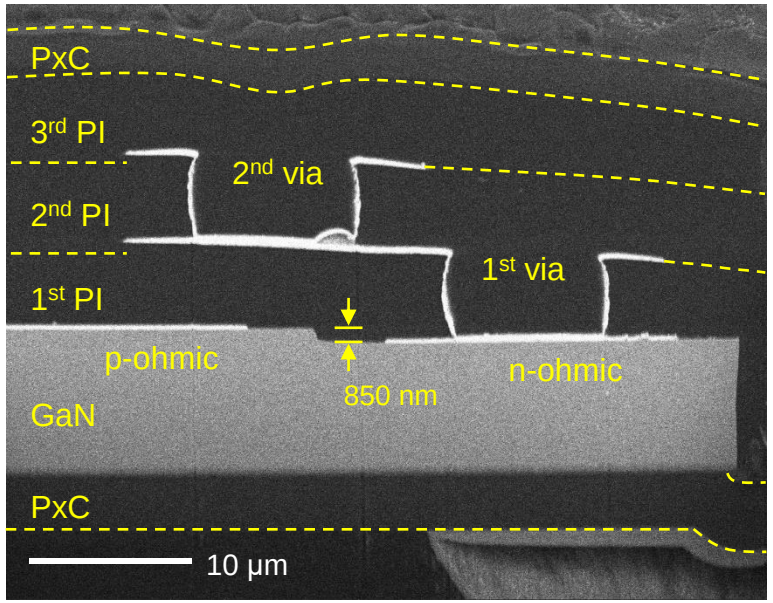
p ohmic



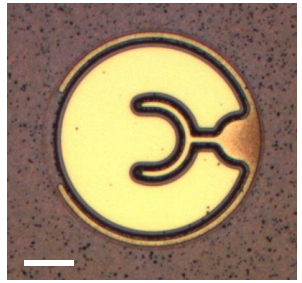
p mesa etch



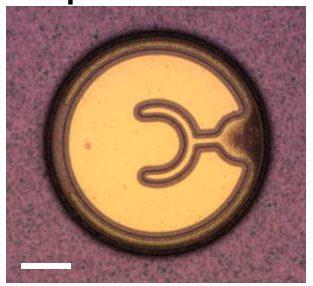
Cross-sectional structure



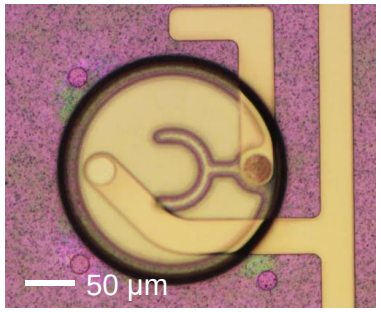
n ohmic



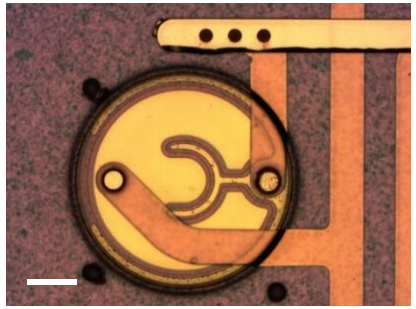
deep isolation etch



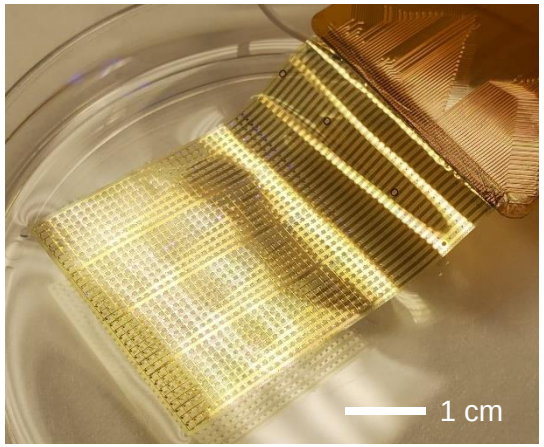
1st PI & metal



2nd PI & Metal leads

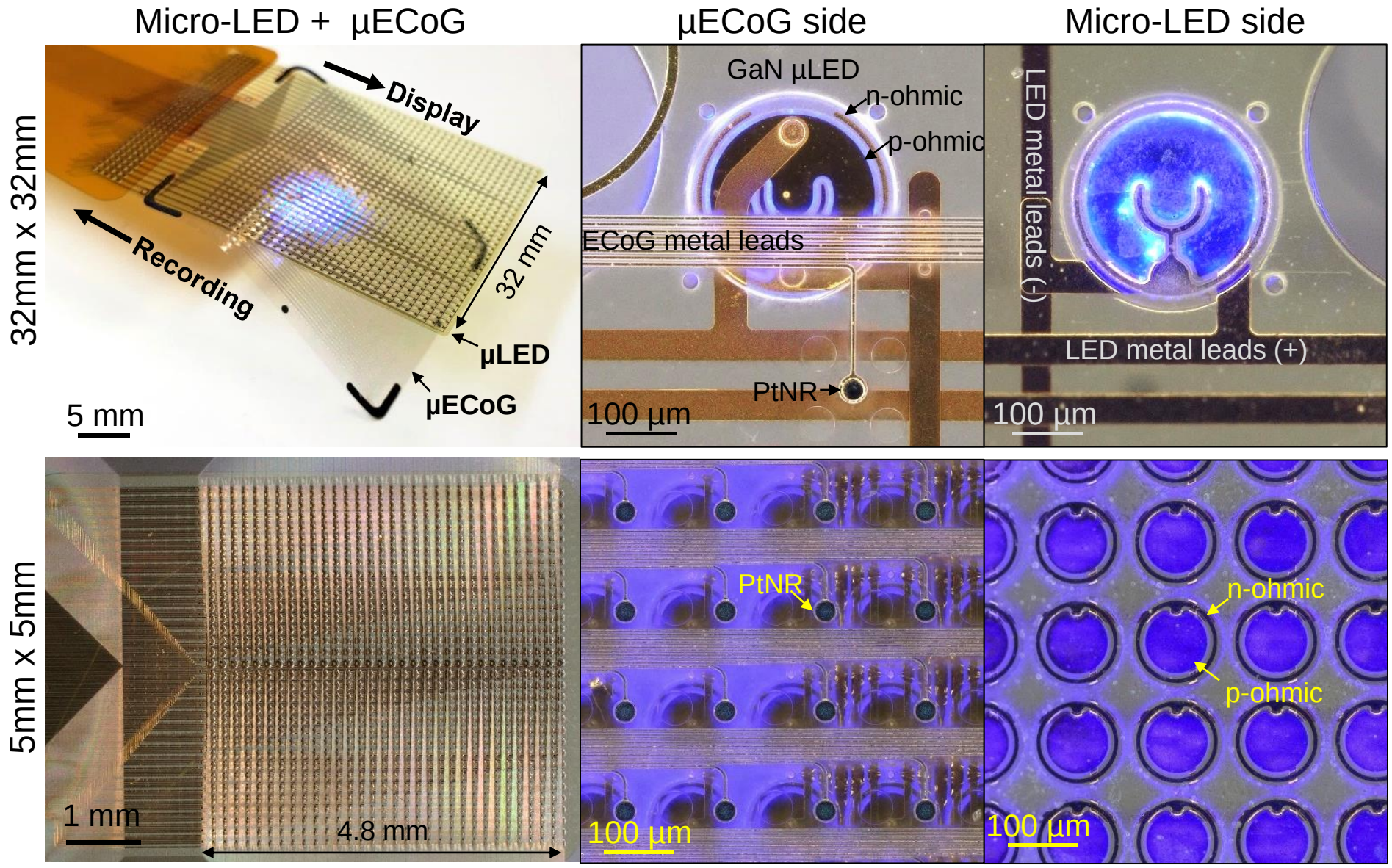


Releasing & packaging



→ Scalable, monolithic process was used to fabricate thousands of micro-LED pixels on 6-inch wafers

