Implantable Neural Electrodes

Implantable Electronics Session

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Version: 2012-03-30

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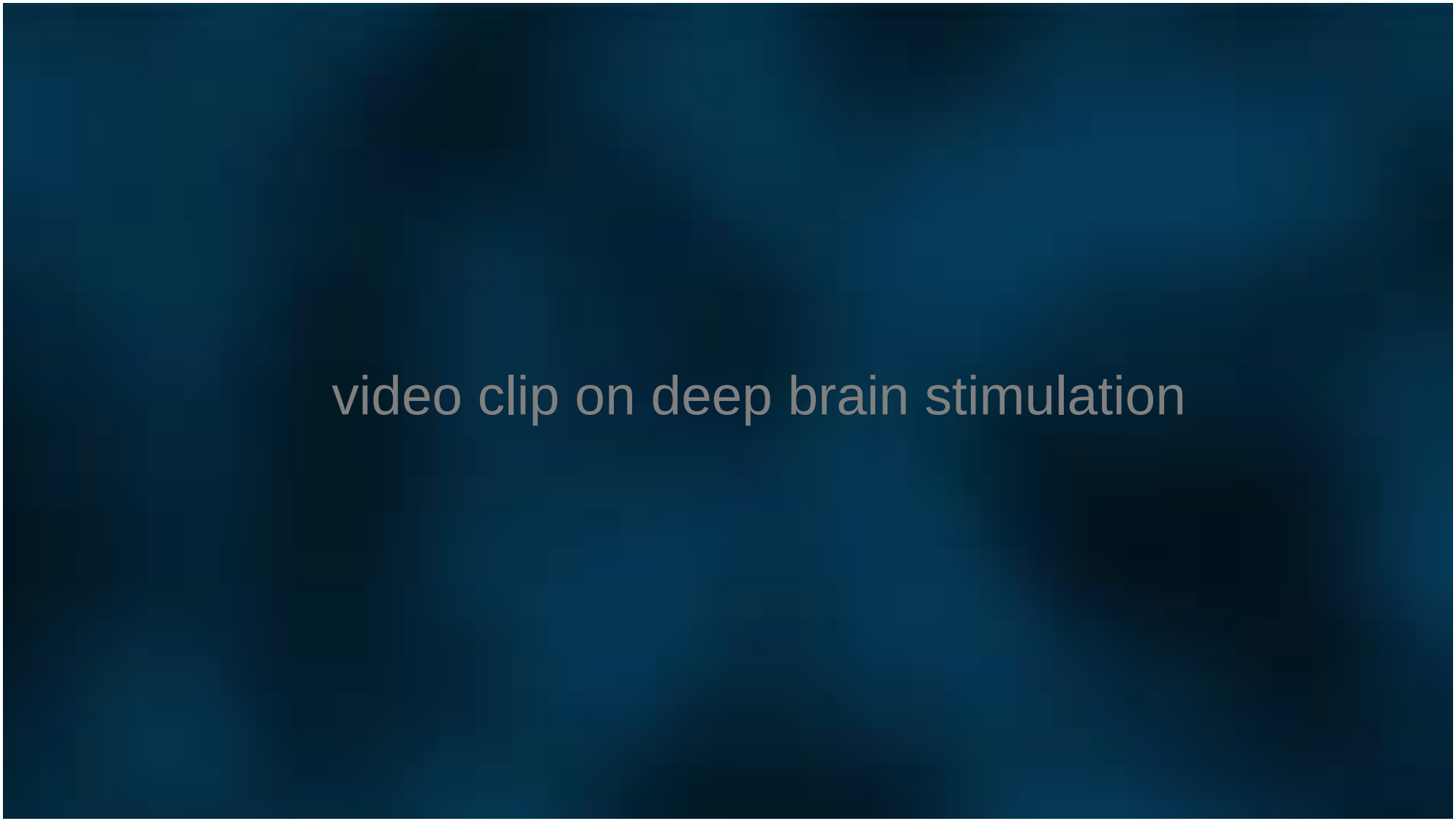
IMTEK

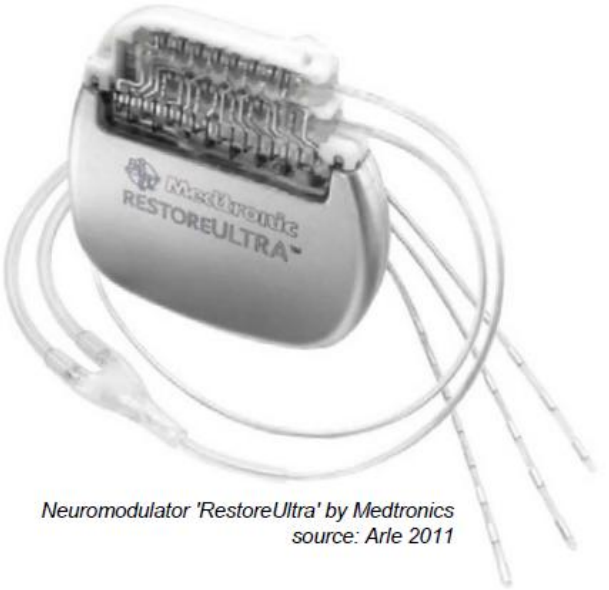
Department of Microsystems Engineering

Opener - Electrodes Implanted in the Brain



Today's clinical application involve

- Peripheral nervous system
  - Cardiac pacing
  - Cochlear implants
  - Bladder management
  - Pain management
  - Epilepsy treatment
  - Breathing
  - Depression
  - (...)



Neuromodulator 'RestoreUltra' by Medtronics
source: Arle 2011

- Central nervous system
  - Parkinson's disease
  - Dyskinesia
  - Obsessive compulsary disorders
  - Retinal implants
  - Epilepsy diagnosis
  - (...)

