Simulations of Micro-electrode and Neuron Interfaces Enable Long-term and High Fidelity Recordings

P. Wijdenes[1], H. Ali[2], N. I. Syed[3], C. Dalton[2]

[1]Biomedical Engineering Program [2]Department of Electrical and Computer Engineering
[3]Alberta Children's Hospital Research Institute. University of Calgary, Calgary, Canada

Introduction: While the use of micro- electrodes has advanced long-term recordings of single neuron activity (Figure 1), their low sealing resistance (defined as the resistance that restricts current leakage through the liquid gap between a neuron and an electrode in a lab on a chip device) considerably decreases the signal resolution. Here we report simulations of sealing resistance from a novel micro-electrode with nano-edges that permits long-term (≥ 1 month) and high fidelity recordings.

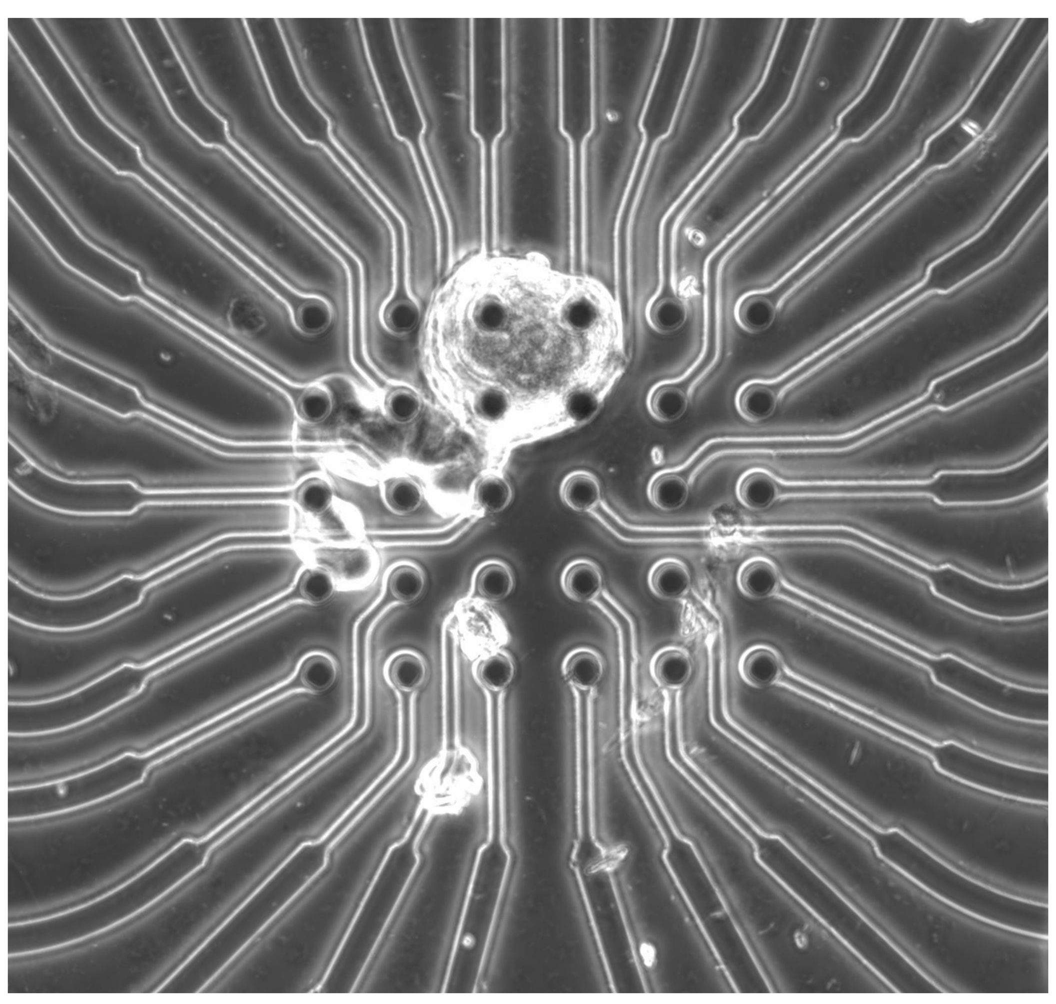

Figure 1. Single invertebrate cell on a multi electrode array

Computational Methods: We improved on a previous neuron-electrode interface model [1-2] using the *Electric Currents* module in COMSOL Multiphysics (COMSOL Inc., Burlington MA) (Figure 2) to determine the effect of the nano-edge on the sealing resistance (modeled values given in Table 1). While a standard free tetrahedral mesh was used for the neuron, a free triangular swept mesh was implemented to mesh the smaller portions of the simulation (thin gold electrode and nano-edge).

