30μm Spacing 519-Electrode Arrays for In-Vitro Retinal Studies

Debbie Gunning

K. Mathieson[1], C. Adams[1], W. Cunningham[1],
A.M. Litke[2], E.J. Chichilnisky[3], M. Rahman[1]

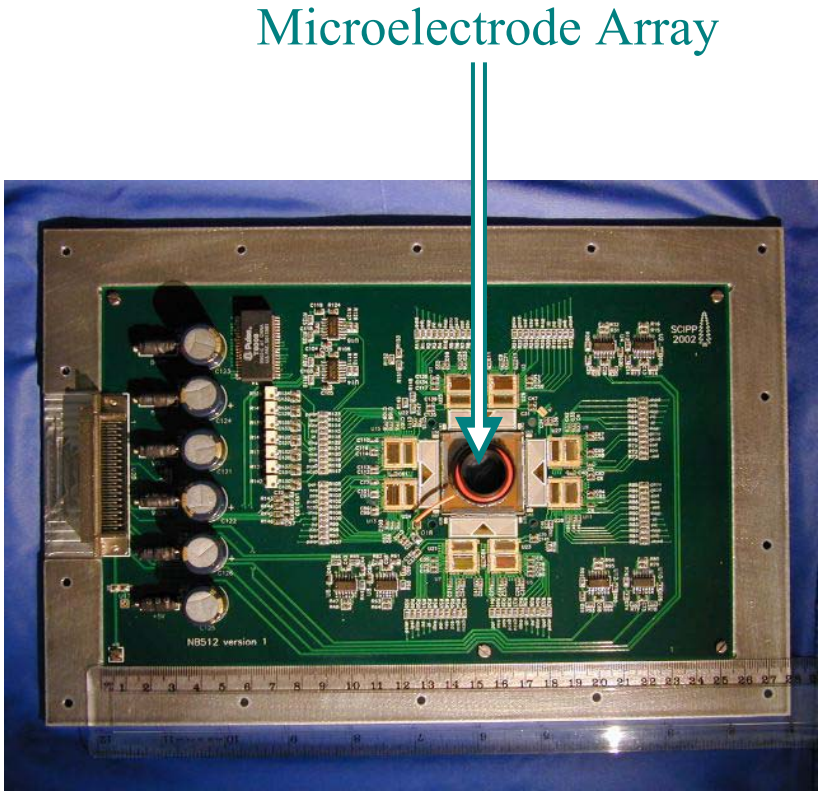
University of Glasgow[1], University of California Santa Cruz[2],
Salk Institute for Biological Sciences[3]

Outline:

- Arrays:
  - Design requirements
  - Fabrication processes
  - Electrical characterisation
- Tests:
  - Possibility of higher density arrays
  - Equivalent circuit predicting properties of future arrays
- Conclusions

Array Requirements

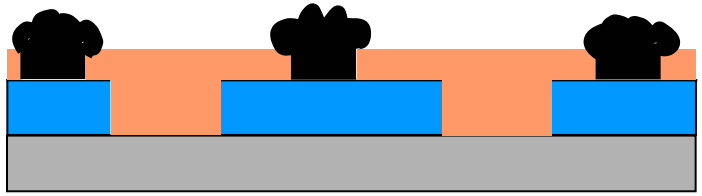
- Transparent electrode array
  - Indium Tin Oxide, transparent semiconductor commonly used in laptop displays
- High density of microelectrodes to ensure good detection of retinal cells
- Large area coverage to allow recording of correllated signalling
- Scalable fabrication process for future studies



512-channel readout board SCIPP, University of California Santa Cruz

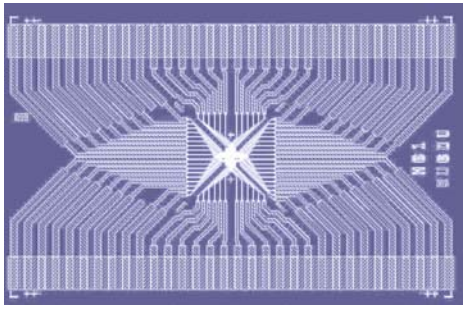
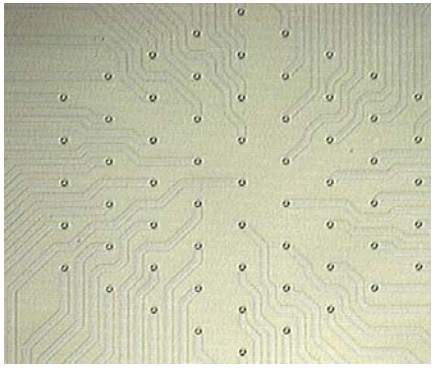
Fabrication of Arrays