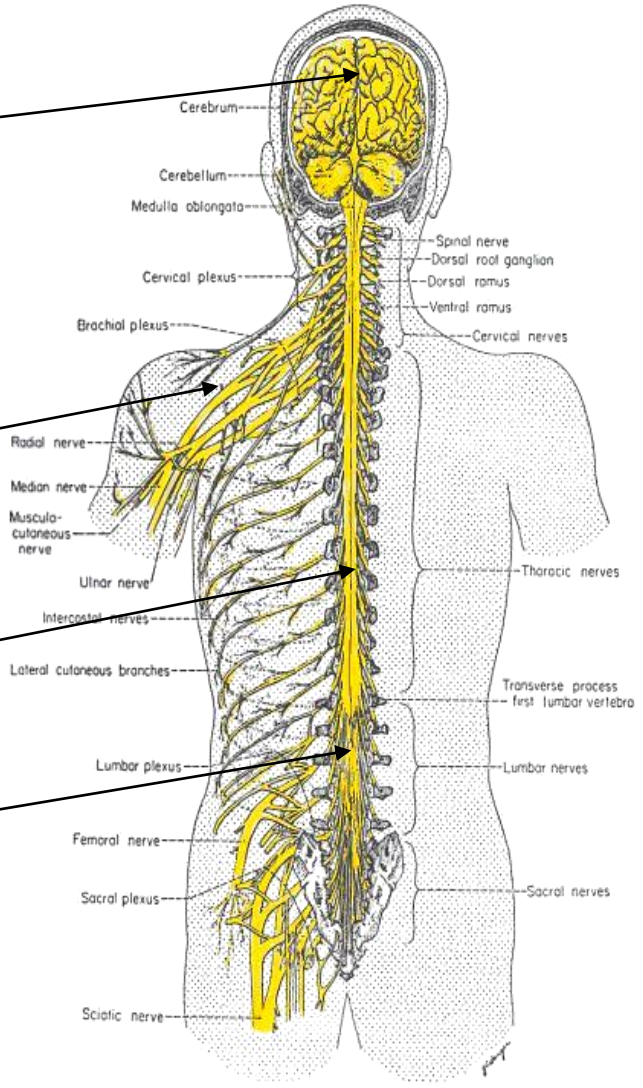
Communication Pathways of the Body

central nervous system

peripheral nerves

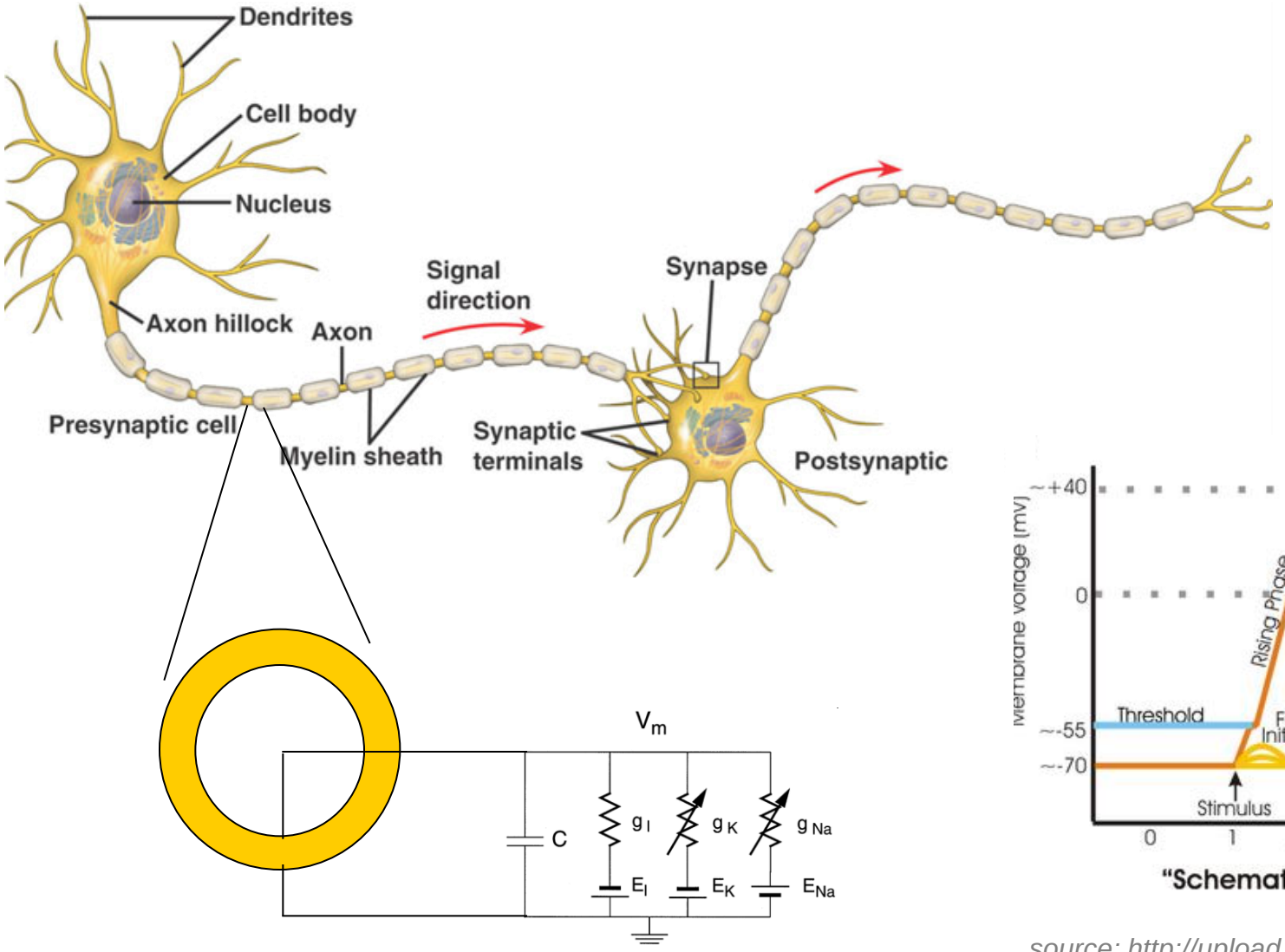
spinal cord

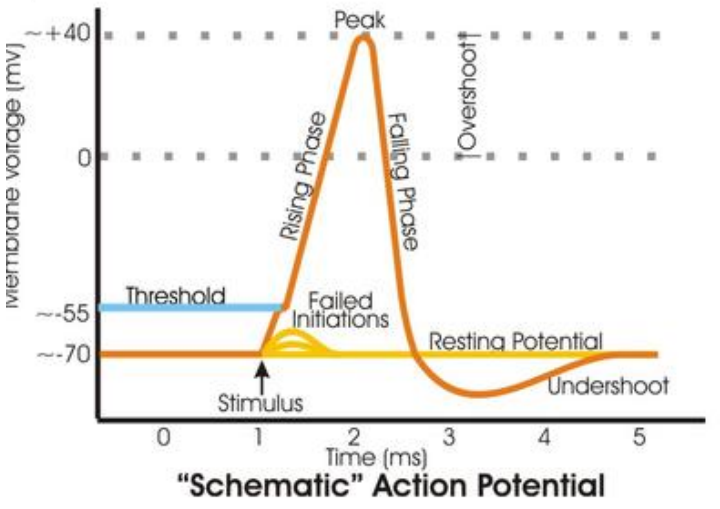
spinal roots



source: www.invanet.org (2012-03-14)

Neural Bioelectricity



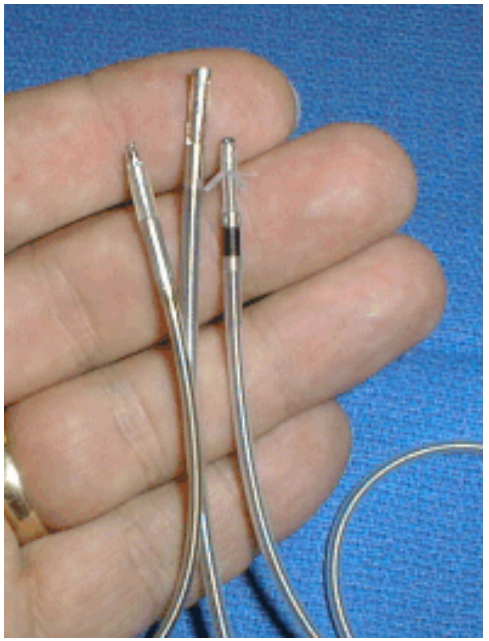


source: http://upload.wikimedia.org (2012-03-14)

Electrode Designs

- Implanted cardiac pacemakers: since 1950s
- Neural stimulation and recording

- Many lessons learned on materials in living host environment
  - Corrosion resistance of metals
  - Polymer degradation
  - Chemical toxicity



source: Love 2006

Biocompatibility (Old School)

Interaction Between Technical Systems and the Body

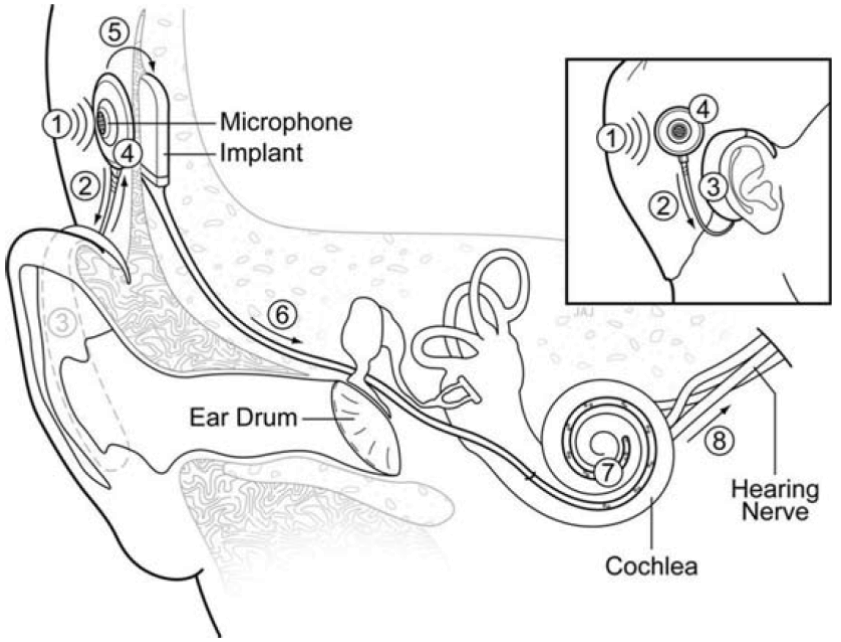
- For a successful implantation, the following is required:
  - The technical system must withstand the harsh body environment
  - The technical system must not disturb body function
- As consequence,
  - The implant location inside the body restricts potential implant shapes
  - Only a limited set of materials can be used for implants: 'Biomaterials'

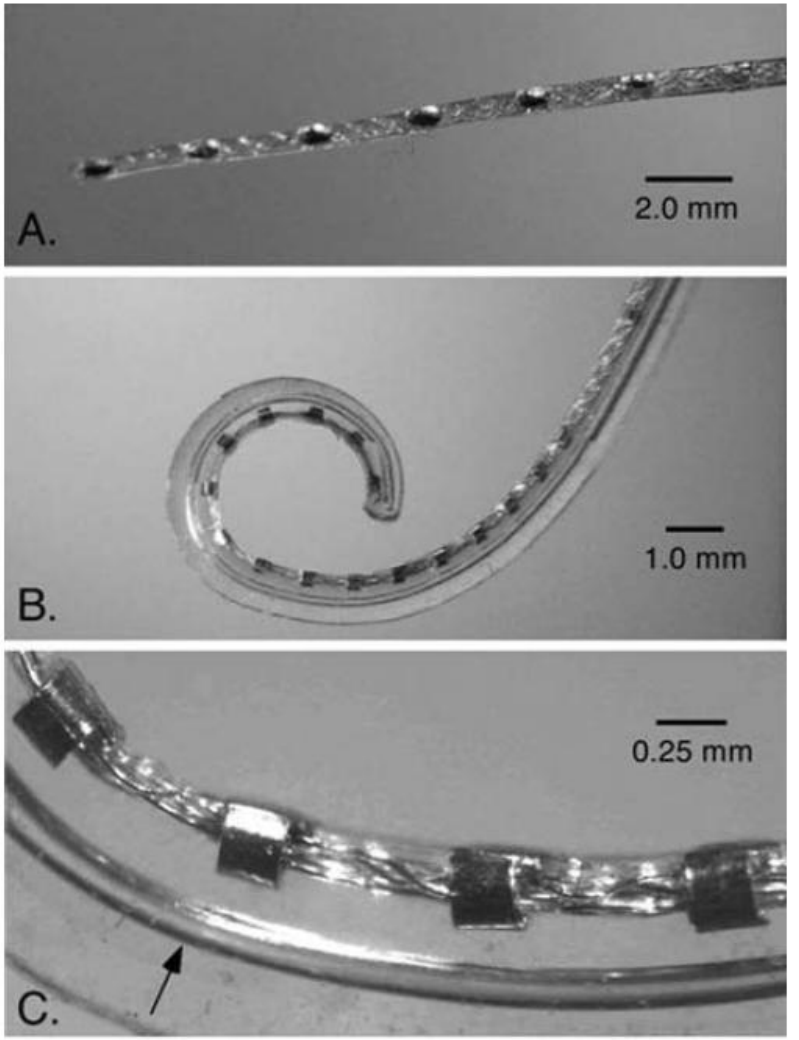
- ***Pt, Ir, PtIr, IrOx, TiN, cobalt-based alloys, stainless steel, gold***
- ***Silicones, PTFE, parylene, polyimide, polyesterimide***

