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SIMULATION OF ELECTRODE-TISSUE INTERFACE WITH BIPHASIC PULSE TRAIN FOR EPI-RETINAL PROSTHESIS

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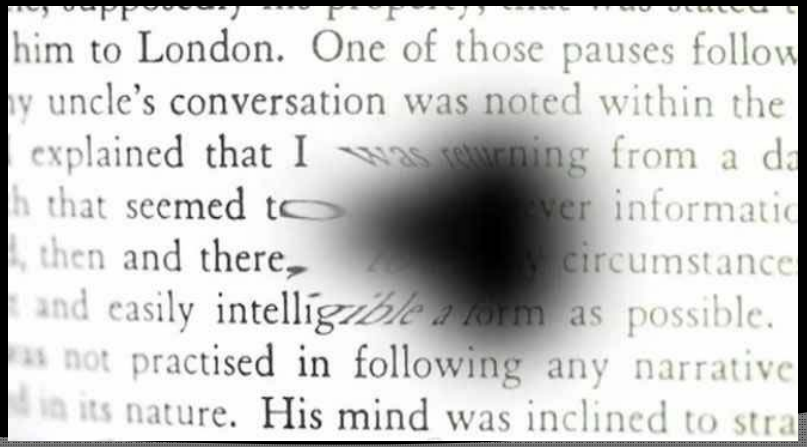
Optic Pathway

Blindness

- Loss of visual perception due to physiological/neurological factors
- Damage to optical pathway or light receiving neurons may cause blindness
- Age related Macular Degeneration (AMD) and retinitis pigmentosa (RP) are major diseases causing blindness



This is how a street scene looks with normal vision.

Example of Retinitis Pigmentosa

Visual Prosthesis

- Microelectronic implants that can partially provide visual perception to the blind.
- The principle behind it is externally stimulating small area of surviving neurons along the visual pathway.
- The different approaches are
  - Cortical implant
  - Optic nerve implant
  - Subretinal implant
  - Epiretinal implant

Background of epiretinal prosthesis

- Visual perception, called "phosphenes" could be elicited in human trials by electrically stimulating the inner surviving RGC layers first shown by Brindley and Lewin (1968)
- M Humayun and his co-workers and J Rizzo are among the few groups working with Multi-electrode arrays (MEA) for stimulating retinal cells in blind to obtain a good quality of perception.
- Starting with 4 electrodes, currently researchers use a 60 electrode array for better temporal and spatial resolution.
- This, on human trial, was able to differentiate basic forms of motion, perceive light and dark and even shoot baskets.

Why simulation of electrical stimulation?

- Epiretinally placed electrodes when interfaces with the retinal tissue, the effects can be studied
- electric potential generated
- electric field distribution
- charge distribution
- Optimization of the design of MEA and effect of varying pulse width are the main objectives behind simulation study.
- The electric current physics of AC/DC module of COMSOL 4.3a is used to solve the electrode tissue interface problem.

Assumptions

- Inhomogeneous retinal tissue layers (9 layers) differentiated by conductivity and permittivity values
- Electrode placed epiretinally i.e., above vitreous layer
- Biphasic 1 millisecond current pulse used at the stimulating electrode surface for electrical stimulation of RGC layer

Electrode specification

- Electrode Substrate
  - Polymide
- Electrode material
  - Platinum
- Thickness of electrode
  - 1 micron
- Safe limit for charge injection

$$I = (d/2T)(\pi * 10k)^{0.5} \qquad k=1.5$$

Equations Involved

Considering electric current in a conductive media, the model solves the continuity equation with a current source Qj given by

$$\Delta.J=Qj$$

From Ohm's law,

$$J = \sigma E + Je$$

where σ is the electrical conductivity (SI unit: S/m), and Je is an externally generated current density (unit: A/m2).