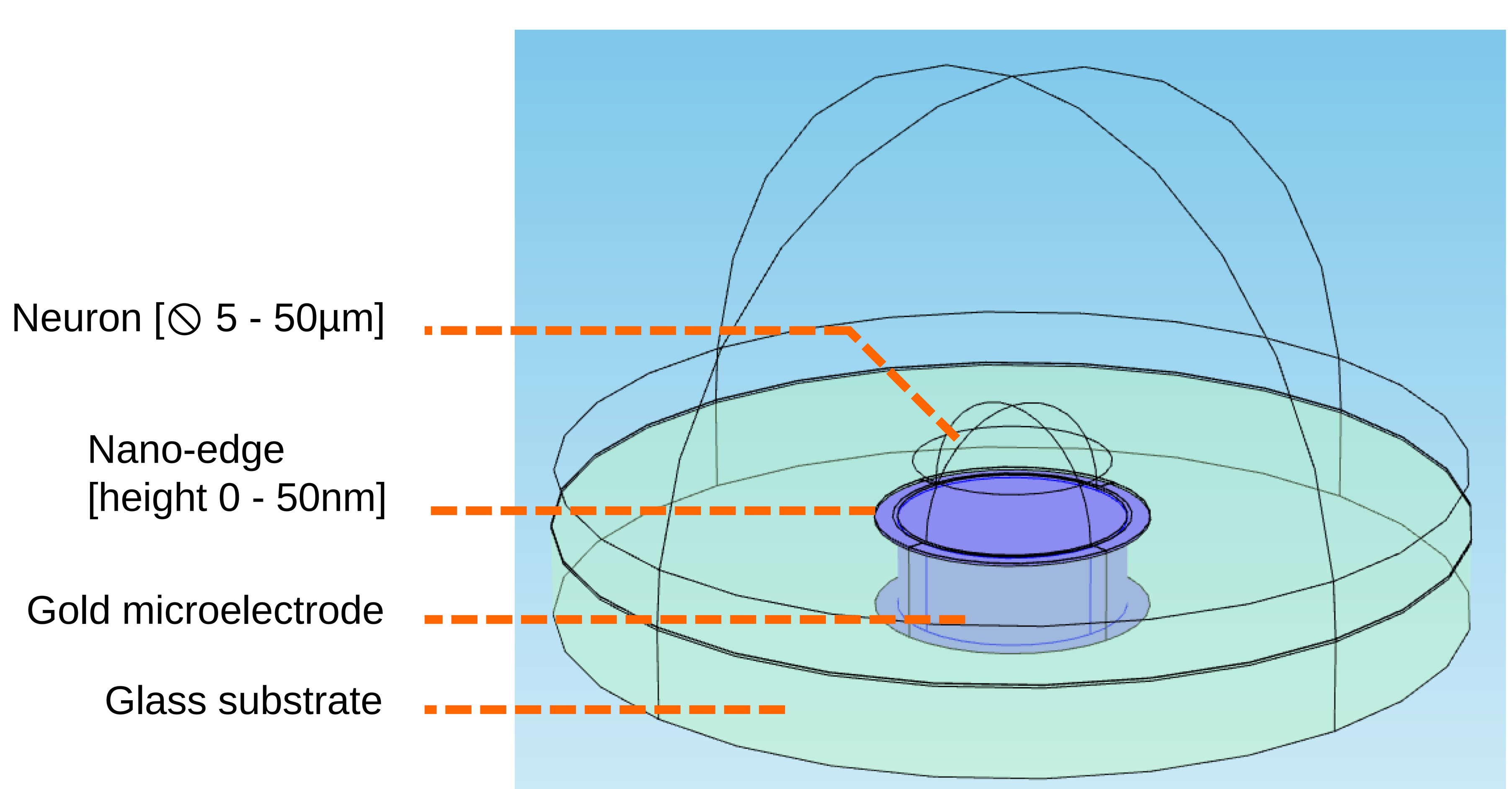

Figure 2. Modeled domains and variation ranges

Materials	Electrical Conductivity	Relative Permittivity
Gold electrode	45.6e6 [2]	6.9 [2]
Cell Membrane	7.93e-8 [3]	5.6470 [4]
Extracellular Fluid	0.84 [5]	80 [5]
Intracellular Fluid	0.68 [5]	80 [5]
Dielectric nano-edge	3.5e-15 [6]	4.1 [6]

Table 1. Values of electrical conductivity and relative permittivity

Results: The sealing resistance values varied significantly (from 0.66MΩ to 8.71MΩ, Figures 3 and 4) depending on the morphologic changes that were simulated by altering the height of the nano-edge and the size of the simulated neuron. In comparison, traditional micro-electrodes with no nano-edge only create a sealing resistance of 1.0 ± 0.2 MΩ. A higher signal-to-noise ratio was experimentally verified with fabricated devices.

