Artificial Vision

Sung June Kim

Nano Bioelectronics & Systems Research Center
School of Electrical Engineering
Seoul National University

Diseases causing vision disorder

- Corneal Diseases
- Cataracts/Glaucoma
- Retina Diseases
  - retinitis pigmentosa (RP)
  - age-related macular degeneration (AMD)
- Brain

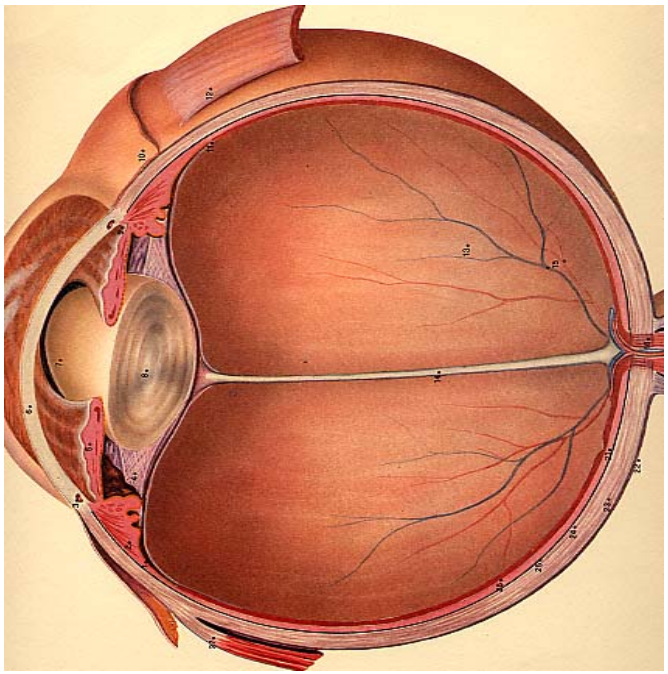
Losing sights

- Most cases of Blindness caused by
  - Age-related Macular Degeneration, AMD 나이관련황반변성
  - Diabetic Retinopathy 당뇨망막병증

- Most serious cause of blindness
  - Retinitis Pigmentosa(망막색소변성)

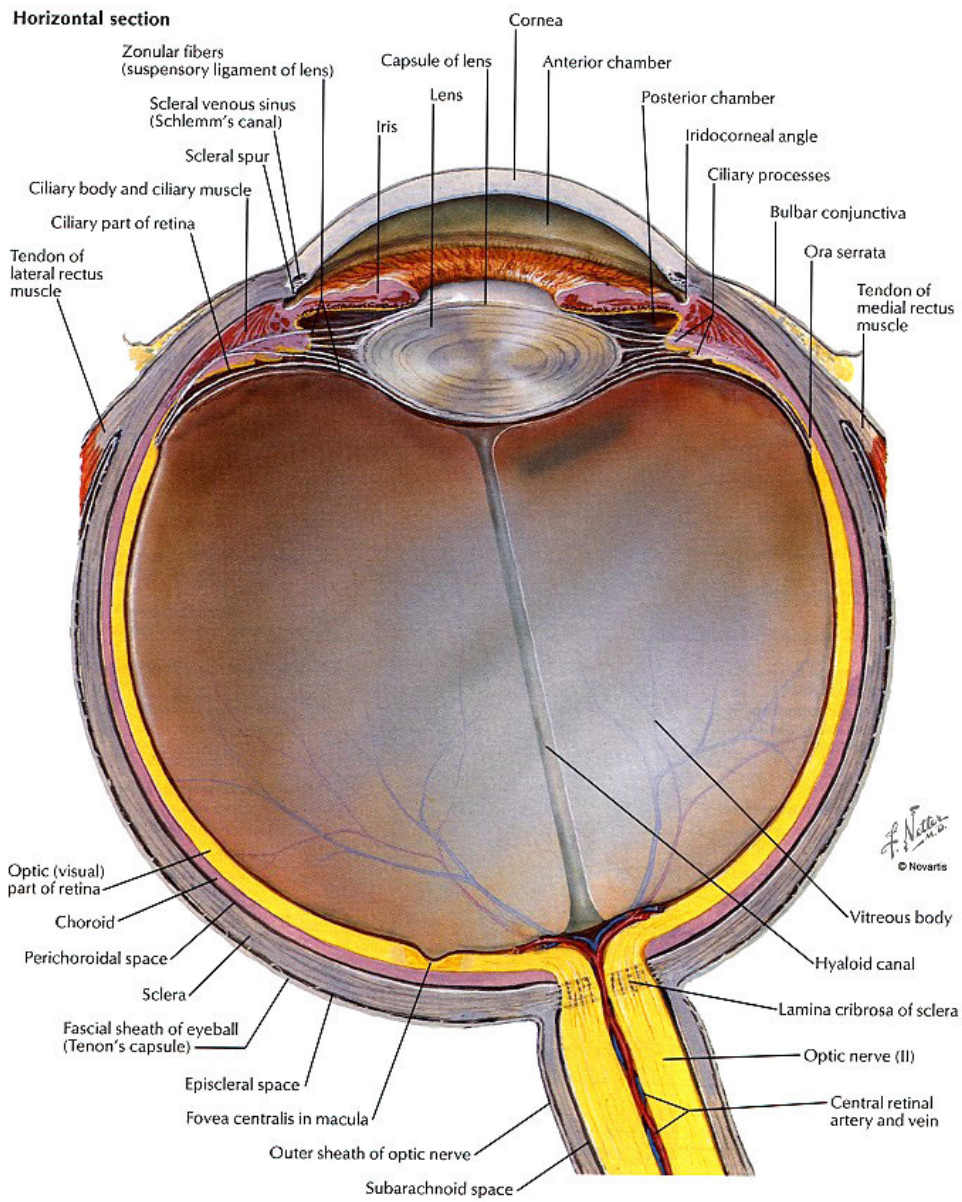
Loss of Vision

- Visual Impairment시력 장애:
  - 24%(single eye), 100%(both eyes)
- 30% of all adult blindeness
  - RP; 1/4000 of normal polulation
  - AMD; 1/20 among 65 years and older



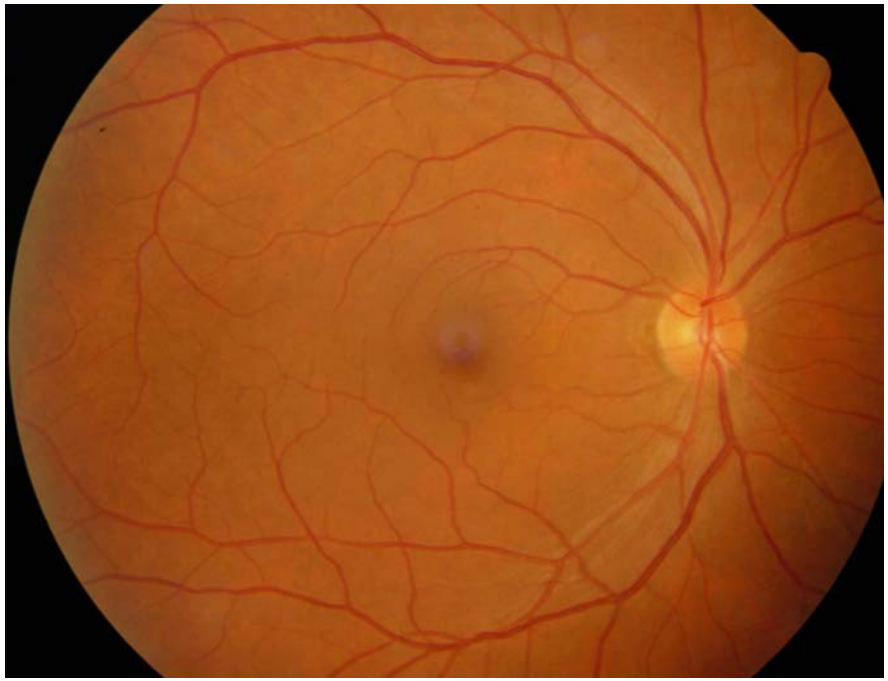
Structure of the eye

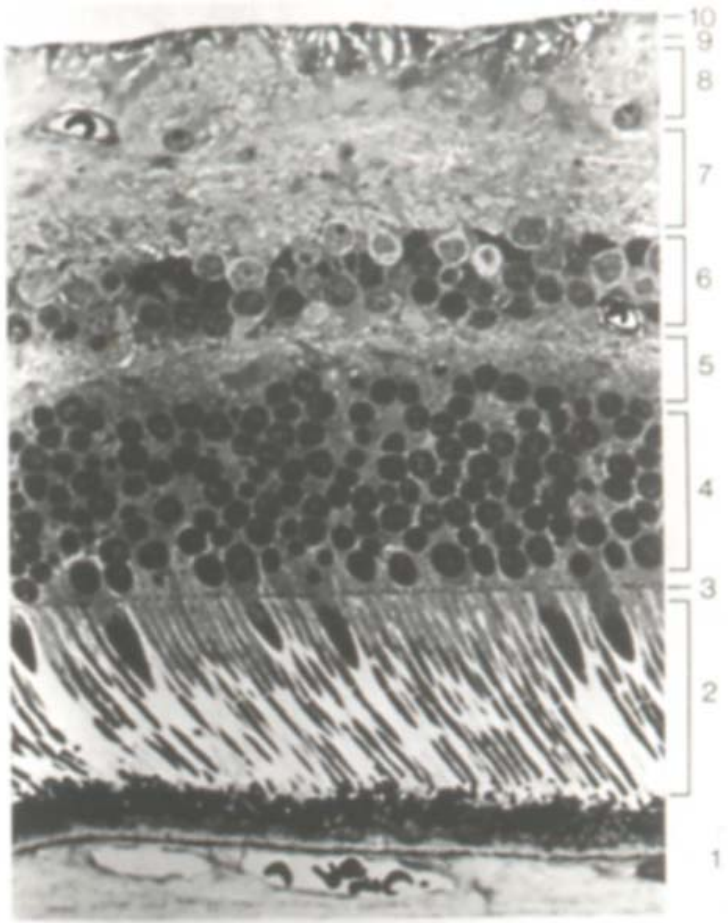
- 망막(retina): 신경조직
- 맥락막 (choroid): 혈관조직
- 공막 (sclera): 결합조직
- 시신경 (optic nerve)



Retina

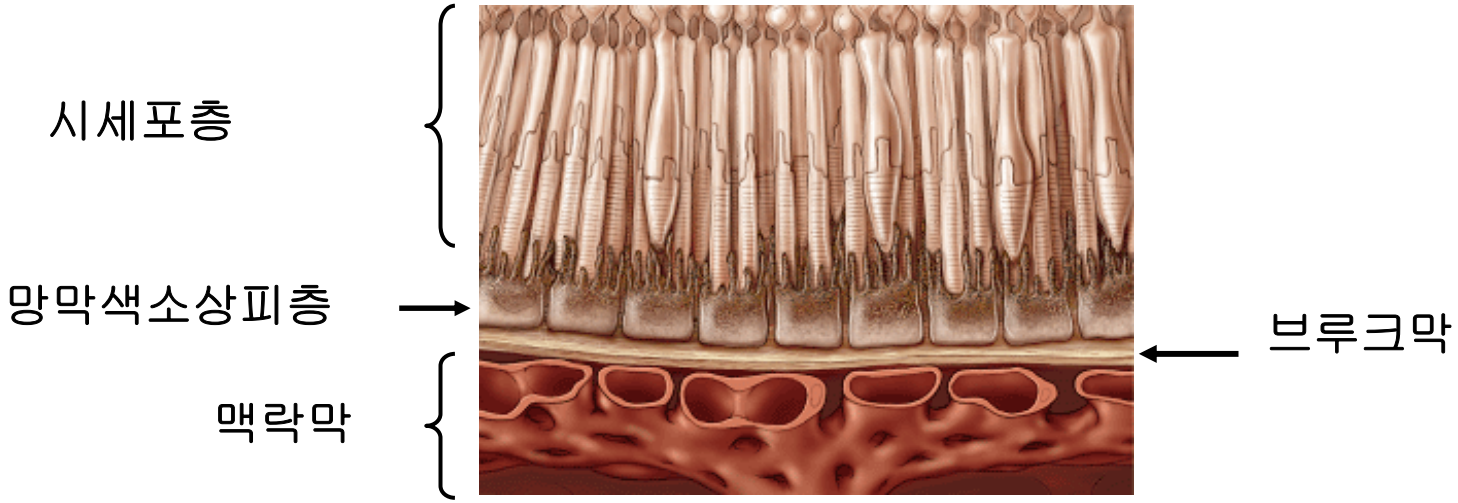
- Recognize the image
- Pass visual info to brain
- Acts like film





