

3-5. Bioelectric Phenomena

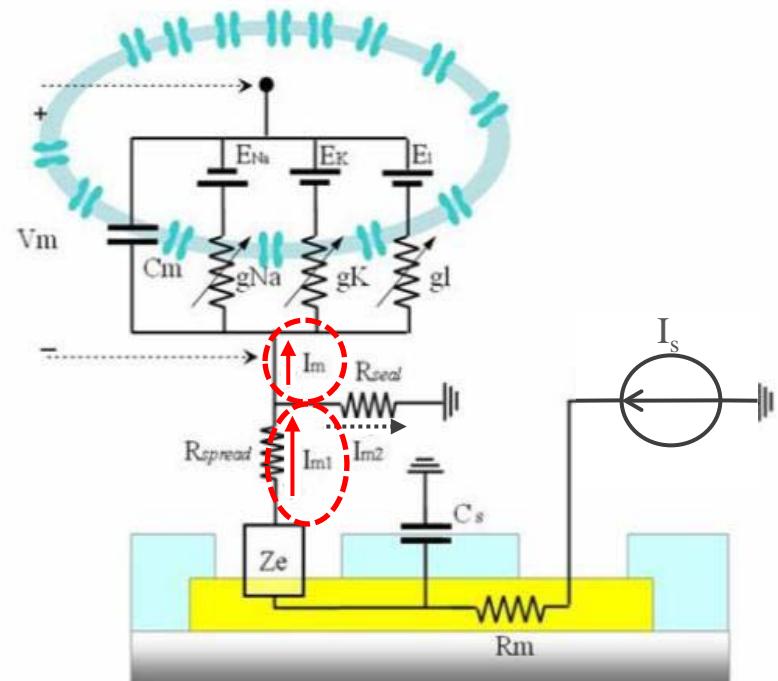
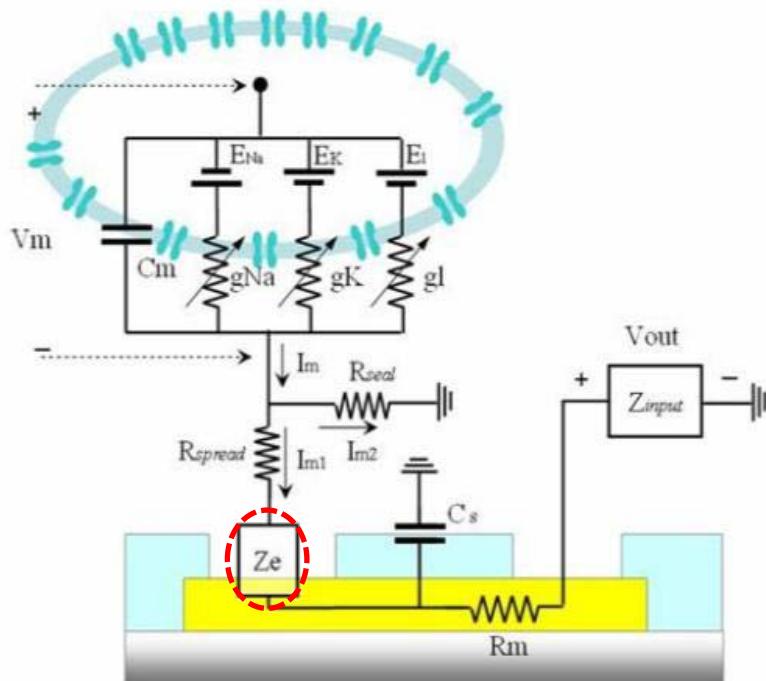
Electrical stimulation



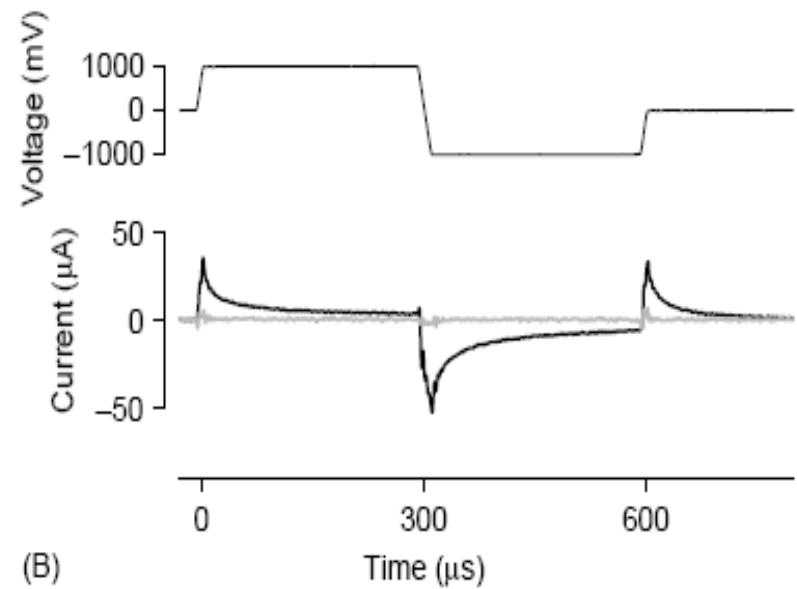
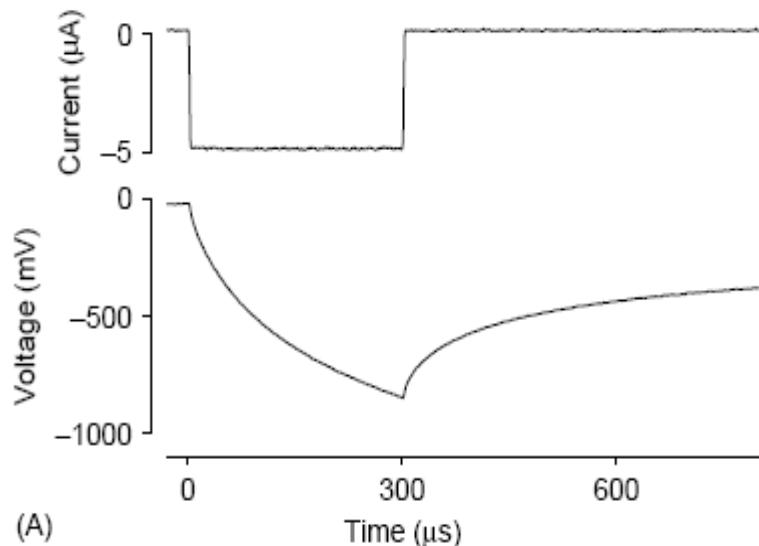
Neural Interfaces

Recording vs. Stimulation

- Recording: **electrode impedance** is a key factor to measure the small neural signals.
- Stimulation: **accurate charge delivery** method is a key factor to open the voltage-gated channels.



Current vs. Voltage stimulation



- **Current stimulation** offers **direct control over the charge delivered to the tissue.**
- **Voltage Stimulation** is relatively safe. (not exceed water window)



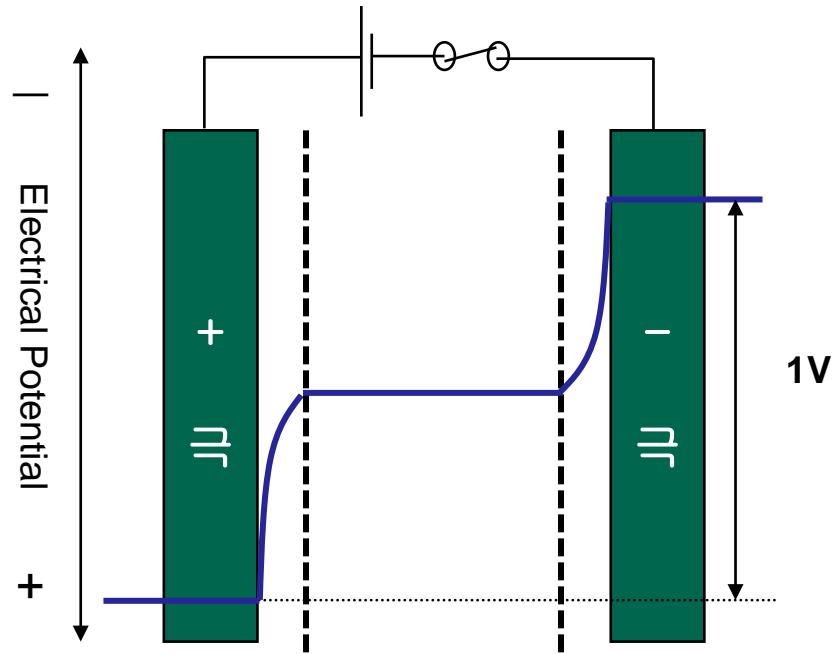
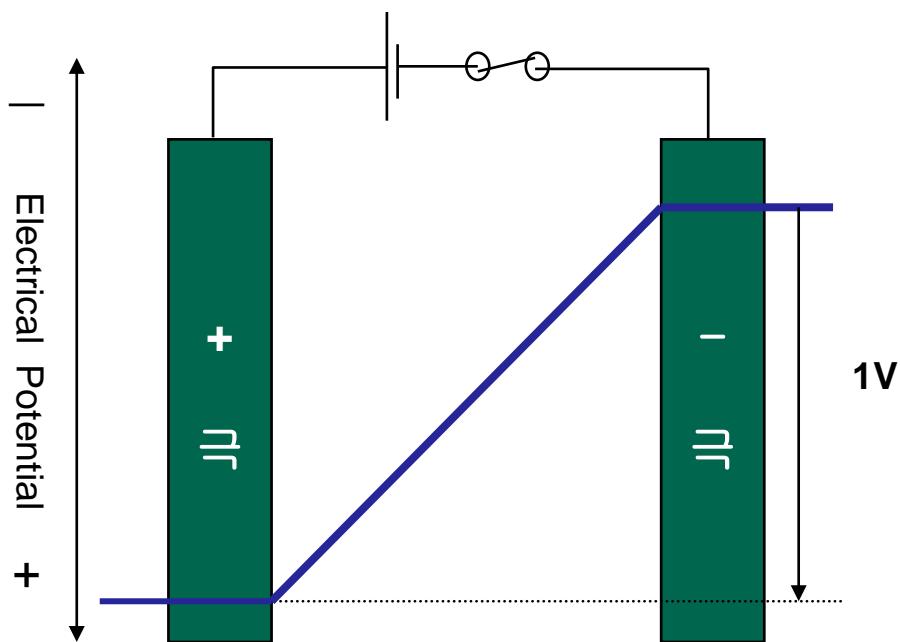
Various stimulation thresholds for neural prostheses

