

Optical Control of Neural Function

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Introduction



- First smartphone: Simon Personal Communicator, 1994.
- First iPhone in 2007.
- VR and AR starting to appear.
- ~2.9B people forecast to own smartphones by 2020.



Megatrends

- Nanotechnology
- Artificial Intelligence
- Internet of Things
- Flexible Electronics
- Wearables
- Customisation



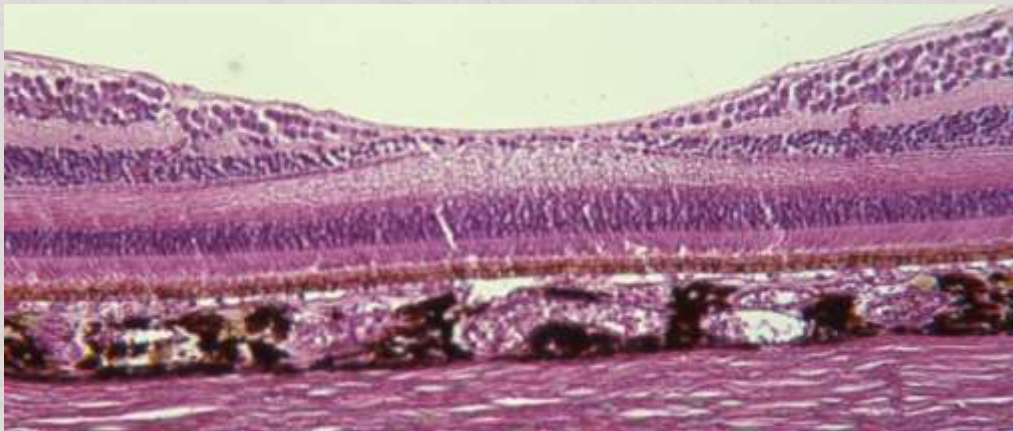
 **Elon Musk** 
@elonmusk Following

Creating a neural lace is the thing that really matters for humanity to achieve symbiosis with machines

1:08 AM - 4 Jun 2016

Interfacing with the Nervous System

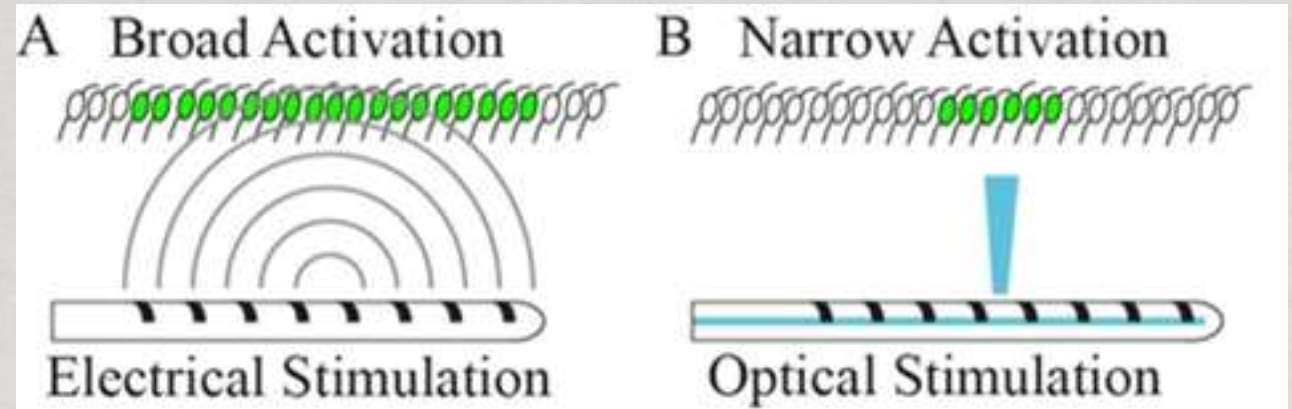
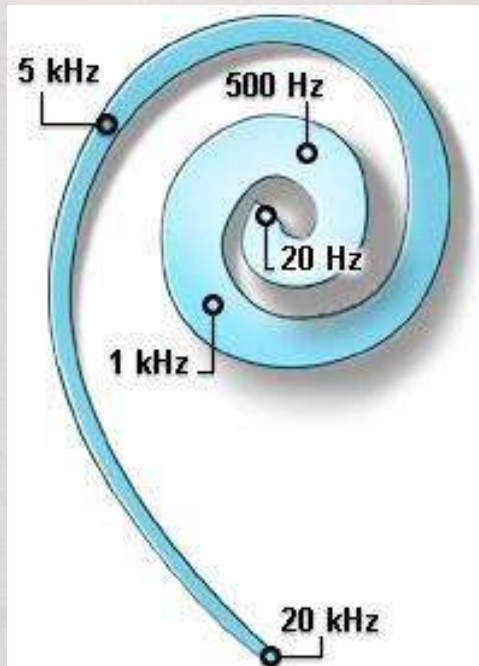
- Bionic Eye: 40,000 retinal ganglion cells/mm² in the peri-fovea.
- Can't address separate ON and OFF receptors upon which visual contrast is based.
- Current spread leads to loss of spatial resolution and contrast.