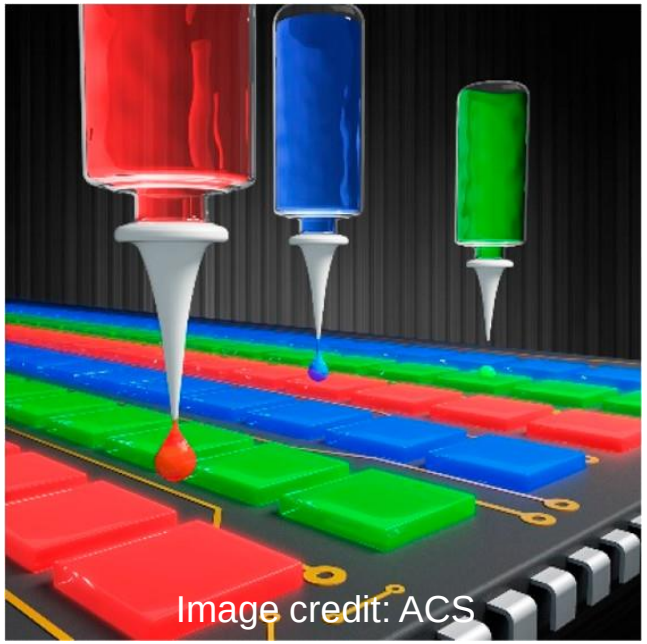
Integrated LED+ECoG grids



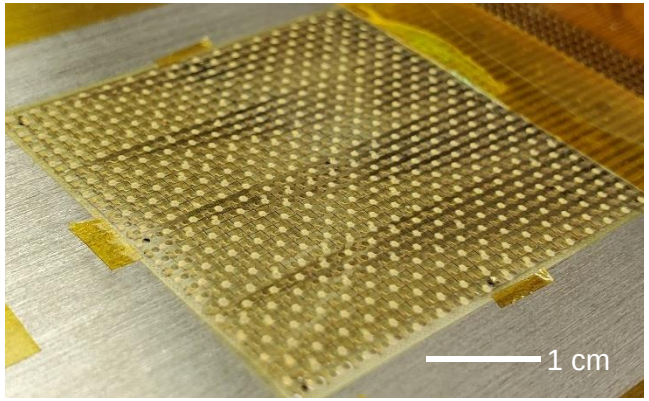
→ Flexible µLEDs combined with µECoG grid were designed to display cortical activity

Multicolor LEDs with Quantum Dot Color Converters

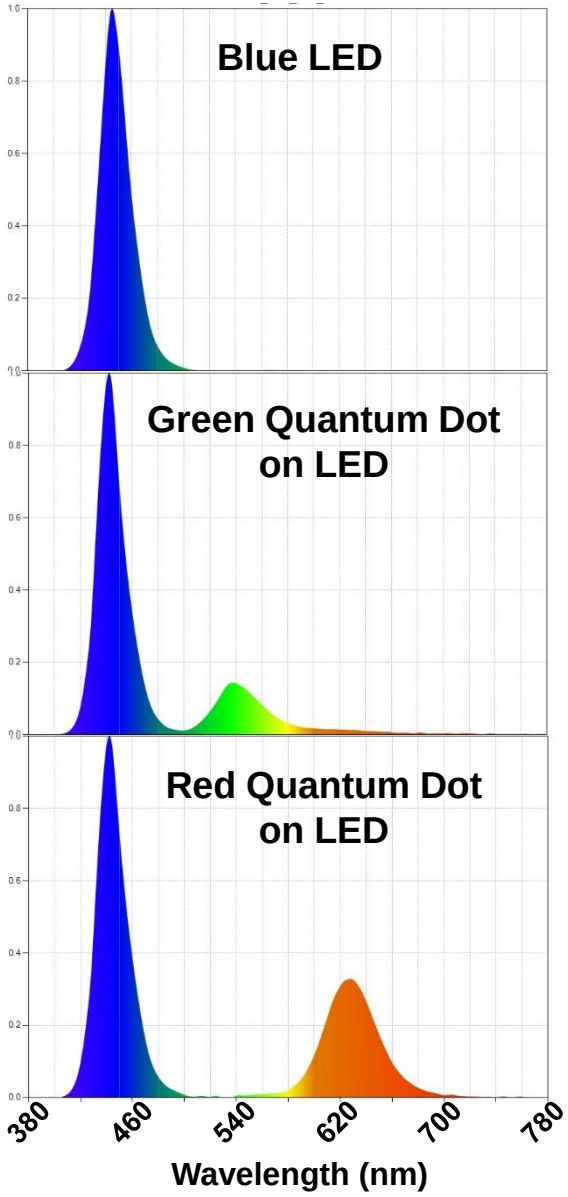
Quantum Dot Color Conversion (QDCC) inkjet printing