Application	Placement	Species	Type	Threshold charge/phase (nC ph^{-1})	Threshold charge density ($\mu\text{C cm}^{-2}$)	Pulse Width (μs)	Reference
Vision	Epi-retinal	Human	Surface	6–1120	5–570	1000	32
Vision	Epi-retinal	Human	Surface	24–100	80–306	2000	33
Vision	Optic nerve	Human	Surface	7–124	4–62	25–400	34
Vision	Intracortical	Human	Penetrating	0.4–4.6	190–2300	200	35
Vision	Cortical	Human	Surface	200,000	11	200	35
Hearing	VCN	Cat	Penetrating	0.75–1.5	60–90	40–150	36, 37
Hearing	AB	Human	Surface ^a	10–200	2.6–52	300	5, 38
Micturition	Intraspinal	Cat	Penetrating	9	4000	100	39
DBS	STN	Human	Penetrating ^b	135–400	2.3–6.7	60–200	40
Motor	Intrafascicular	Cat	Penetrating	4 ^c	0.5	50	41
Motor	Sciatic nerve	Cat	Penetrating	5 ^c	96	200	42
Motor	Sciatic nerve	Cat	Surface	46	0.35	200	42

S. Cogan, "Neural Stimulation and Recording Electrodes" *Annu. Rev. Biomed. Eng.* 2008. 10:275-309



Voltage distribution

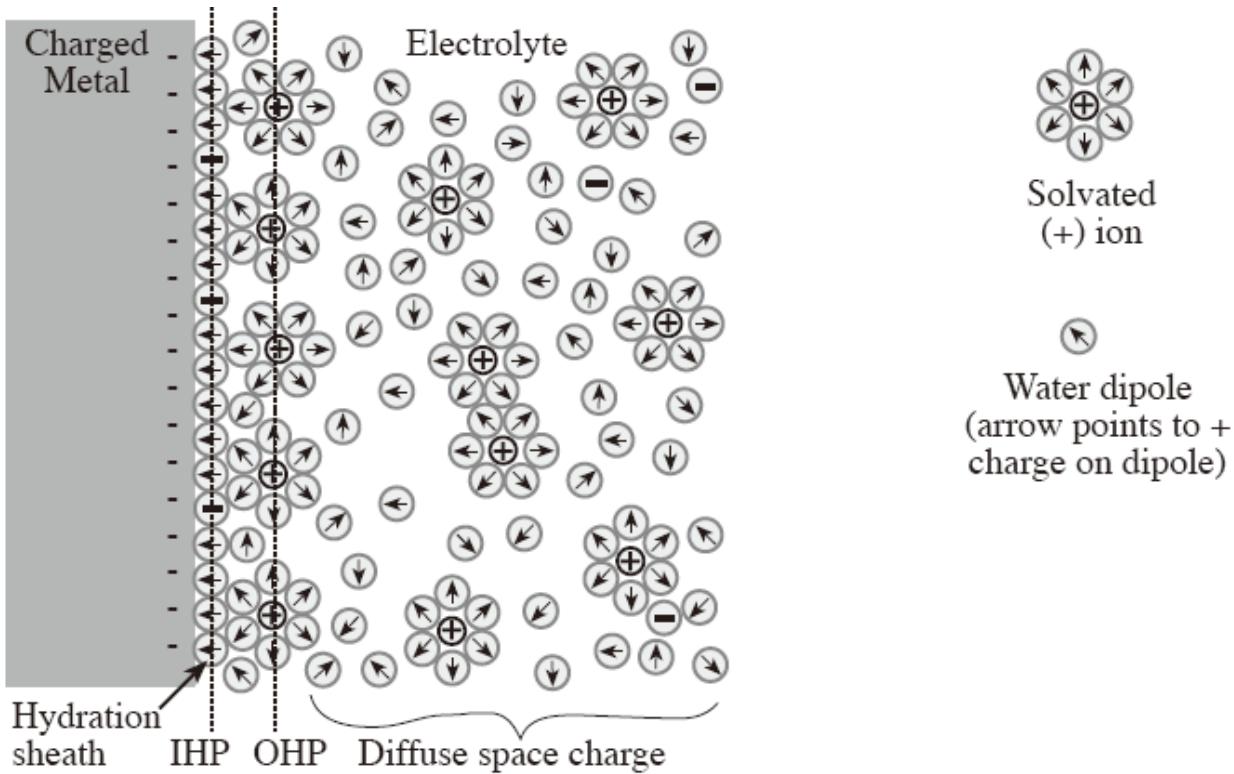


- $t = 0 \text{ sec}$
- Linear potential distribution

- $t > 0 \text{ sec}$
- Most voltage drops happen at the each electrode interface.



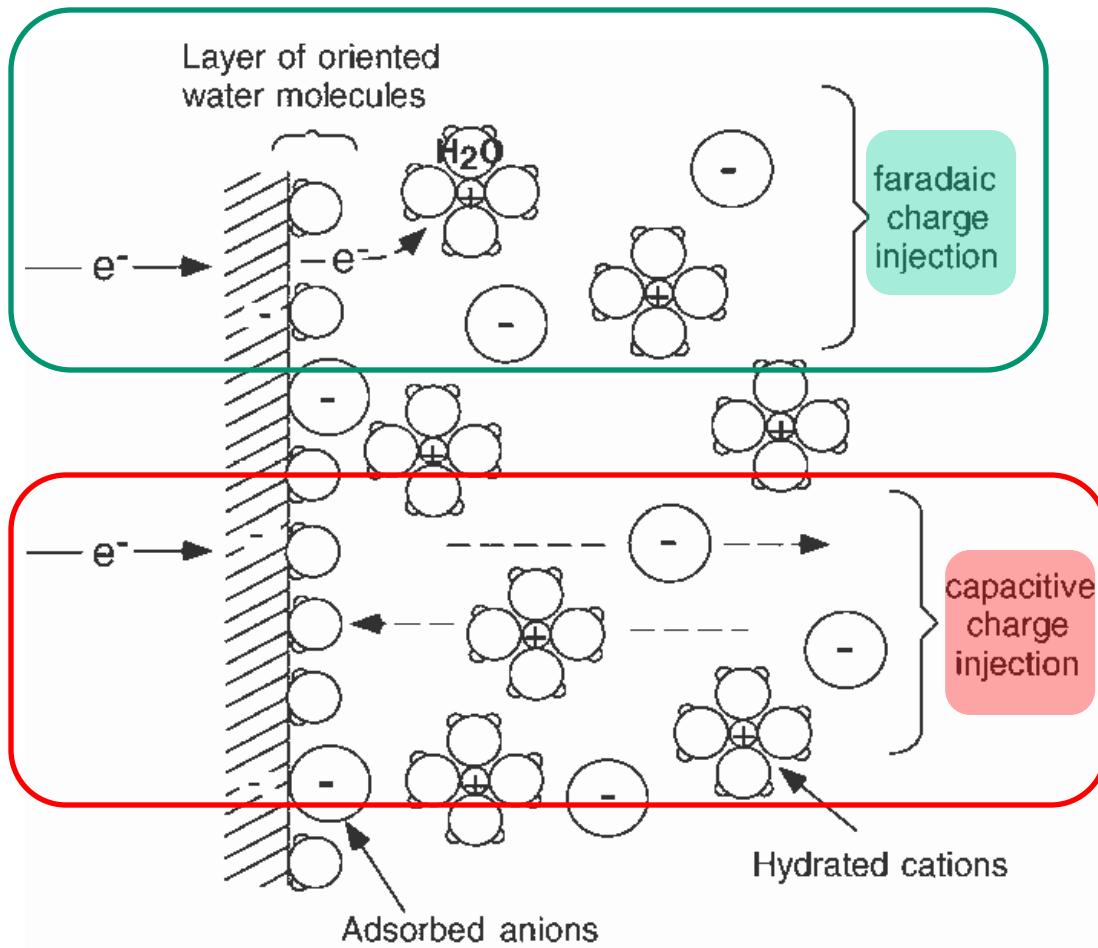
Electrical double layer



- Double-layer structure and change of potential with distance from the electrode surface.



