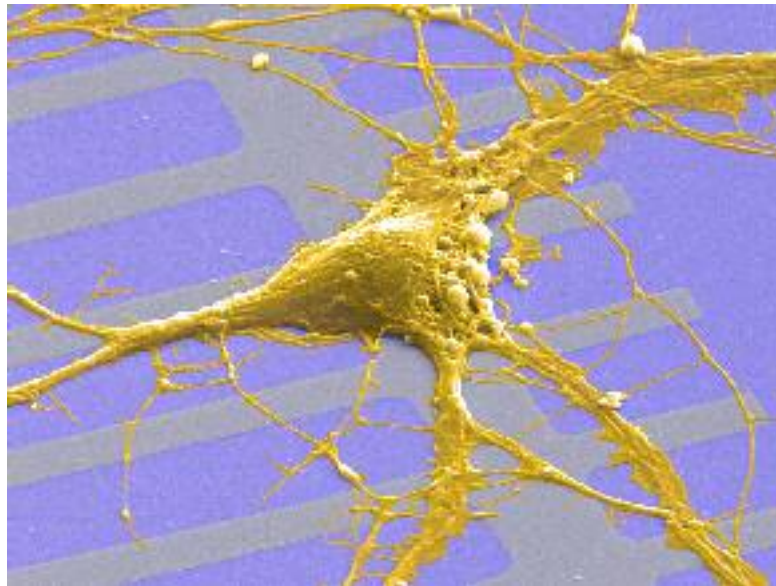


Neurochips

field-effect devices for communication with cells

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Max-Planck-Institute for Biochemistry, Martinsried, Germany



SRC/NSF Forum on Nano-Morphic Systems, 8 Nov 2007

cell signals

objective: to communicate with cells

- intracellular

- + direct access
- + control
- injures cell

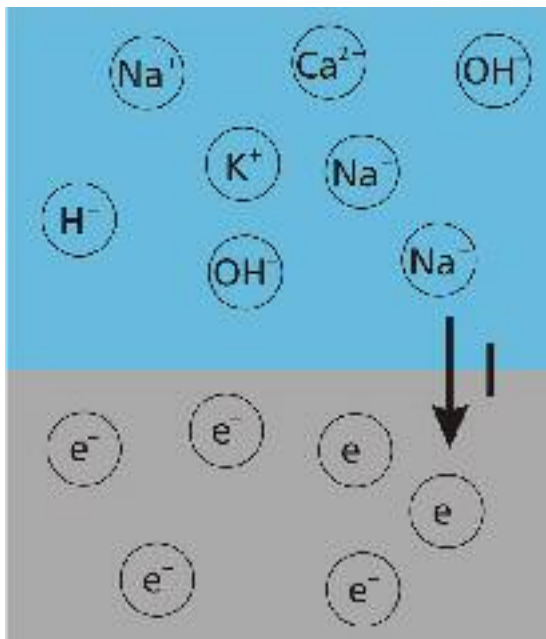
- extracellular

- + preserves cell integrity
- + long-term
- signal strength

- available signals

- chemical
- electrical

electronics vs. ionics

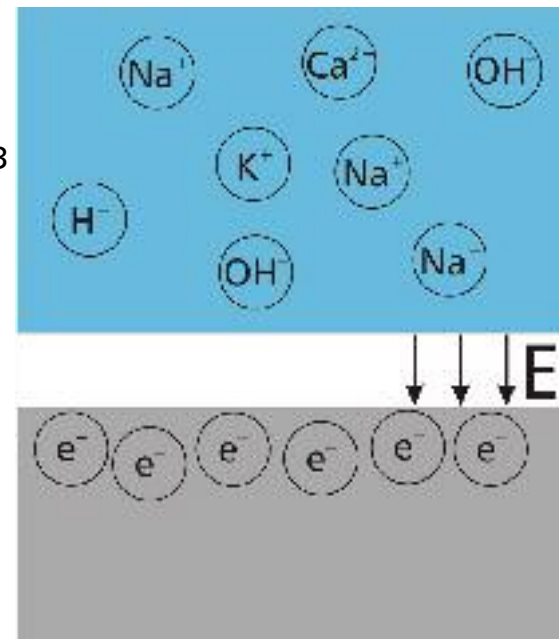


electrolyte, $[Na] \sim 10^{20} \text{ cm}^{-3}$

metal

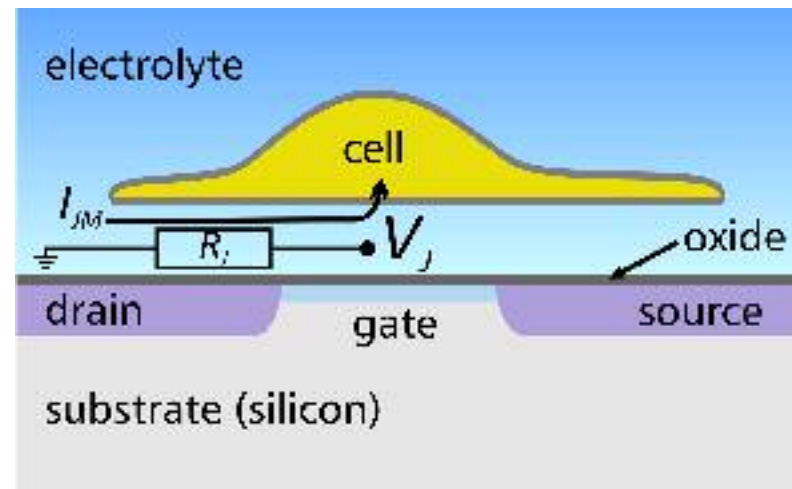
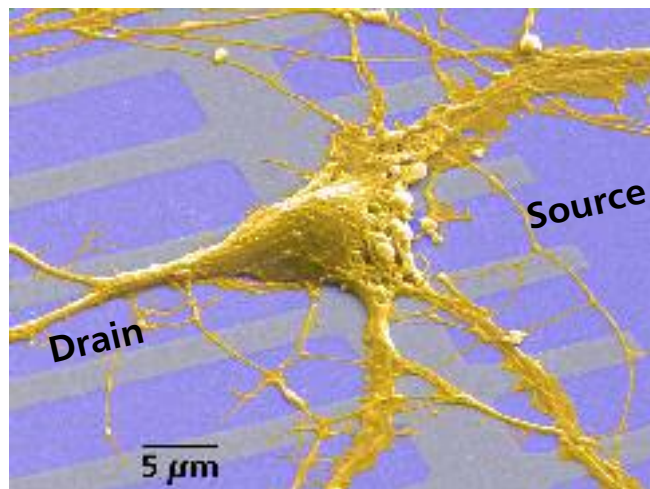
undefined electrochemistry