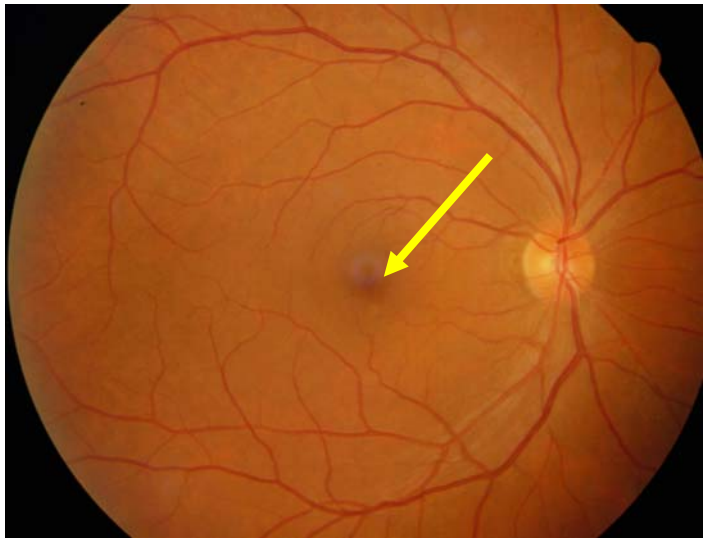
Structure of retina

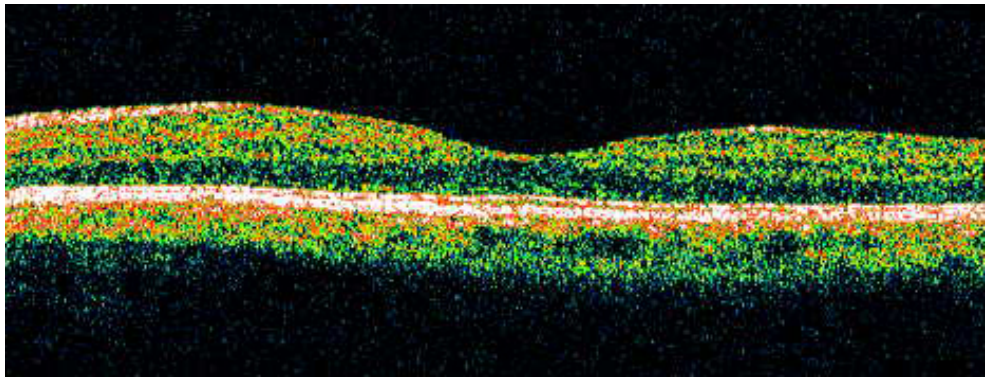
- 시세포층 (photoreceptors): 빛 신호 -> 전기신호
- 망막색소상피 층(RPE): 빛 흡수, 영양공급, 장벽 기능
- 브루크막 (Bruch's Membrane) - 망막과 맥락막의 경계조직



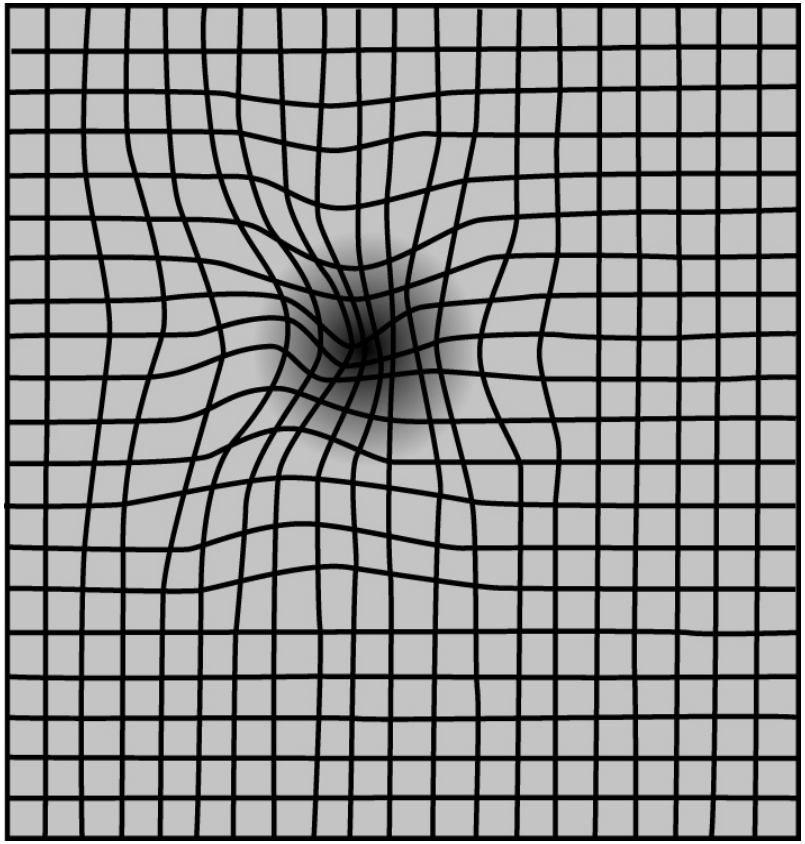
황반 (黃斑, Macula)

- 황반(macula): 직경 5mm의 망막중심, 중심시력을 담당함
- 엽황소(Xantophyll)가 많아 짙은 황색을 띔





RP Patient's view of the world
황반변성 환자들이 보는 세상



Recovery of vision

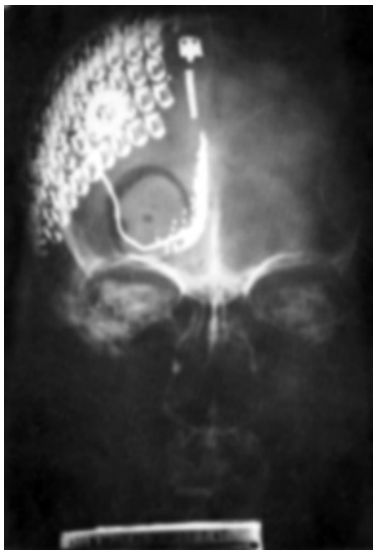
- Drugs
- Stem cells theraphy (differentiation problem)
- Implantation of photoreceptors
- Imitation by electrical stimulation

Why artificial retina?

- Development for past 20 years
  - It was found that the inner layers of retina are well preserved in RP Patients
  - Inspired by success in Cochlear implant
  - IT technologies for miniaturization
- Research from late 1980's

History

- Foerster (1929): 시피질을 전기 자극 하였을 때 작은 불빛이 느껴짐을 관찰 – '인광(phosphene)'
- Brindley & Lewin(1968)
  - 52세의 환자에게 내장형 시피질 자극기를 삽입
  - 지속적인 영상 자극을 위한 적절한 자극 회수를 정할 수 없었음



- Dawson & Radtke (1977):
  망막을 전기적으로 자극→ 인광이 느껴짐을 발견

Artificial Vision

인공시력전달장치

- Basic Concept:

  Replacing the function of photoreceptors by electronics

- Hypothesis:

  Vision can be evoked by electrical stimulation.

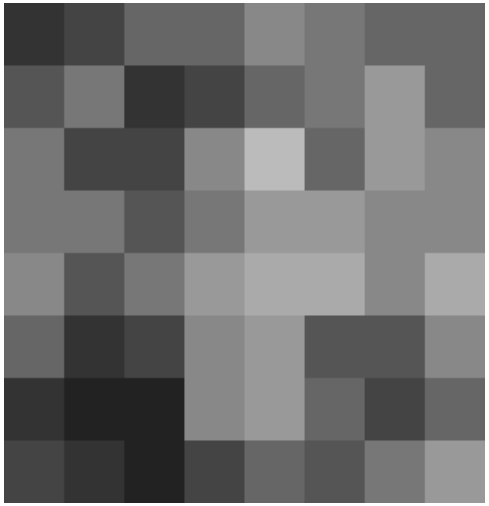
- Goal:

  Implantable Microchips

Number of electrodes

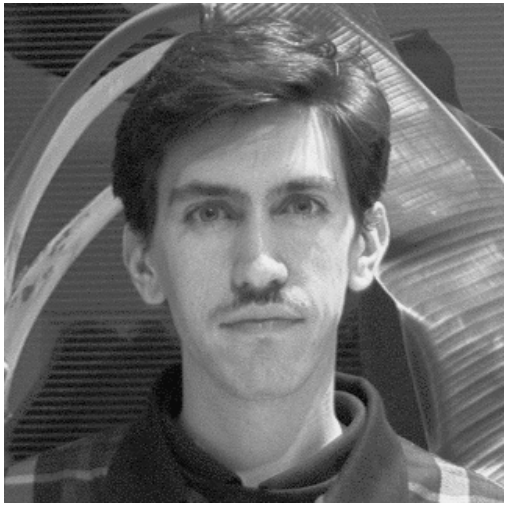
- 인공와우
  - 6 개의 전극 << 30,000 개의 청신경절세포
  - 어마어마한 대뇌의 적응능력 →
    훈련에 의해 새로운 감각정보를 해석할 수 있음
- 축소된 감각정보에 따른 시력 정도:
  물체의 상을 화소로 나누어 망막에 투사해 봄
  - **25 x 25** →움직임이 가능한 시력
  - **32 x 32** → 보조구를 쓰면 책 읽기 가능

Required number of pixels



8 x 8

32 x 32

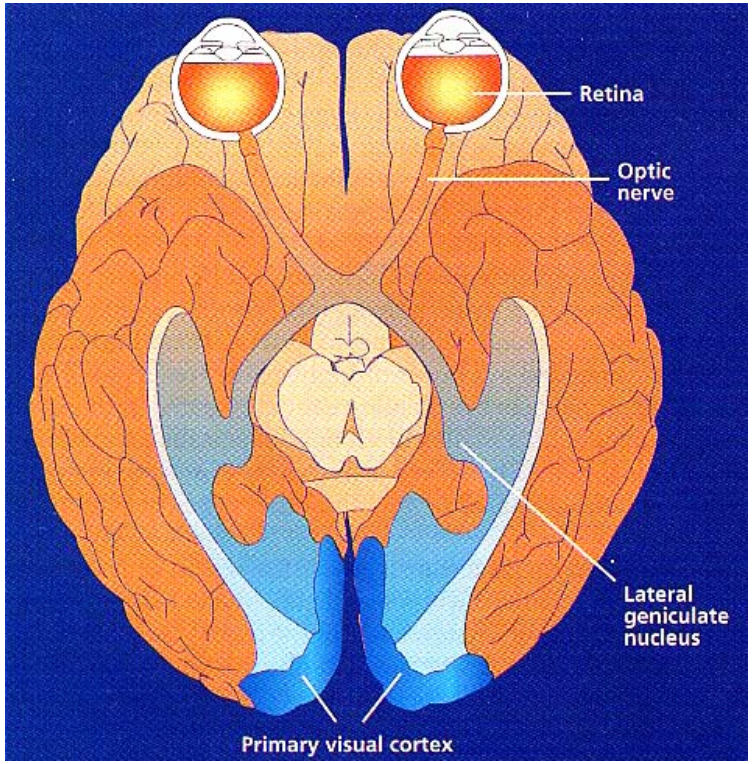


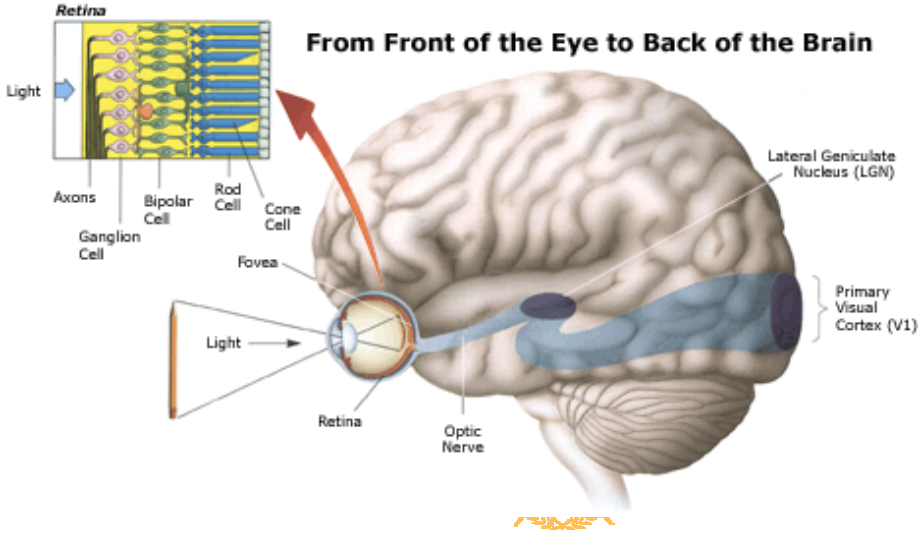
320 x 320

- 100 pixel image (10 x 10)
- 625 pixel image (25 x 25) : enable mobility
- 1024 pixel image (32 x 32) : partially useful vision
- 10,000 electrodes (100 x 100) : ambitious goal