Cochlear Electrode Arrays - Manual Production at Limit

Electrode Designs

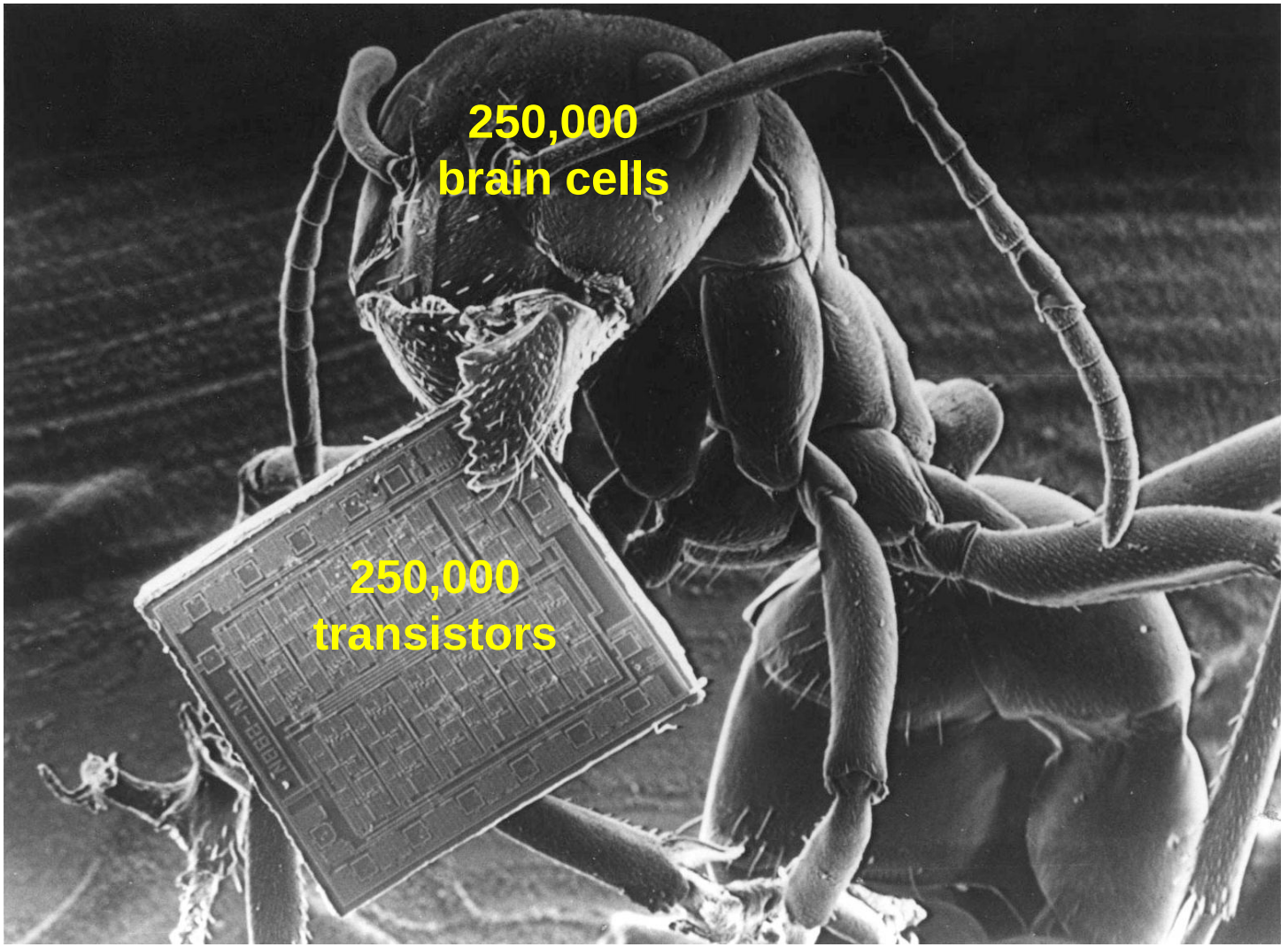
- Cochlear electrode array
- Stimulation and recording
- Platinum or PtIr
- 16 electrode sites





source: Zhou 2011

Micromachining (1960s)



source: www.livenano.org (2012-03-12)

Micromachining

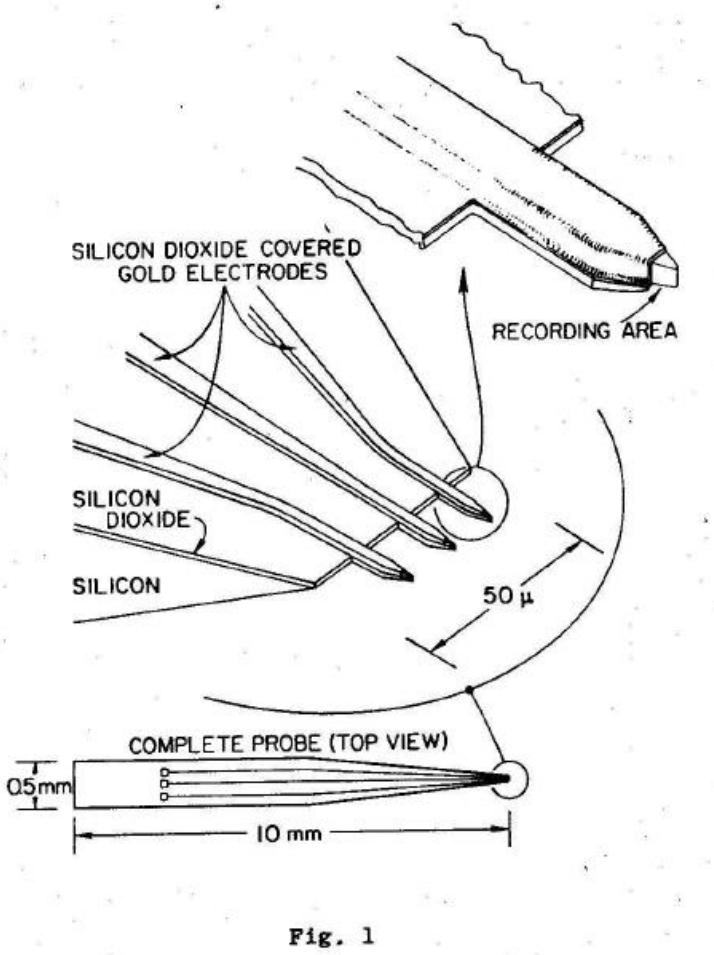
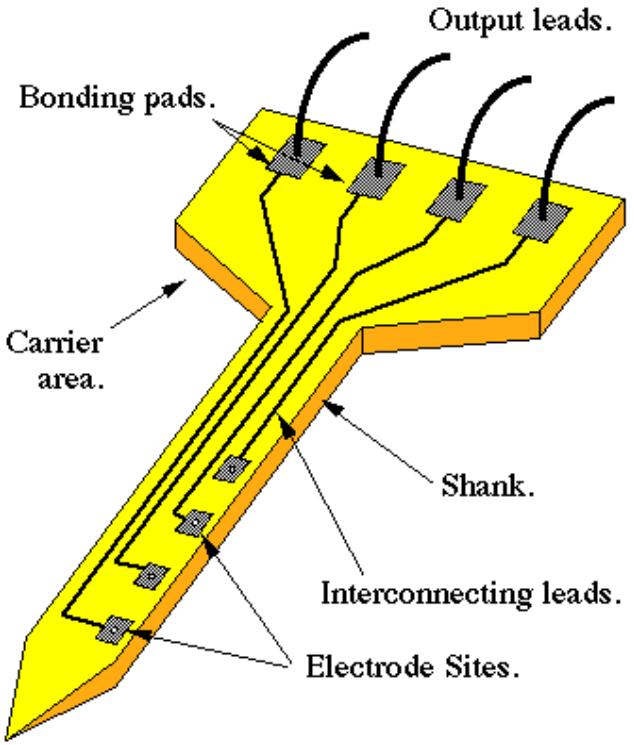