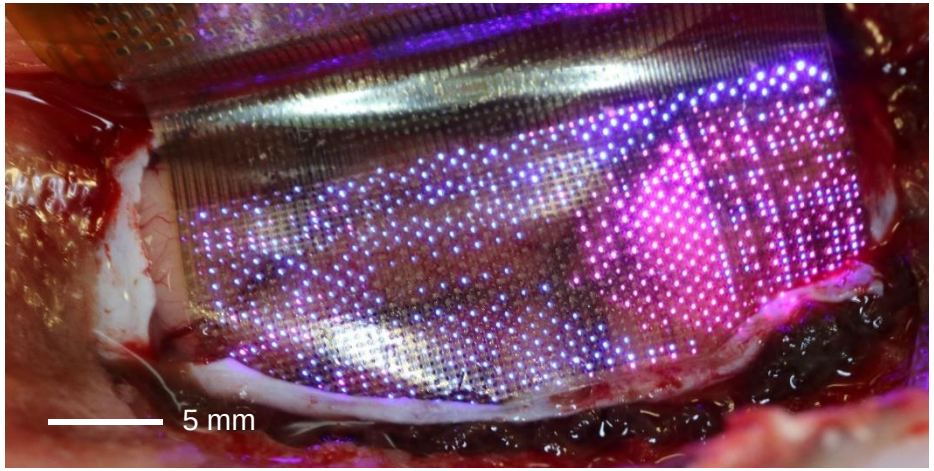
QDCC printed on micro-LEDs



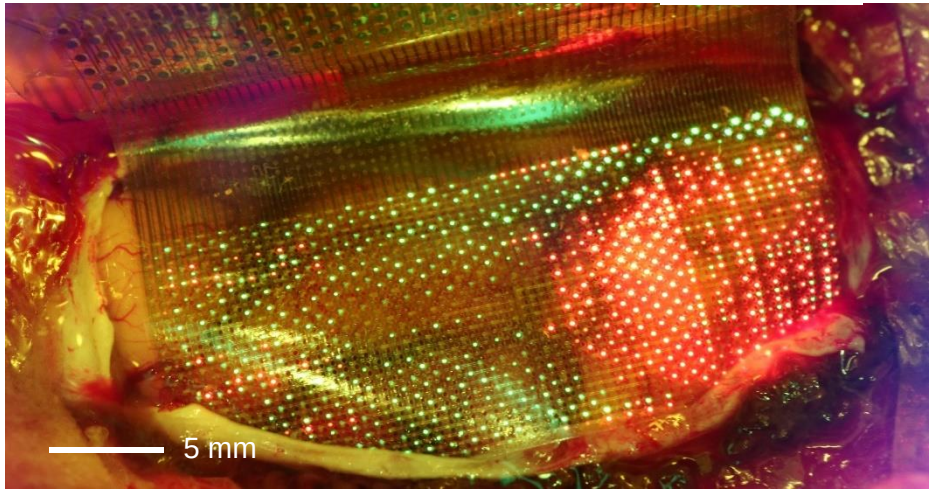
Electroluminescence spectrum



Dual-color LEDs

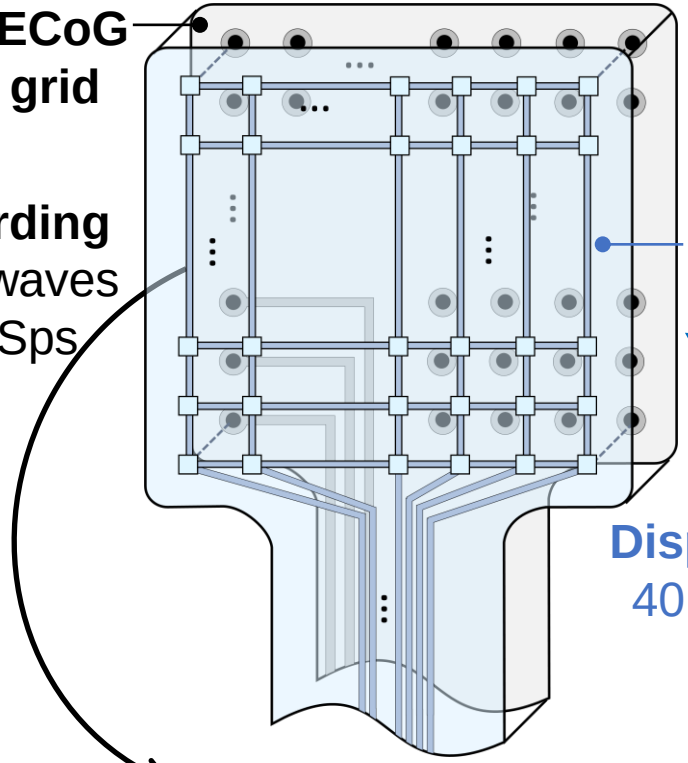


Dual-color LEDs viewed under blue color filter (>550 nm)



Real-time display of ECoG activities on micro-LED arrays

micro-LED array + µECoG grid



Computer (Qt C++)

Automatic Signal Processing
& Real-time RMS mapping

Closed-loop control sequence

µECoG grid + micro-LED array on cortical surface

Recoding from cortical surface /µECoG grid interface

Electrophysiology data acquisition system

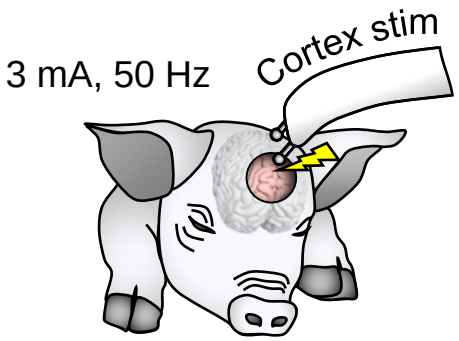
Automatic Signal **Processing** & Real-time mapping [Processing computer]

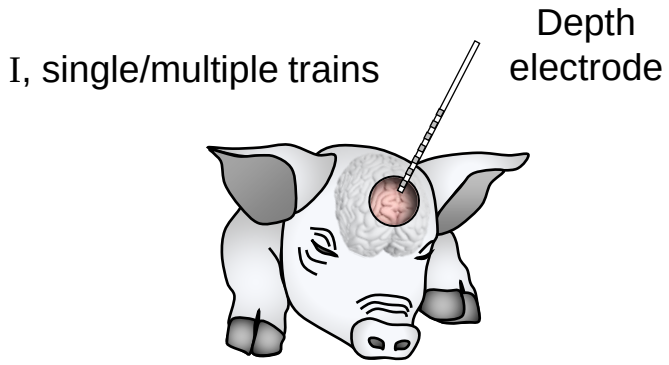
Microcontroller

LED matrix driver IC

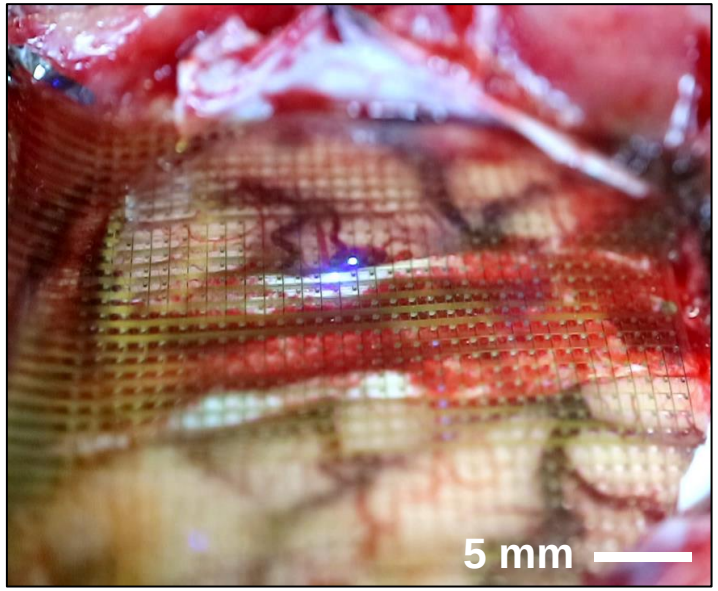
Display on micro-LED array

Direct Cortical Stimulation visualization in real time

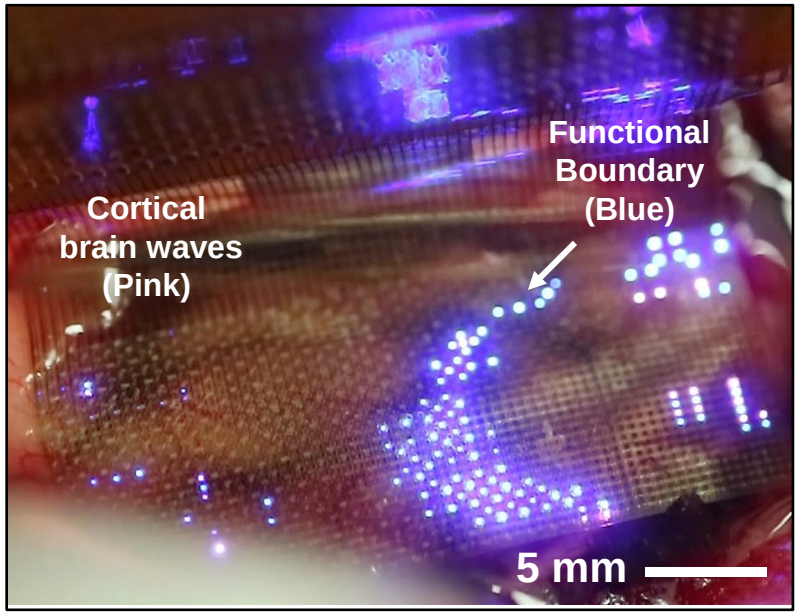




Surface stimulation (Ojemann)