Visual Pathway

- Photoreceptor → bipolar cell (BC) → ganglion cell (GC) → optic nerve (ON) → lateral geniculate nucleus (LGN) → primary visual cortex (VC)
- in brief, BC → GC → ON → LGN → VC

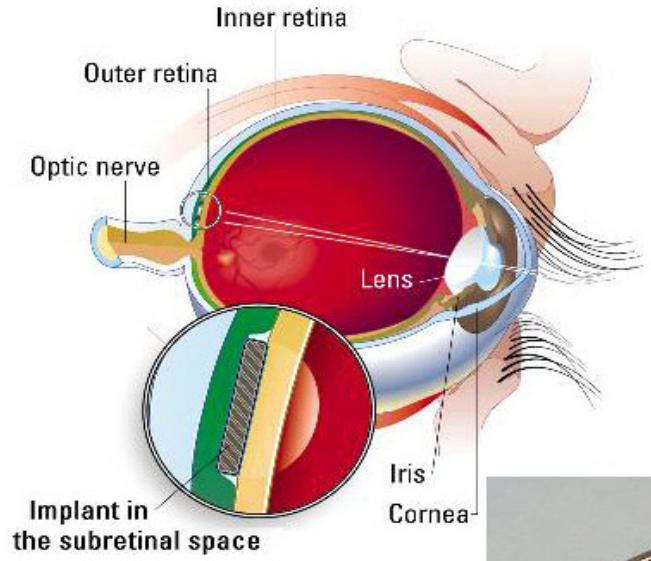


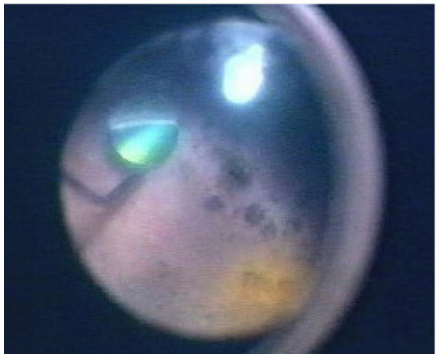


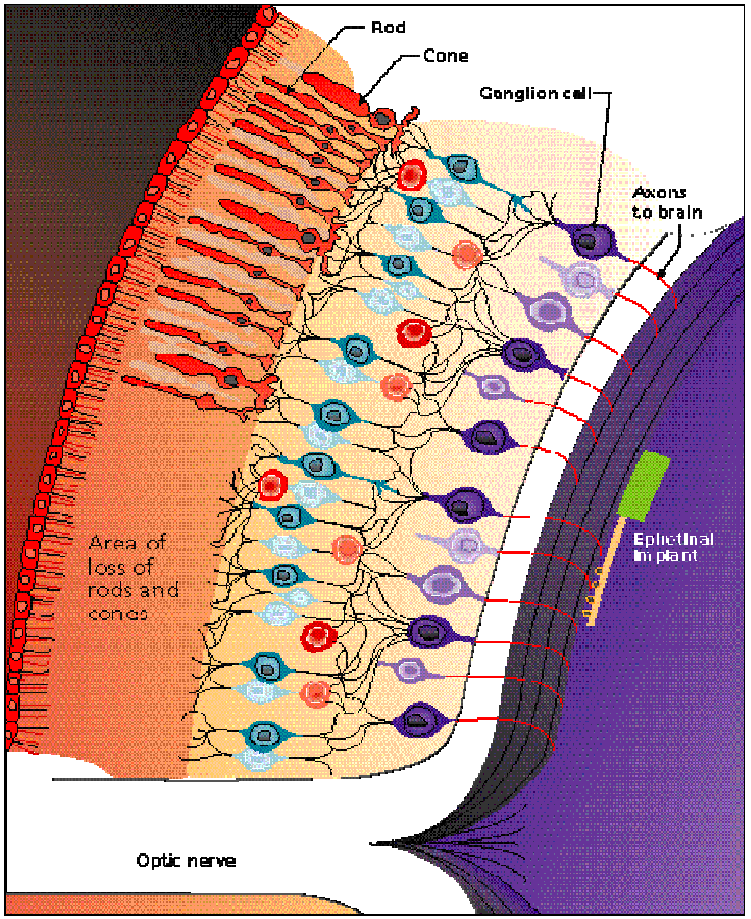
Kinds of Artificial Vision (electrical)

- Subretina implant
- Epiretina implant
- Superchroidal Implant
- Optic nerve stimulation
- Visual cortex stimulation

Subretinal vs. Epiretinal

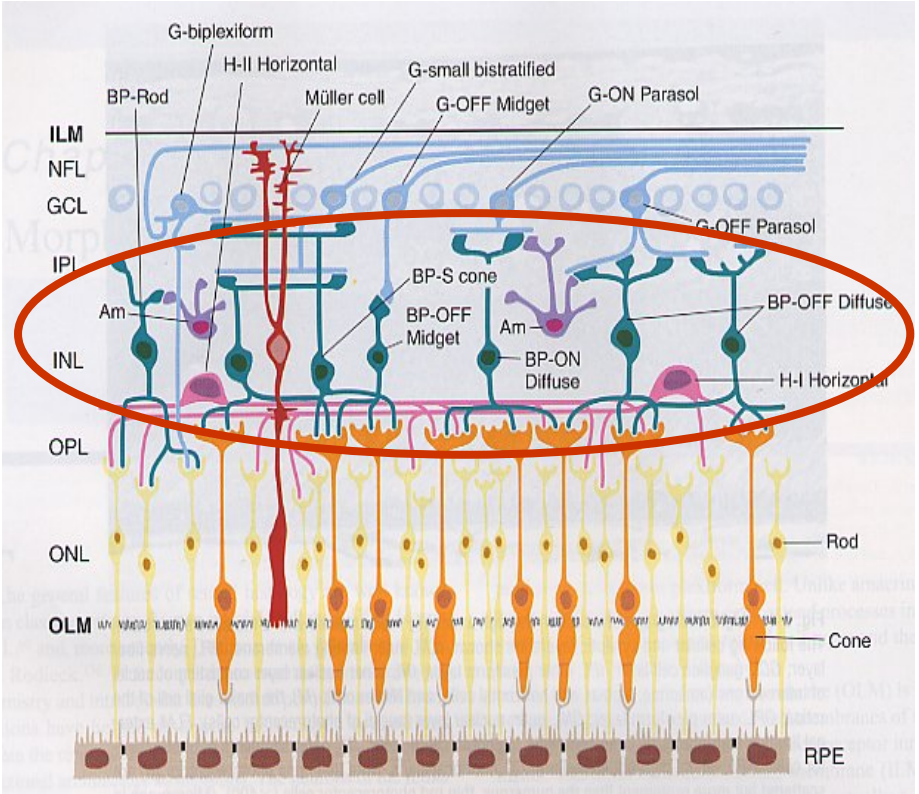






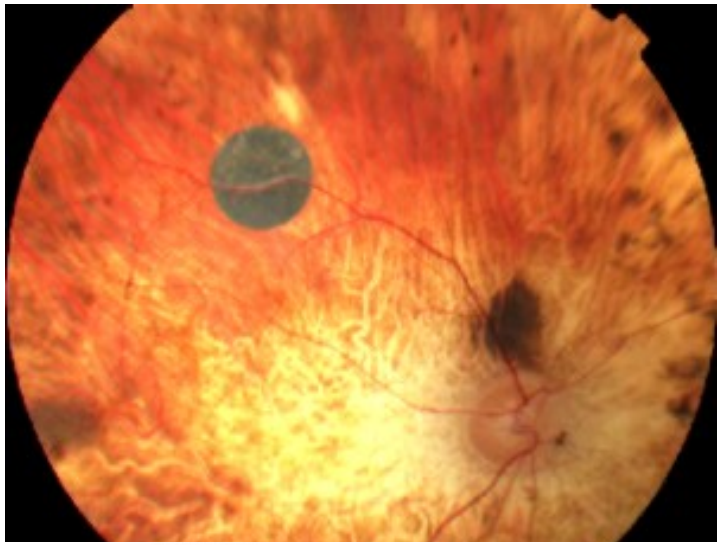
Subretina stimulation
망막하 자극기

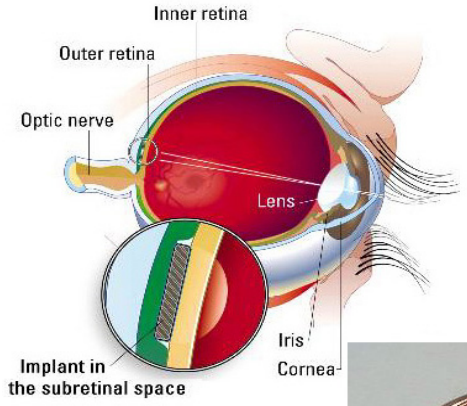
- Inner Neural Layers
- Bipolar cells are stimulated

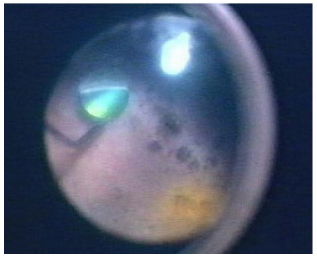


Optobionics

- **Photodiode** 이용, 간단한 구조:
  빛 감지와 신경자극을 하나의 칩으로
- 단점
  - 현단계로는 자연광으로 충분한 전기발생 불가능
- 미 식약청으로부터 '생체적합성 검증'으로 인체시술 허가를 받음
- 2000년 45~76세 사이의 RP 자원자 12명에게 시술
- 자연광으로는 ASR™에 의한 망막전위도가 기록 안됨, 적외선레이저 자극으로는 기록됨