- Spin Resist onto Indium Tin Oxide (ITO) /Glass substrates
- Selective UV exposure of Resist, where ITO is to be removed
- Develop sample cleaning off exposed (weakened) Resist
- Dry etch ITO using Methane and Hydrogen
- Insulate with 1µm Silicon Nitride (Si_3N_4)
- Etch holes in Si_3N_4 to allow electrical contacts to be made to ITO electrodes and bond pads
- Platinise electrodes to increase their surface area thereby decreasing impedance

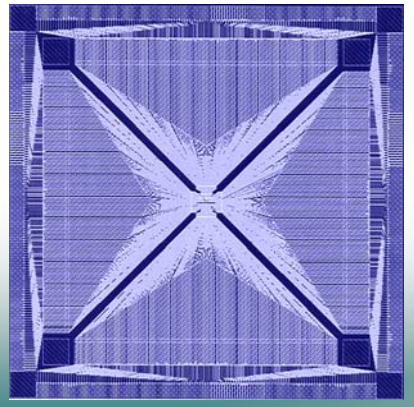
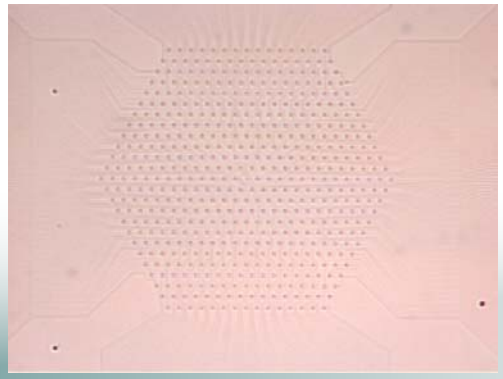
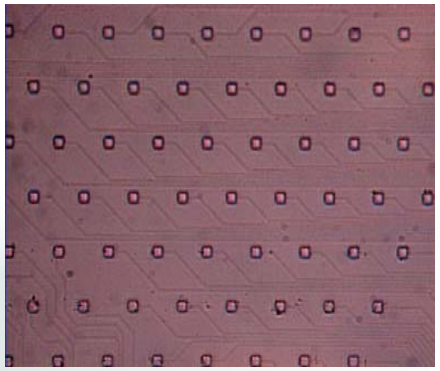


Array Designs

- 61 Electrodes:
  - 60µm spacing = 0.17µm^2 coverage, 30µm spacing = 0.04µm^2 coverage