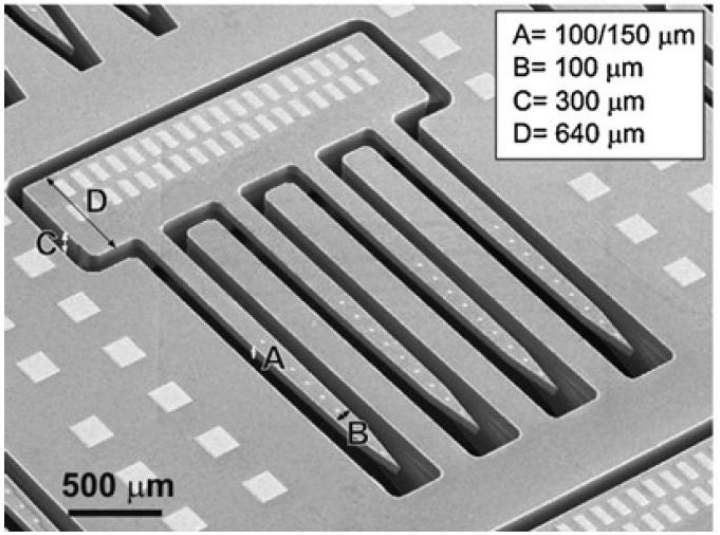
Fig. 1

source: Wise et al., 1969

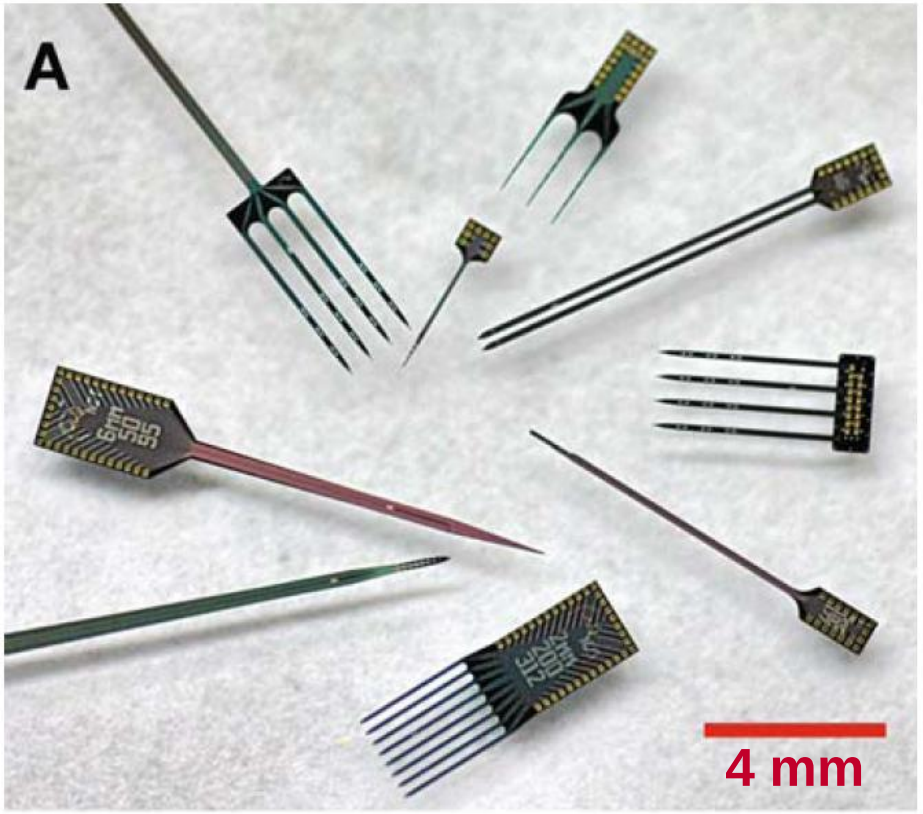


Silicon-Based Microelectrode Arrays

- silicone substrate
- min. feature sizes ~ 5 µm
- metallisation layers: some 100 nm
- insulation layers: some 1 µm

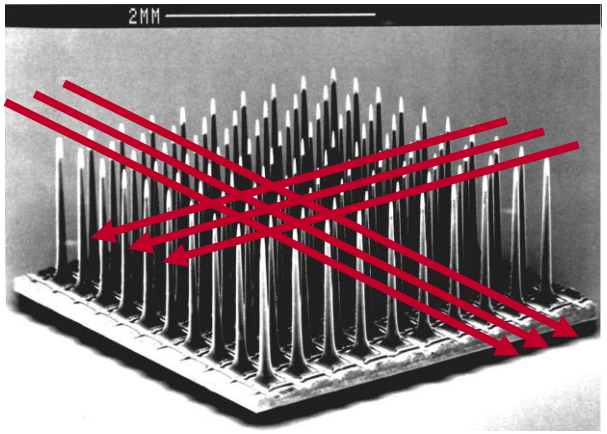


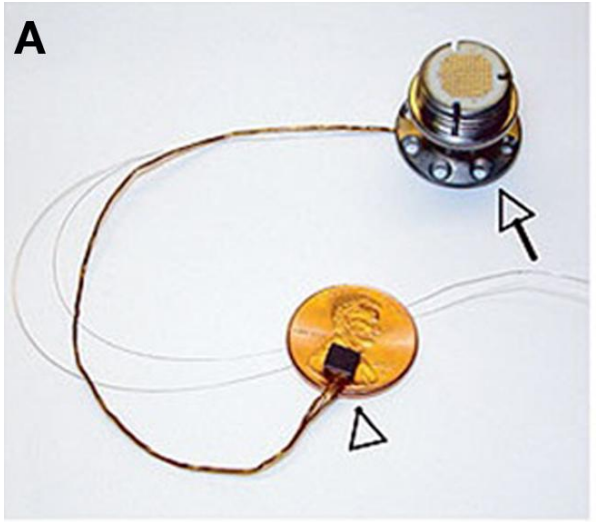
source: Grand 2010



source: Zhou 2011

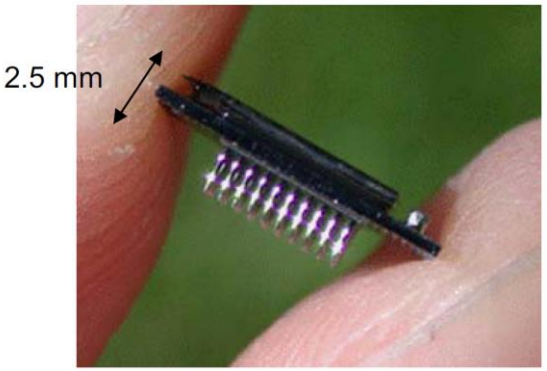
Micromachining: 3D Arrays

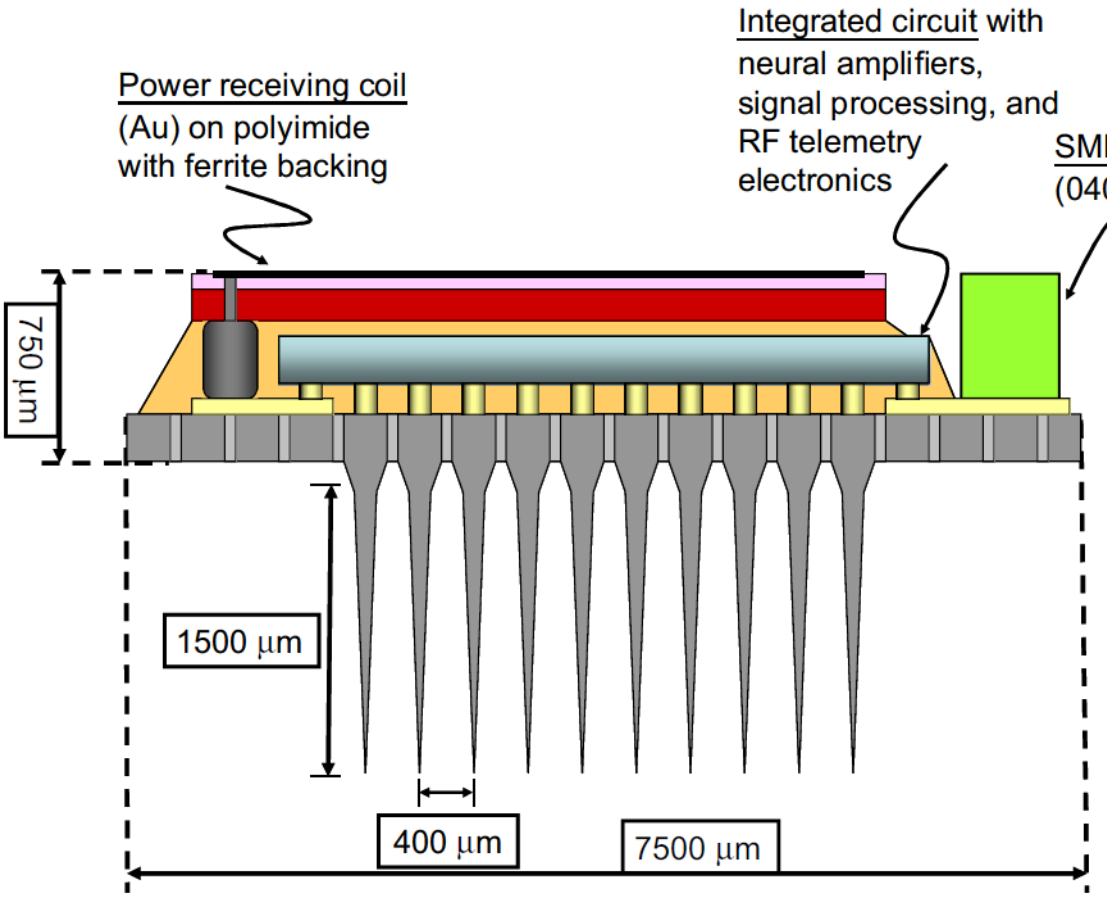




Smart Electrodes

- on-board electronics:
  - radio transmitters
  - amplifiers, etc.
- difficulty: small size hermetic package
- CHECK POSTER!