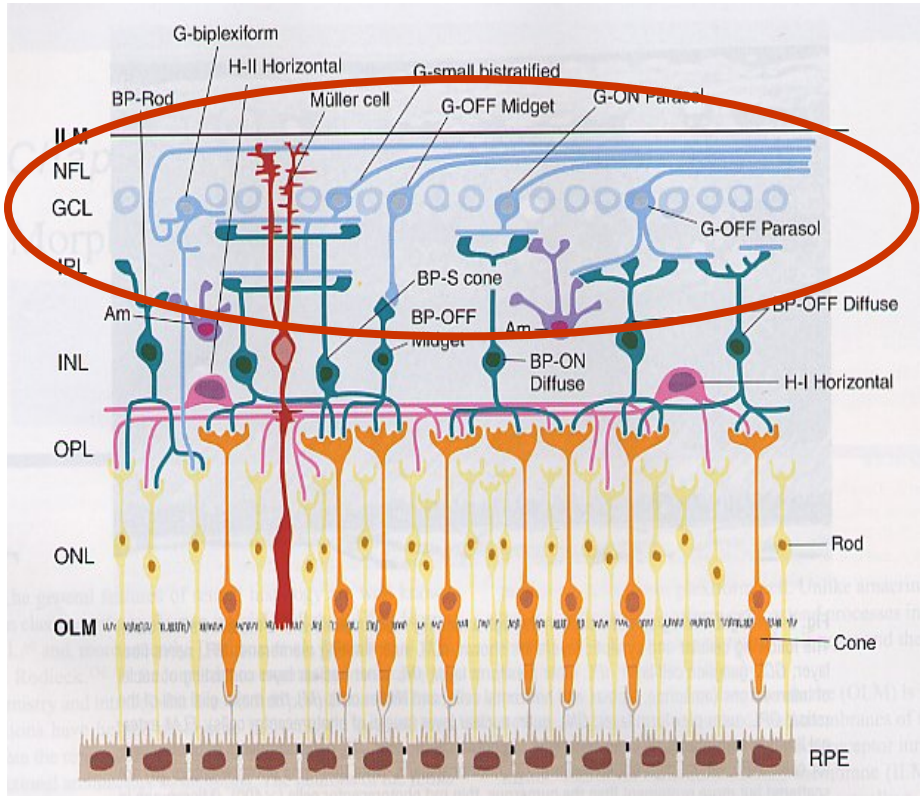






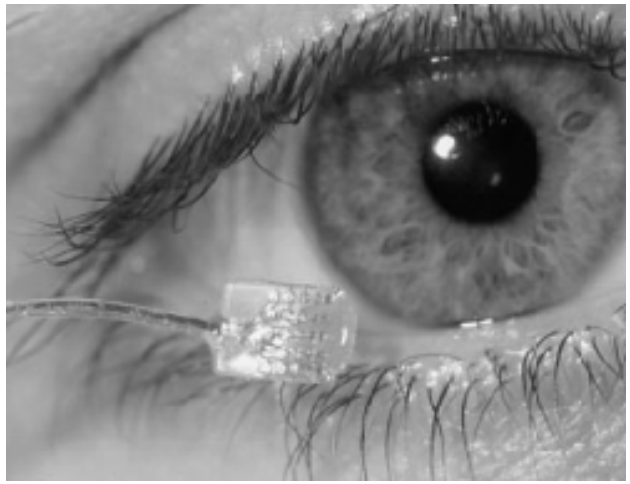
Epi Retina Stimulation
망막앞 자극기

- Ganglia Cells are stimulated (망막 신경절세포
- Doheny / NCSU / SecondSight

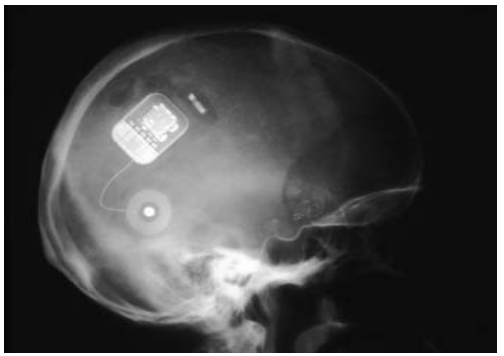


Doheny / Second Sight

- 4 x 4 백금 전극
- Clarion® 인공와우 자극기로 구동
- 2001년 12월 이후 3명의 자원자에게 실험 결과
  - 불빛의 방향 판정: 90-100%
  - “L” 형태의 방향성 판정 : 75%
  - 검은 배경 위의 흰 물체 위치 지적: 80%



visual prosthesis
video

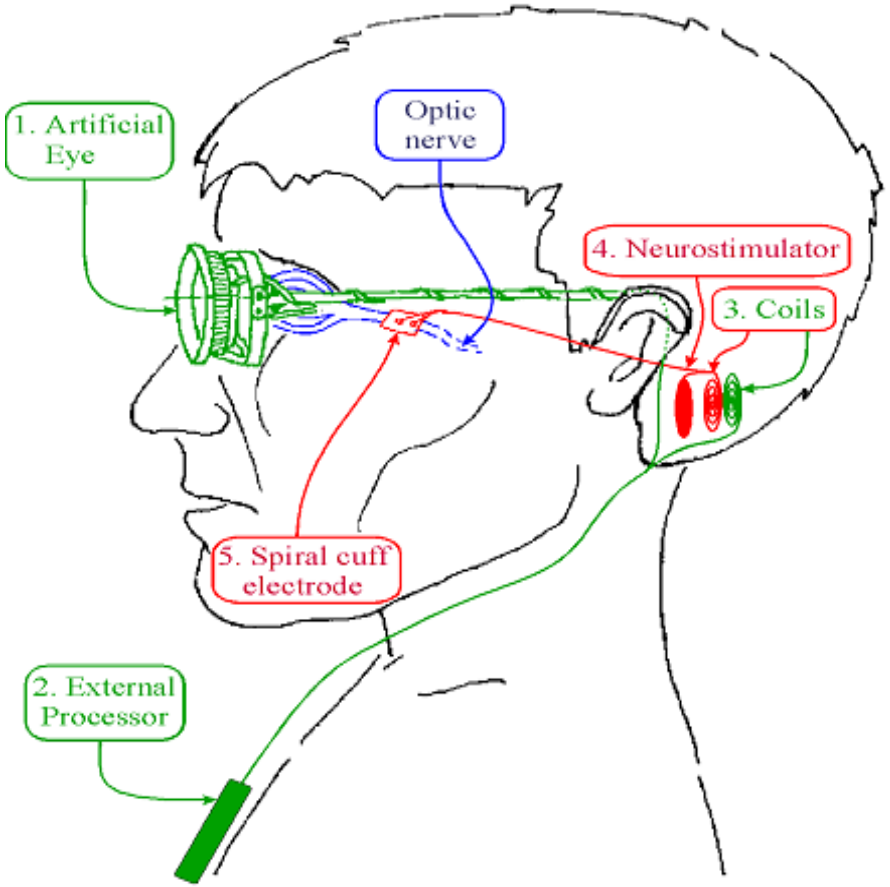


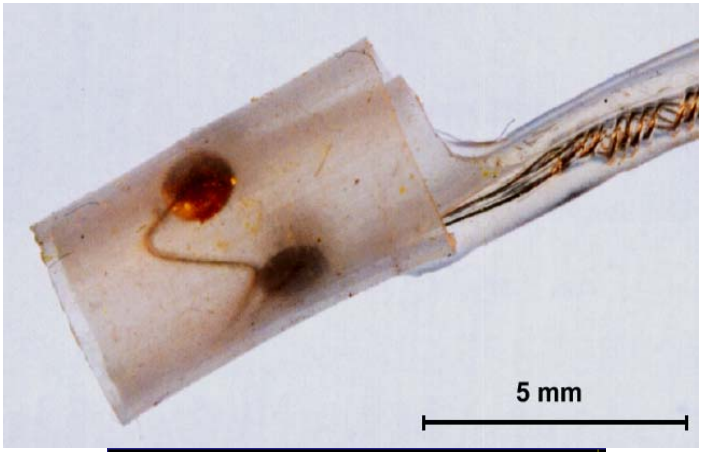
Courtesy of Dr. Claude Veraart, Université catholique de Louvain, 2004

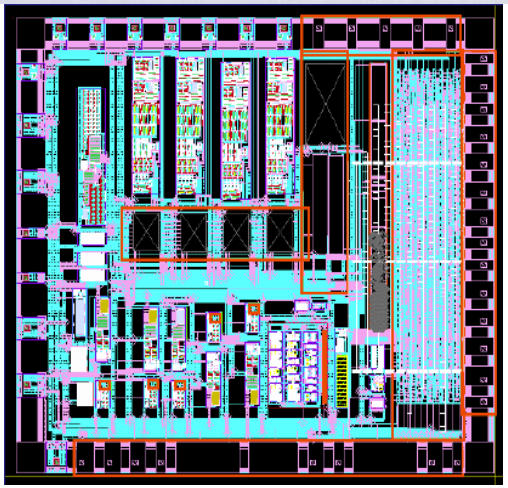
Stimulating Optic Nerve
시신경 자극기

- 자극 단계: 시신경
- 단점
  - 신경이 밀집해 있고 뇌경막이 두껍다.
  - 망막위치에 대한 신경섬유의 상대적 위치가 불확실하다
- UCL (Universite Catholique de Louvain), Belgium
- 1998년 4월 인체 시술
  - 4개의 전극이 있는
    spiral cuff electrode (Au-Ti)
- 2003년 하반기에
  두 번째 시술
  - 8개의 전극

Functional prototype of visual prosthesis interfaced with the optic nerve.