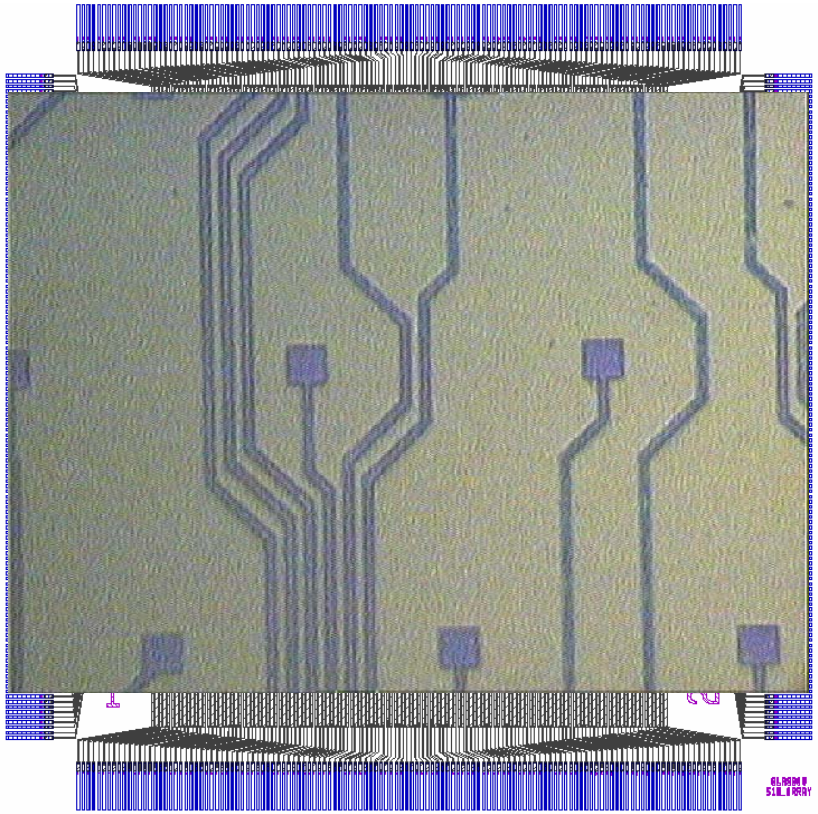




- 519 Electrodes:
  - 60µm spacing = 1.7µm^2 coverage, 30µm spacing = 0.4µm^2 coverage

Fabrication of 519-Electrode Arrays

- Electron-beam lithography:
  - Inner section (wires, electrodes)
  - Feature size range: 1µm-10µm
  - Using UVIII as a fast e-beam resist
- Photolithography:
  - Outer section (wires, bond pads, vias)
  - Feature size range: 10µm-100µm
- Reactive ion etching:
  - Gases such as $SiCl_4$, CH_4/H_2, SF_6 used to etch Ti, ITO and Si_3N_4 respectively throughout fabrication of array