The static form of the equation of continuity then states

$$\nabla \cdot J = -\nabla \cdot J (\sigma \nabla V - Je) = 0$$

To handle current sources, it can be generalized to

$$-\nabla \cdot J (\sigma \nabla V - Je) = Qj$$

Boundary Conditions

Interfaces between different media and interior boundaries is continuity, $n_2 \cdot (J_1 - J_2) = 0$ which is the natural boundary condition.

Domain/Boundary name	Type of condition	Equation (s)
Vitreous fluid Retinal layers Electrode thickness Insulating substrate	Current Conservation	$\nabla \cdot J = 0$ $J = \sigma E$ $E = -\nabla V$
Bounding box	Electric insulation	$-n \cdot J = 0$
Entire domain	Initial Value	V2=0
Stimulation electrode	Electric current	I = pulse(t)
Ground electrode	Ground	V = 0

Notations:

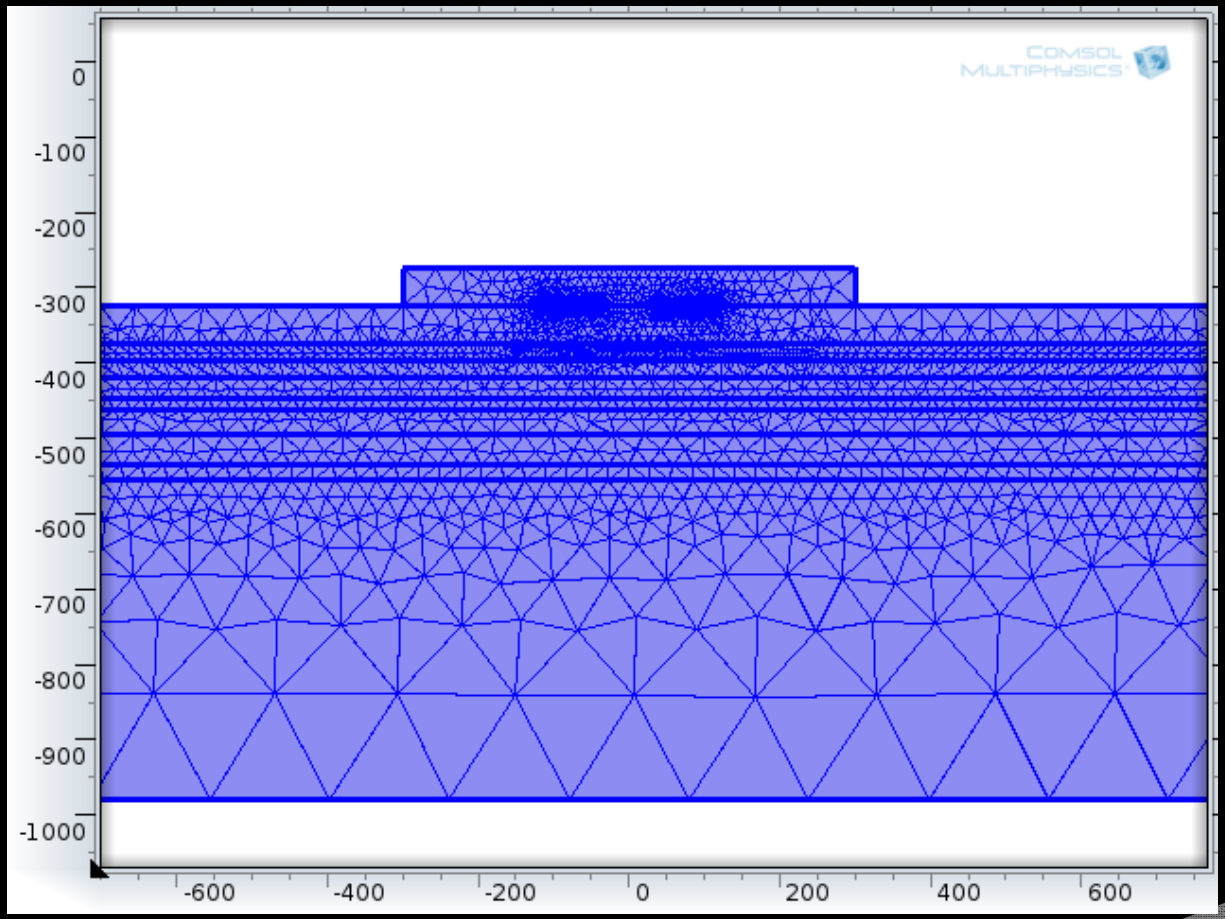
J - current density on the electrode, E - electric field vector,