insulator
semiconductor

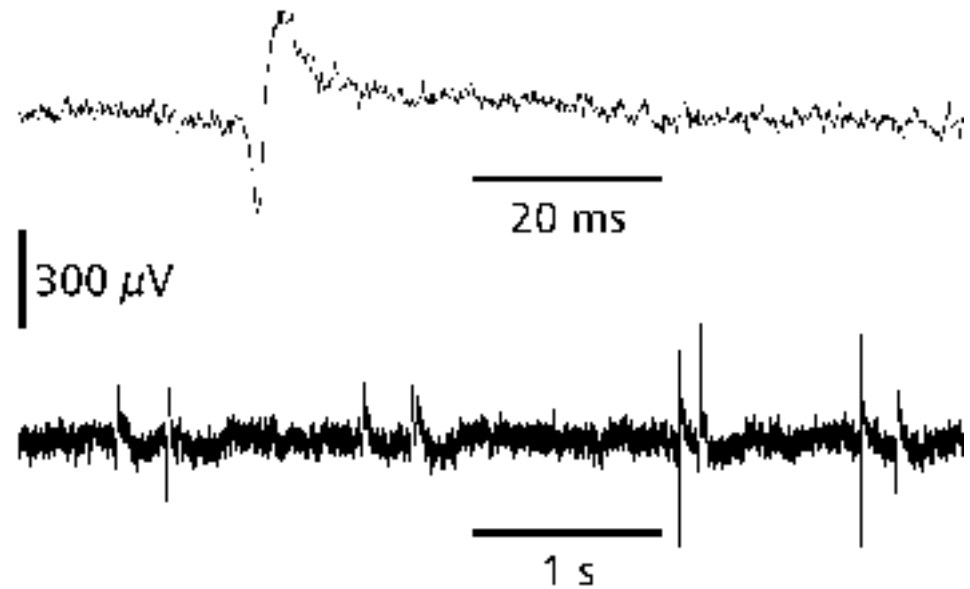
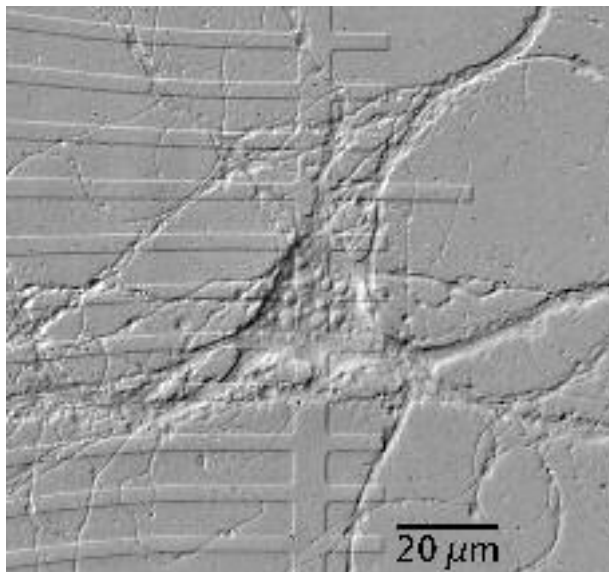


field-effect
no electrochemistry

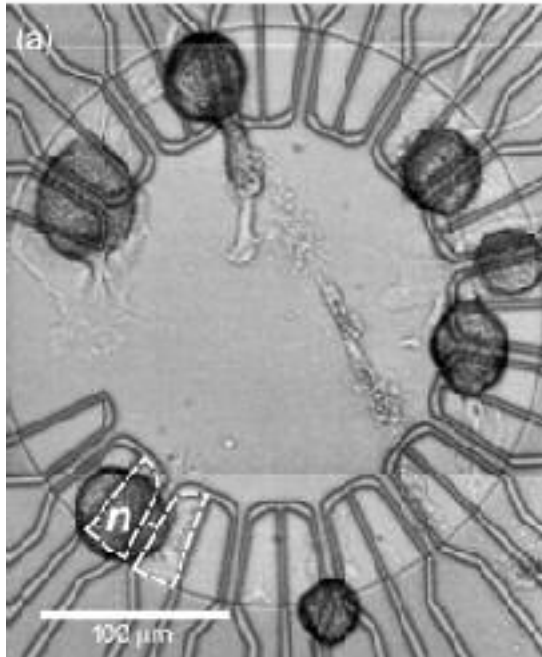
measurement principle



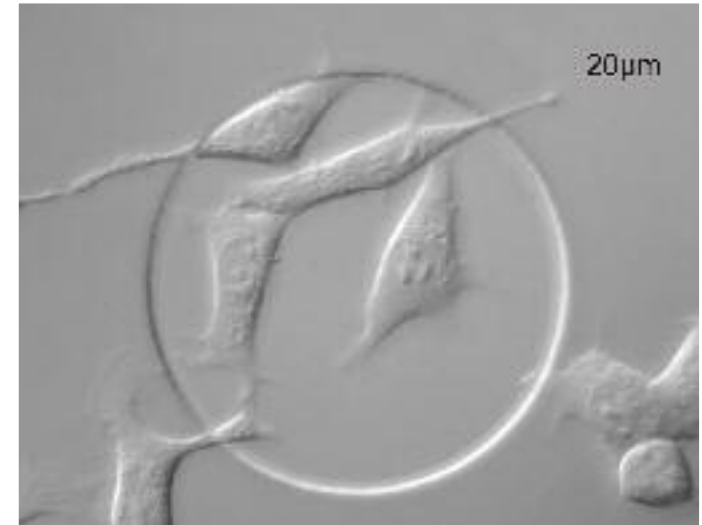
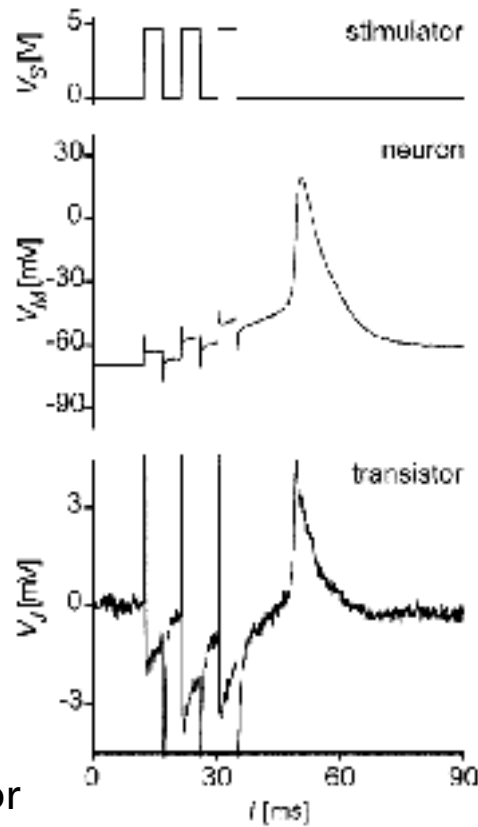
detection of action potentials of a single neuron



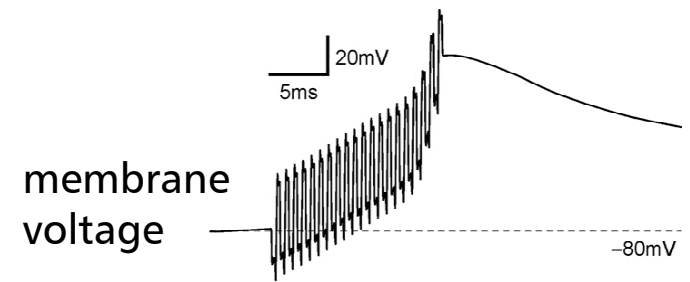
stimulation



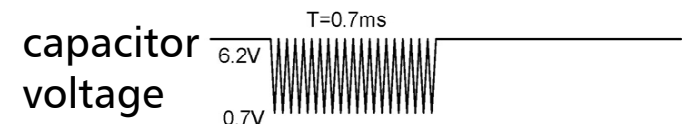
snail neurons on SiO₂ capacitor



HEK cells on EOS capacitor
(TiO₂/p⁺Si heterojunction)