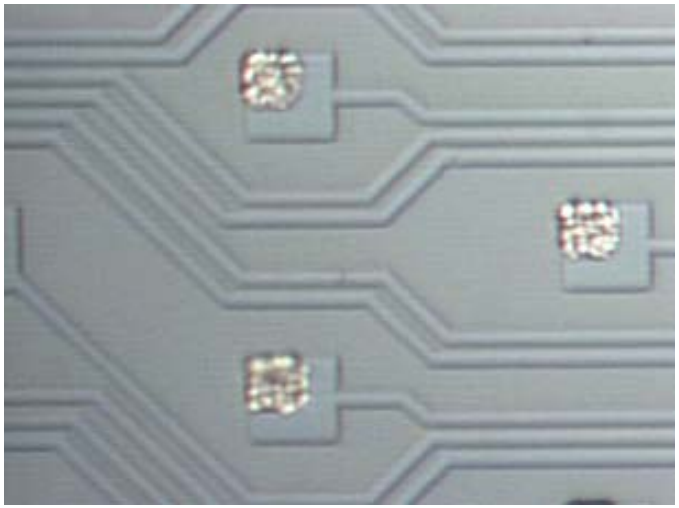


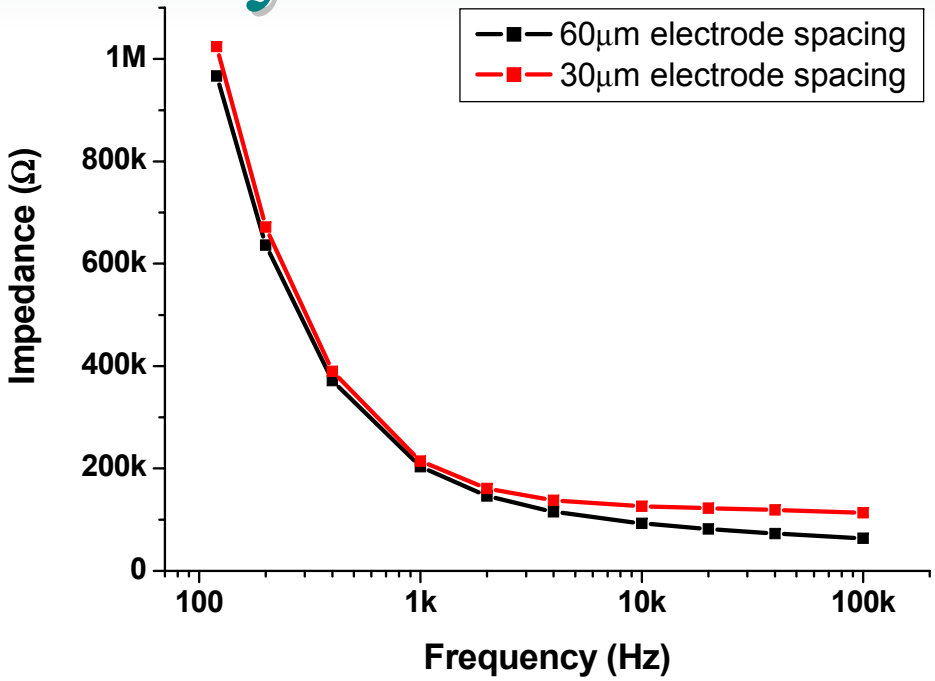
Characterisation of Array

- Short tests:
  - Ideally < 5 % of channels shorted
  - ~10% shorts possible i.e. ~50 shorts on 519-electrode array has been achieved

- Impedance Measurements:
  - Measure the electrodes response to a sinusoidal voltage stimulus
  - Impedance (magnitude) measured at 1kHz since retinal signals have a duration ~ 1msec
  - Confirms that the electrode impedance will not overwhelm small retinal pulses (<1mV)

30µm Electrode Array

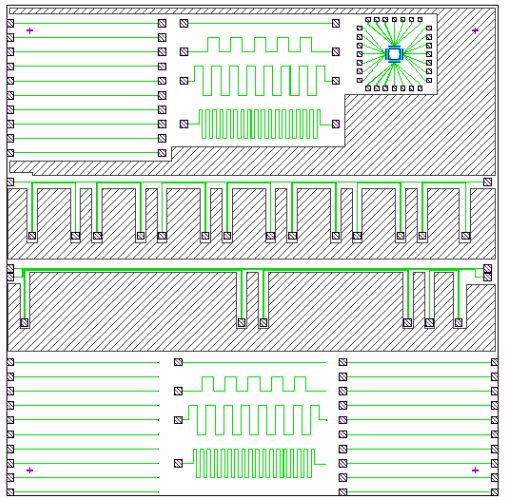


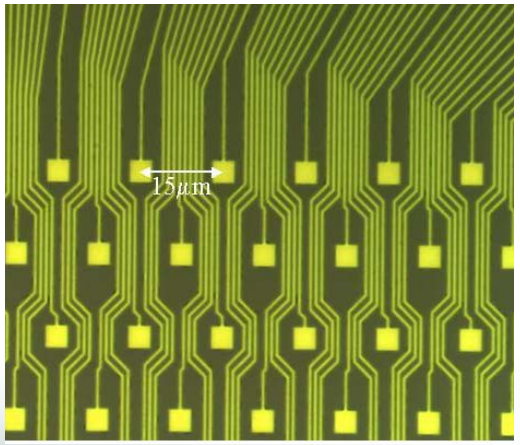


- Arrays platinise well, showing good electrical connection between electrode and bond pad
- Difference in impedances between 60µm and 30µm spaced electrodes, but not significant for retinal recordings