Pulse(t) - amplitude of the current pulse stimulus at time t, σ - conductivity of the physiological medium, n - normal vector.

Study steps

- Time domain study
  - Varying electrode diameter (10 to 500 micron)
  - Varying pulse train parameters
- Frequency domain study
  - Impedance study with varying distance between the retina

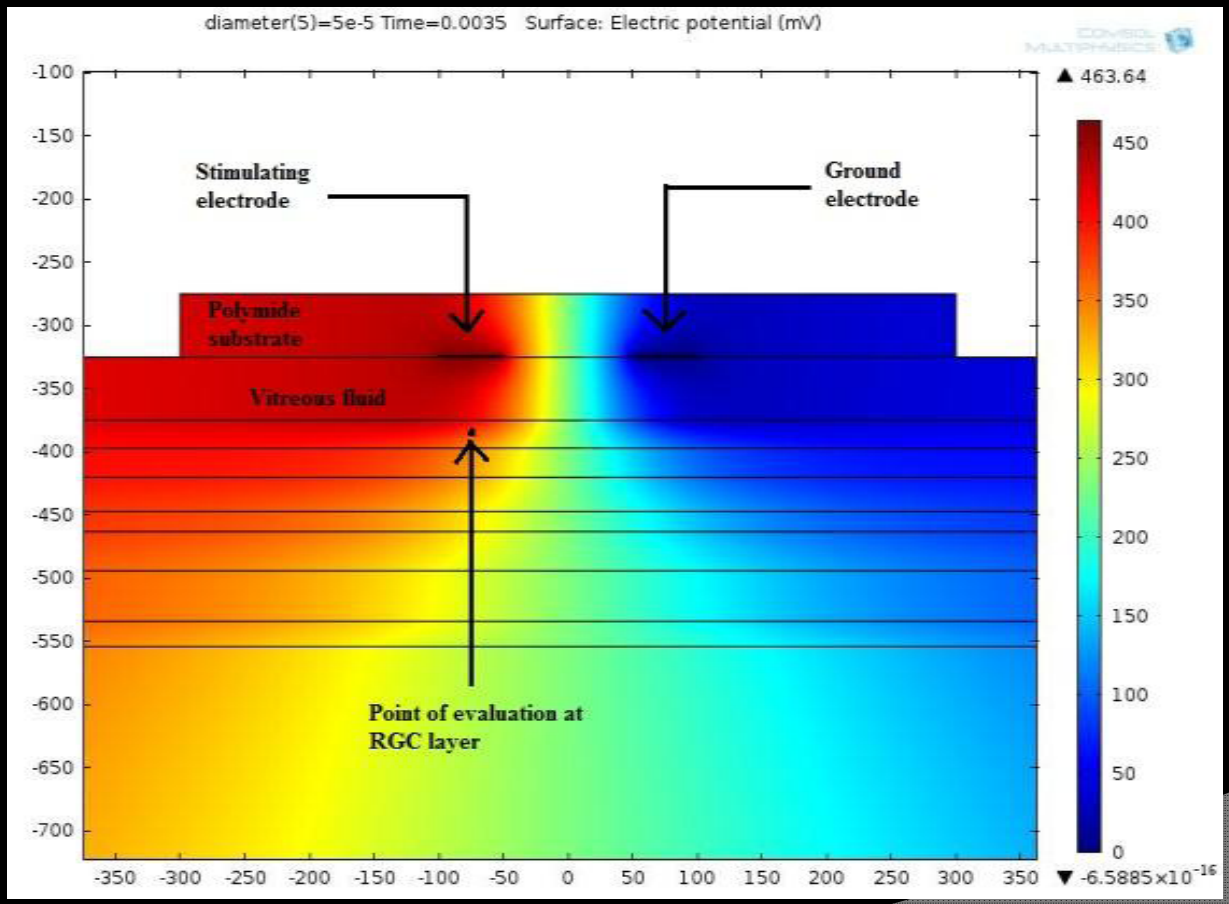