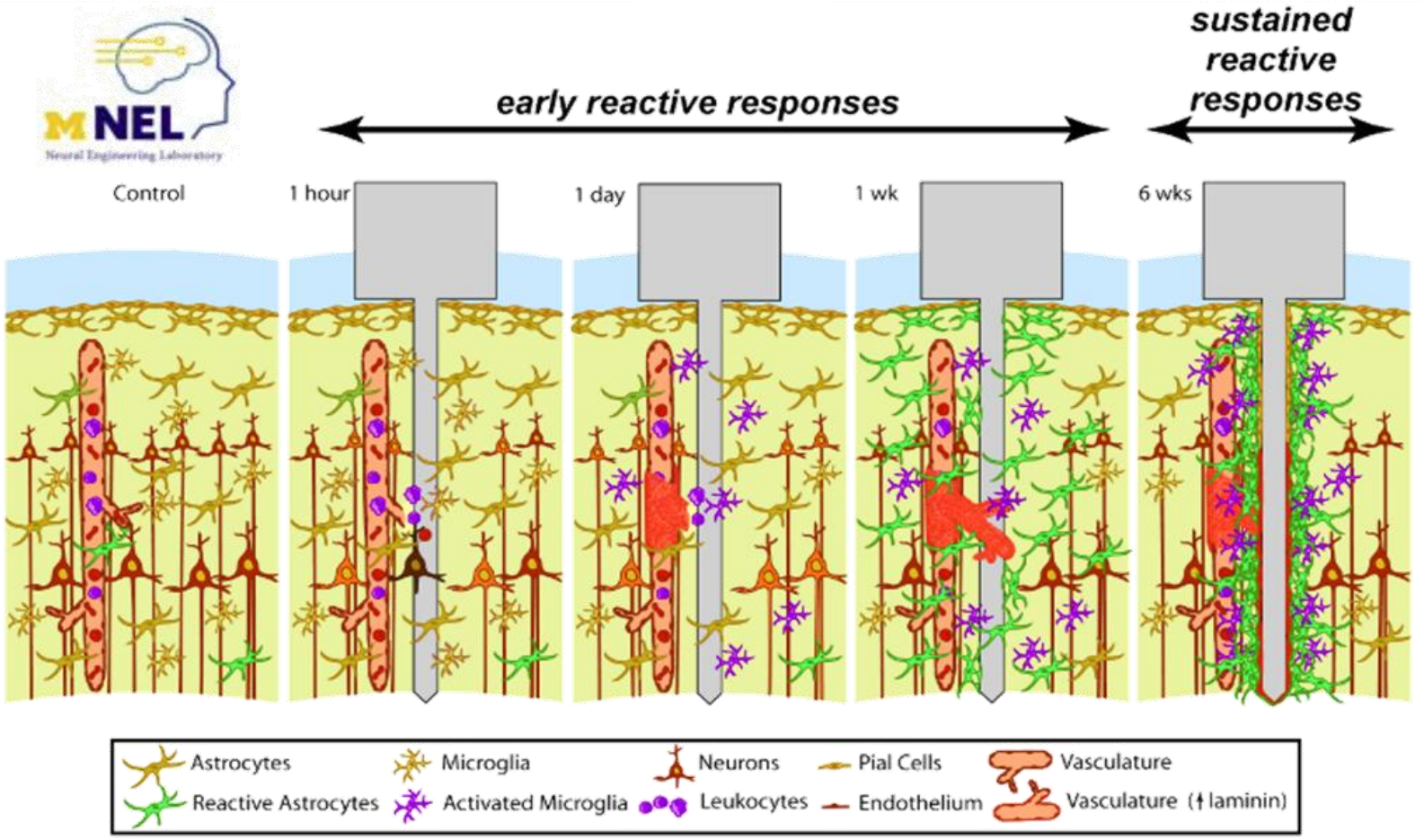




source: Kim 2009

Biological Response

Reduction of signals quality months (inflammation)

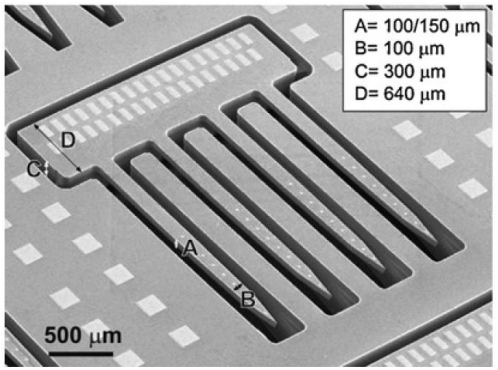


source: Shain, Wadsworth Cemter, 2009

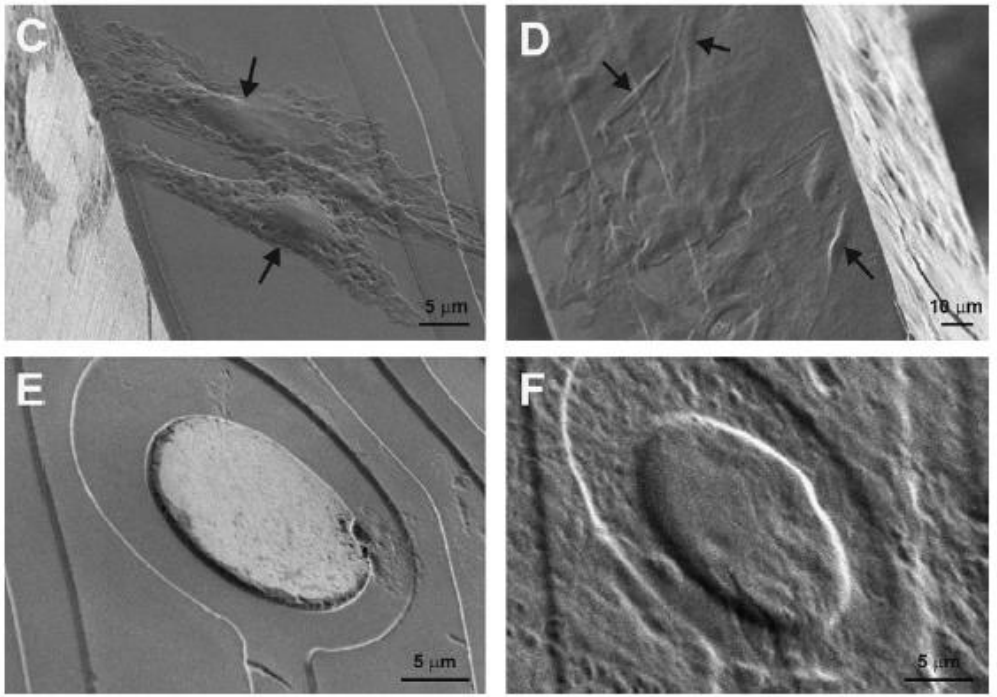
Biocompatibility (Modern)

Definition Today

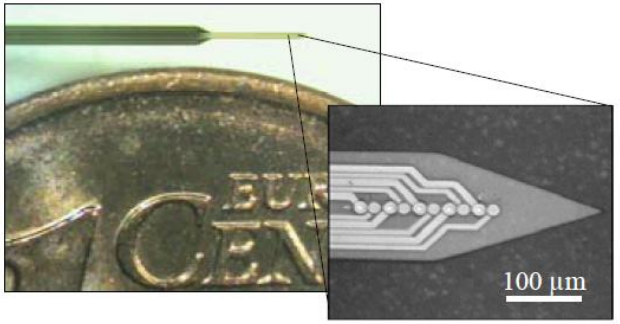
Biocompatibility *refers to the ability of a material to perform with an appropriate host response in a specific situation.*