<http://neural.iit.edu/visualprosthesis2.htm>

Interfacing with the Nervous System

- Cochlear implant: discrete frequencies are sensed at specific locations in the cochlear spiral.
- Multiple electrodes can activate an auditory neuron by current spread.
- Significantly reduced sound quality and speech perception.



What are the Challenges?

- We need to stimulate with better spatial resolution.
- Nerves are touchy, have complex 3D structure.
- We don't understand the nervous system well enough.

<https://bionicvision.org.au/eye>



<https://www.monash.edu/bioniceye/technology>

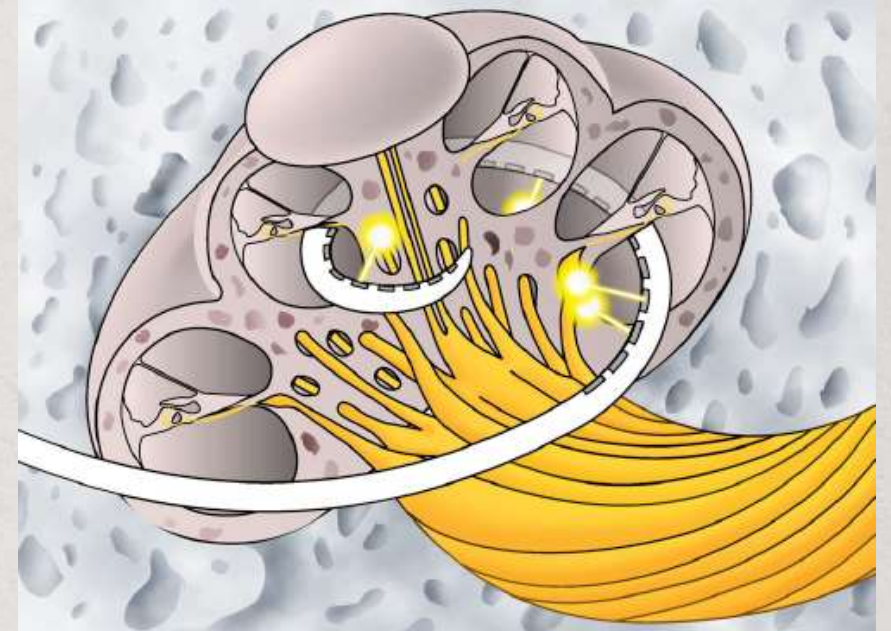
Optical Stimulation

- Optogenetics: introduction of light-responsive ion channels in neurons that are not normally light sensitive.
- Caged molecules: light-induced uncaging of bound neurotransmitters.
- Infrared Neural Stimulation: infrared lasers can be used to excite nerve cells directly (1870 nm, pulses 100 μ s – 10 ms).
- Nanoparticle-enhanced INS: optocapacitive effect via extrinsic absorber (770-1100 nm).



Advantages of Optical Stimulation

- Action at a distance: optical stimulation can be relatively non-invasive.
- No electrochemical junction, no inflammation.
- Spatial selectivity:
 - Light can be focussed to a small spot.
- Multiplexing:
 - Both stimulation and inhibition, plus read-out.
 - No stimulation artefact.