Charge injection mechanisms



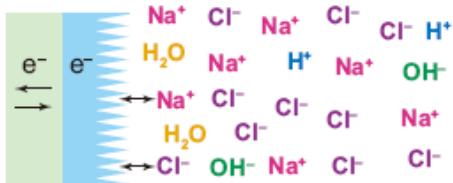
■ Charge Injection

- Amount of charge per area or phase
- Unit: mC/cm^2 or mC/phase



Charge injection mechanism

■ Examples of capacitive & faradaic reaction material



Titanium nitride
Double-layer charging
with a porous coating

Capacitive

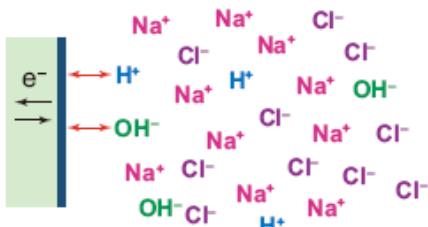
(Chemically stable metal conductors, i.e., noble metals) and (TiN, Ta/Ta₂O₅, carbon nanotubes)



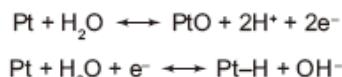
Iridium oxide
 $\text{Ir}^{3+} \longleftrightarrow \text{Ir}^{4+} + \text{e}^-$
 $\text{Ir(OH)}_n \longleftrightarrow \text{IrO}_n(\text{OH})_{n-x} + x\text{H}^+ + x\text{e}^-$

Faradaic

(IrOx, PEDOT(a new polymer))



Platinum surface reactions



Capacitive & Faradaic

(Pt, PtIr alloys)

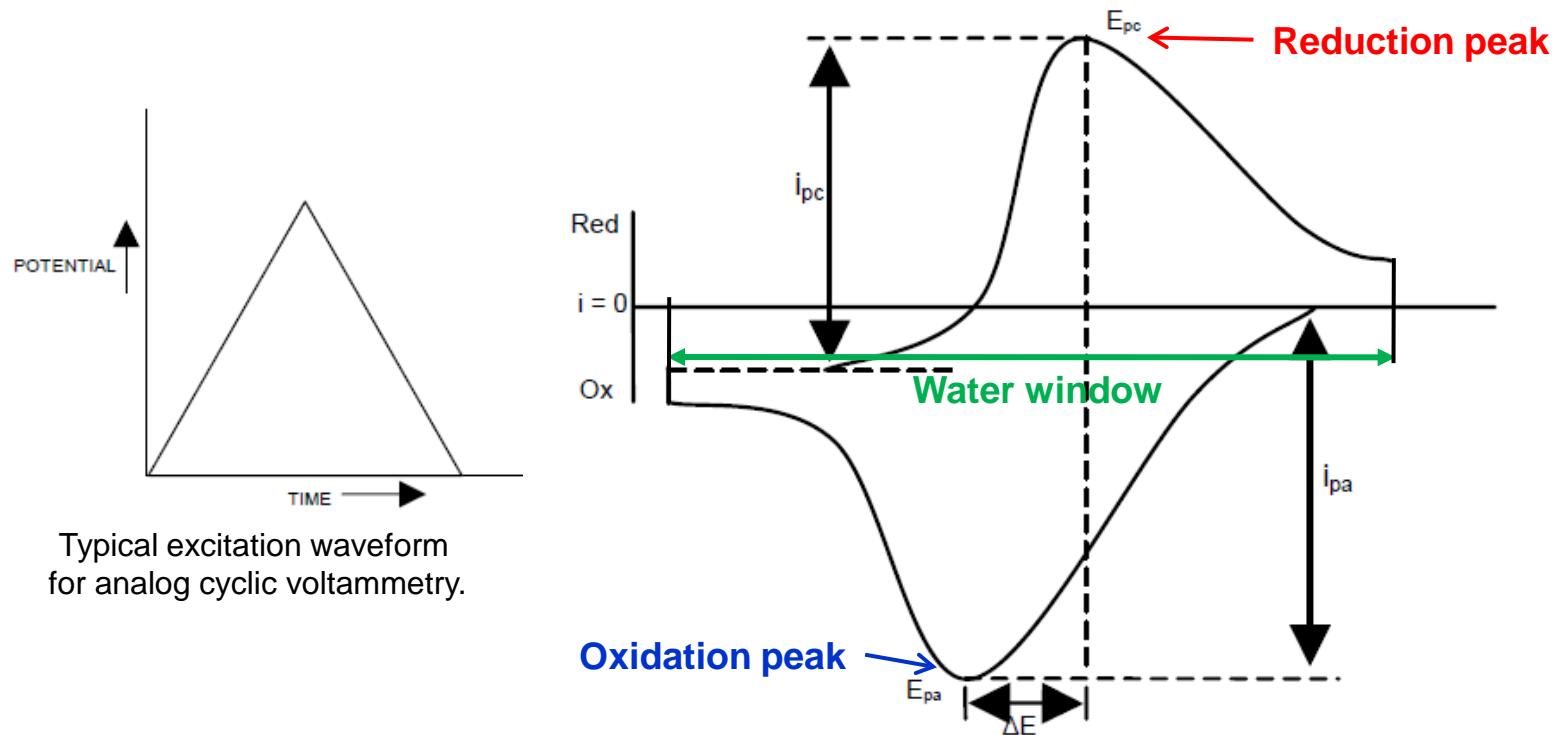


During Stimulation of nerve tissues, watch out for

- 1. Excessive voltage can lead to oxygen and hydrogen evolution**
 - Have to stay within the water window.
 - $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$ (reduction of water)
 - $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$ (oxidation of water)
 - This can further induce pH reduction and subsequent neural tissue damage.
- 2. Excessive current can lead to undesirable chemical reaction such as corrosion. This can be monitored with Cyclic Voltammetry.**



Cyclic voltammetry (CV)

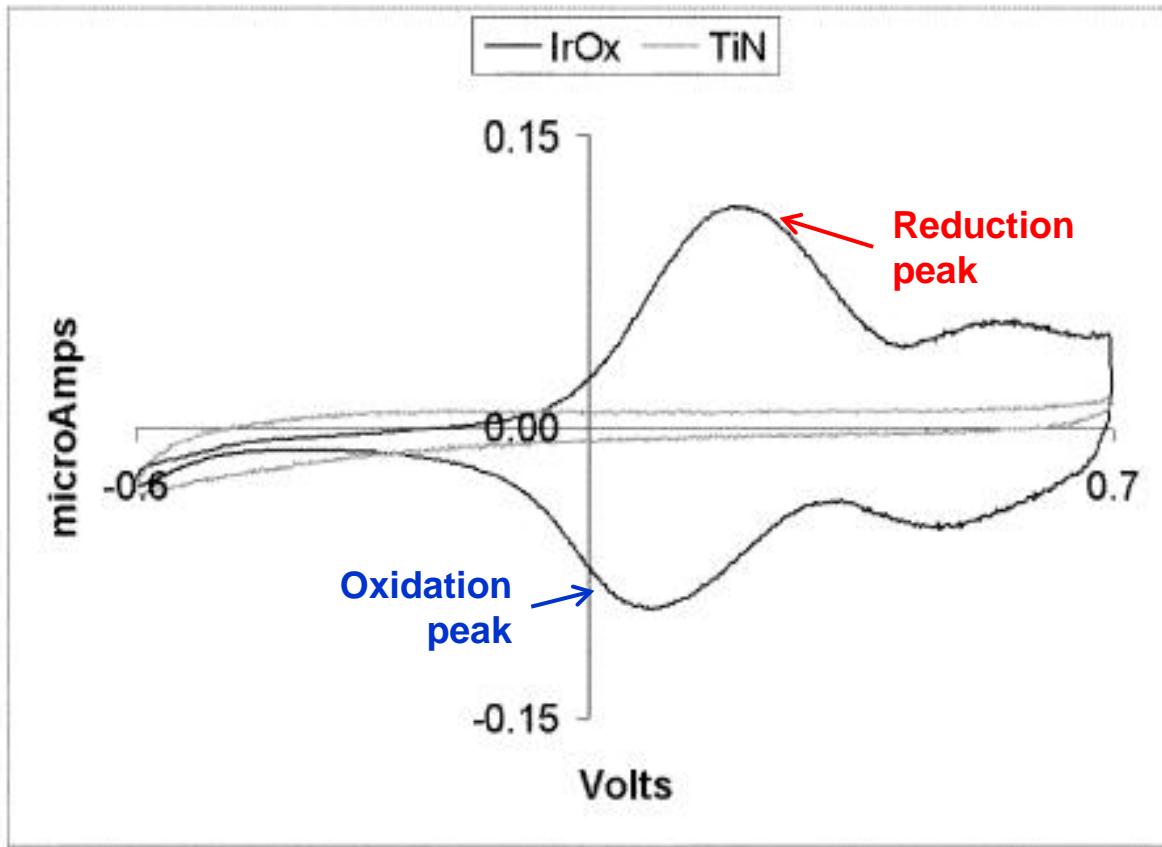


Typical excitation waveform for analog cyclic voltammetry.

- A potential ramp is applied to the working electrode to gradually change potential and then reverses the scan, returning to the initial potential.



CV comparison of faradaic and capacitive reactions



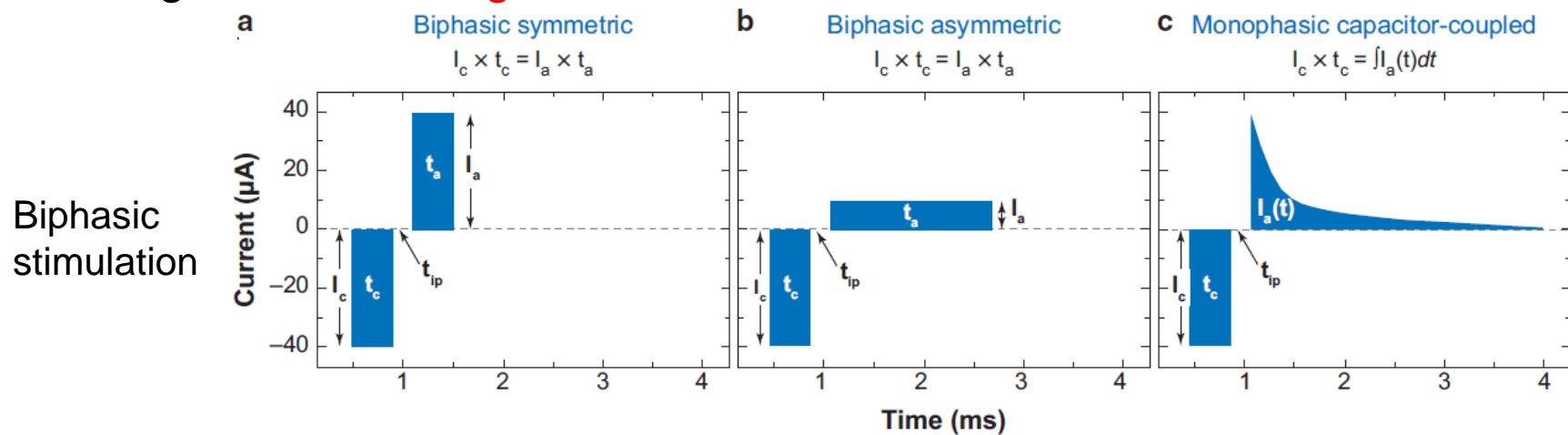
IrOx: Faradaic reaction

**TiN: Capacitive reaction
(No reduction & oxidation peak)**



Biphasic vs. Monophasic stimulation

- **Biphasic stimulation:** delivers energy in two phase's one positive and one negative. **No charge accumulation.**