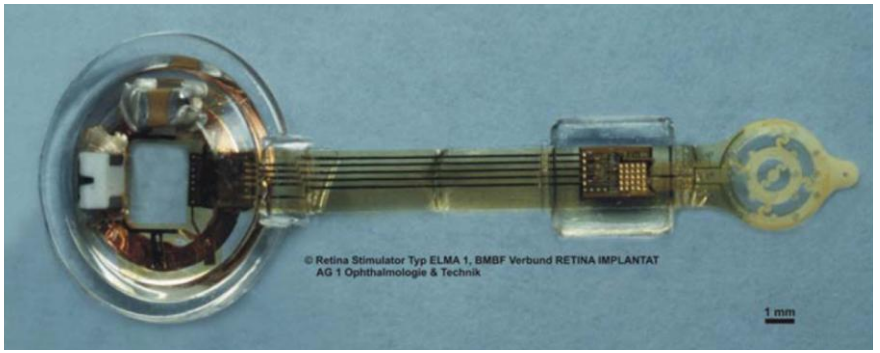


source: Grand 2010

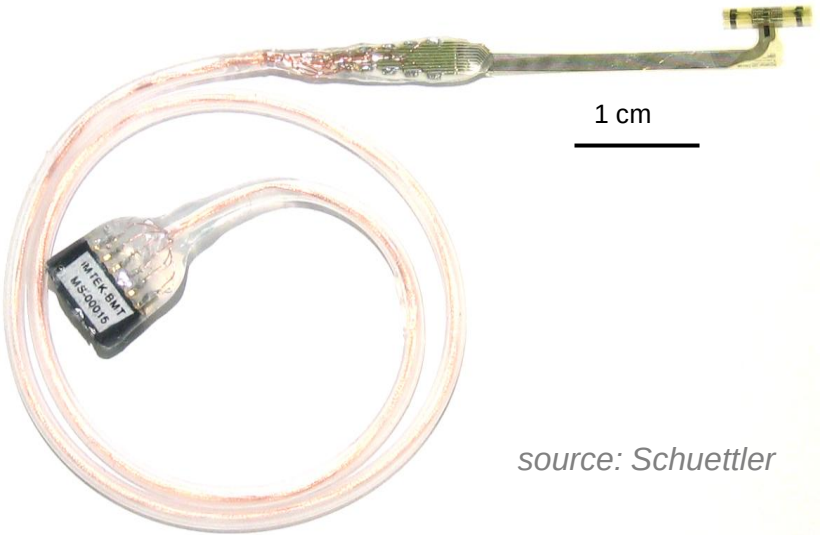


Polyimide Electrode Array (plain + electronics)

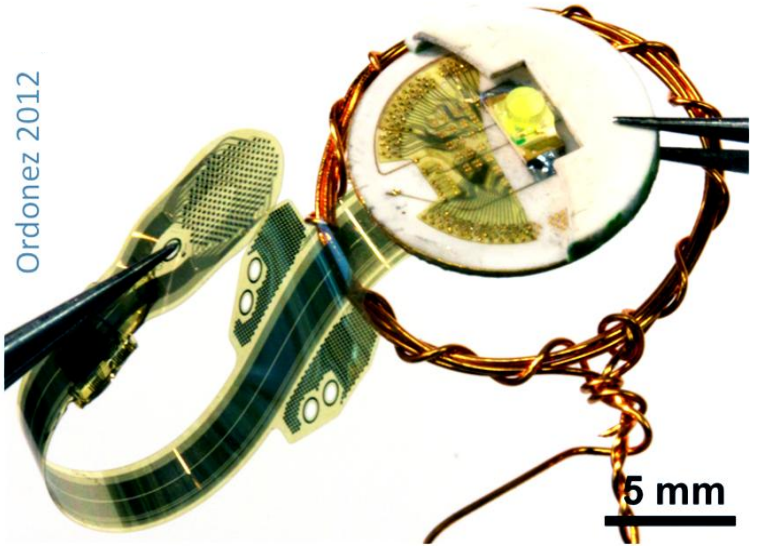




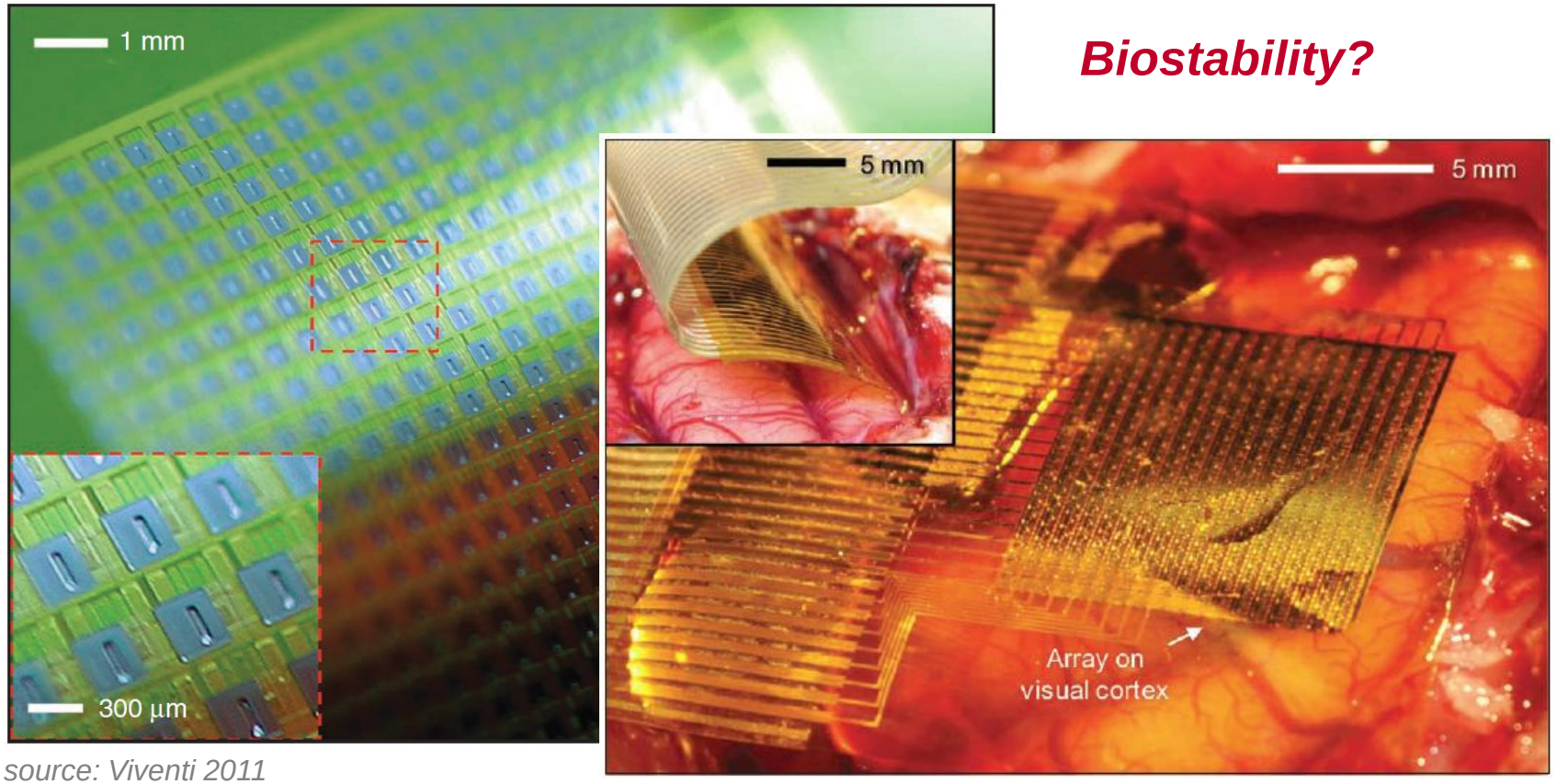
souurce: Stieglitz 2009



source: Schuettler



Active Arrays (360 channels, integrated silicon switches)

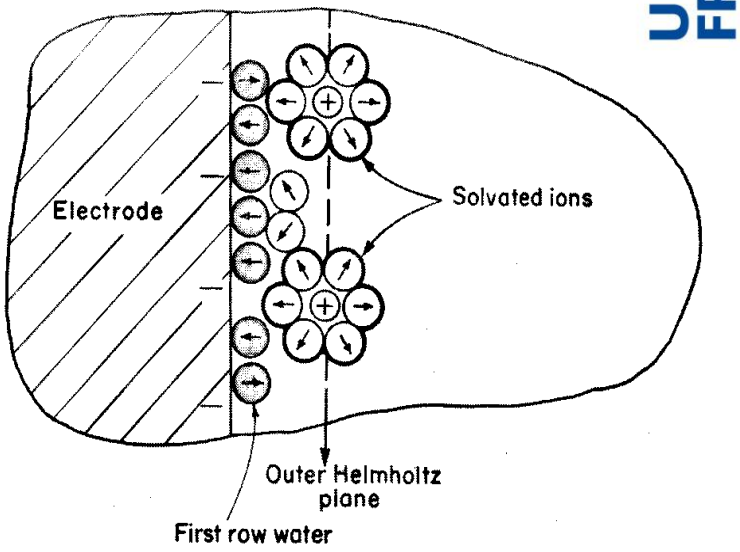


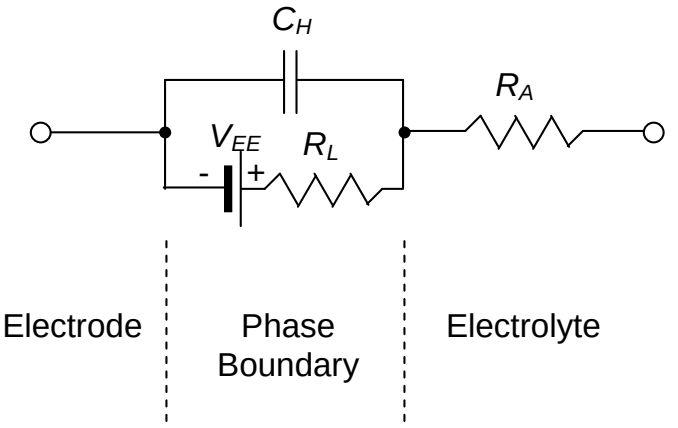
Biostability?