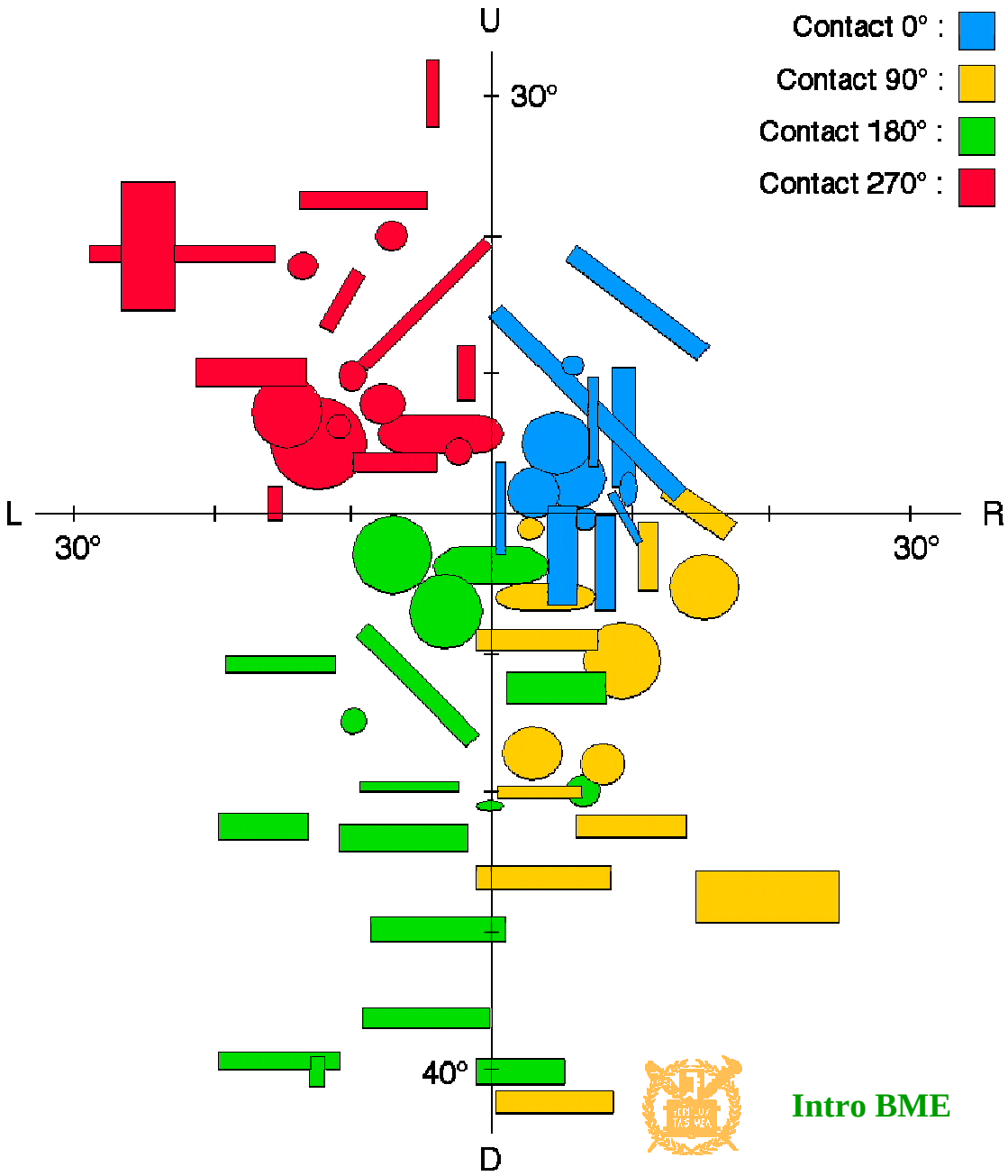




http://www.dice.ucl.ac.be/Mivip/

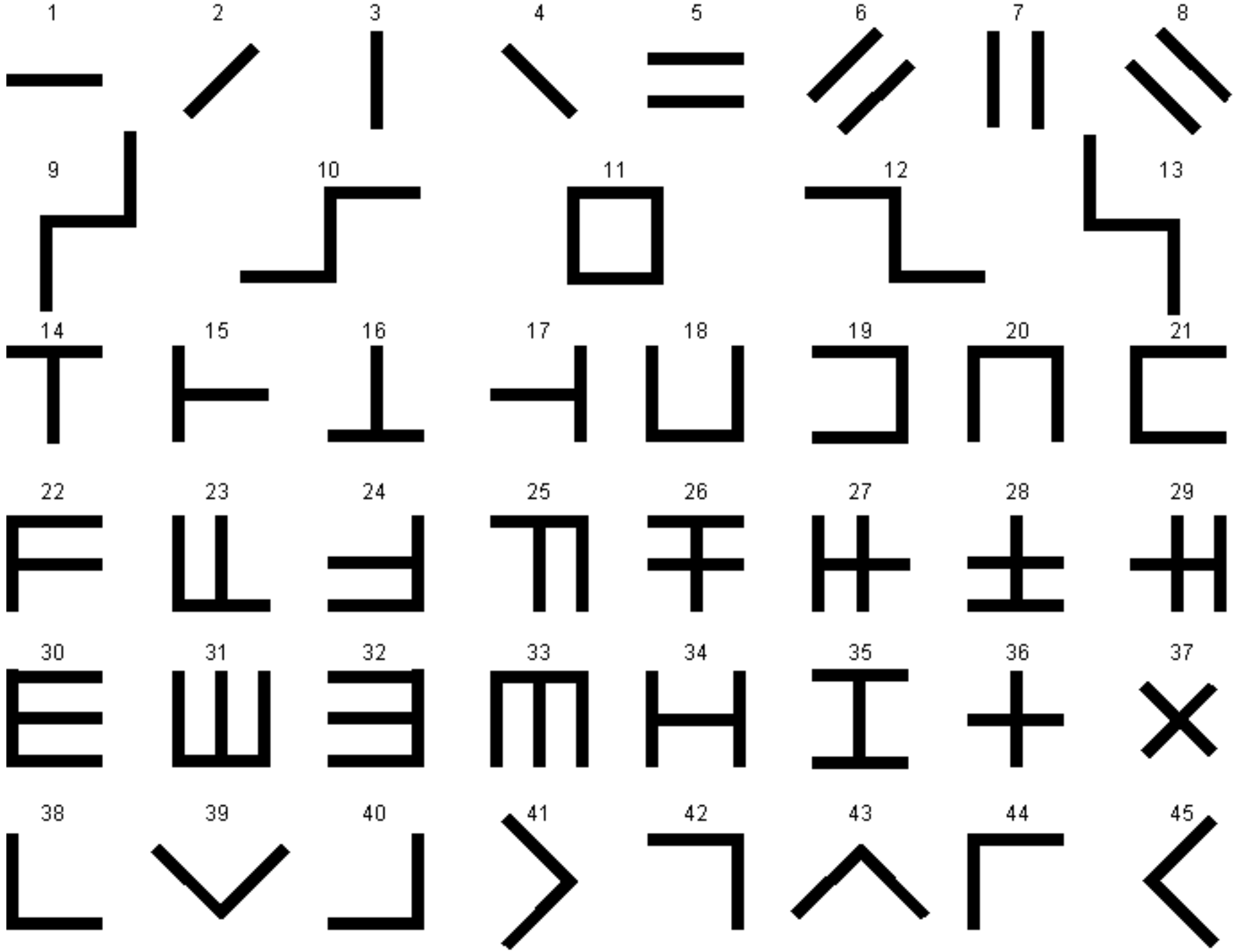
Claude Veaart, Universite Catholique de Louvain, Belgium

Optic nerve selective stimulation



Phosphene position depends on the cathodic contact selected to deliver the stimulation

(Veraart et al, Brain Research, 1998,813:181-186)

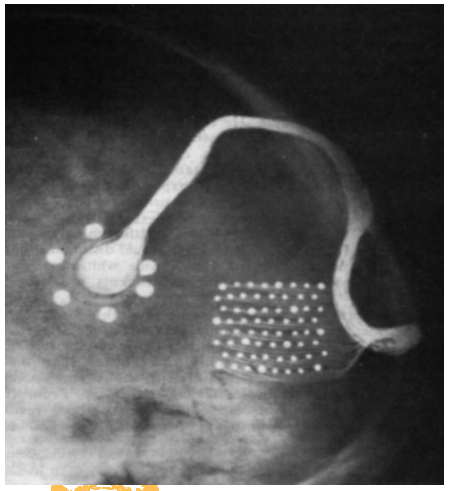

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45

Stimulating Visual Cortex
시피질 자극기

- 자극 단계: 시피질
- 장점
  - 적용범위가 넓다.
- 단점
  - 뇌신경의 구조는 매우 복잡함.
  - 피질에 광범위한 전기 자극
    → 간질 발생가능성
- Utah, Dobelle Inst., Kresge

Visual Cortex Stimulation
피질 자극기

- Dobelle (1976):
  - 64 Pt electrode, 8 x 8 array on 3 mm centers in Teflon ribbon cable matrix
  - 이 중 6개의 전극만 활동
  - penrose drainage 로 외부와 연결
- Dobelle (2002):
  - 시술받은 사람이 운전을 하고 색각을 느낀다고 주장



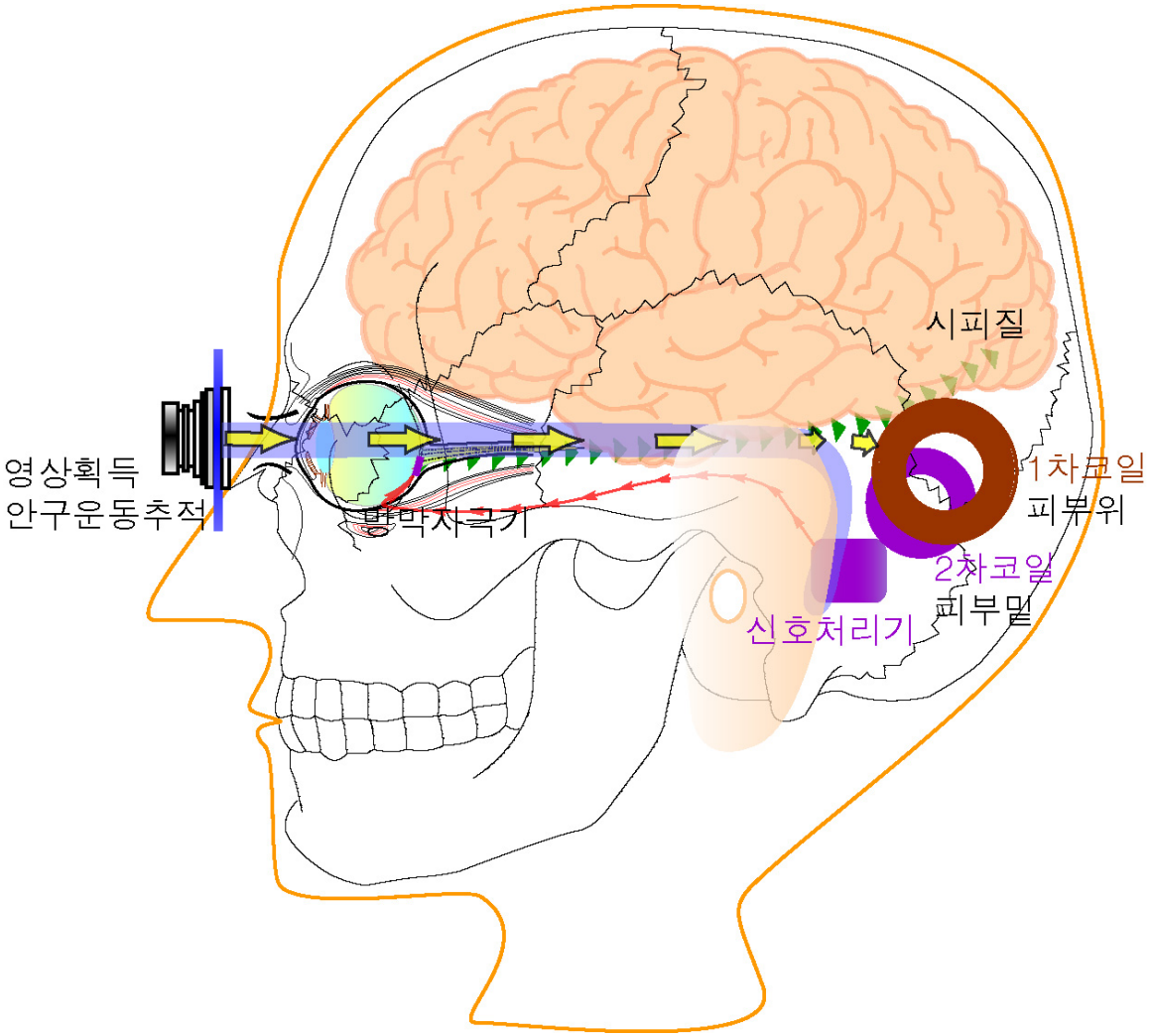
Problems to solve
인공망막: 해결해야 할 과제

- 어디에 자극기를 이식할 것인가?
- 이식한 자극기에 시각정보를 어떻게 전달할 것인가?
- 이식한 자극기에 어떻게 에너지를 공급할 것인가?
- 이식한 자극기에서 최선의 자극형태는 무엇인가?
- 절대 변하지 않는 최선의 자극기를 어떻게 만들 수 있나?