- **Monophasic stimulation:** delivers energy in one direction from positive to the negative electrode. **Effective, but unsafe.**

Monophasic stimulation



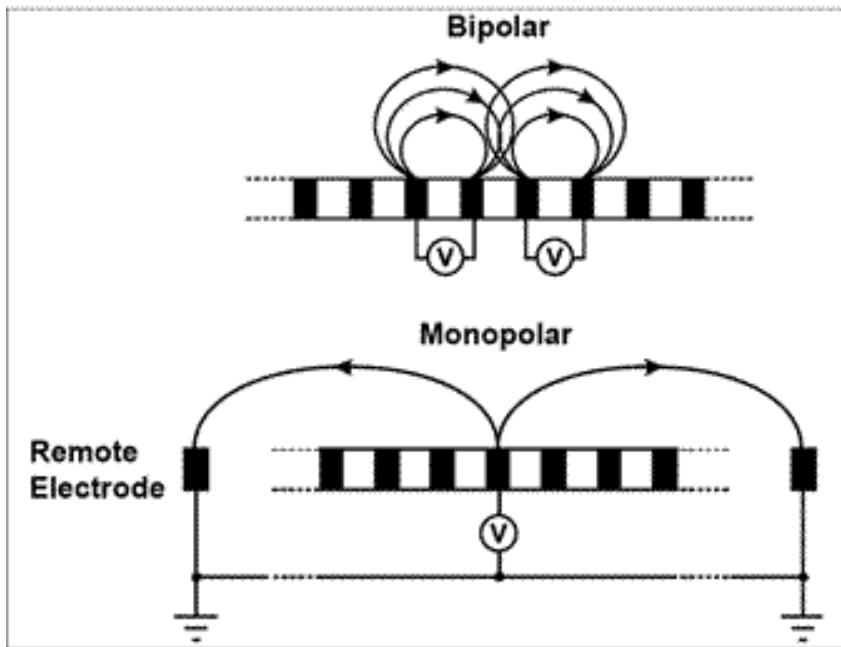
Anodic sti.



Cathodic sti.



Bipolar vs. Monopolar stimulation



- **Bipolar stimulation** produces a concentrated current around the tip of the electrode in which electrons run from the negative to the positive pole.
- **Monopolar stimulation** basically produces a current in which electrons diffuse from the negative pole through the “way of the least resistance”. This kind of stimulation might influence a larger area especially when the current density is relatively high.

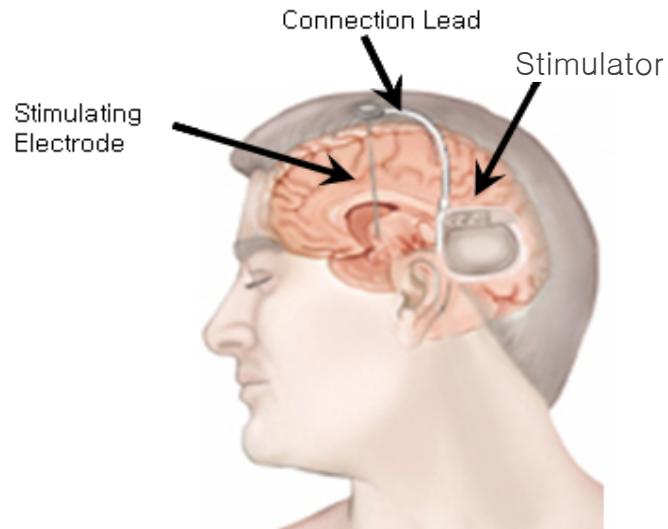
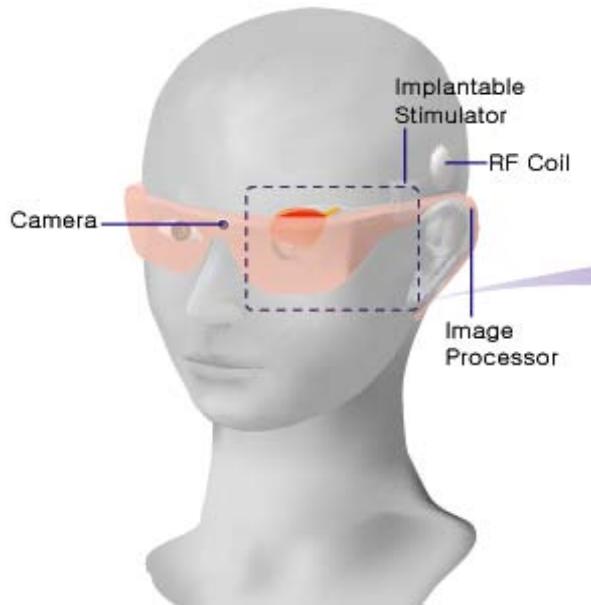
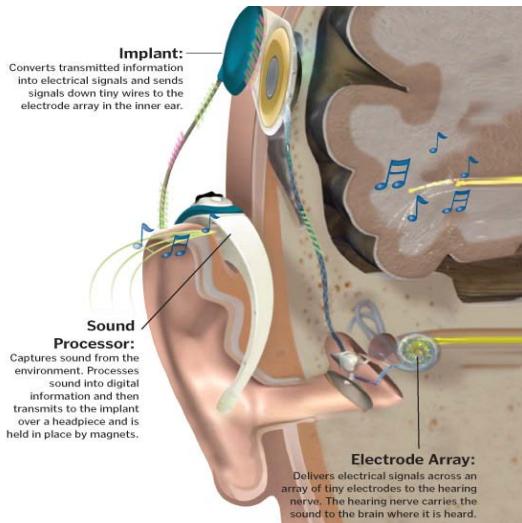


Applications: Neural prostheses



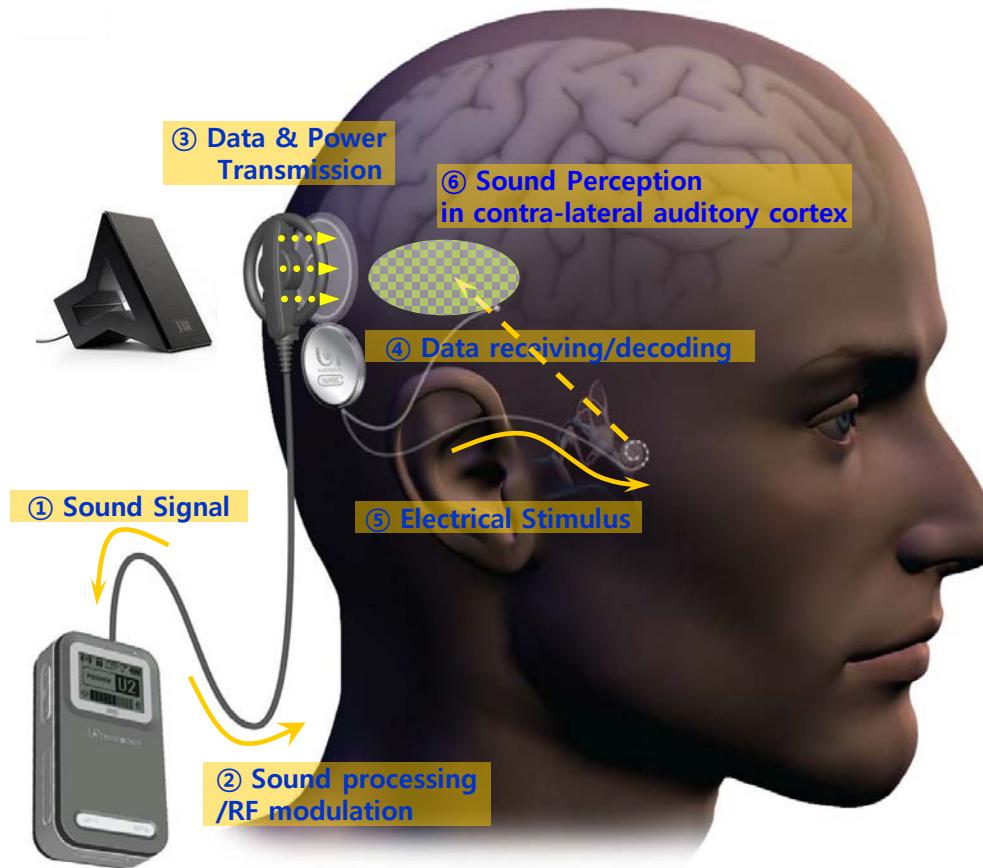
Neural prosthetic stimulation systems

- Cochlear Implant
- Artificial Retina
- Deep Brain Stimulation(DBS)
- Nerve Regeneration