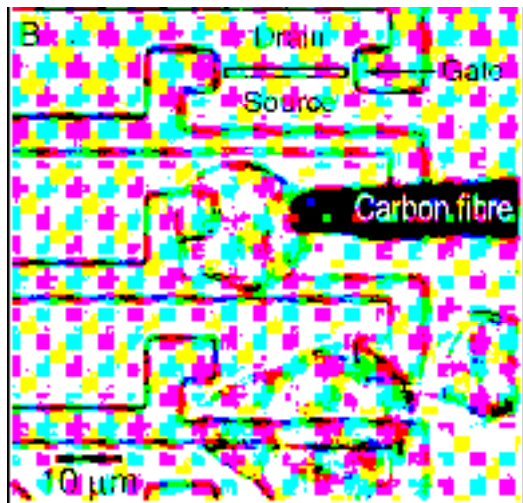
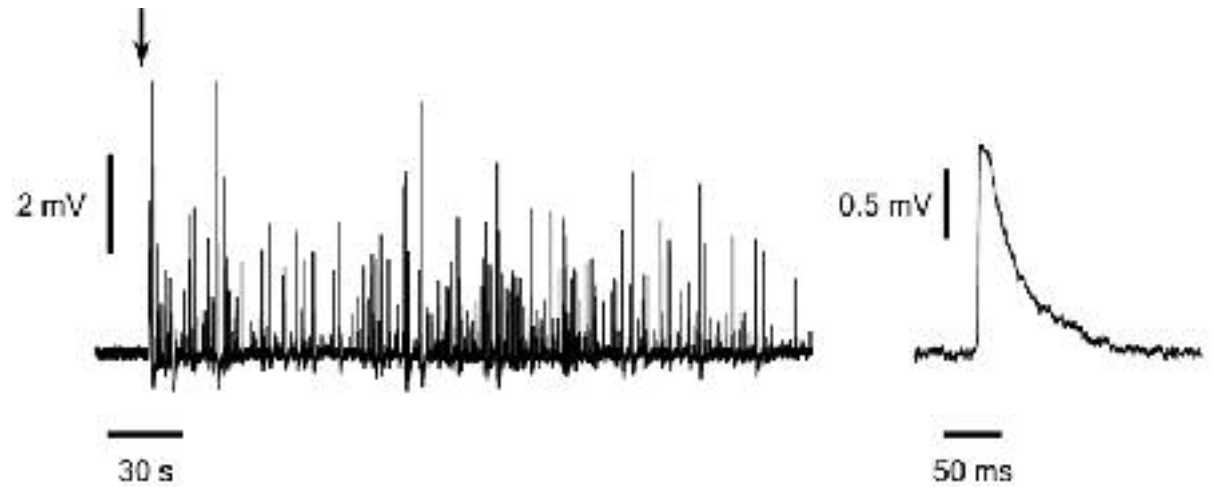
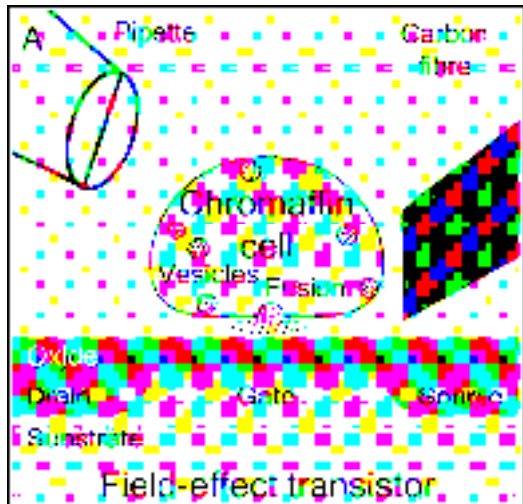


membrane
voltage



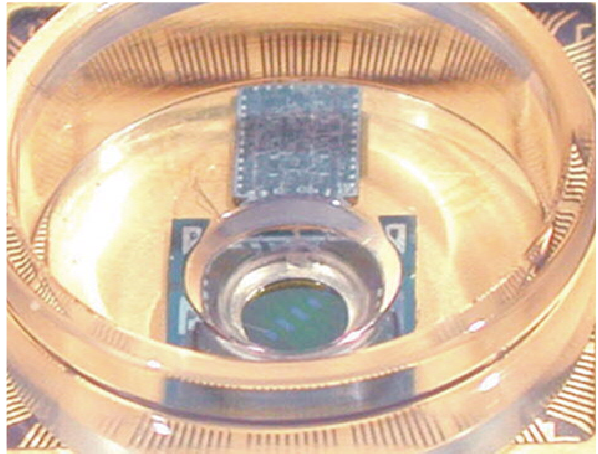
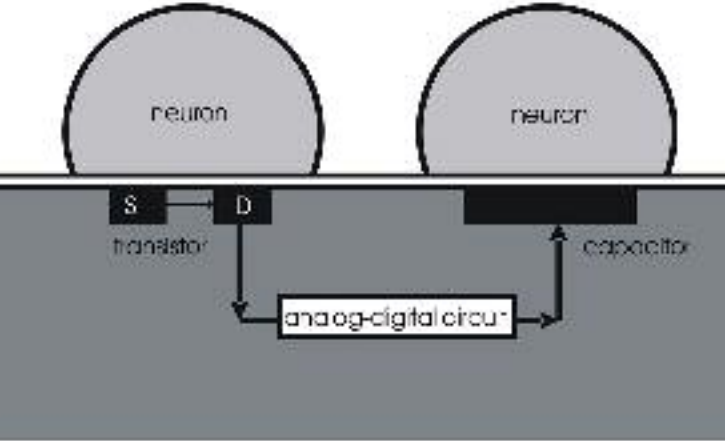
capacitor
voltage

the cell-semiconductor synapse

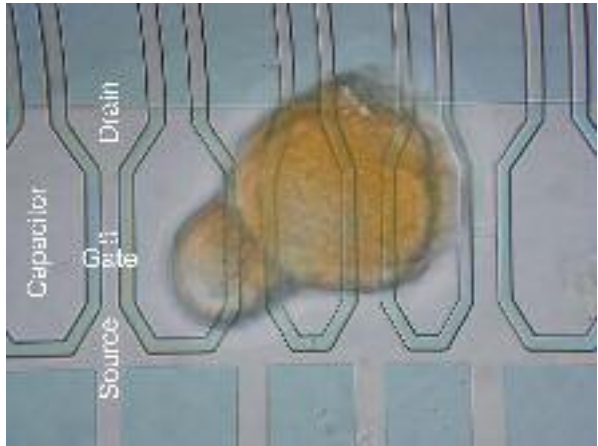
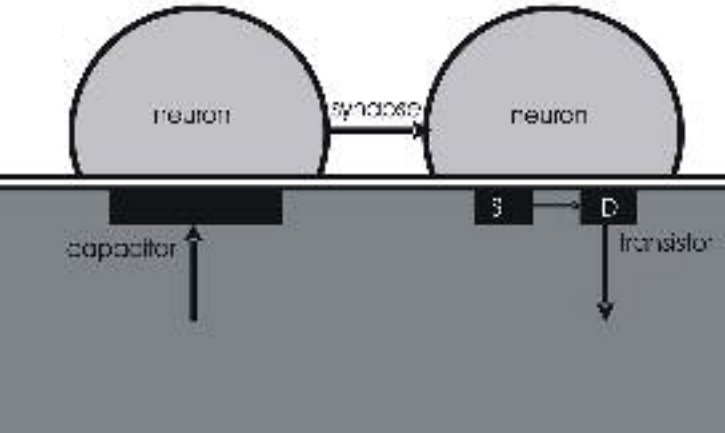