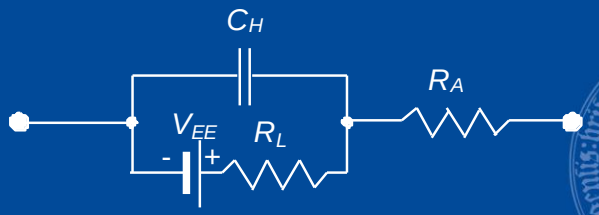
source: Viventi 2011

Simple Equivalent Circuit

- C_H = Helmholtz Capacitance
  defined by electrode surface area
- V_{EE} = Electrode / electrolyte voltage
  dominated by electrode material and electrolyte
- R_L = Leakage resistance
  dominated by electrode surface area, and electrode material, allows current to leak through C_H
- R_A = Access Resistance
  dominated by electrode size and electrolyte resistivity ρ







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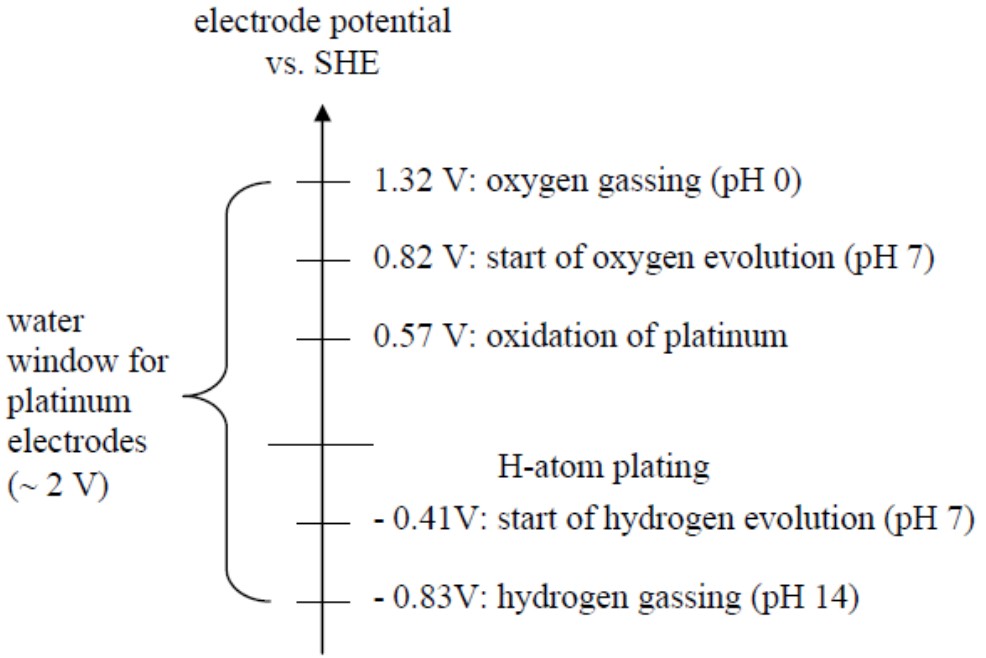
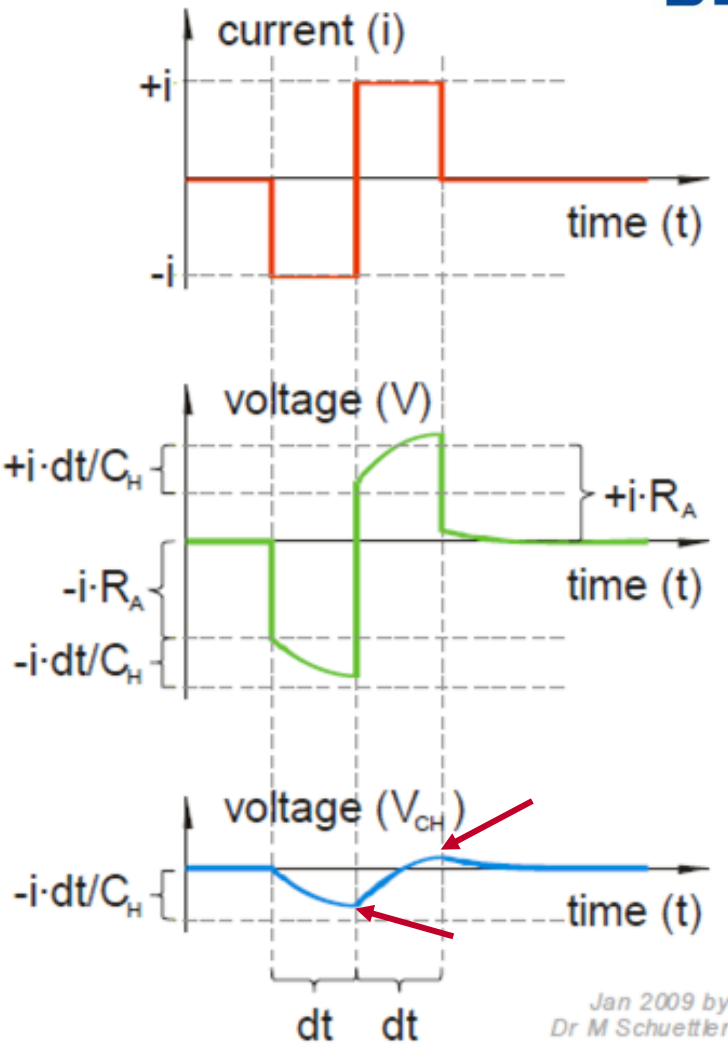
Stimulation Properties

- Pulse testing
- Max. injectable charge

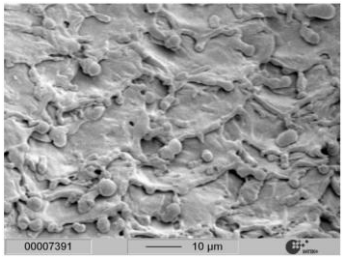




Shrinking Geometrical Electrode Area

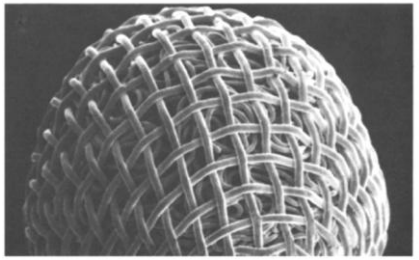
- Decreases electrode capacitance
  - reducing safe charge injection limit
- Increases access resistance
  - increases thermal noise
  - increases compliance voltage required

laser-roughened Pt



source: Schuettler, 2007

mesh electrode

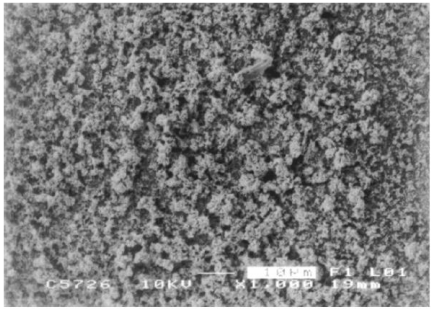


source: Park, 2007

Increasing Active Electrode Area

- Surface roughness increases electrode capacitance
  - Mesh electrodes
  - Platinum black / grey