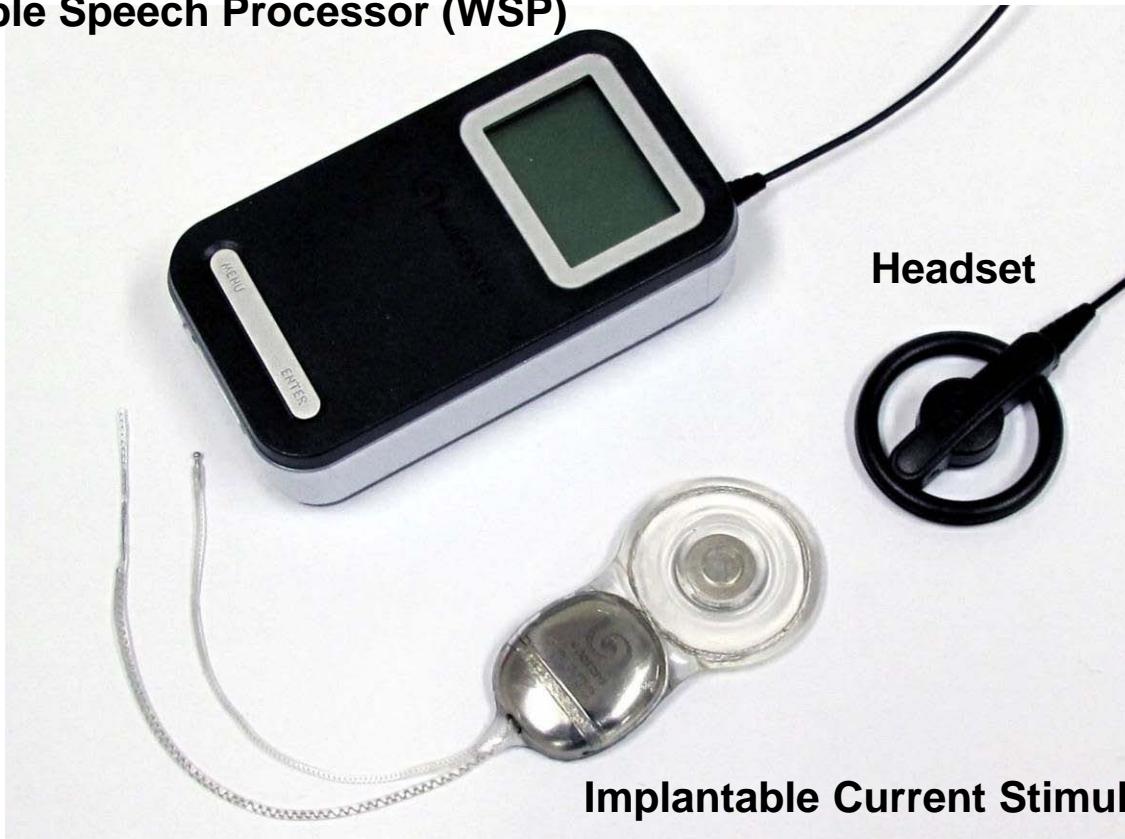
Cochlear implant (CI)

- A cochlear implant device can provide a sense of sound to people who are deaf or profoundly hearing-impaired by stimulating auditory neurons electrically.



SNU-NUROBIOSYS CI system

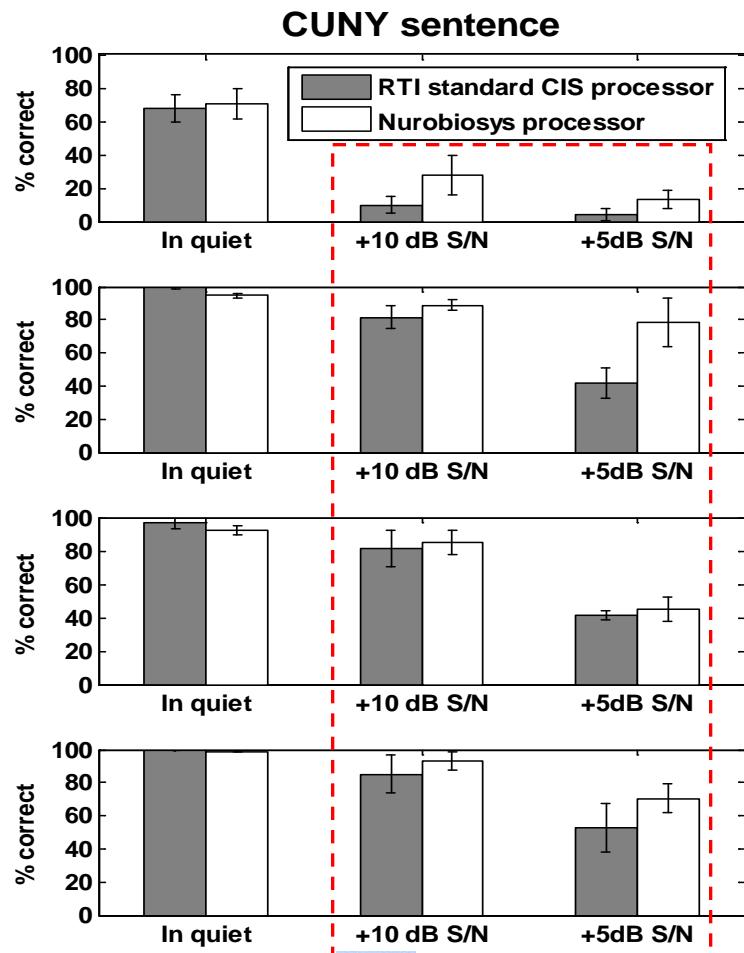
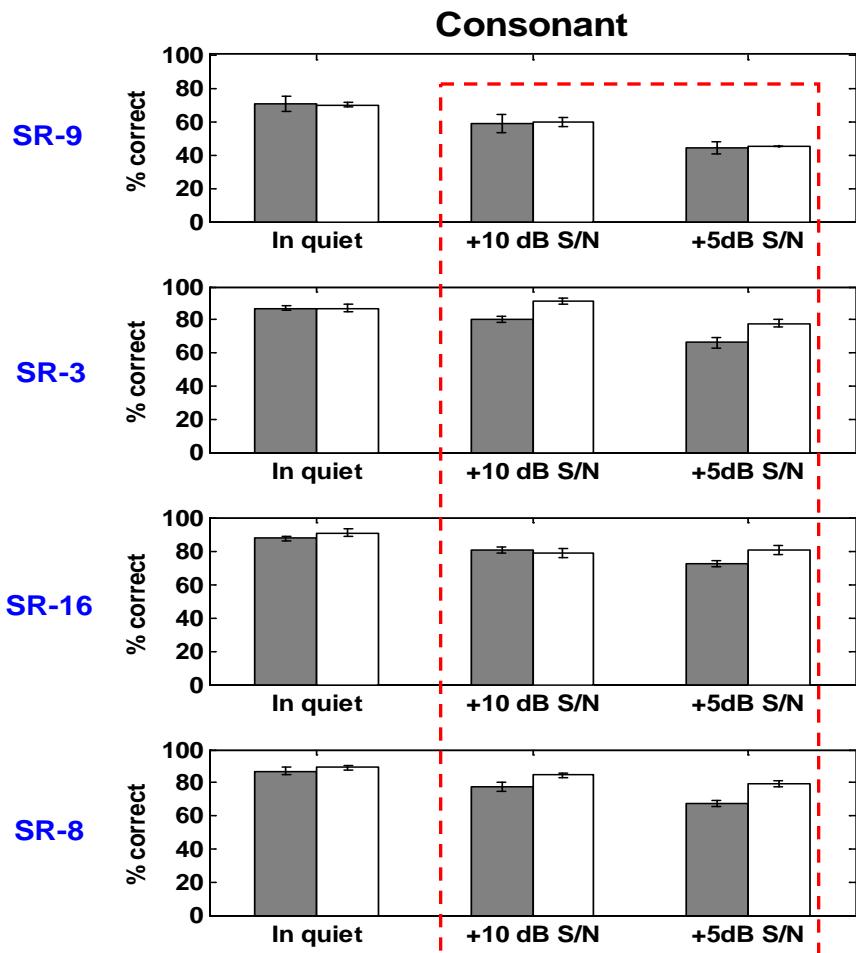
Wearable Speech Processor (WSP)



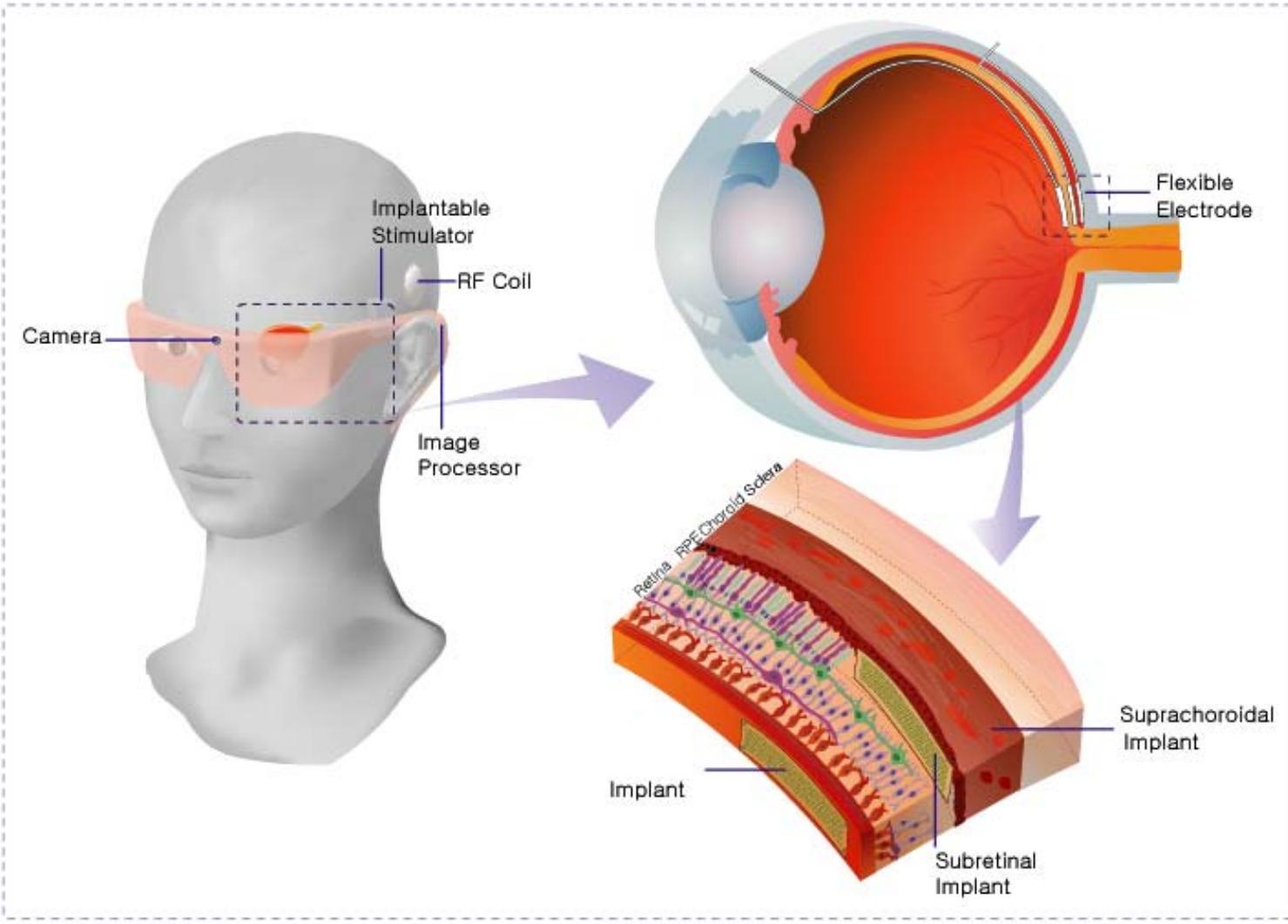
Implantable Current Stimulator (ICS)