Meshing



Free triangular meshing with refinement at the layer of interest

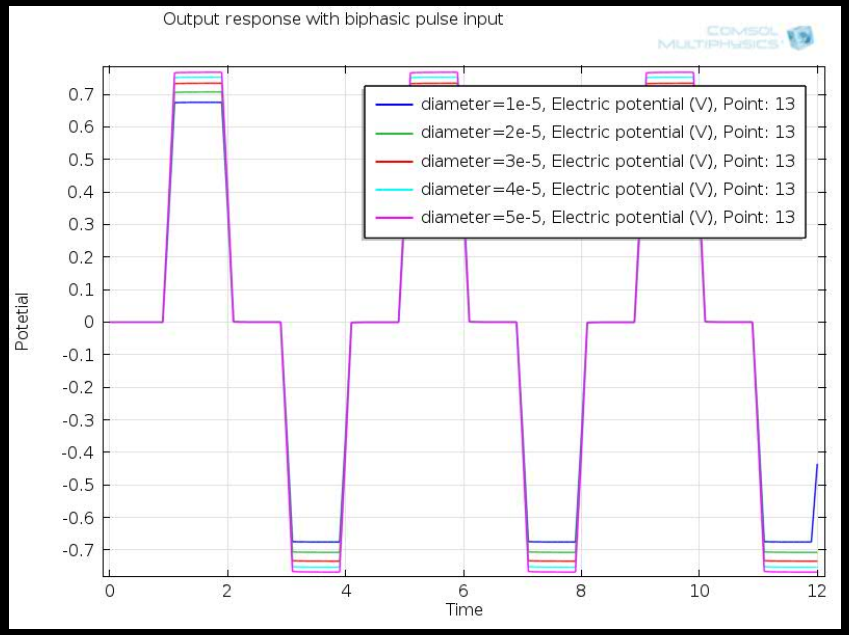
Results

- 2 D representation of the electrode tissue interface

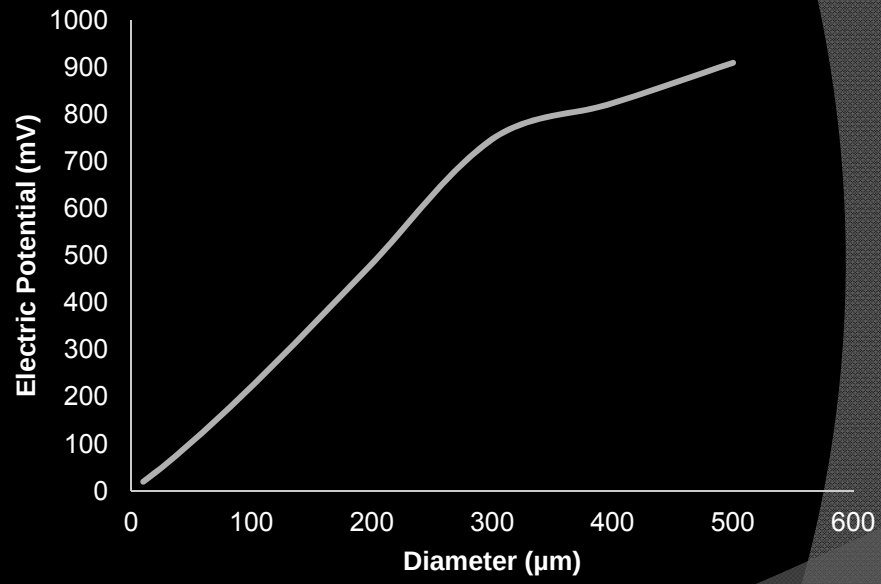


Electric potential distribution across the retinal layers at the onset of positive cycle of the biphasic pulse