platinum black



source: Schuettler, 2005

Electrode Coatings

Metal / Metaloxides

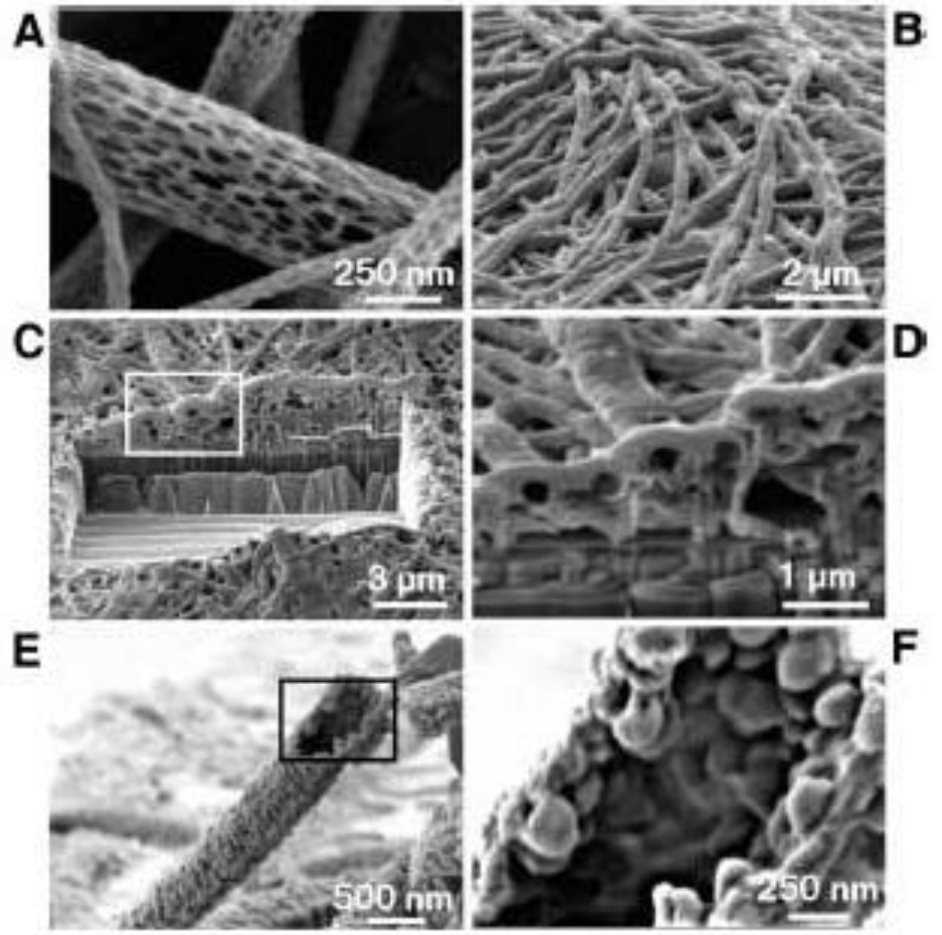
- Pt gray / black
- Iridium oxide

Polymeric Electrode Materials

- Nanotubes, doped PEDOT, doped diamond, ...
- Very high (initial) charge injection capacity
- Option of *filling* with chemical agents, controlled drug release

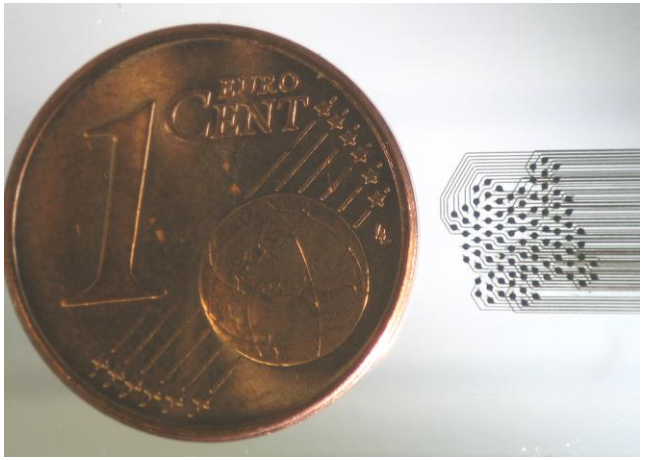
Long-Term Biostability?

source: University of Michigan



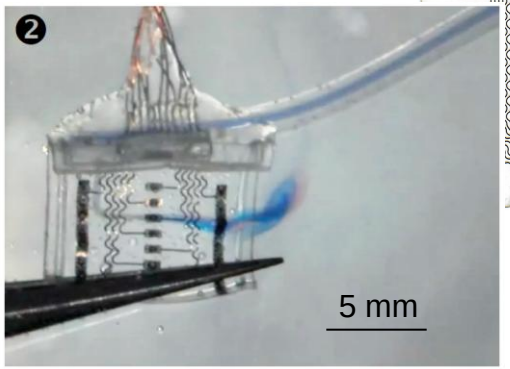
Laser Fabrication

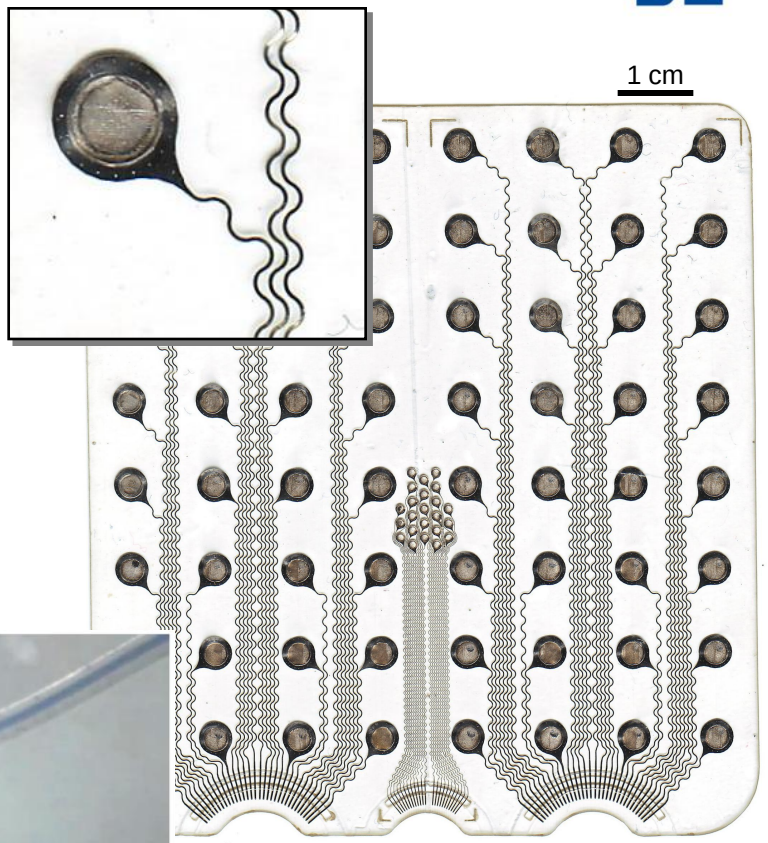
- Only approved implant materials
- Lean production line
- Limited definition (~25 µm)
- Soft & stretchable
- Fluidic channels (controlled drug release)
- Integration of electronics (see poster)



Source: Suaning 2007

Source: Schuettler 2011



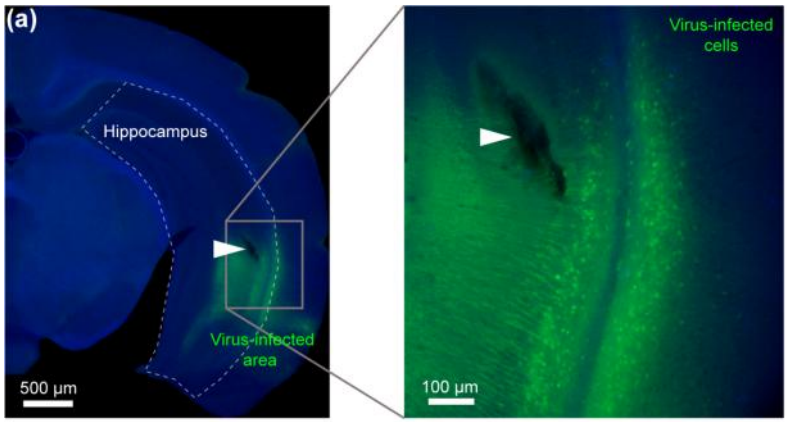


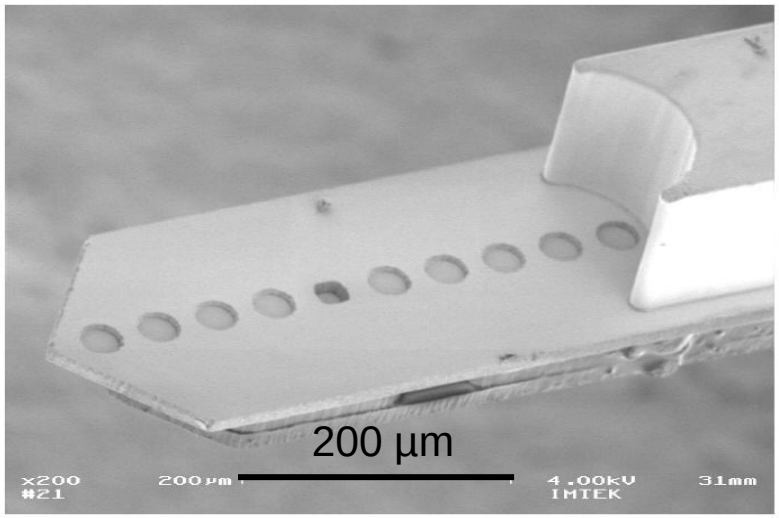
Source: Schuettler 2009

Optogenetics

(*nature*: method of the year 2010)

- Virus infection of selected nerve cell population
- Cell activity becomes sensitive to light
  - 473 nm (facilitate)
  - 593 nm (inhibit)
- Facilitated or attenuated spiking activity (detected electrically)
- Investigation of local function of specific nerve cell population within complex neural circuits (behaviour).





source: Rubehn 2011

In a Nutshell

- Neural electrodes have to be **designed** according to the application
- Each application is associated with a most suitable **fabrication technology** (hand / laser / photolithography)
- Microfabrication of neural electrode arrays is now transferred (after 40 years!) to **clinical applications**.
- This (among the technological progress in hermetic packaging) permits the fabrication **RELIABLE** active implantable medical devices with high channel count, opening the door for many challenging applications like
  - Retinal implant
  - Brain computer interfaces
- Optogenetics: Neuroscience gets a novel, powerful tool
- Problems: Mechanical properties / active electronics / wiring