applications

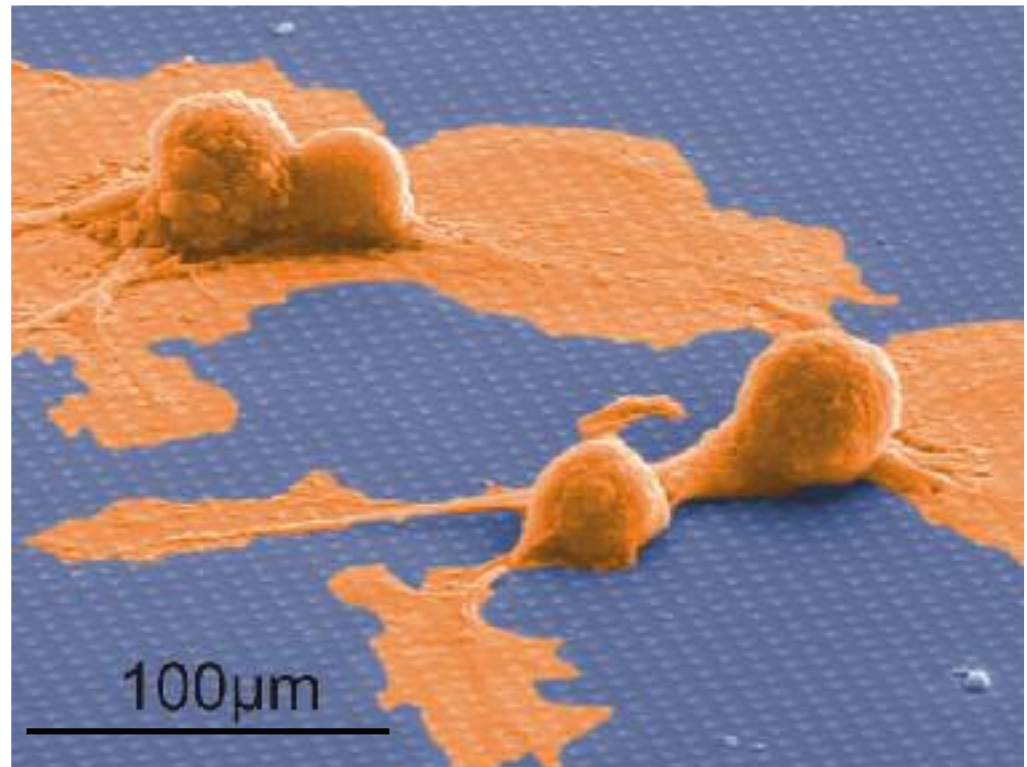
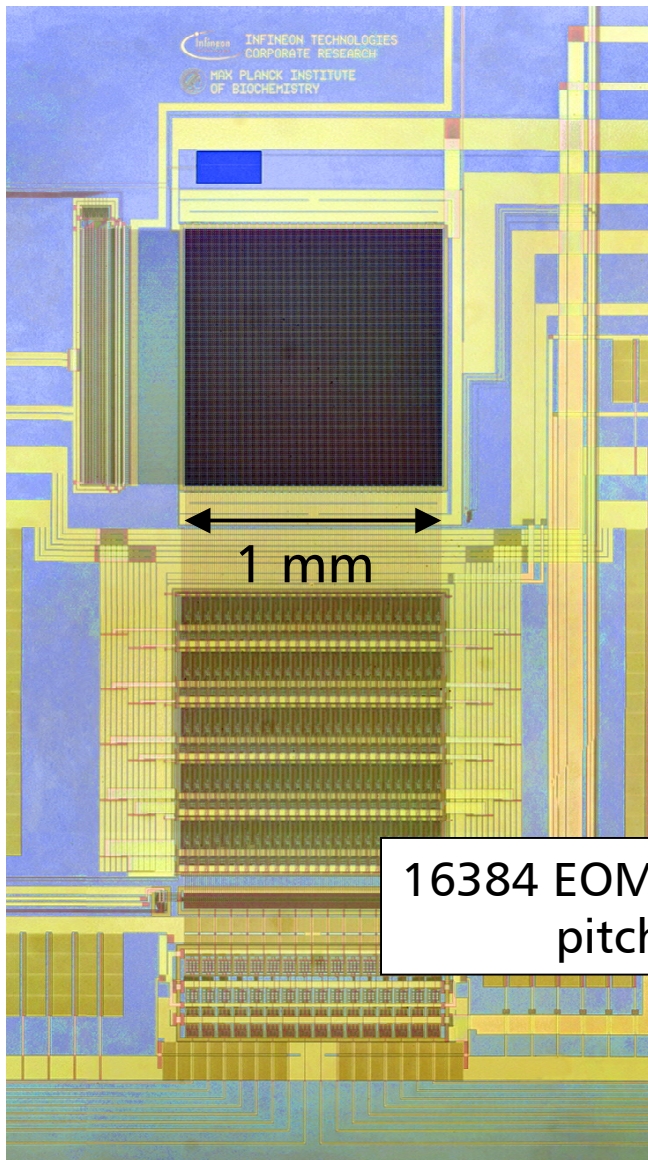
“neuroprosthesis”



“neuromemory”

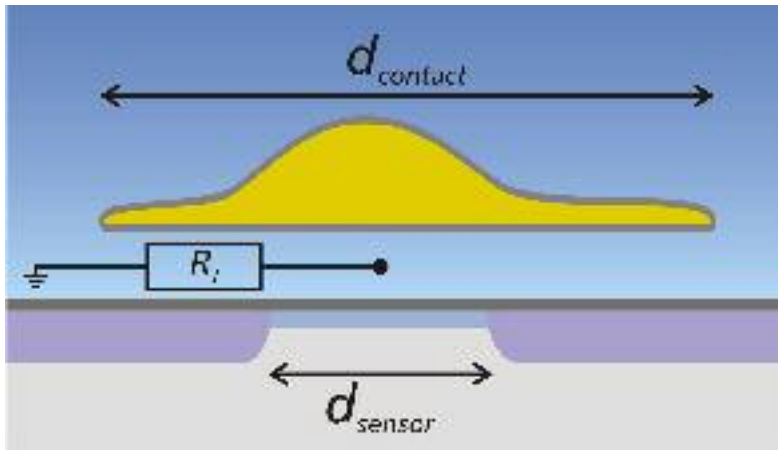


large-scale integration



16384 EOMOS transistors
pitch $7.8 \mu\text{m}$

device size

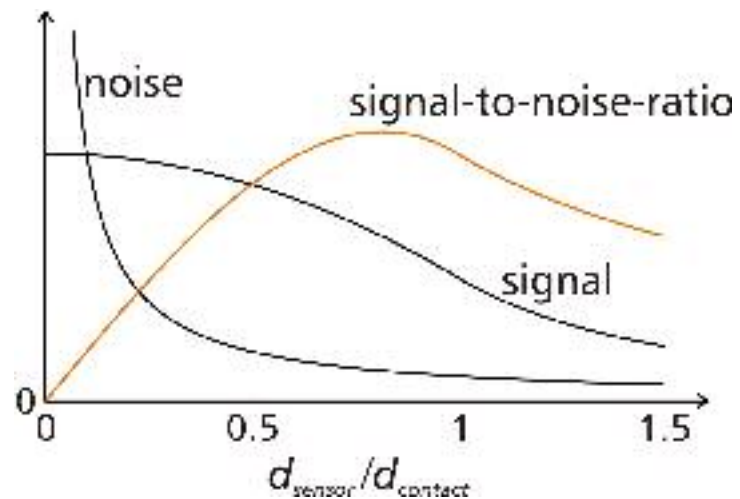


$$\text{signal} \propto d_{\text{contact}}^2$$
$$\text{noise amplitude} \propto \frac{1}{d_{\text{sensor}}}$$

$$\Rightarrow \text{SNR} \propto d_{\text{contact}}^2 \cdot d_{\text{sensor}}$$

for given contact size (e.g. cell size):

voltage profile
+ sensor noise
= optimal sensor size

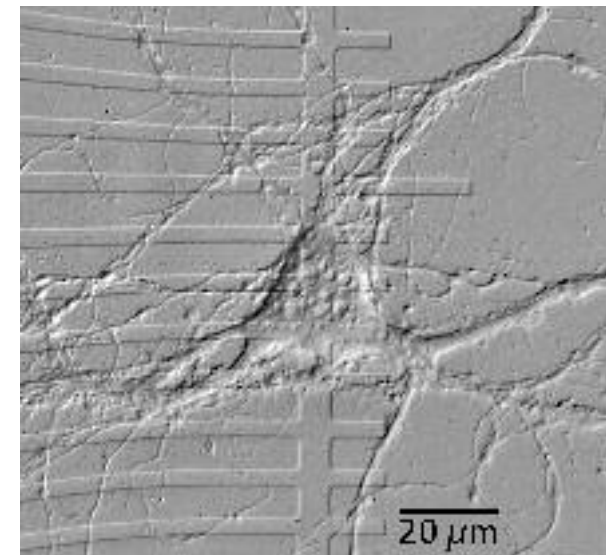
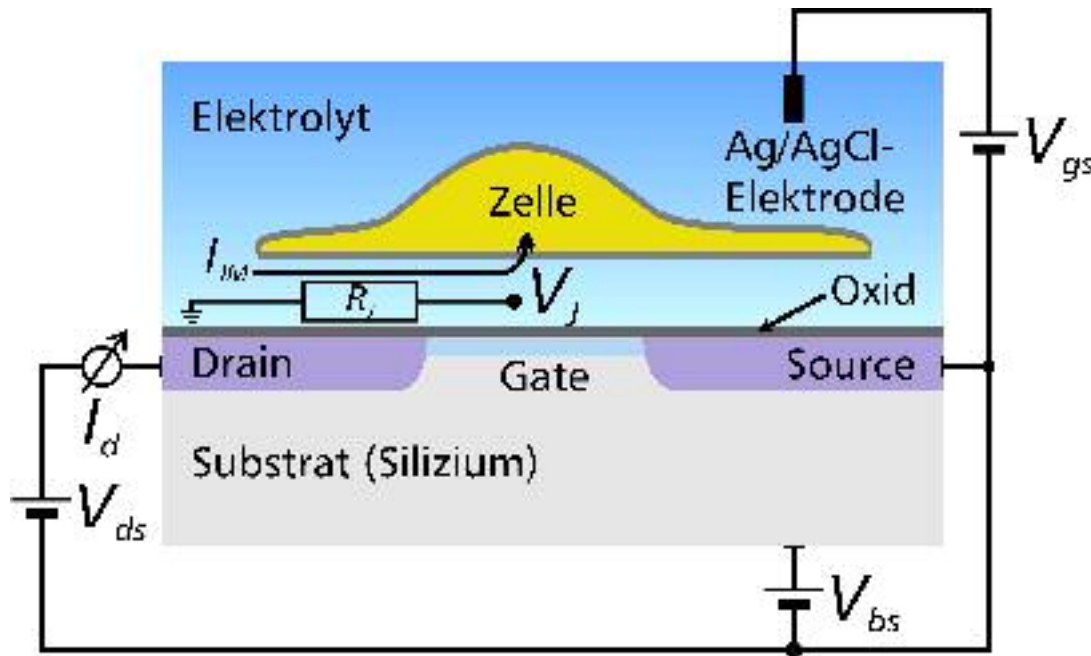