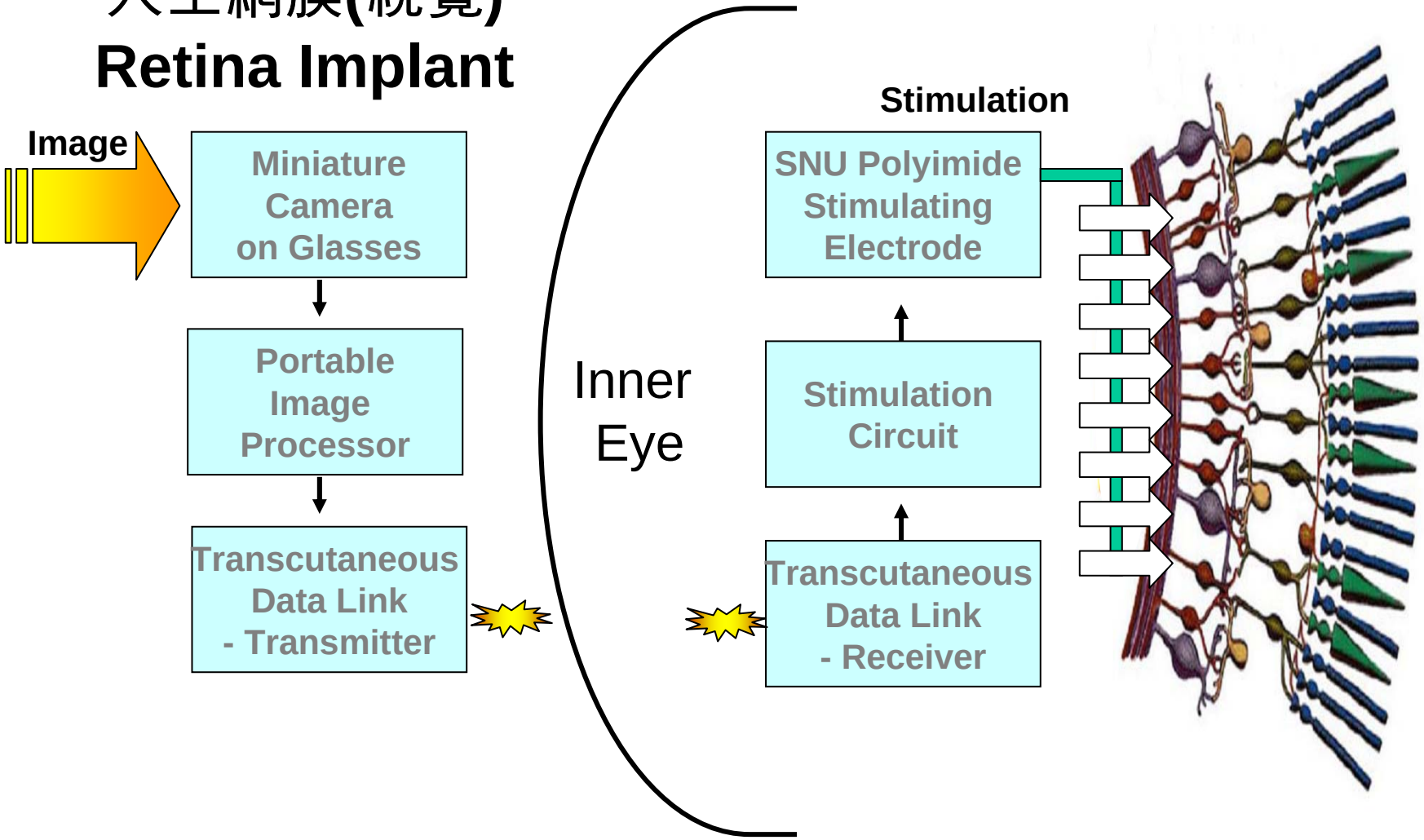
Seoul Artificial Retina
서울형 인공 망막

- 나노바이오시스템 연구센터 (9년 과제, 3개의 대주제)
  - 한국과학재단 지원
  - Neural chip/MEMS 의 한 과제로서 망막자극용 전극 개발
- 나노인공시각센터 (6년과제)
  - 보건복지부 지원
  - 서울형 인공망막 시스템 개발과 생체 적용
- 구성
  - 안과학
  - 생리학
  - 전기컴퓨터공학
  - 의공학

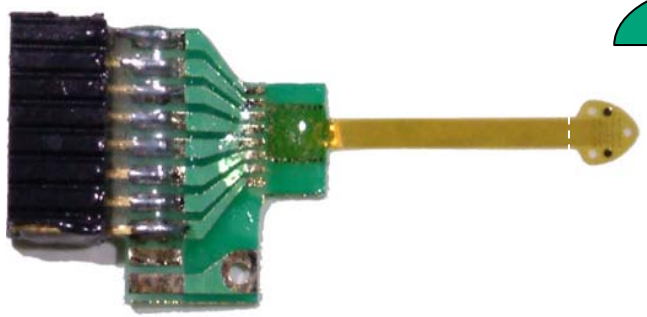
Seoul Artificial Retina
서울형 인공 망막

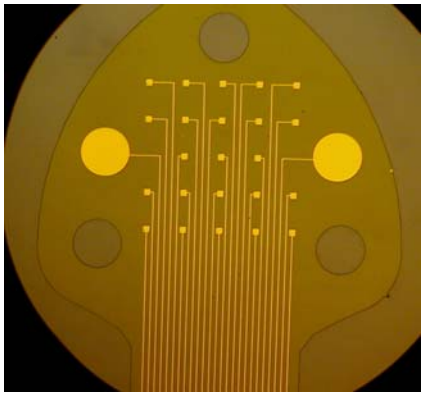


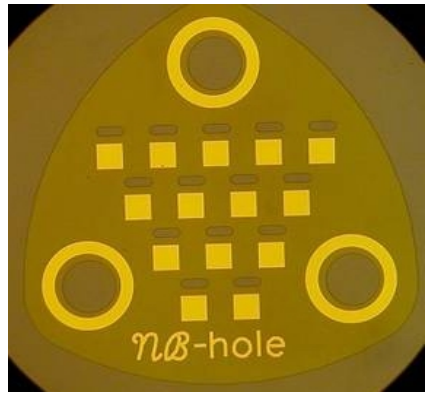
人工網膜(視覺)
Retina Implant



Polyimide-based Retinal Prosthesis







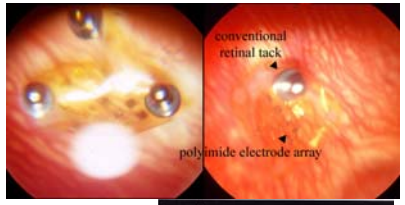
Electrode spec.

Whole structure size : 3mm x 17.8mm x 16um
Size of each site : 50um x 50um
Number of sites : 25
Site spacing : 300 um
Insulation layer : Polyimide (PI2525)
Shape of head : Rectangular, Triangular
Head size: 3mm x 3mm

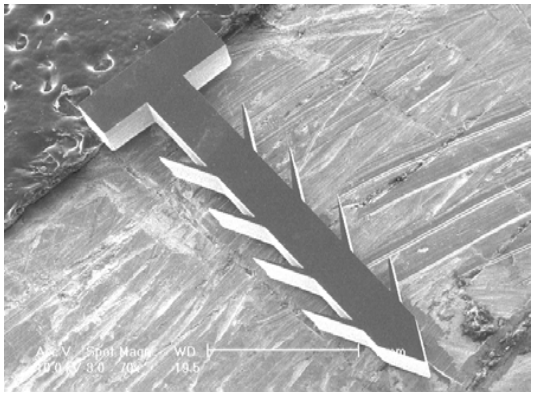
Acute stimulation

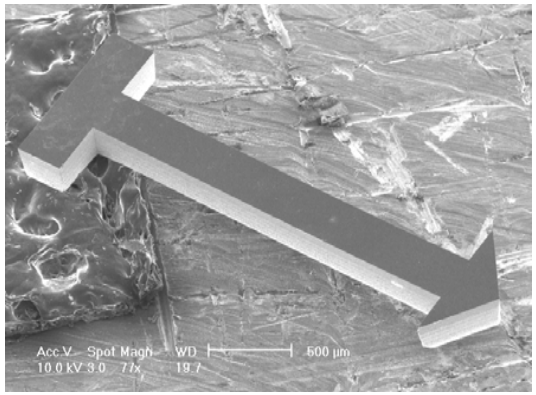
Experiment (rabbit)

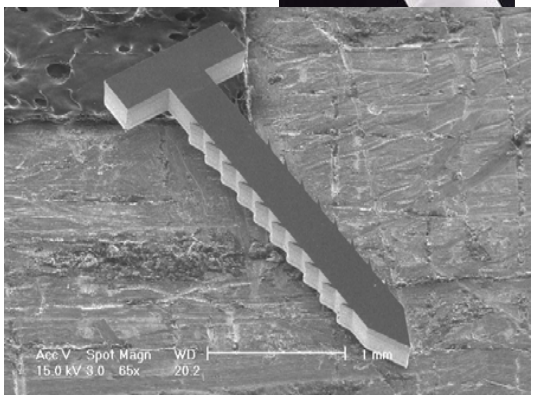
Micromachined Silicon Tacks

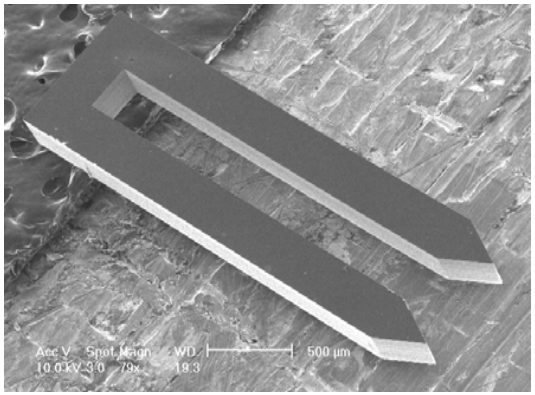


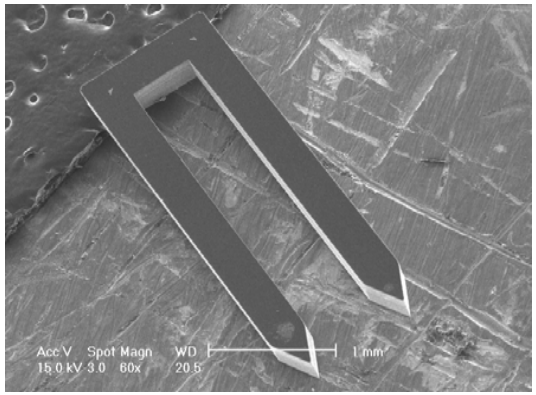
- Fabrication
  - material: silicon, oxide on silicon, parylene on silicon
  - full scale dimensions: length 3 mm, width 300 µm, height 300 µm
  - half scale dimensions; length 1.5 mm, width 150 µm, height 150 µm

