uGC2: Si meets Life

(a personal view)

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Where are we coming from?

- Silicon/life interfacing
  - From switches to paper tape and cards, and fanfold printout
  - To keyboards and text based screens
  - To WIMP interfaces, with graphics screens and mice
  - To multi-touch interactive screens, and voice input
- Or living organ/brain computer interfaces:
  - ECGs and EEGs
  - Cochlear implants
  - Retinal, brainstem and cortical implants
- Or sensory systems
  - Mircophones and silicon cochleae
  - Image sensors (CCD, CMOS, silicon retinae
  - Olfactory sensors

Where are we going?

- Man/machine interfacing
  - Richer, more natural user interfaces
    - Better hardware and software
- Better, more effective brain/computer interfacing
  - Better than EEG? Higher bandwidth?
- Effective systems for interfacing electronics and living systems
  - For diagnostics, for understanding neural systems, for (invasive) BCI
  - Perhaps for hybrid machines and cyborgs?

Brief review: interfacing to the nervous system

- Si/life in the nervous system:
  - Peripheral nervous system
  - Sensory system
  - Central nervous system

- Common issues:
  - Device lifetime
  - Device power

Peripheral nervous system

- Issues:
  - Keeping (damaged) nerves alive
    - Nature of interface (cuff electrode, other transduction)
  - Unidirectional interfacing
    - Brain to motor system for patients with nerve injuries
  - Bidirectional interfacing
    - Brain to motor and proprioception
    - How to stimulate peripheral nerves

Sensory system

- Sensory surface replacement
  - Loss of any remaining sensation
  - Keeping the sensory surface alive
- Where does the artificial sensory signal enter the nervous system
  - At the original sensory surface
    - Cochlear implant, retinal implant
  - At the brainstem
  - At the cortex itself
- Unidirectional interfacing
  - Detecting the sensory signal only
- Bidirectional interfacing
  - Altering the sensory transduction system

Central nervous system

Implants

- Not damaging the brain surface
  - Brainstem, or cortex
- Keeping the brain area alive
  - Toxicity
- Unidirectional interfacing (brain to elsewhere)
  - Signal coding
- Bidirectional interfacing (elsewhere to brain)
  - Stimulation techniques
  - Not damaging anything

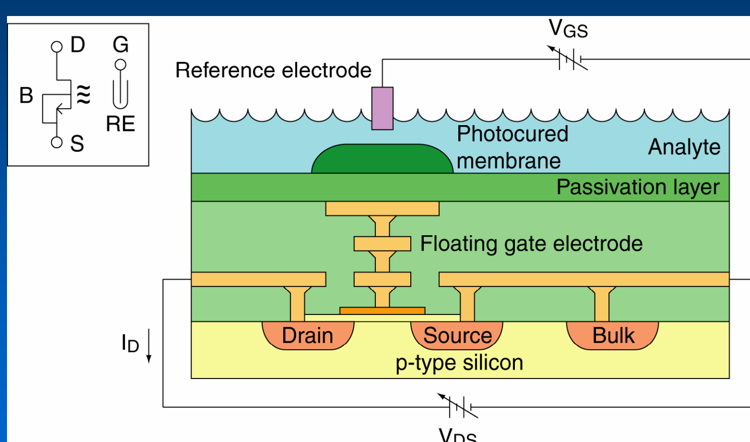
Technologies for interfacing

- Electrophysiological or ionophysiological
  - Sensing
    - Electrical signal caused by ion flow, or
    - Direct sensing of ion flow
  - Stimulation
    - Electrical pulse (balanced) stimulating neural activity or
    - Causing ion flow through opening ion channels
- Number of channels
  - How many recording/stimulating sites?
  - Size of each
- Accuracy of placement
  - Both for recording and stimulating

Possible technical ways forward

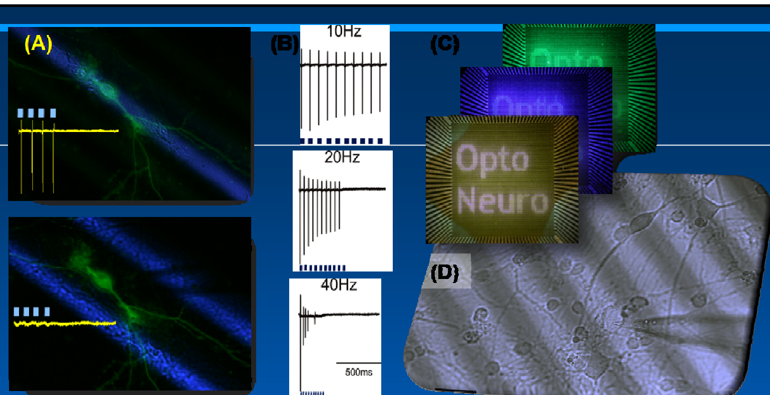
- Micro-fabricated electrodes
  - Multi-electrode arrays for electrophysiology
    - With large numbers of electrodes
    - 64 normal now, but work at Glasgow and Santa Cruz on much higher densities
  - Electrodes (iodes?) for directly sensing ion flow
    - Based in ion-sensitive FETs (ISFETs)
    - Or based on patch clamp (recording)
    - For stimulation?
      - Uncaging ions?
      - Optical techniques

Ion-sensitive FET (Cumming, Glasgow)



Bidirectionality …

- Need to be able to stimulate as well as record
  - Purely electrical stimulation is possible
    - Using biphasic signals
    - Bit unsubtle! Large voltages.
  - Other possibilities?



Optical stimulation of neurons (A) by defining the intensity and location of stimulation (in this case using lined LED's) we can stimulate individual action potentials with pulses of light. (B) by varying the pulse frequency we can achieve up to 40Hz which is sufficient for most tonic firing neurons. (C) We now have matrix addressable GaN arrays which can be flip chipped with CMOS controllers allowing independent oscillation patterns for each LED. (D) the present experimental setup using LED stimulation combined with patch clamp recording.

Patrick Deganaar (Imperial College, London)

Further stimulation possibilities

- Micro-designed electrostatic fields for ion channel protein reconfiguration
  - Requires very precise placement
- Genetically engineered neural interfacing cells
  - Cells which are “happier” than neurons to receive electrical signals
  - And which synapse onto real neurons

What GC2 is aiming for

- Brain computer interfacing for helping the disabled
  - Brain computer interfacing for augmenting human capabilities ?
- Better research tools for neuroscience
- Hybrid systems?
  - Silicon/living system working in harmony
    - With the accuracy of silicon and the adaptability of carbon?