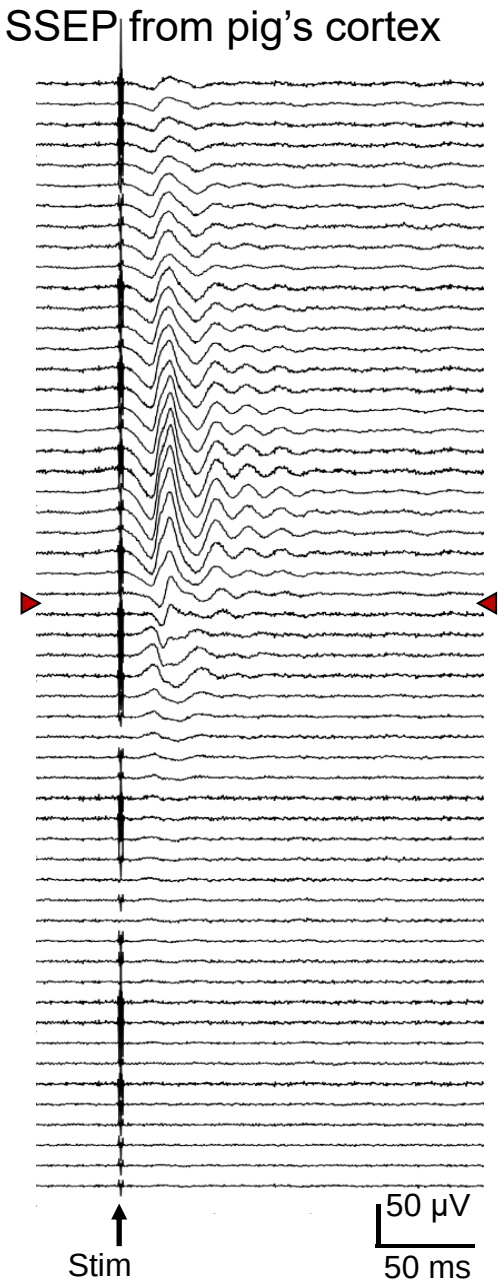


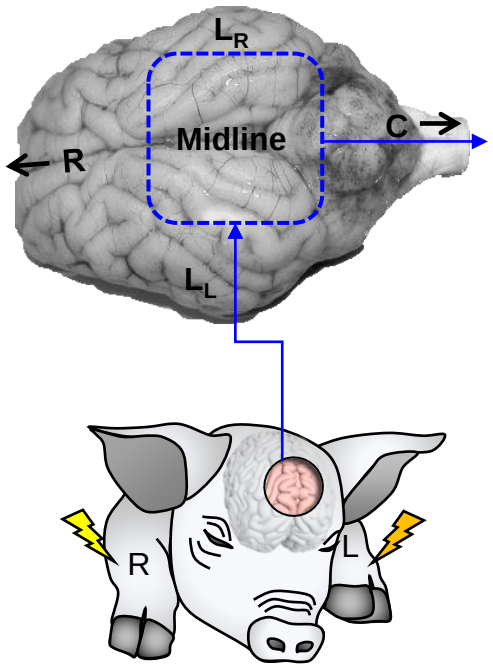
Depth stimulation (sEEG)



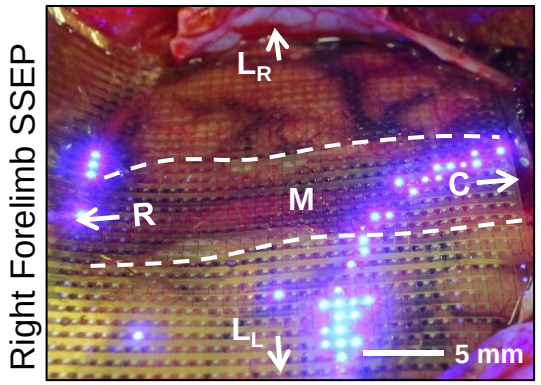
→ The extent of electrical potential field & stimulation-evoked activities could be visualized