summary

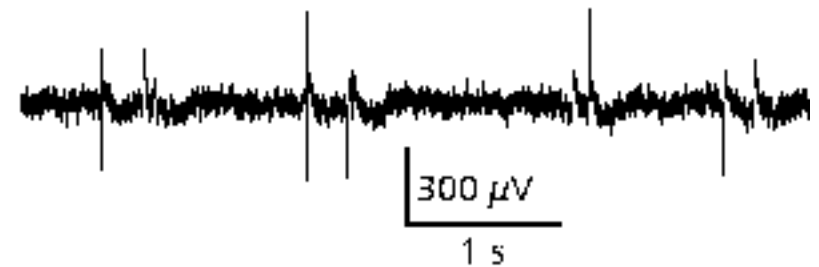
- cell signals: electrical and (bio)chemical
- ionic vs. electronic current
- silicon devices for recording and stimulation
- large-scale integration
- device size matters!

(backup slides)

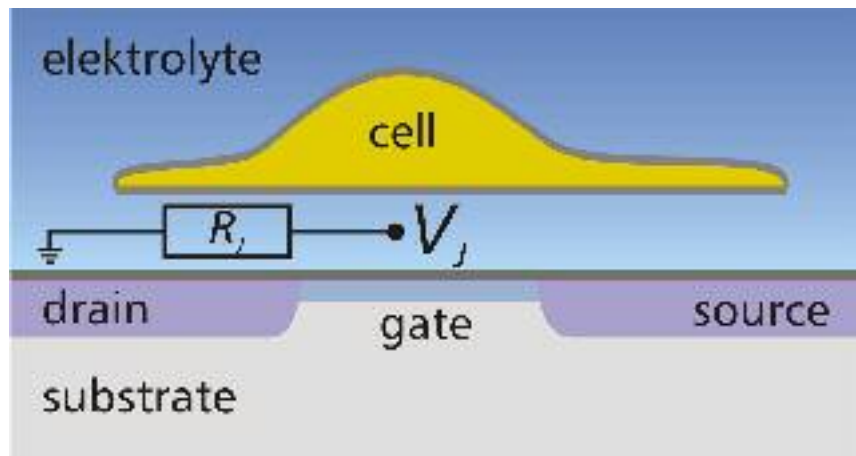
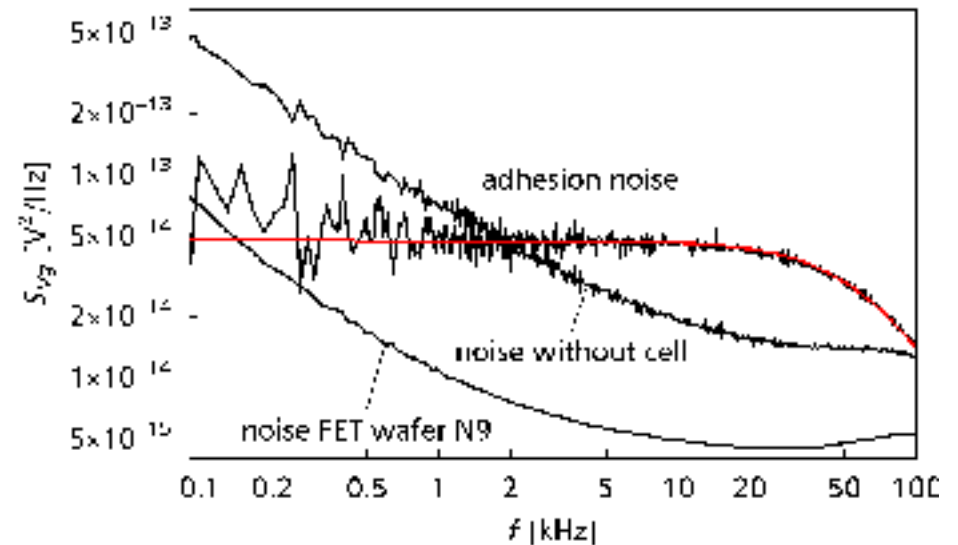
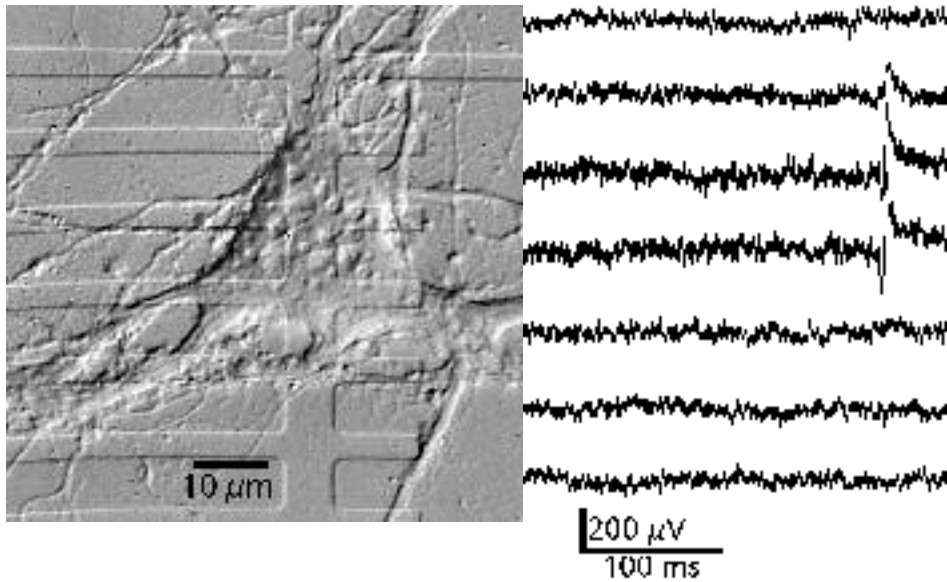
measurement setup