Pre-clinical test results



Artificial retinal implant



Artificial retinal implant

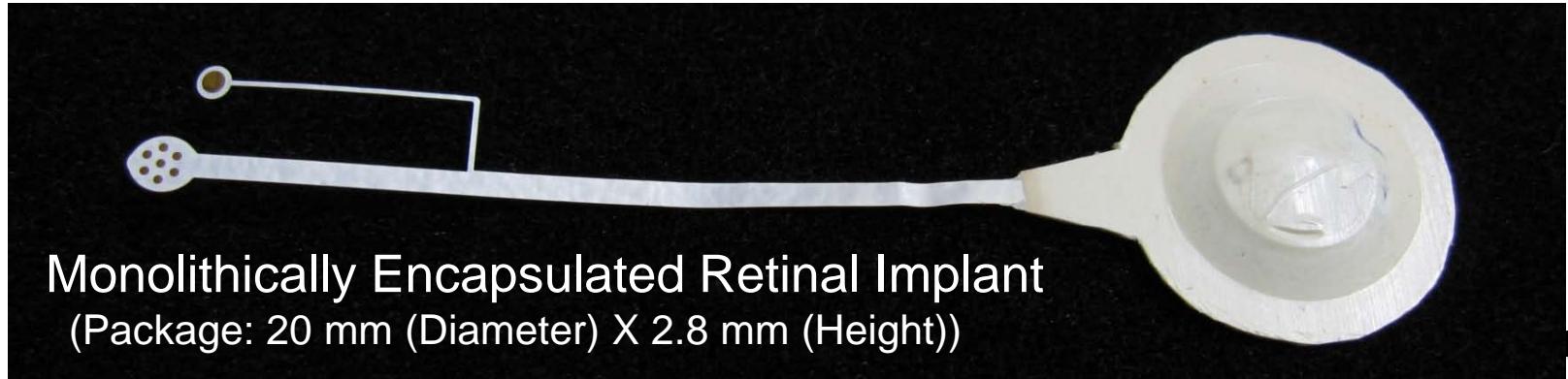
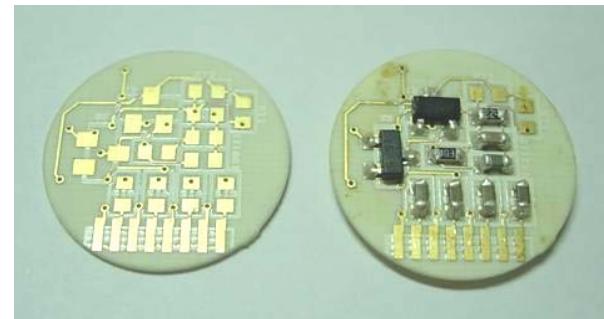
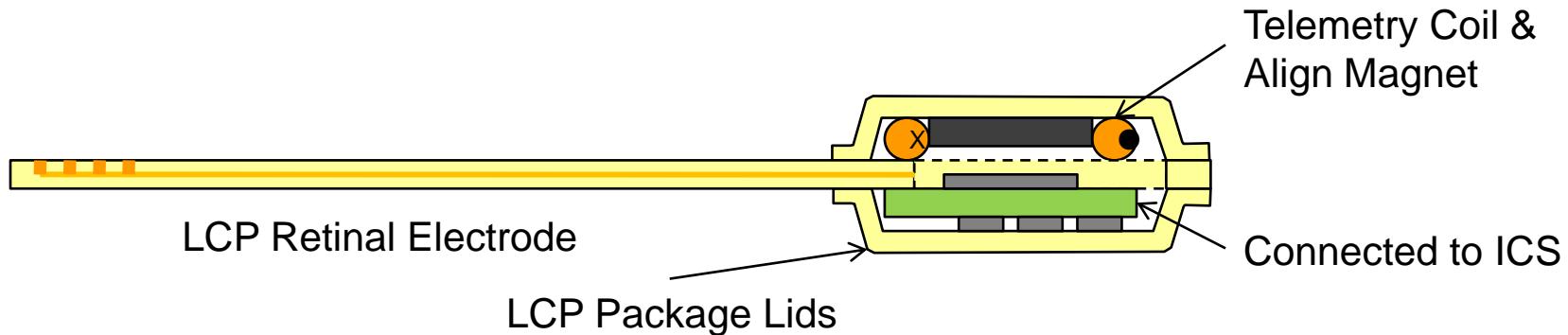


Courtesy of Dr. Claude Veraart, Université catholique de Louvain, 2004

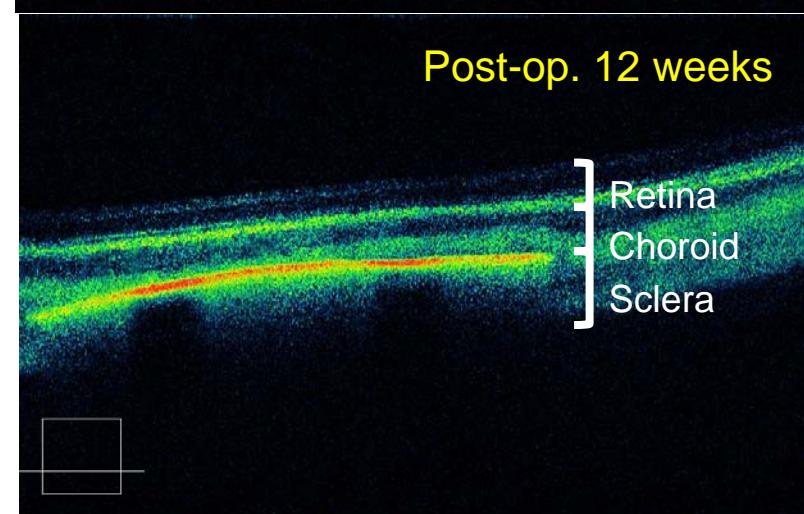
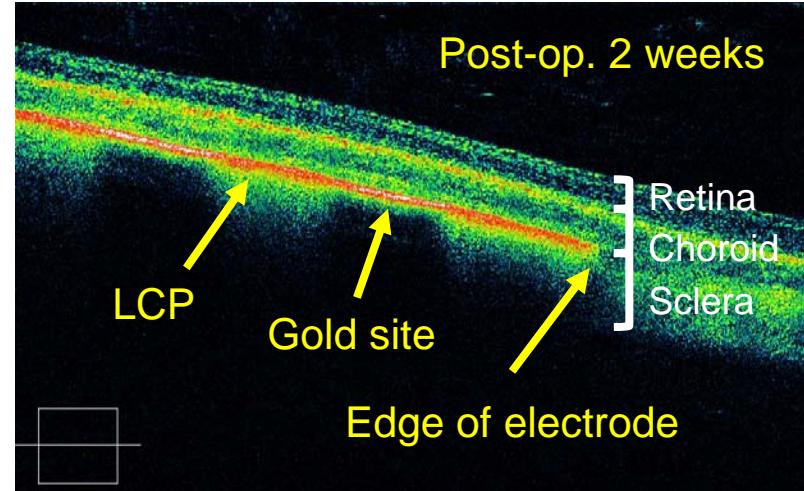
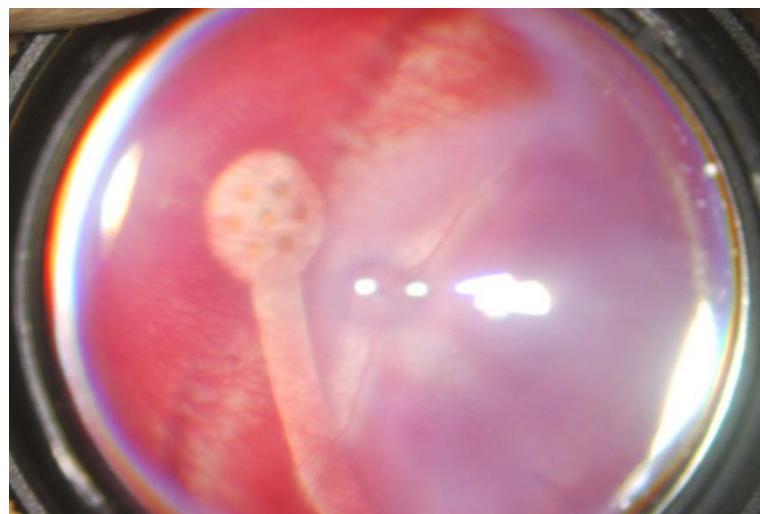
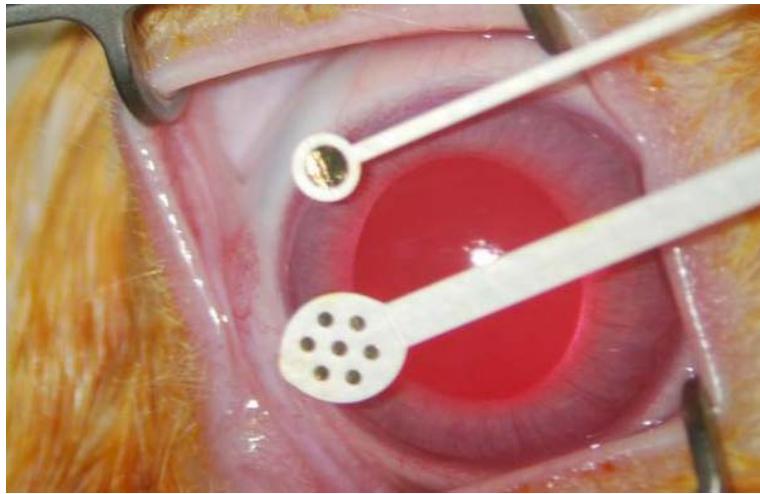