LED+ECoG: Motor-Sensory Functional Boundary Visualizations

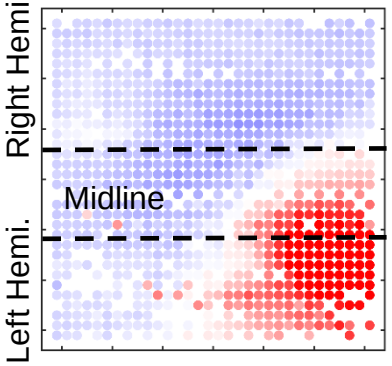




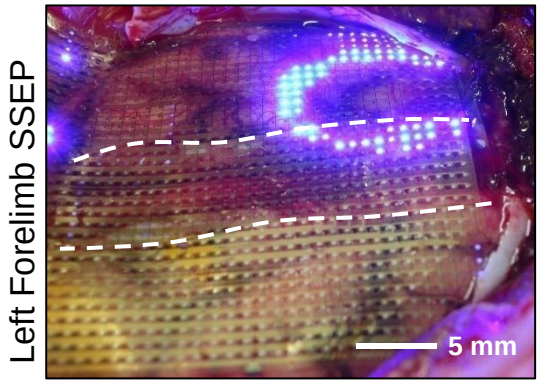
Line depiction of FB



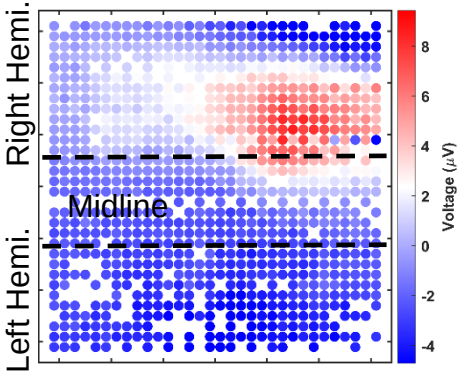
P20-N20 Mapping



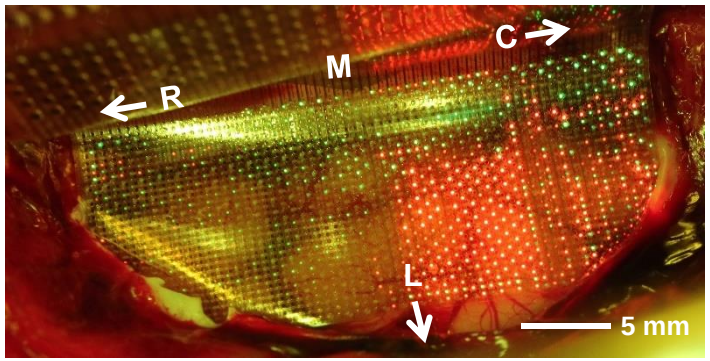
Line depiction of FB



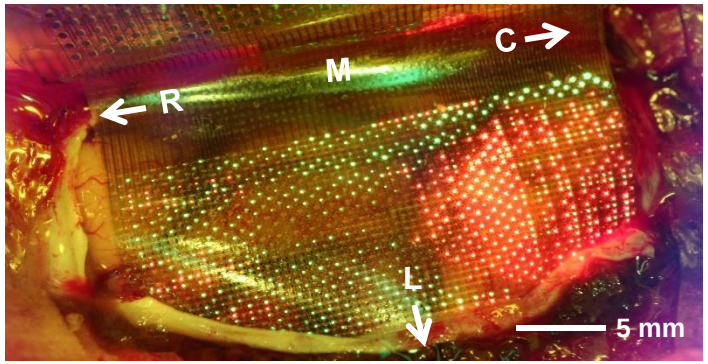
P20-N20 Mapping



Dual-color map depiction of FB (Pig A)

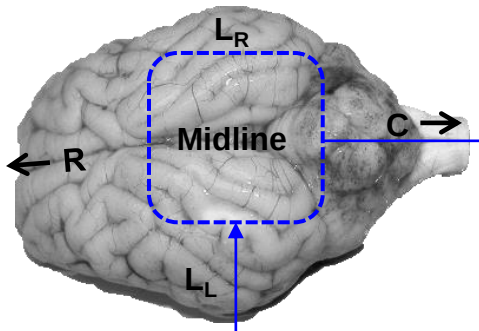


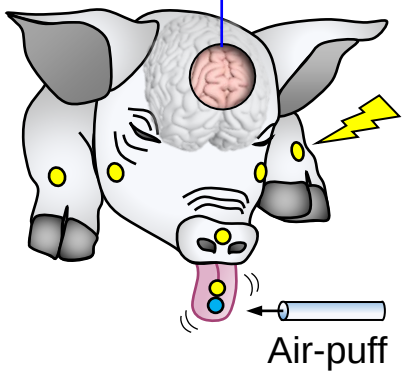
Dual-color map depiction of FB (Pig B)

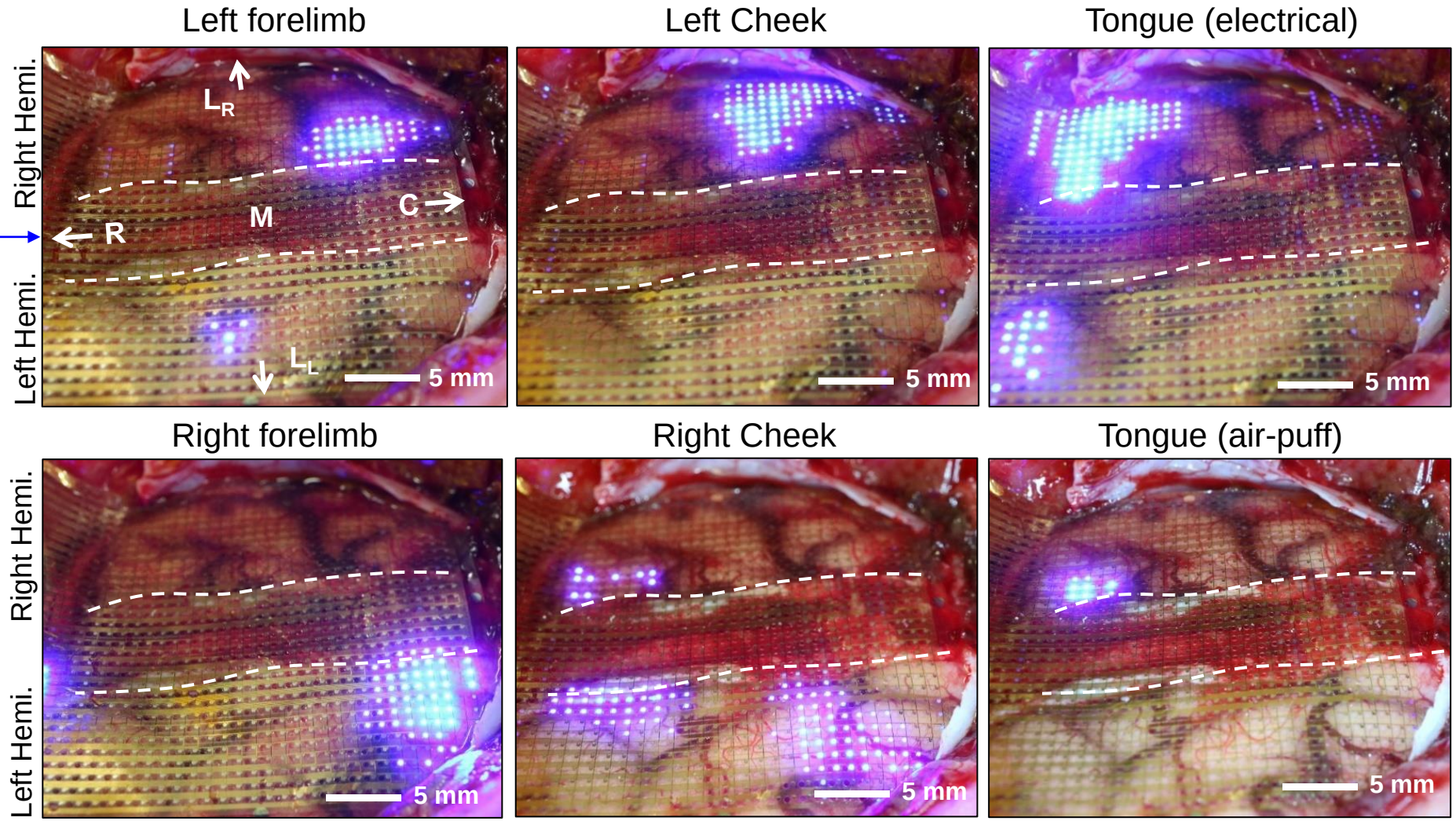


→ Motor-Sensory functional boundary could be identified and visualized in sub-mm scale precision

LED+ECoG: Sensory Mapping of the Pig Brain



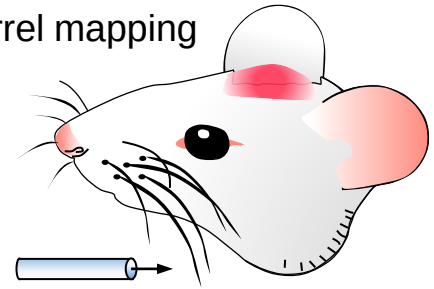




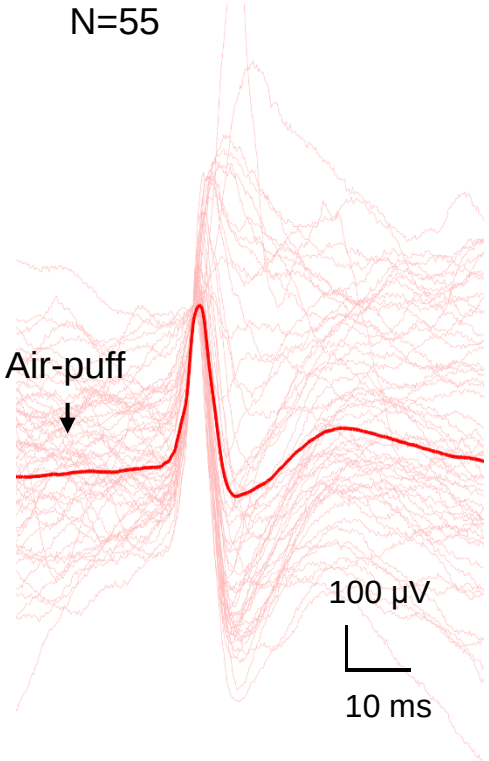
→ Sensory stimulus-evoked HGA could be precisely be mapped and visualized on the cortical surface