Tests for Limits of Fabrication

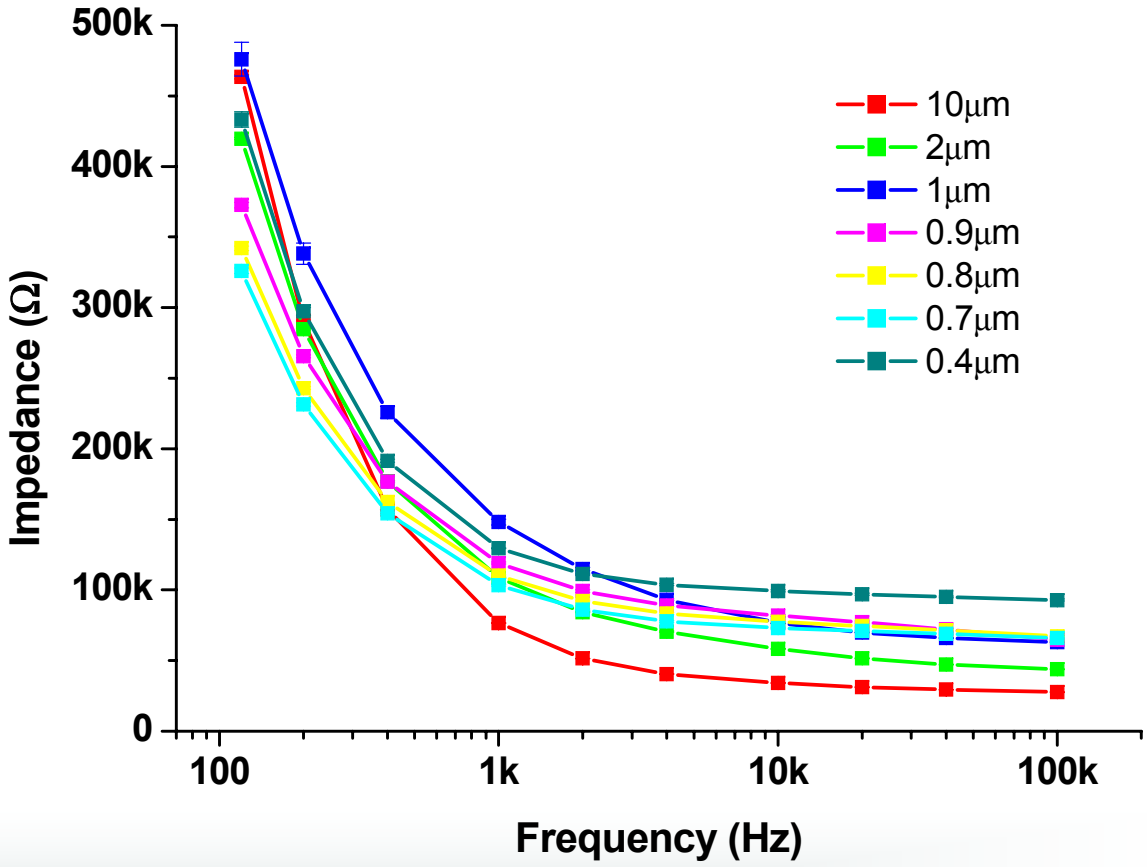
- What are the limits of fabrication for these arrays?
- Impedance and crosstalk tests on varying length, width and separation of traces
- Width: 10µm - 300nm
- Length: 40mm - 5mm
- Short tests 15µm spaced 519-electrode array
- Each ITO trace is passivated with Si_3N_4 and has a 5µm diameter electrode



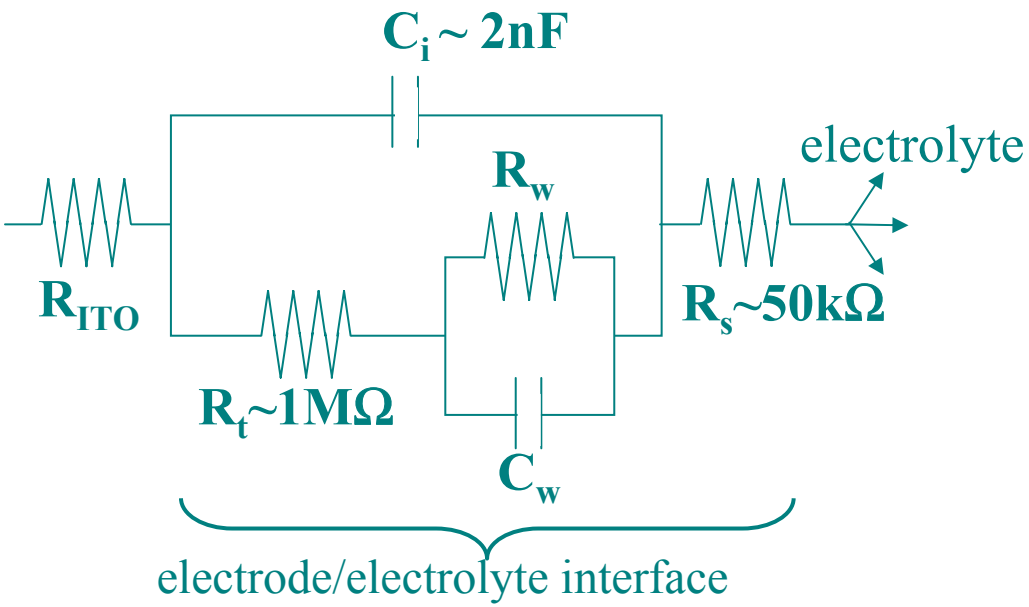


Results: Trace Width Investigations

- Limitations of this fabrication process ~300nm ITO width
- Impedances vary between 75kΩ and 150kΩ at 1kHz
- Impedance depends mainly on electrode/electrolyte interface not on ITO wire width