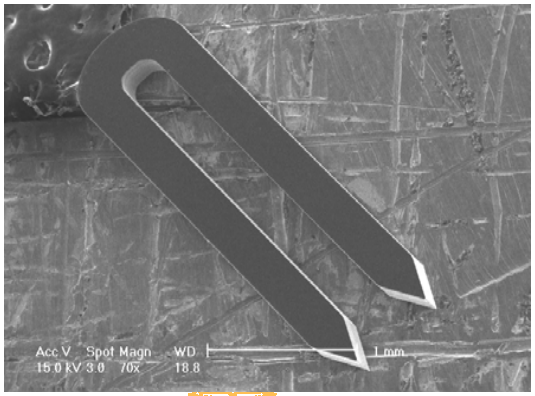






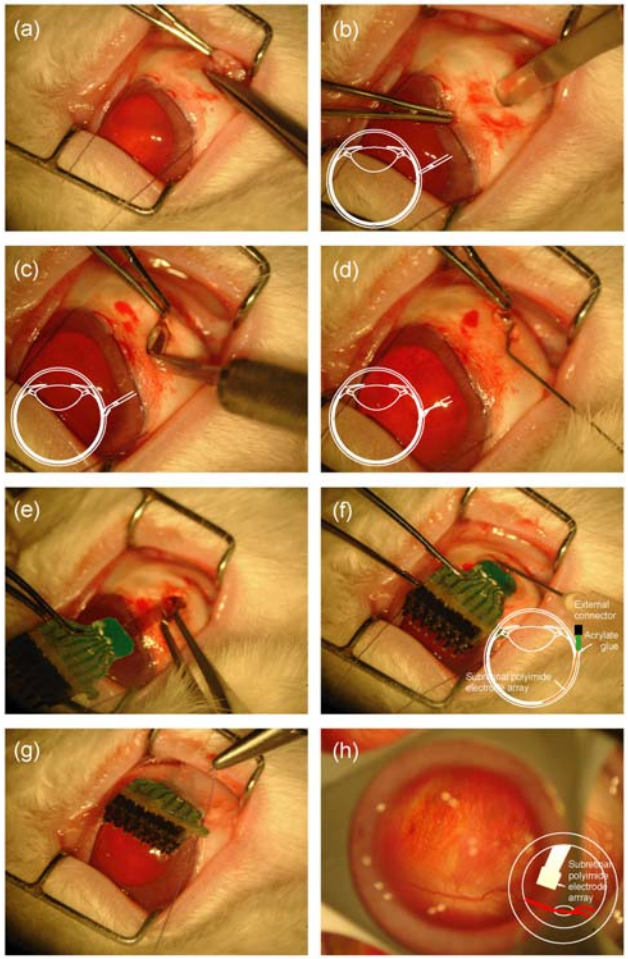




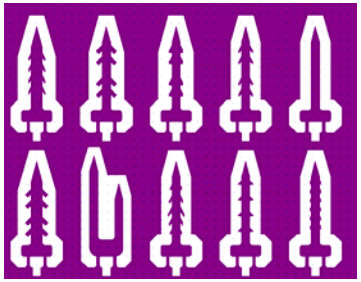


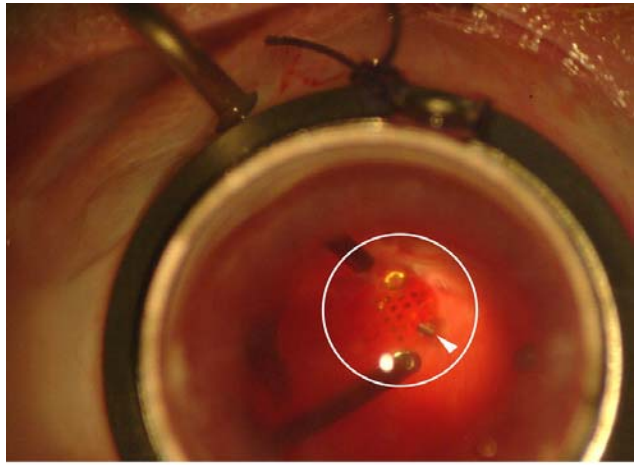
망막자극용 전극 수술법 연구

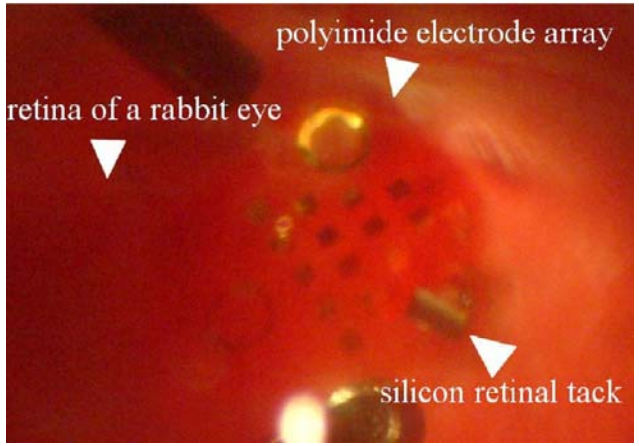
- 망막밑 삽입



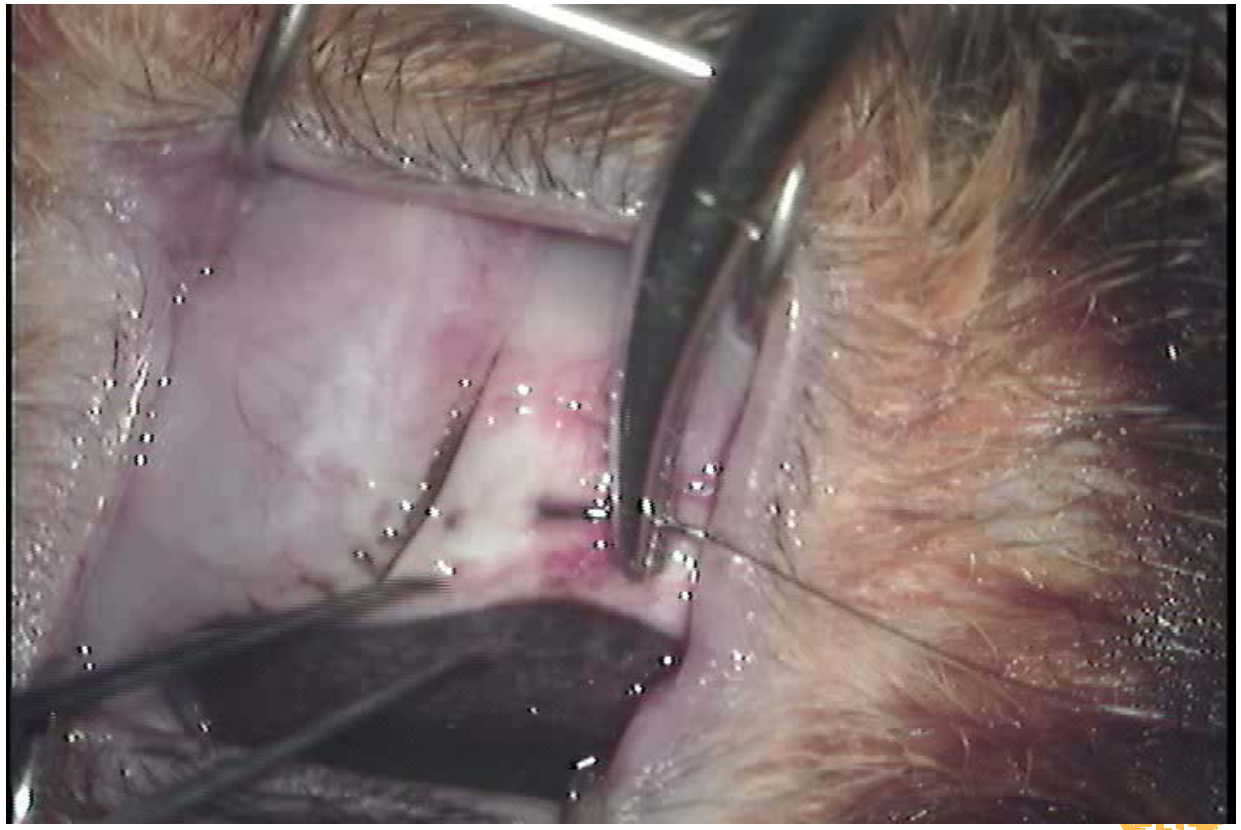
- 망막앞 고정



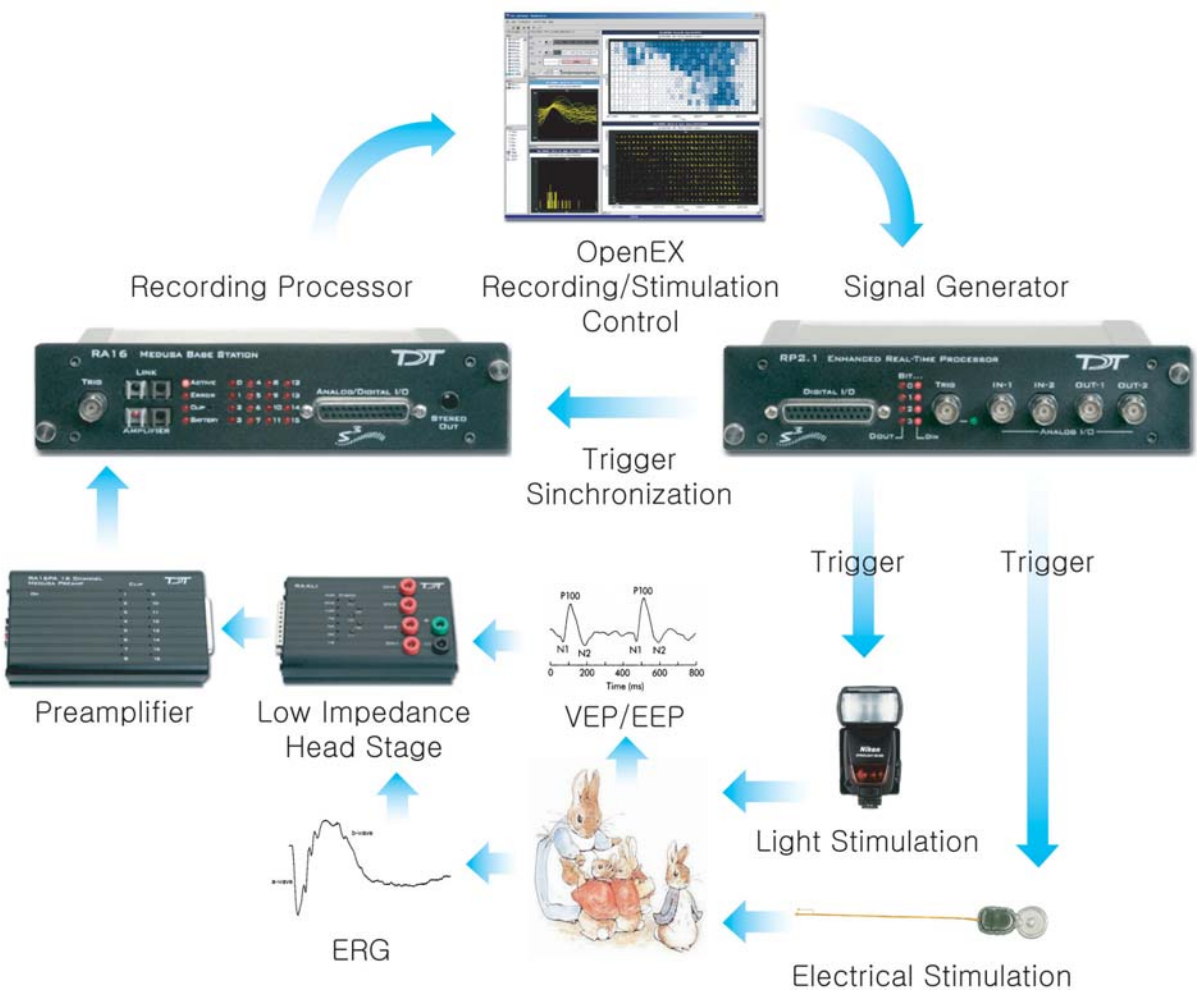


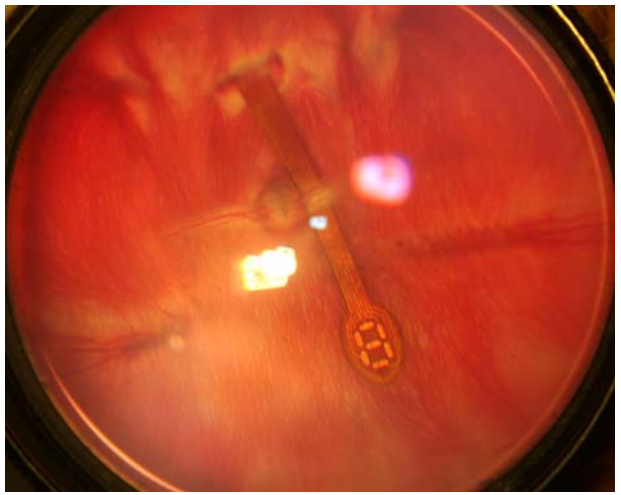


Epi-retina implant using
Polyimide electrode and Micromachined Tacks

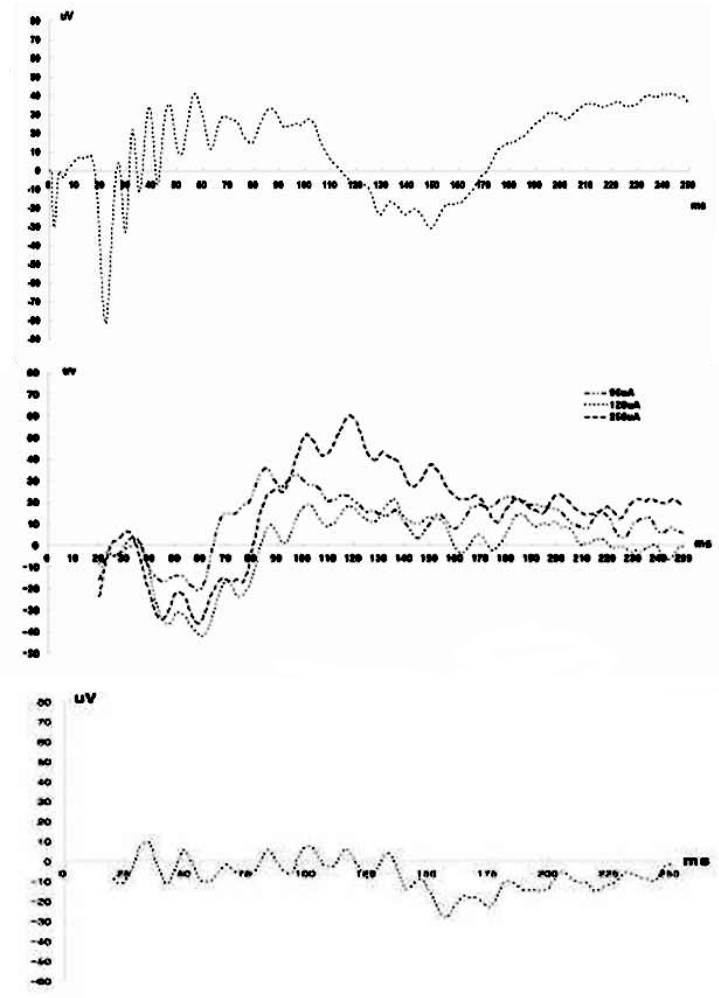


Experimental Detail
삽입전극/시스템을 이용한 자극 실험 세팅





Post- implant Electrophysiology
망막자극기 삽입 후 전기생리학적 기록

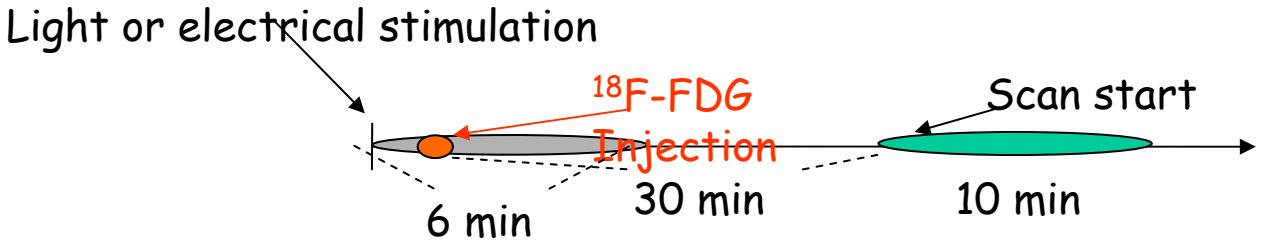


Visual evoked Cortical potential (VECP)