LED+ECoG: Individual Cortical Column Mapping from the Rat Brain

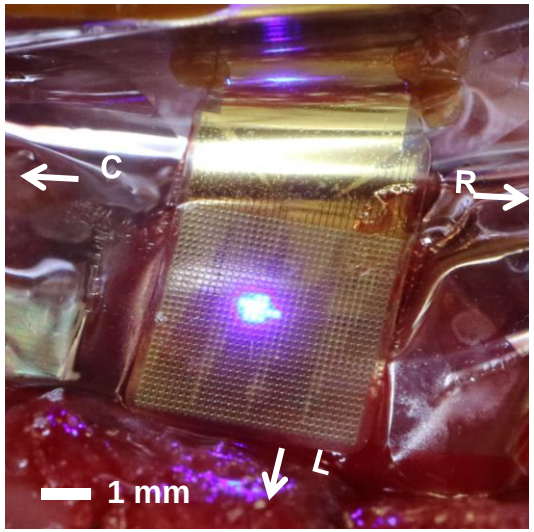
Whisker
barrel mapping



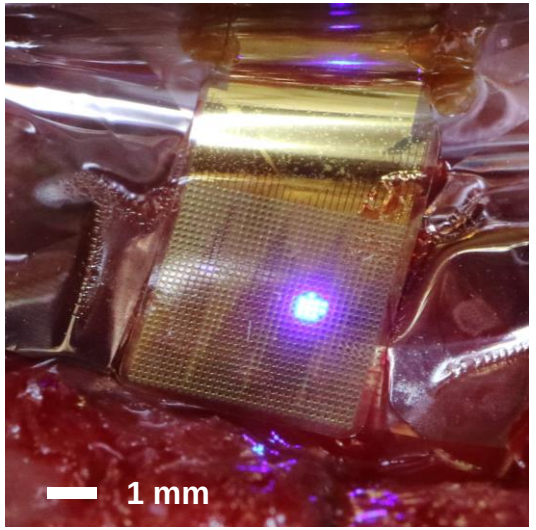
N=55



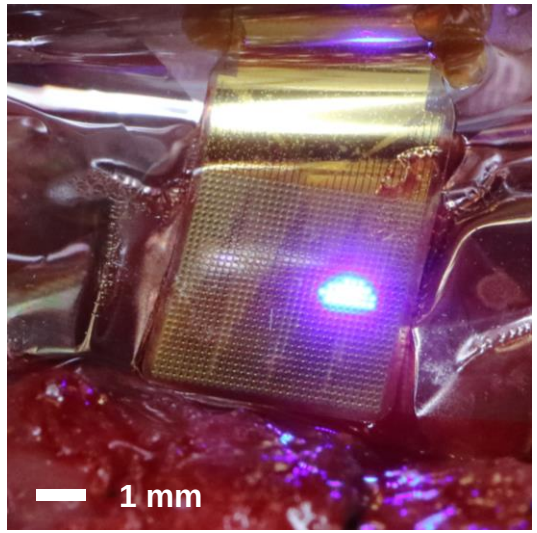
B5



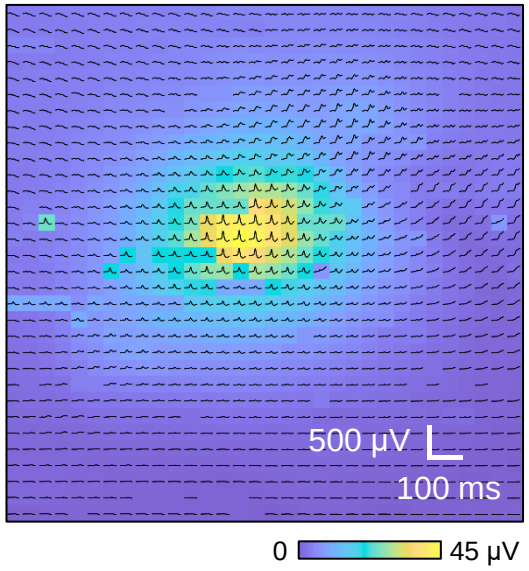
C3



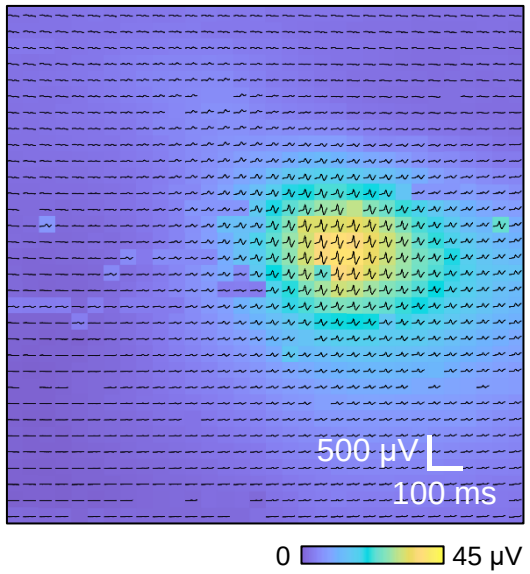
D4



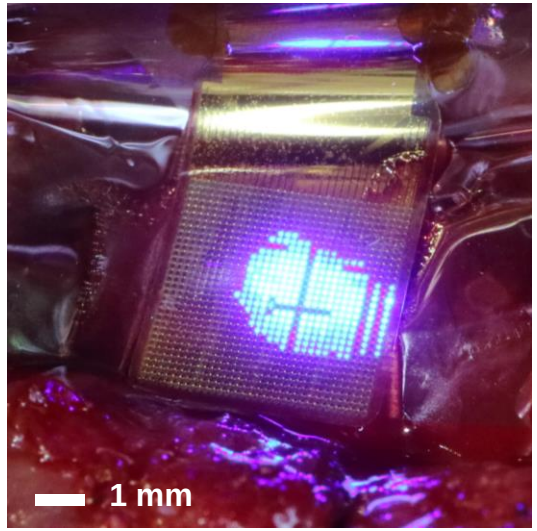
Spatial Mapping of waveforms (B5)



(C3)