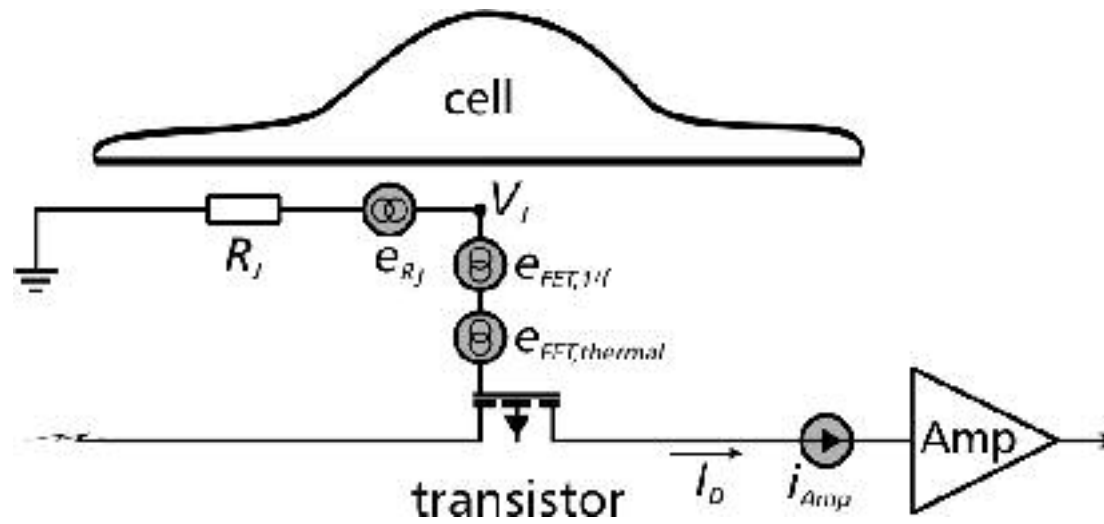
$$g_m := \frac{\partial I_d}{\partial V_{gs}} \quad I_d \rightarrow \Delta V_J = \frac{\Delta I_d}{g_m}$$



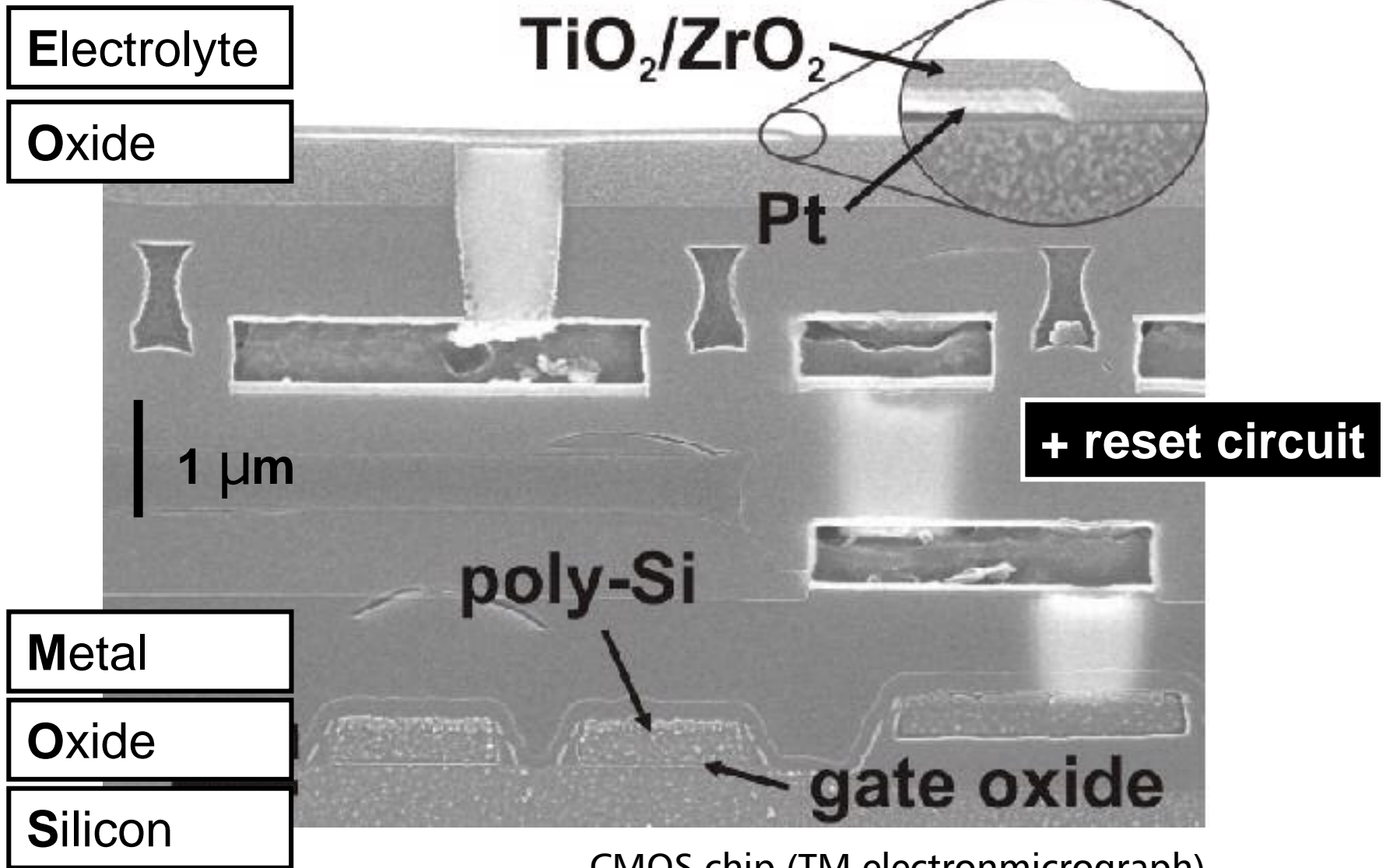
thermodynamic limit of extracellular recording