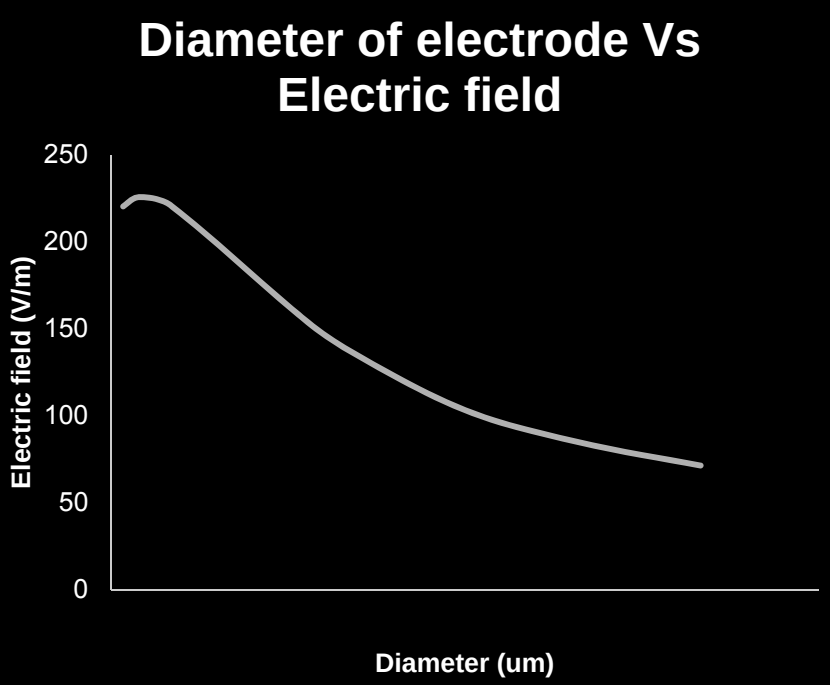
Variation of Electric potential

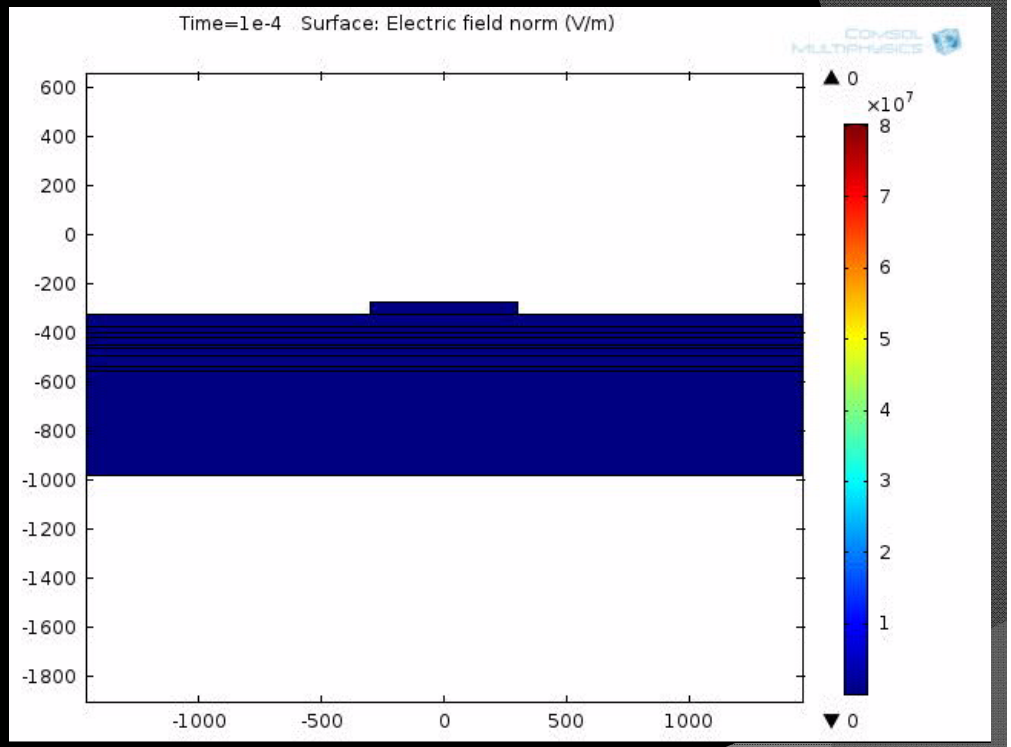


Diameter Vs Electric potential at a point in the RGC layer



Variation of Electric field





Variation of pulse train

- Variation of amplitude
  - Proportional increase in output response
- Variation of interpulse duration/delay
  - Duration of peak charge delivery time inversely proportional
- Variation of frequency
  - Yet to be studied

Impedance Study

- The electrode tissue impedance was observed with varying frequency (1~105 Hz).
- The impedance varied to a large extent with the variation of vitreous thickness below 1 kHz

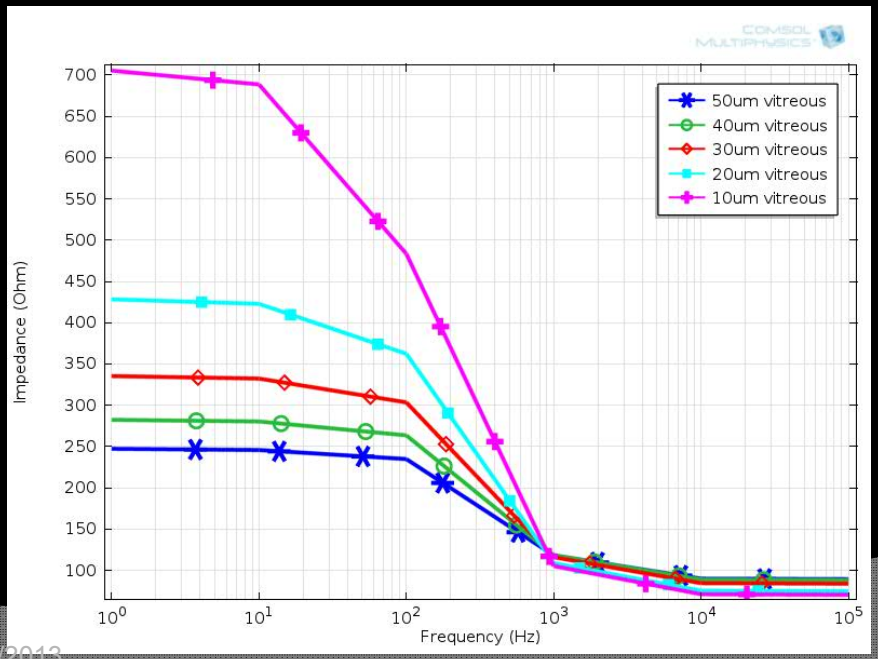


Figure shows Impedance within the retinal layer with varying distance from electrode

Future work

- Extending geometry to 3D for design optimization
- Variation of frequency of the input pulse
- Heat generated due to the electrodes at the retinal layers
- Validation with experimental data.

Conclusions

- A theoretical study on stimulation of retinal tissue by epi-retinal electrodes.
- Electric potential at a point in the RGC layer increased with increasing diameter
- Electric field decreases exponentially with increasing diameter
- Impedance was found to be a function of frequency as well as distance from the electrode.
- Variation of amplitude has proportional change in output response.
- Increased interpulse delay caused decreased peak stimulation time

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Thank You!