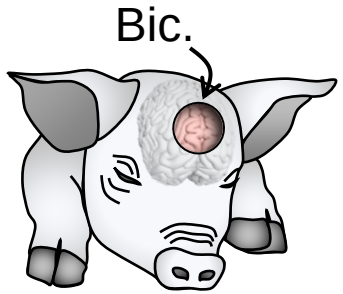


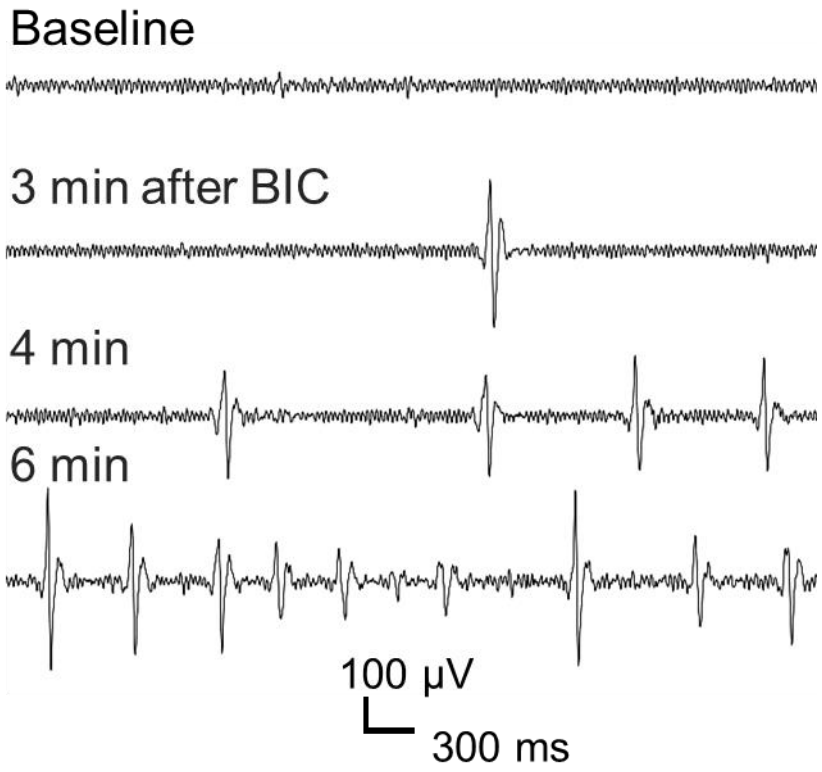
Whole whiskers

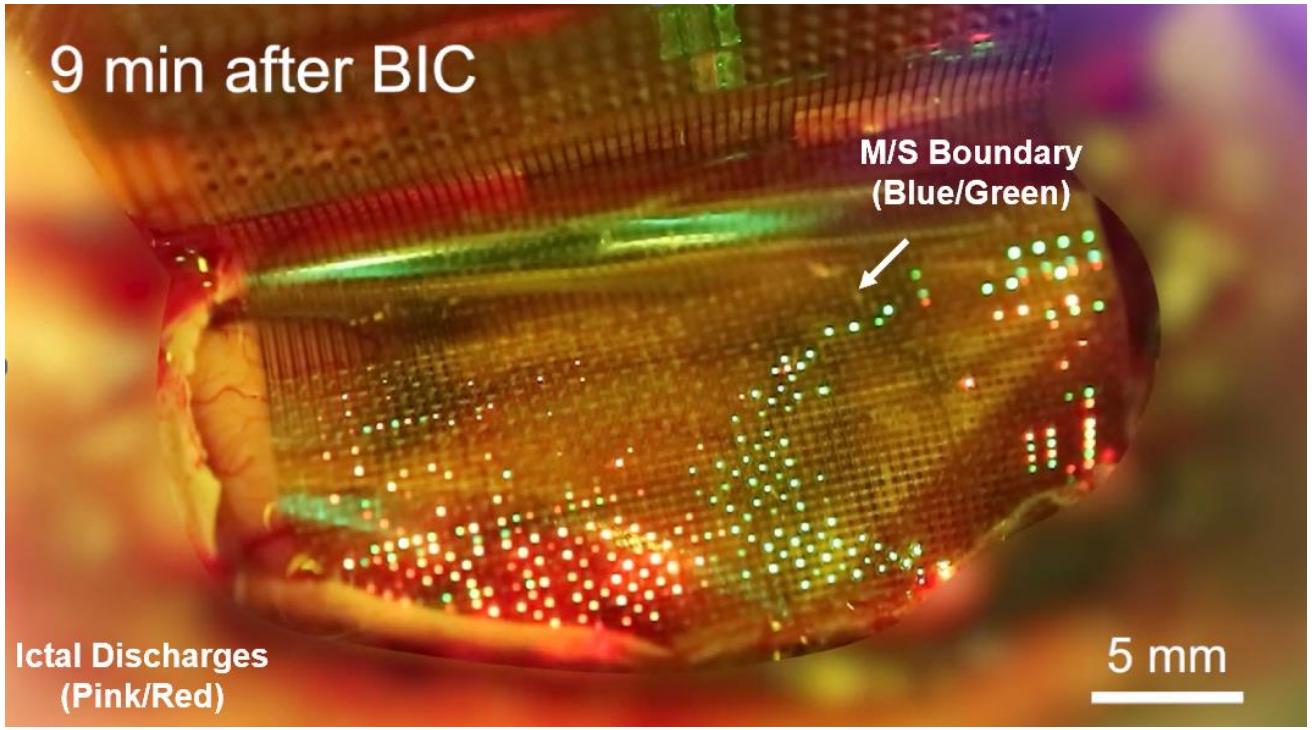


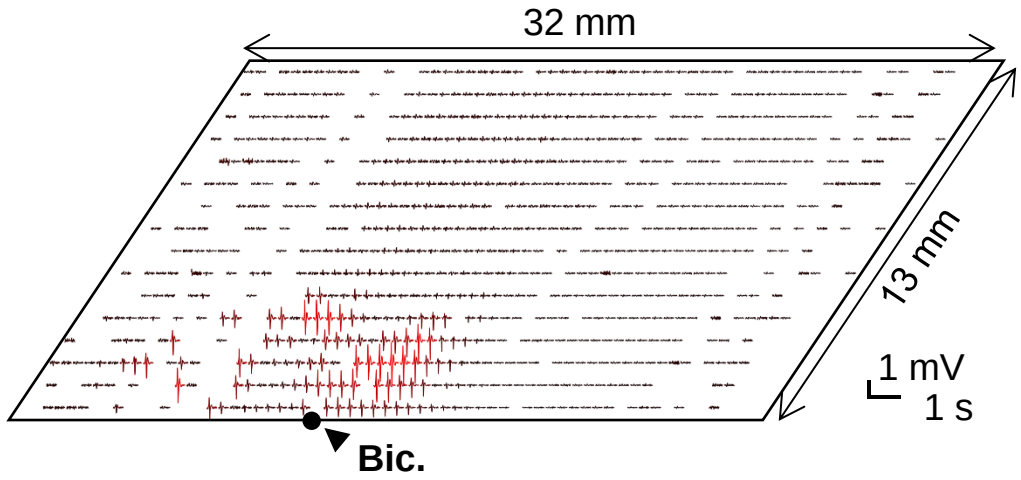
→ The sub-mm scale individual cortical column could be visualized