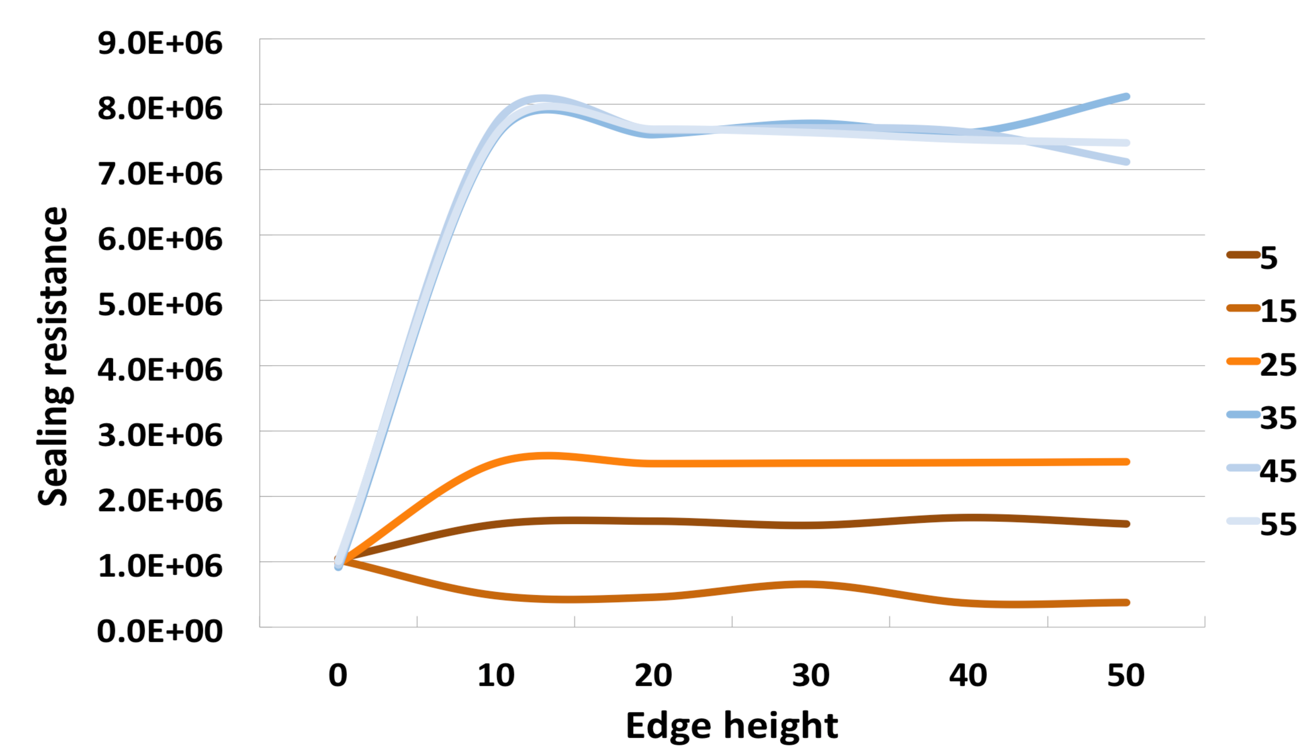

Figure 3. Variation of the sealing resistance for different cell diameters (electrode's diameter fixed at 30µm)