noise sources

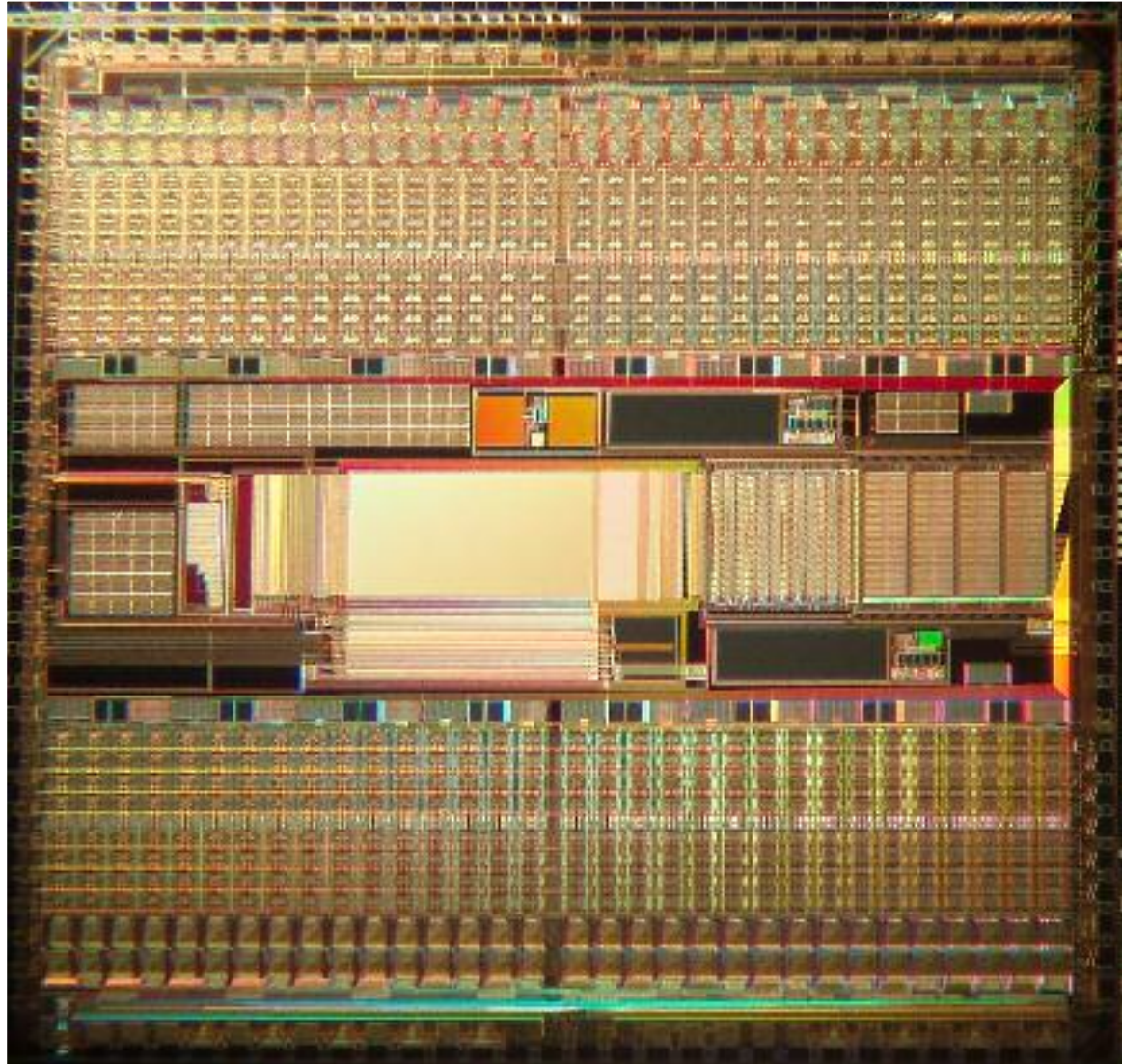


extended CMOS for integration

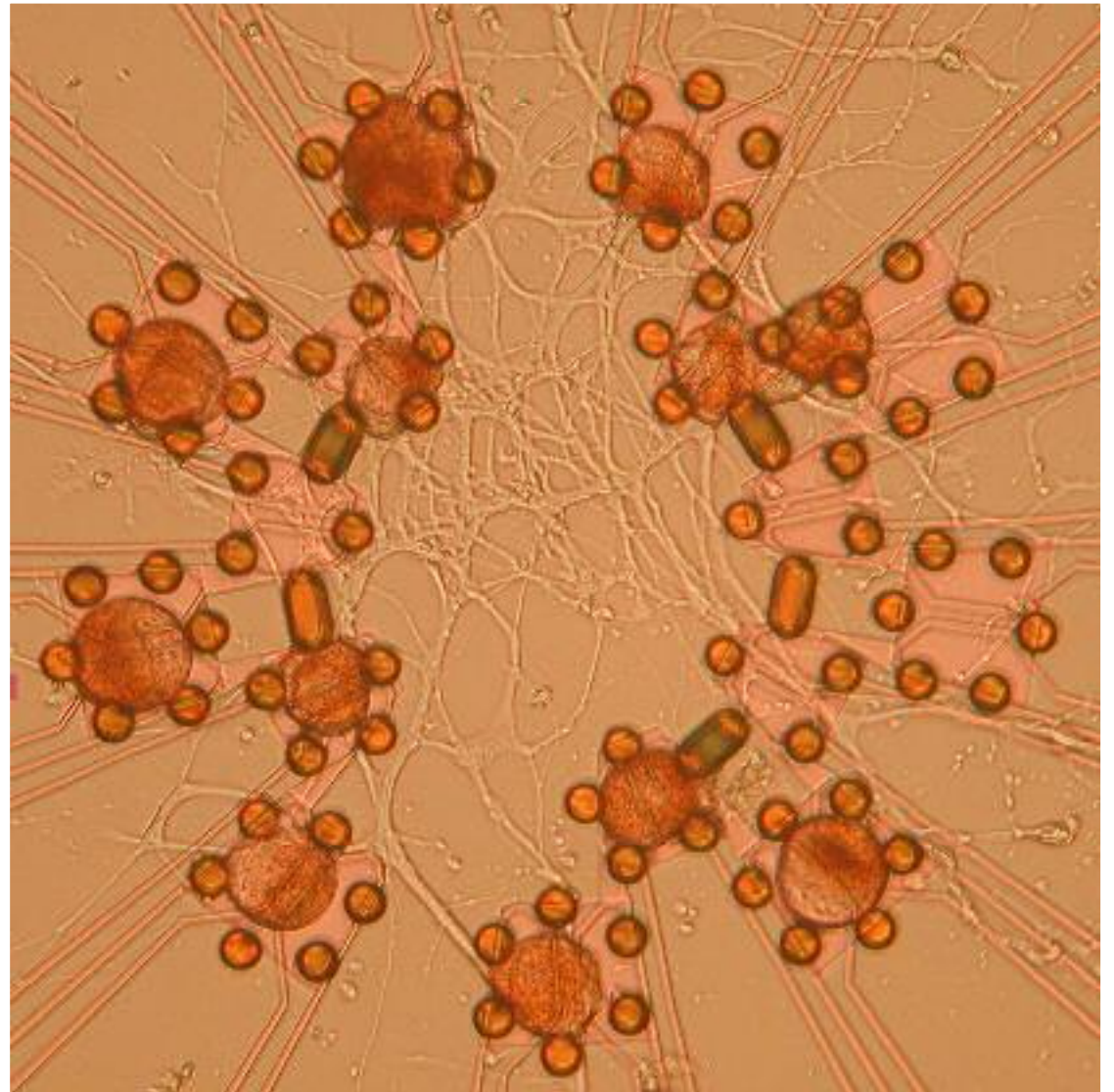
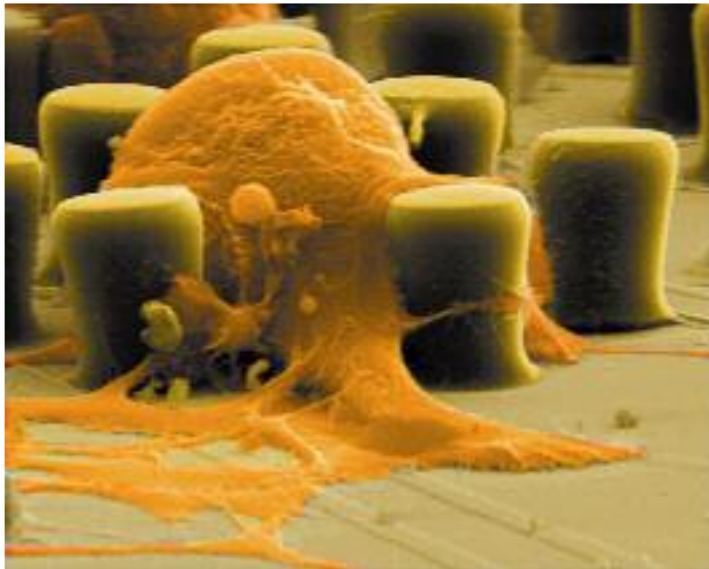


CMOS chip (TM electronmicrograph)