Epileptiform activities visualization in real time







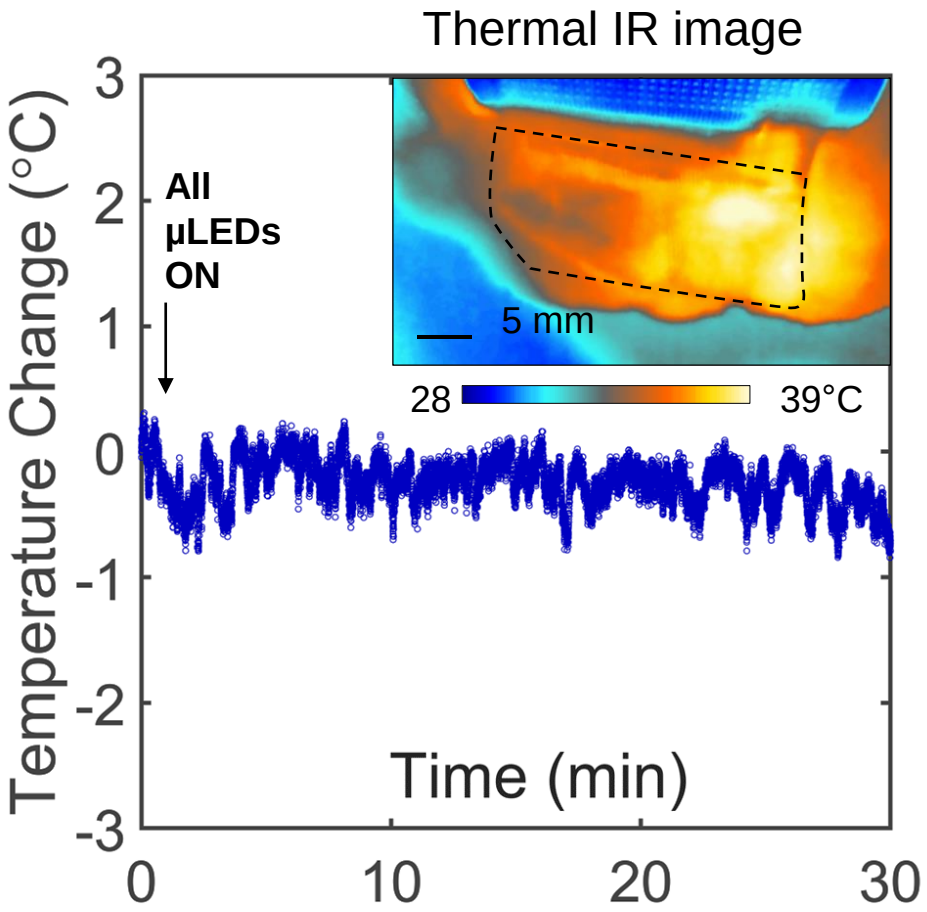


Spatial Mapping of Epileptiform Activity Waveforms

Y. Tchoe *et al.*, Sci. Trans. Med. (2024)

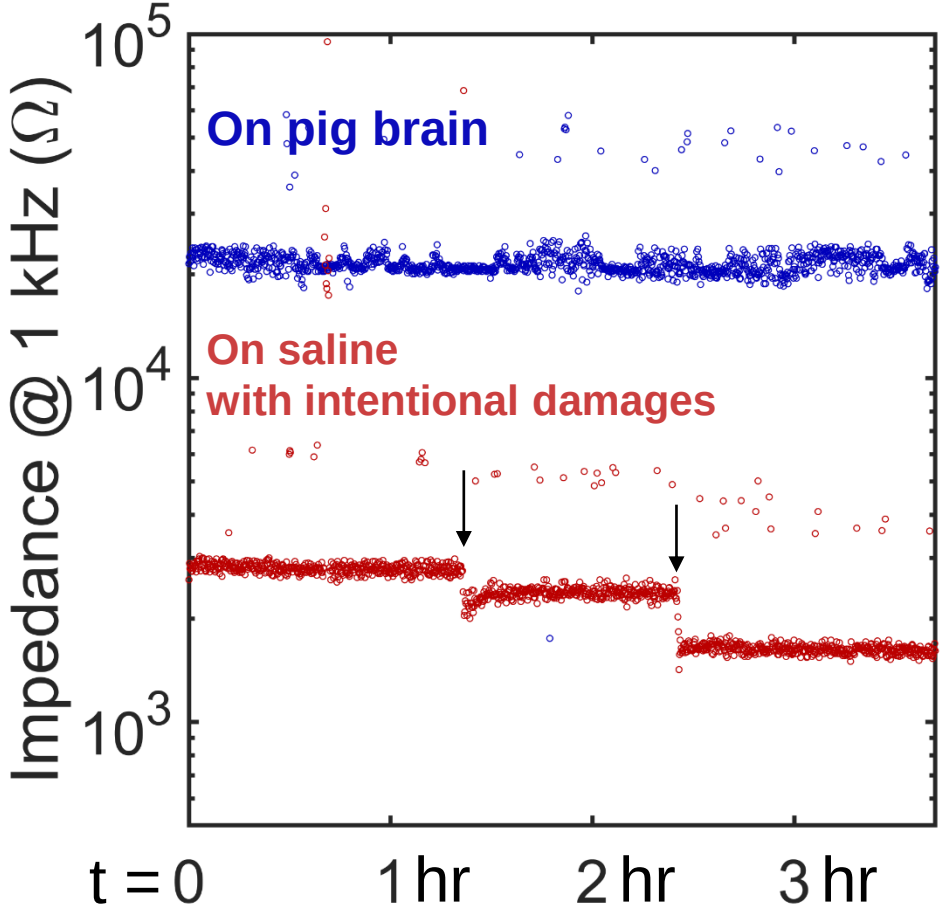
Safety of the technology

Temperature monitoring



→ Minimal thermal effects on the brain tissues were observed

Electrical Leakage Monitoring

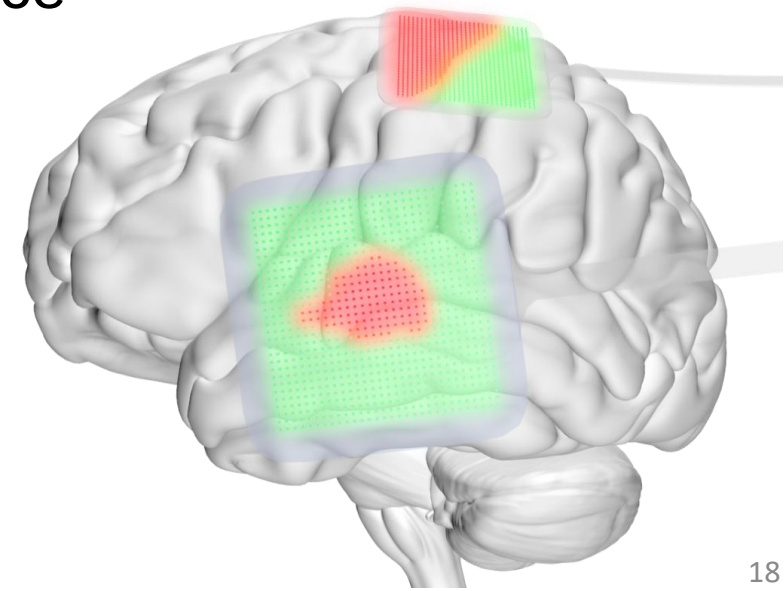


→ No electrical leakage path developed during the 3.7 hours operation on the pig brain

Summary

- Human brain recording with multi-thousand channel electrode could reveal unprecedented details of the cortical map

- Flexible micro-LED array combined with brain interface electrode visualized cortical activities in real time directly on the brain surface



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