Modelling the Electrode



R_{ITO} ~ Resistance of ITO wire

R_s ~ Spreading resistance, $Z \alpha 1/\sqrt{A_{geometric}}$

C_i ~ Interfacial capacitance, $Z \alpha 1/A_{surface}$

R_t ~ Charge transfer resistance, $Z \alpha 1/A_{surface}$

R_w ~ Warburg resistance

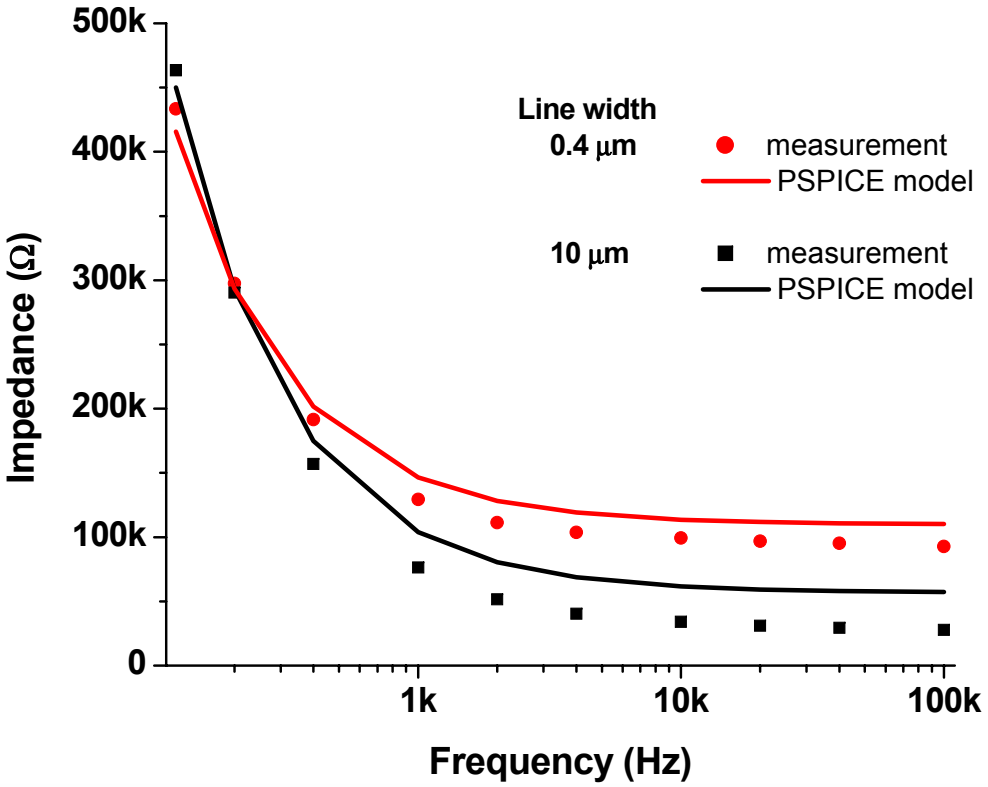
C_w ~ Warburg capacitance

- All parameters are fixed by theory and only $A_{surface}$ is altered (platinisation)

Model adapted from G.T.A. Kovacs (Stanford)

Simulations

- Model predicts trends in experimental data
- Small offset at high frequencies
  - Due possibly to variations in electrolyte concentration
- Model accurate enough over range of interest



Conclusions

- Possible to fabricate 519-electrode arrays with 30µm spacing
- Possible to fabricate ITO traces down to 300nm width using current processes
  - Impedance measurements indicate that they should record retinal signals in a manner similar to existing arrays
- Dominant contribution to impedance results from electrode/electrolyte interface
- High density arrays with large area coverage could offer a valuable insight into how the brain functions
  - The ability for microelectronics and computing to record and analyse large data sets means there is now a need for these arrays