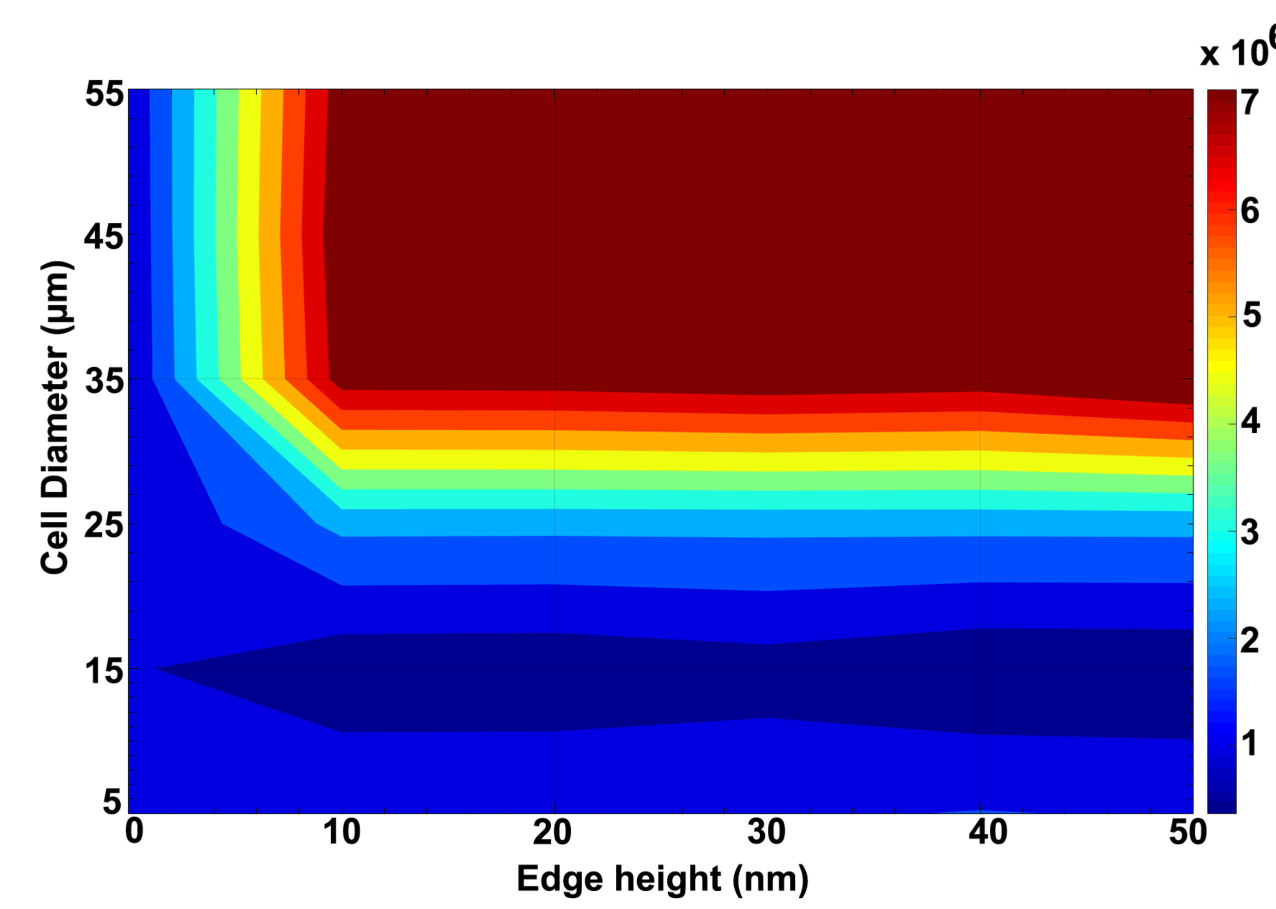

Figure 4. Variation of the sealing resistance depending on the cell diameter and the edge height (electrode's diameter fixed at 30µm)

Conclusions: The simulations support that our newly developed micro-electrodes with nano-edges permit a significantly higher sealing resistance that in turn allows for a better signal-to-noise ratio. These effects have been verified experimentally, and will now enable better understanding of brain function, pathological neural conditions to better develop bionic hybrids and drug discovery lab on a chip devices.

References:

1. Buitenweg, et al., Finite element modeling of the neuron-electrode interface. IEEE Eng Med Biol Mag. 19(6): p. 46-52 (2000)
2. Ghazavi, et al., Effect of planar microelectrode geometry on neuron stimulation: finite element modeling and experimental validation of the efficient electrode shape. J Neurosci Methods. 248: p. 51-8 (2015)
3. Martina, et al., Recordings of cultured neurons and synaptic activity using patch-clamp chips. Journal of neural engineering. 8(3): p. 034002 (2011)
4. Molleman, A., Patch clamping: an introductory guide to patch clamp electrophysiology. John Wiley & Sons (2003)
5. Elia, S. and P. Lamberti, The Reproduction of the Physiological Behaviour of the Axon of Nervous Cells by Means of Finite Element Models, in Innovations in Intelligent Machines-3. Springer. p. 69-87 (2013)
6. Taghavi, M. and M. Bahrami, Design and simulation of a micro-channel for separating the particles with nearly constant dielectrophoretic force in channel space. Molecular Simulation. 37(10): p. 865-874 (2011)

NSERC CRSNG

Excerpt from the Proceedings of the 2016 COMSOL Conference in Boston

Antje Graupe Pryor Foundation