Richter et al., *Laser Photonics Rev.* (2011)

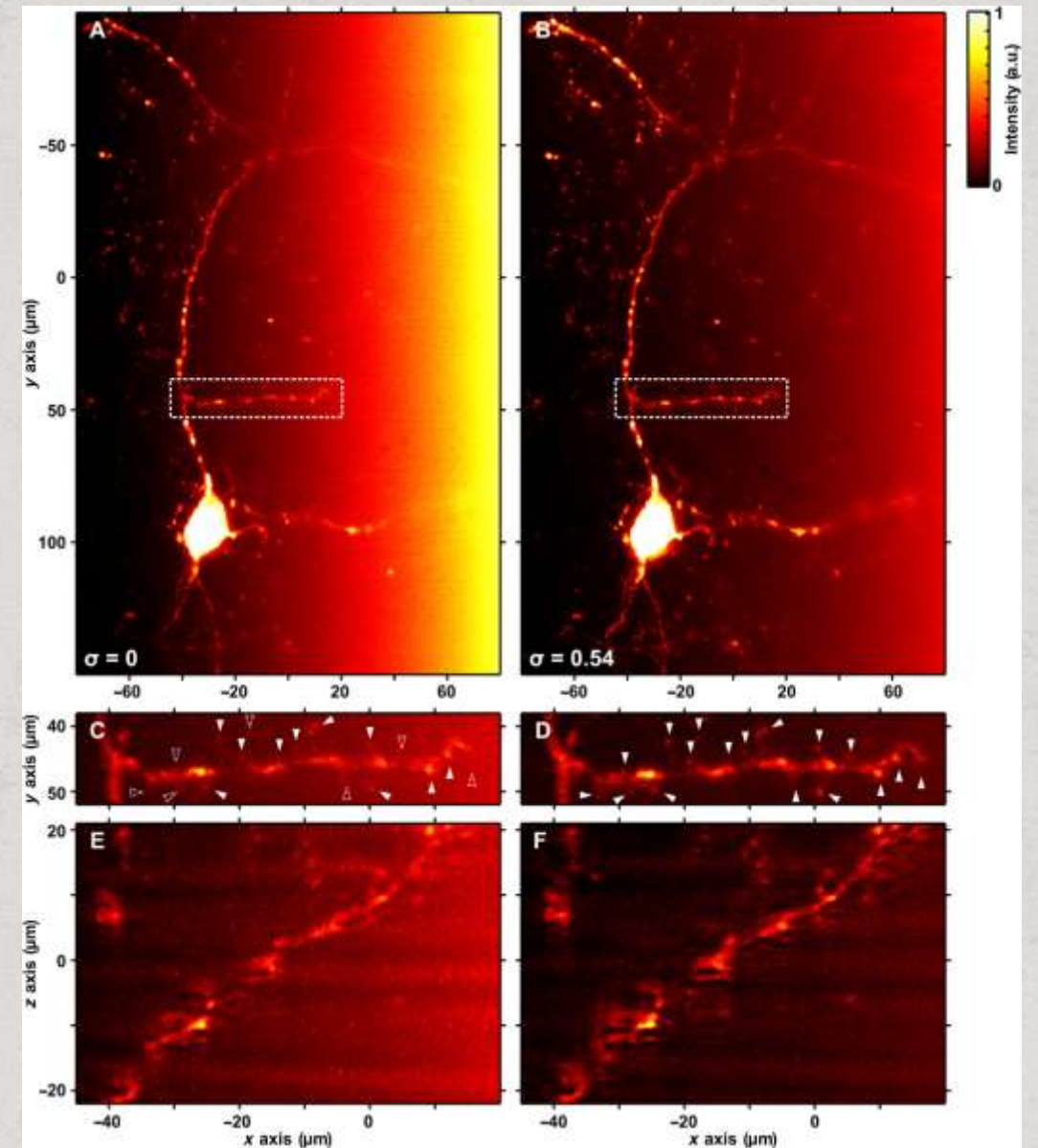
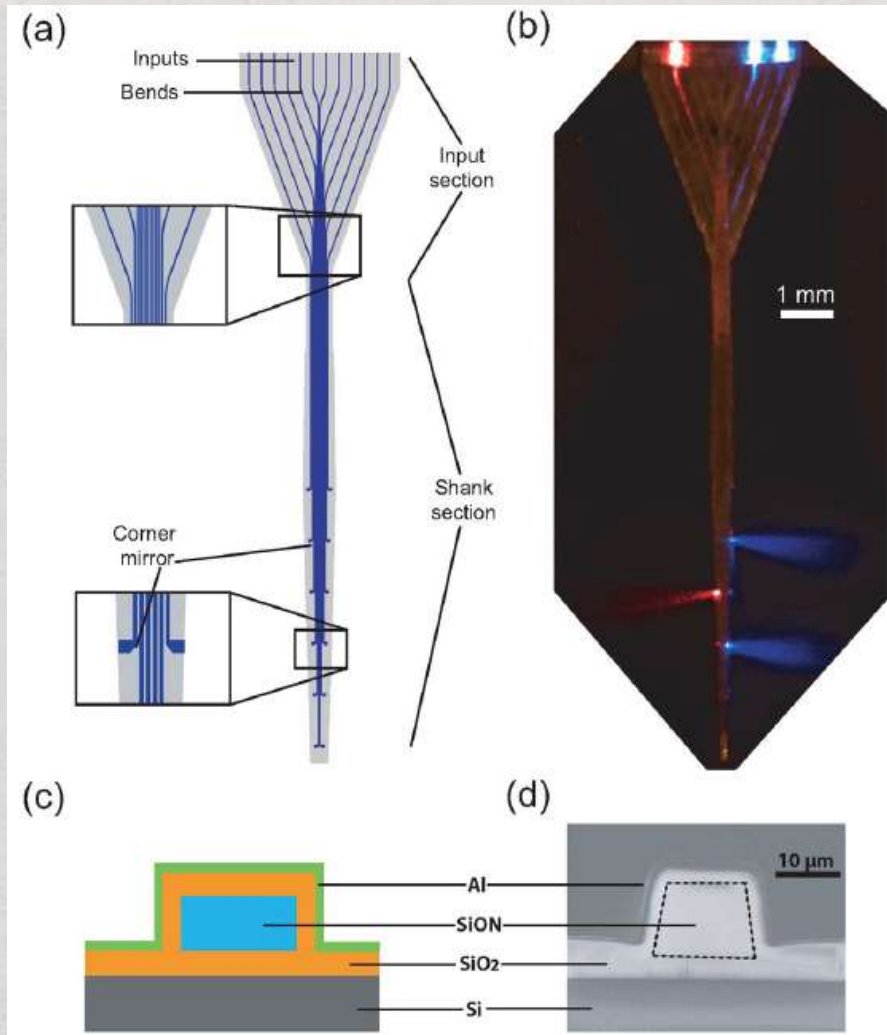
| Features | Optogenetics | INS | NP-enhanced INS |
|-----------------|------------------------------|-----------------------------|--|
| Non-invasive | X | ✓ | X |
| Resolution | X | X | ✓ |
| Penetration | X | X | ✓ |
| <i>In vivo</i> | ✓ | ✓ | ✓ |
| <i>In vitro</i> | ✓ | X | ✓ |
| Selectivity | ✓ | X | ✓ |
| Inhibition | ✓ | ✓ | ✓ |
| Threshold* | >2 $\mu\text{J}/\text{mm}^2$ | ~10 mJ/mm^2 | 13 NPs @ 14 μJ (0.75 pA /NP) |