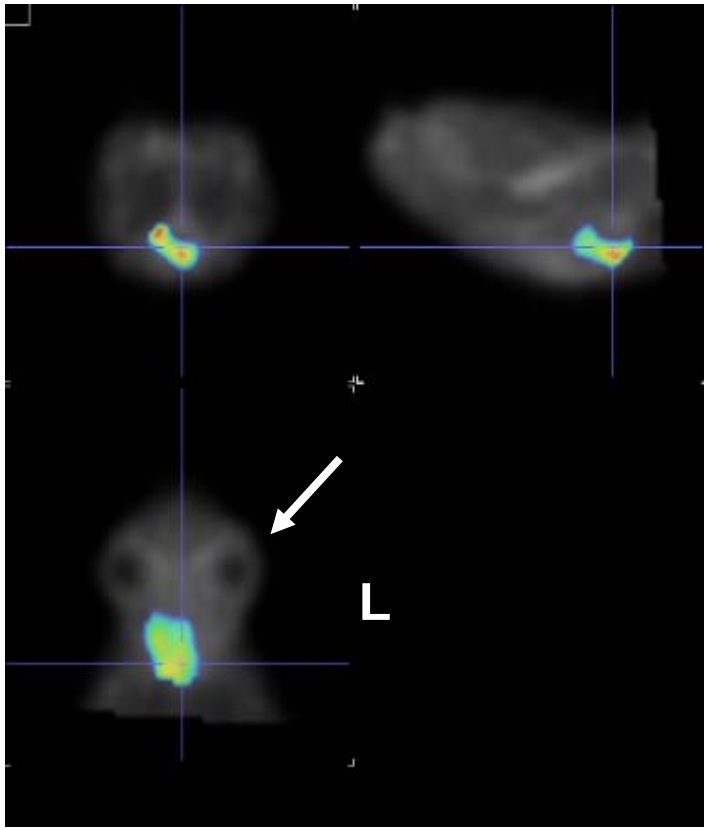
Electrically evoked cortical potential (EECP)

After optic nerve cutting

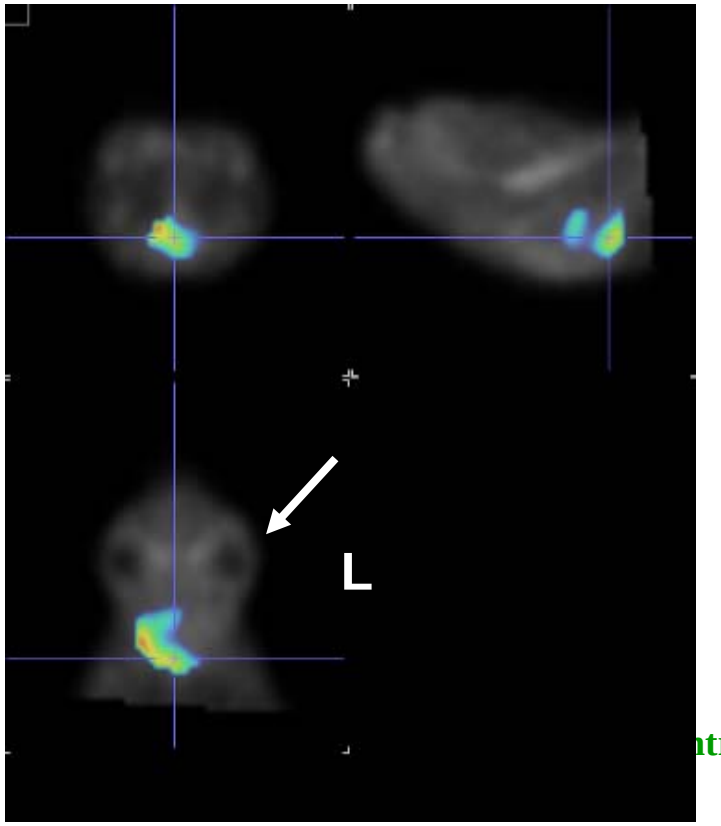
Increase in Glucose Consumption after electric stimulation
시피질의 당대사 증가 범위 (PET 촬영)



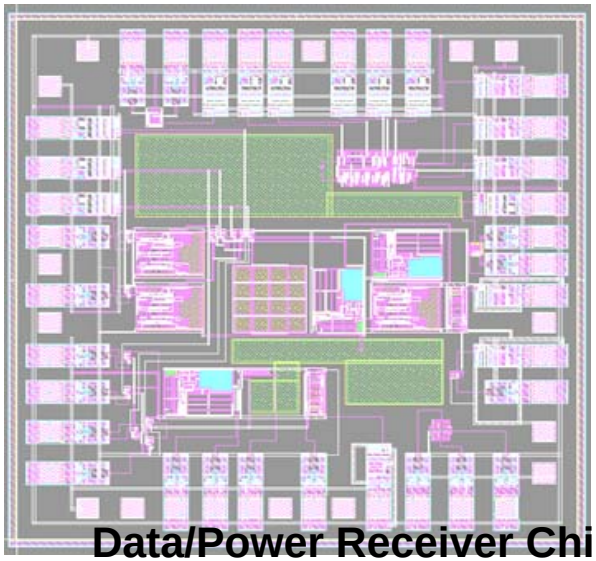
빛 자극 (좌안)



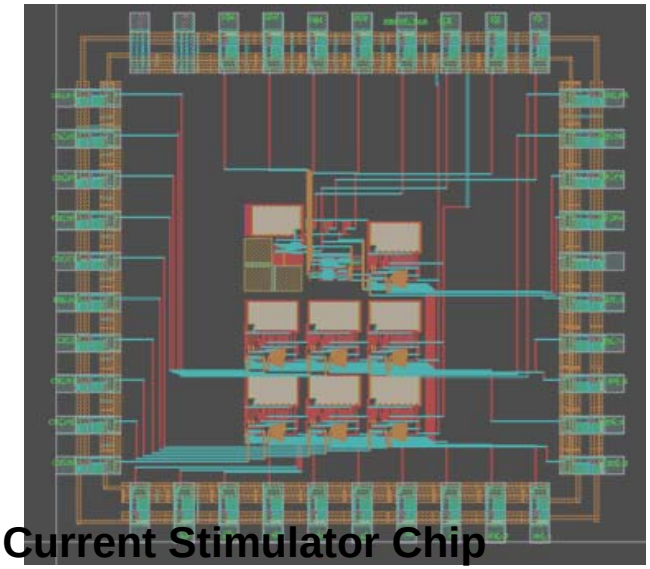
전기 자극 (좌안)



ICs



Data/Power Receiver Chip

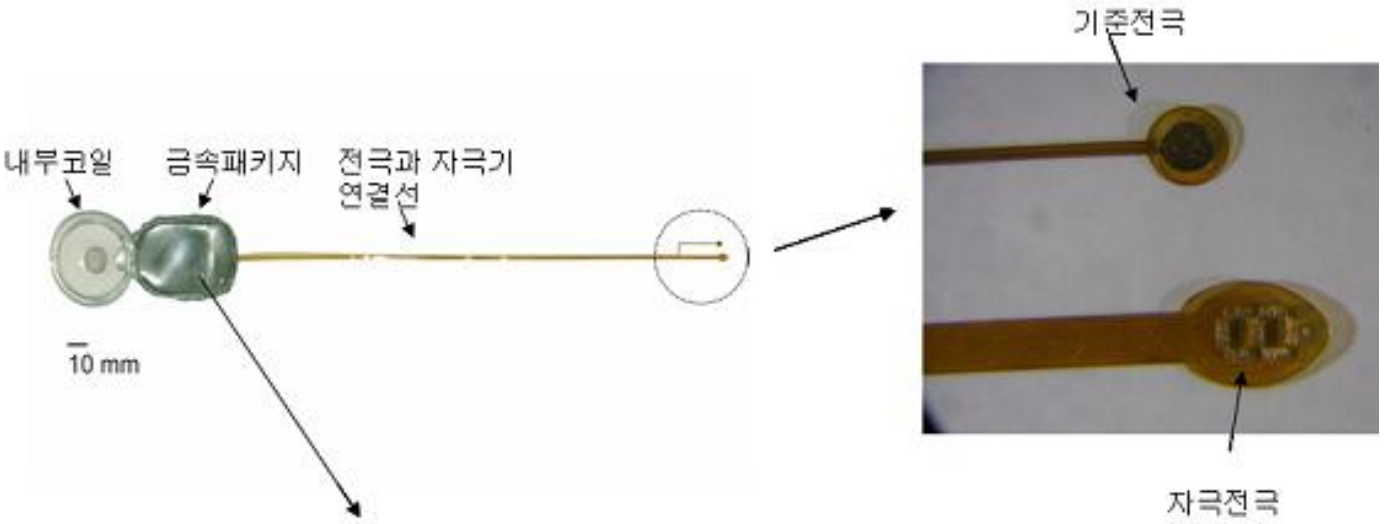


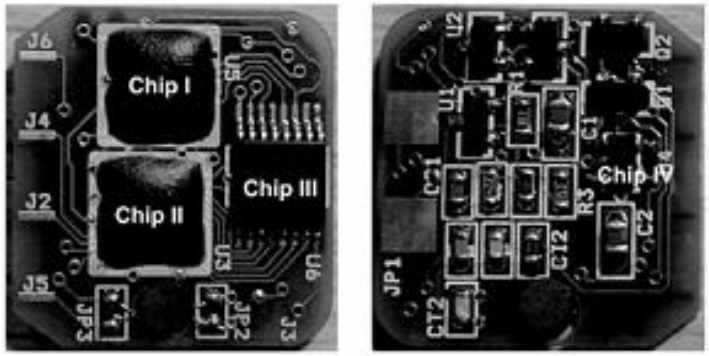
Current Stimulator Chip

- Rectifier/Amplifier
- Data Decoder (125Kbps)
- Voltage Regulator (5V)
- Internal Clock Generator(125KHz)

- Current Source (7 channel)
- Biphasic Wave Form Generator

Seoul Retina Implant
서울형 인공망막자극 시스템





전기회로 앞면 전기회로 뒤면