Intro. To BME

LCP based retinal implant system



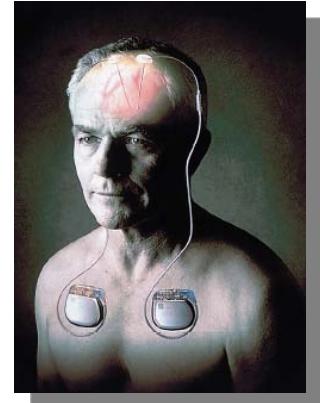
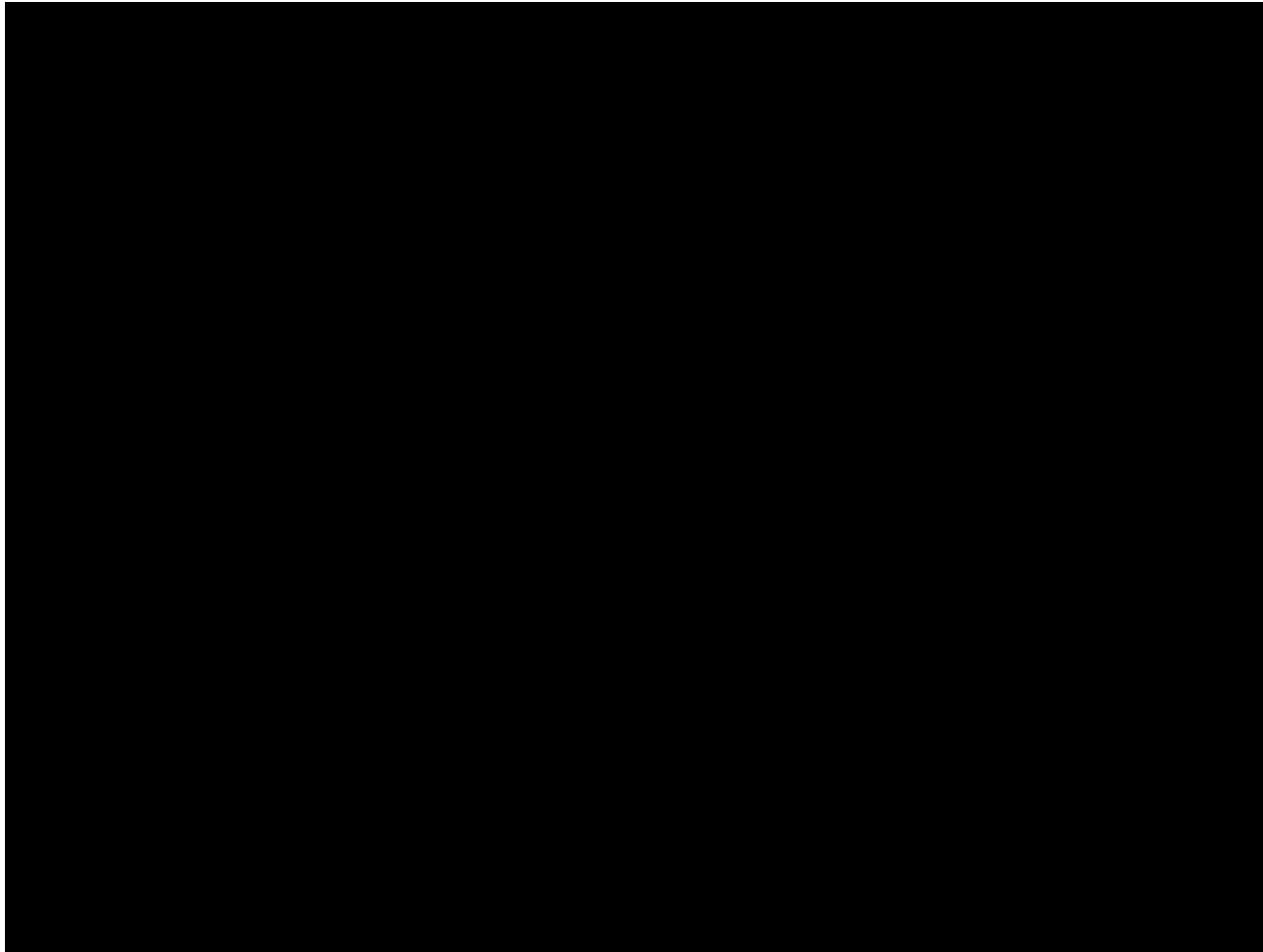
Animal experiments – suprachoroidal implantation



Fundus Image of LCP based Electrode Array OCT observation of implanted array



Deep brain stimulation



Medtronic Inc. Activa® Tremor Control Therapy

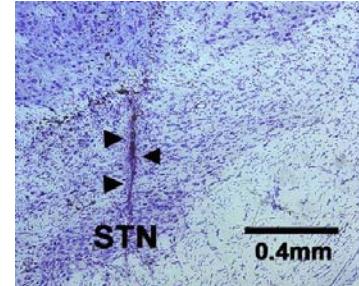
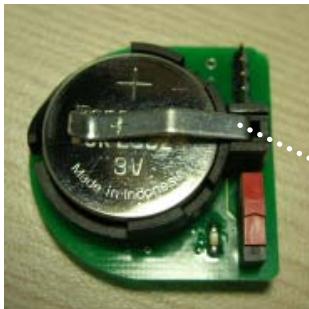


Intro. To BME

DBS animal system

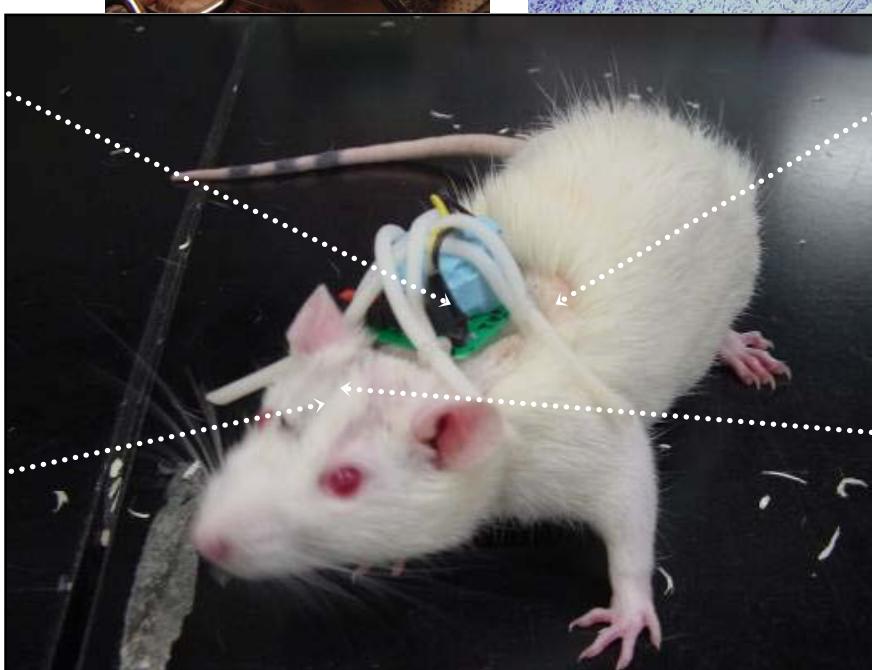
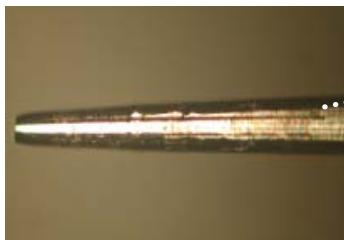
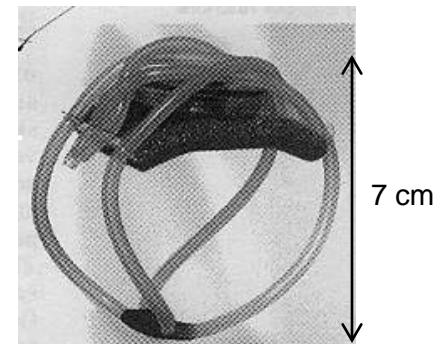
Current stimulator

- More miniaturized form
- Size : 30 X 30 X 15mm
- Stimulation parameters adjustable



Tether with rodent saddle

- Soft molded elastomer
- Well-tolerated by animals
- Reduced risk of hyperthermia



Metal electrode

- Tungsten electrode
- Rod O.D. 200um, tip 100um
- Parylene coating 5um

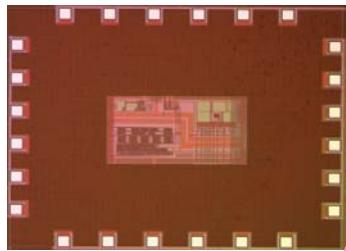


Metal anchor

- Biocompatible Stainless steel
- Fix the stimulation electrode
- Minimize infections

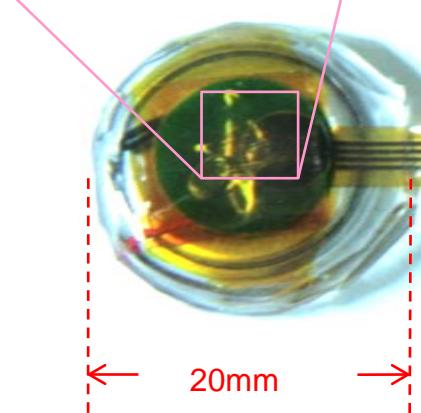
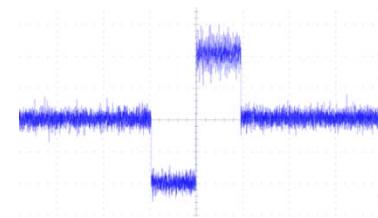


Nerve regeneration system (Polymer cuff electrode-based)



