Hierarchical Micro- and Nano-Scale Devices
for Neural Electrophysiological Applications

Abstract:
The initial intent of this project consisted of the design and fabrication of silicon dioxide trenches to be used for the synthesis of horizontally- and vertically-aligned carbon nanotubes directly on a chip. Since the growth of aligned nanotubes on the fabricated structures was found to be unsatisfactory, an alternative approach was pursued here to combine (i) the design and fabrication of an integrated circuit (IC) and (ii) the synthesis ex situ of electrically insulated and aligned carbon nanotube arrays within a single device. The final device is intended for applications in the field of neural prostheses and electrophysiological imaging.

Summary:
Three geometrically different types of IC platforms have been designed and fabricated. Each device features 224 individual channels and has identical geometric arrays of patterned electrical connections at the external periphery. The central recording area for each integrated circuit consists of an array of equi-spaced electrode tips with the capability to map neural signals at increasingly finer spatial resolution. The device platform with the coarsest spatial resolution is intended to overcome many of the problems associated with conventional microelectrodes, and to stimulate and record extracellular biopotentials. The circuit with the intermediate spatial resolution has a smaller and more densely packed recording array designed to monitor the interaction between one cell and selected neighboring cells. The device platform with the finest spatial resolution is intended for probing the functions of individual cells.

The IC platforms of the first two types were fabricated using optical lithography techniques. Electron-beam (e-beam) lithography was used on the central portion of the device with the finest spatial resolution to achieve minimum feature sizes of 200 nm.

The three different types of devices have been manufactured and characterized by optical, scanning electron and atomic force microscopy, showing that the specific manufacturing processes which have been selected have proven to be successful.

Carbon nanotubes were synthesized ex situ on silicon dioxide substrates using a chemical vapor deposition method. The carbon nanotube arrays were subsequently infiltrated with in situ polymerized polymethylmethacrylate to achieve electrical insulation between adjacent nanotube bundles. The resulting composite construct between the IC and the cells exhibited electrical conductivity and connectivity between two faces of the composite along the length of the nanotubes. The composites were then positioned in intimate contact with the previously manufactured multiple electrode array, therefore constituting an interface layer between underlying IC platform and neuronal cells.

Current research efforts lie in the standardization of the fabrication conditions, in order to reduce defects and increase quality of the finished devices. The three types of devices can be used for future experimental recordings of field potentials, action potentials and ionic potentials respectively at the multicellular, intercellular and intracellular levels.

References:
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Figure 1:

Optical micrograph at three different magnifications respectively for:

(A) the multicellular device,

(B) the intercellular device, and

(C) the intracellular device.

(A) 3.7 mm 220 µm 220 µm

(B) 3.7 mm 22 µm 22 µm

(C) 300 µm 15 µm 3 µm