* Cochlear implant : 0.2 $\mu\text{J}/\text{pulse}$

Paviolo & Stoddart, *Nanomaterials* (2017).

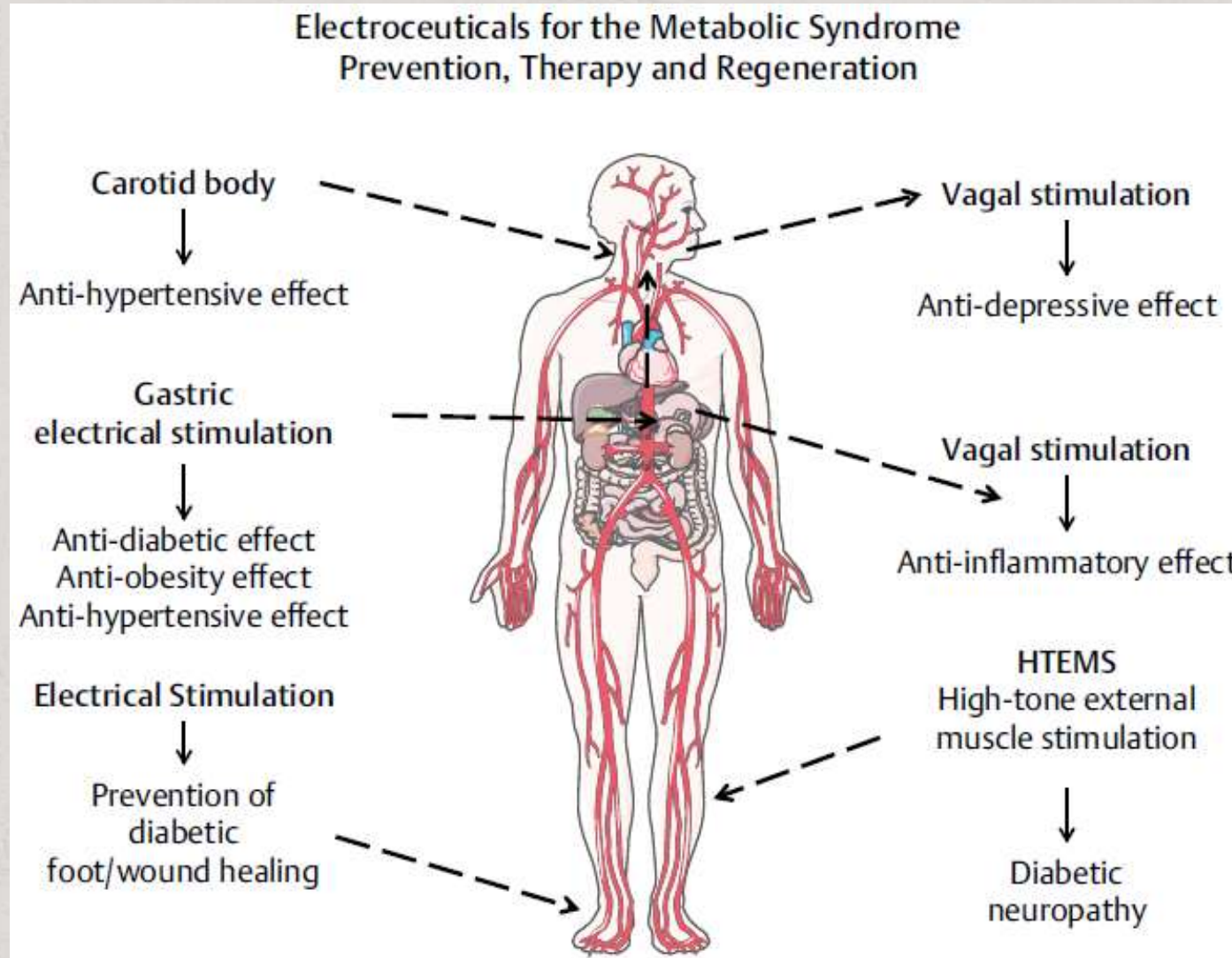
Optical Technology

Multi-site probe, Boyden Lab (Zorzos et al., Opt. Lett. 2010)



Attenuation-compensated Airy LSM in mouse brain section (Nylk et al., Sci. Adv. 2018)

Beyond Web-enabled Personnel



Conclusion

- Optical stimulation techniques are progressing.
- Energy efficiency needs further improvement.
- Potential for improved spatial resolution in neural prostheses.
- Major ethical and safety concerns.



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www.swinburne.edu.au/biodevices



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