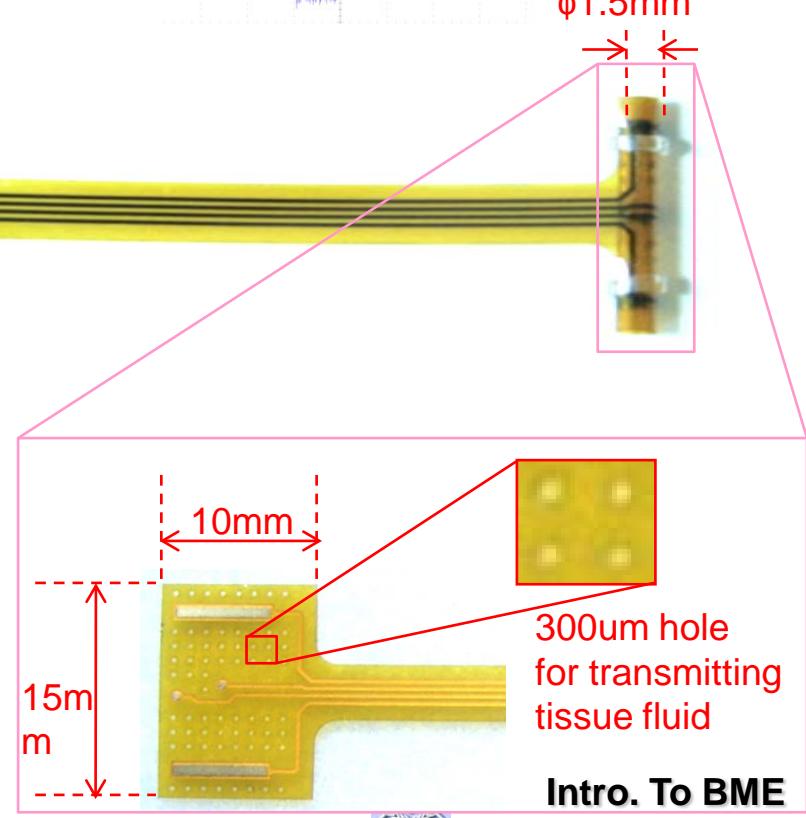
Design of the current stimulation IC

- Process: MAGNA 0.35um semiconductor process
- Dimensions: 2.1mm x 1.7mm
- Output: Controllable biphasic current pulse:

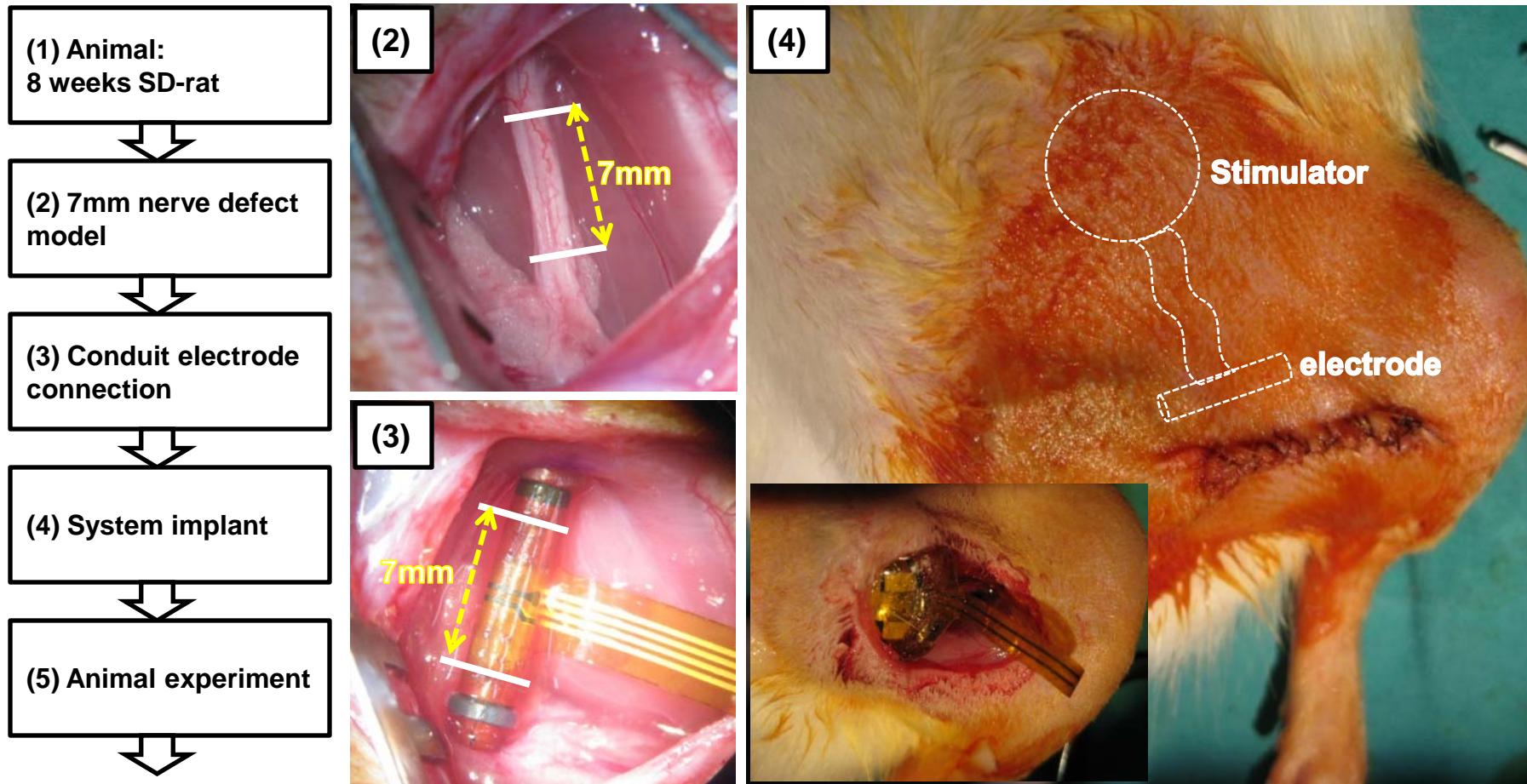


Fabrication of the electrode

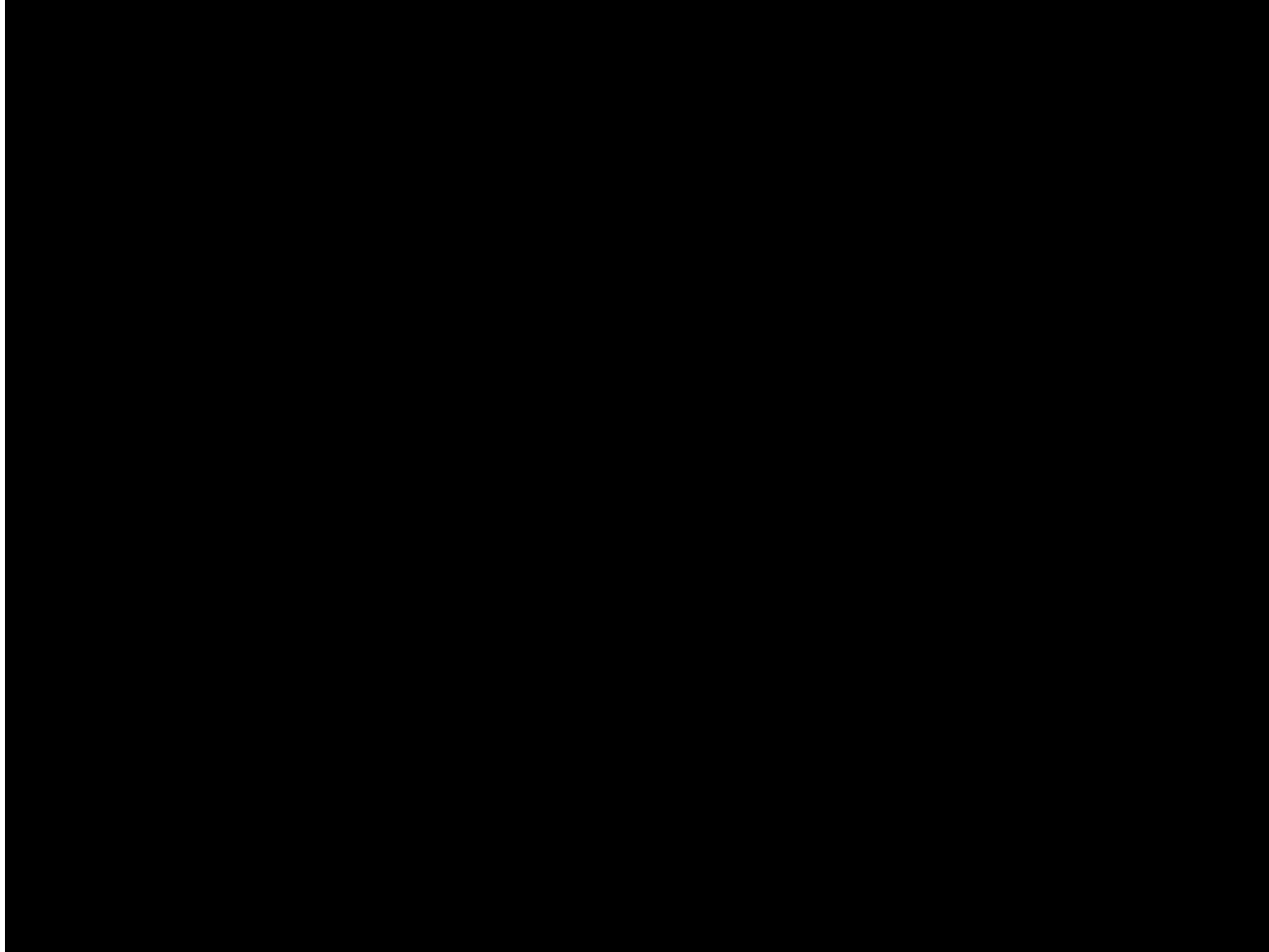
- Process: semiconductor process
- Material: polyimide (substrate & cover)
Gold (pattern & site)



Nerve implant system for functional regeneration



Walking test: immediately after surgery



Walking test: 4 weeks after surgery with continuous stimulation