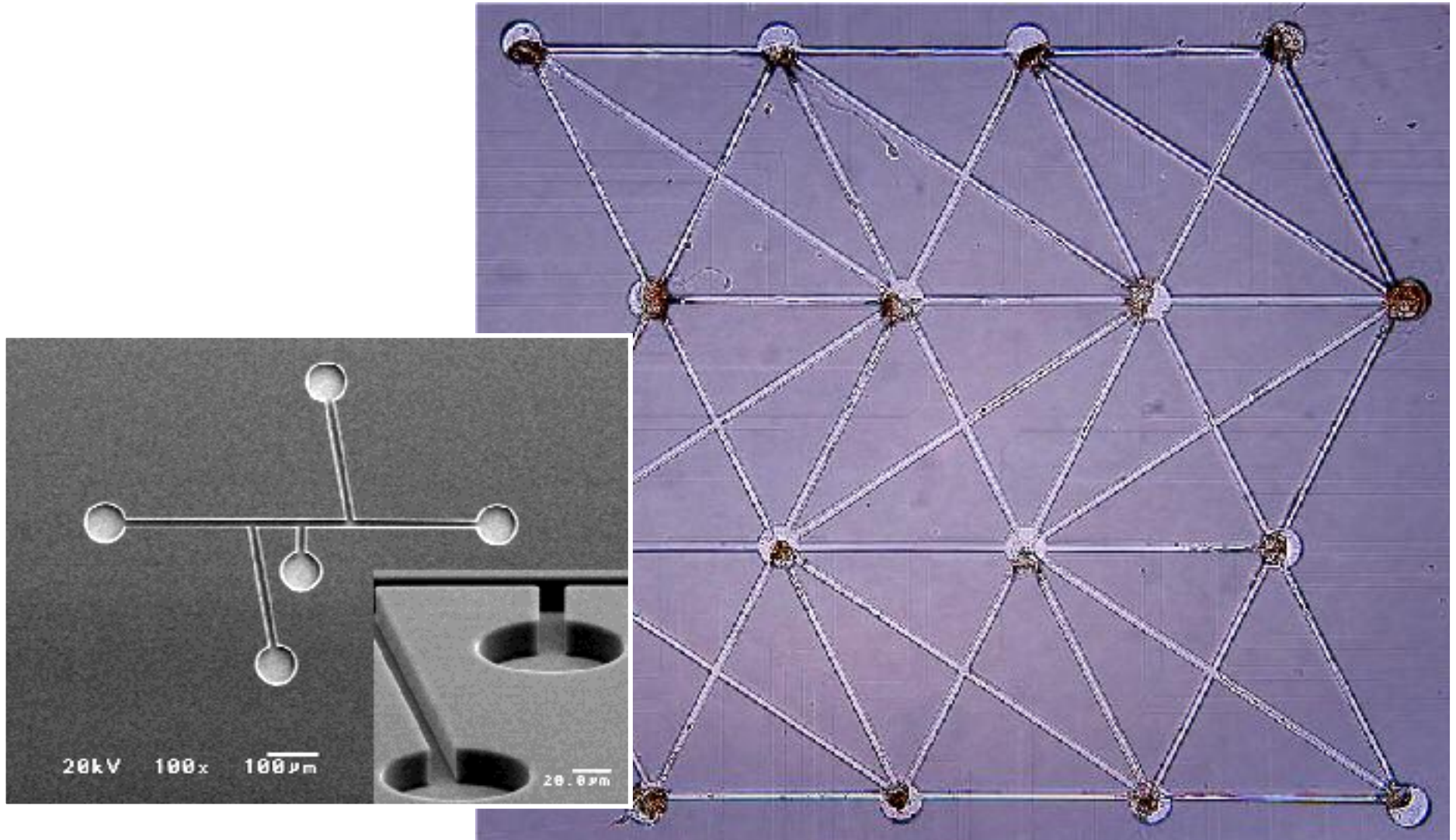
two-way CMOS neurochip



stable interfacing

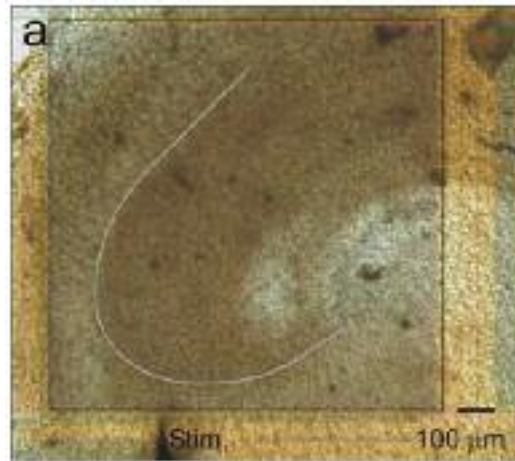


defined networks

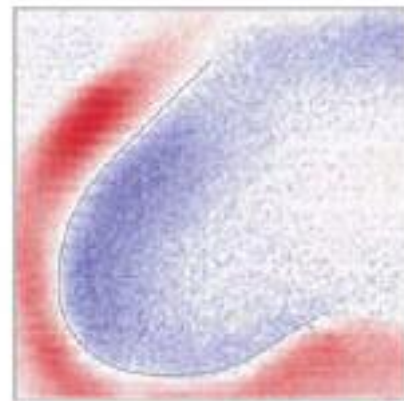


high-bandwidth interfacing

hippocampal
brain slice

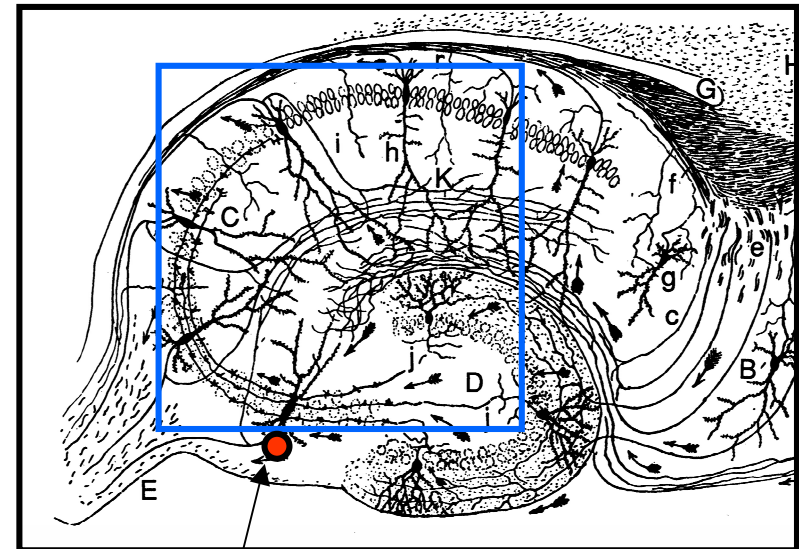


readout
6 kHz, 7.8 μm pitch



-4.0 mV

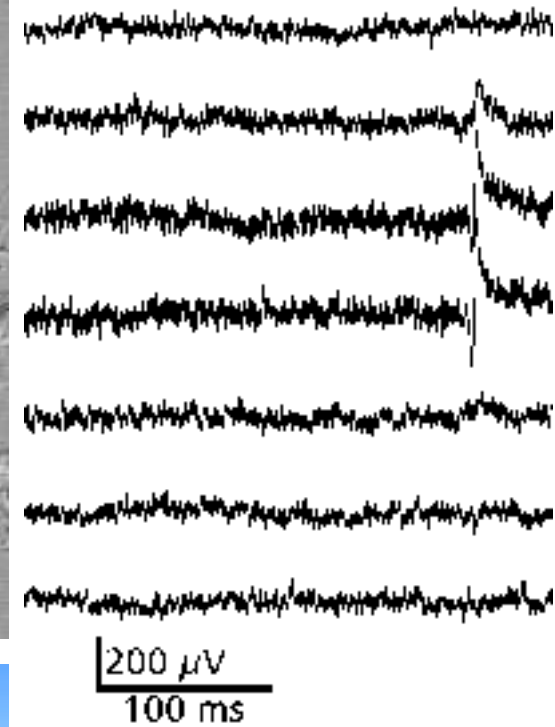
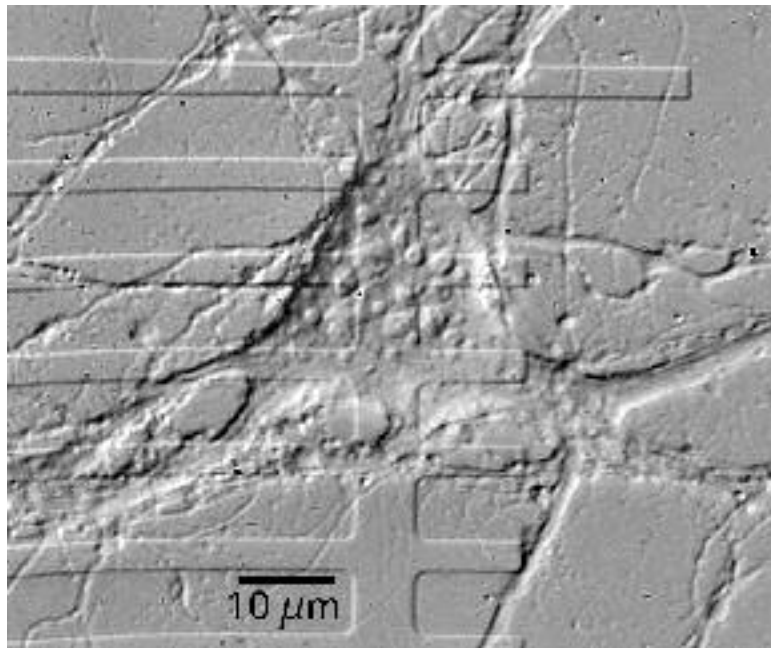
+5.5 mV



stimulation

extracellular voltage recording

rat neuron
on transistor array



extracellular voltages

voltage recording
with
field-effect transistor

