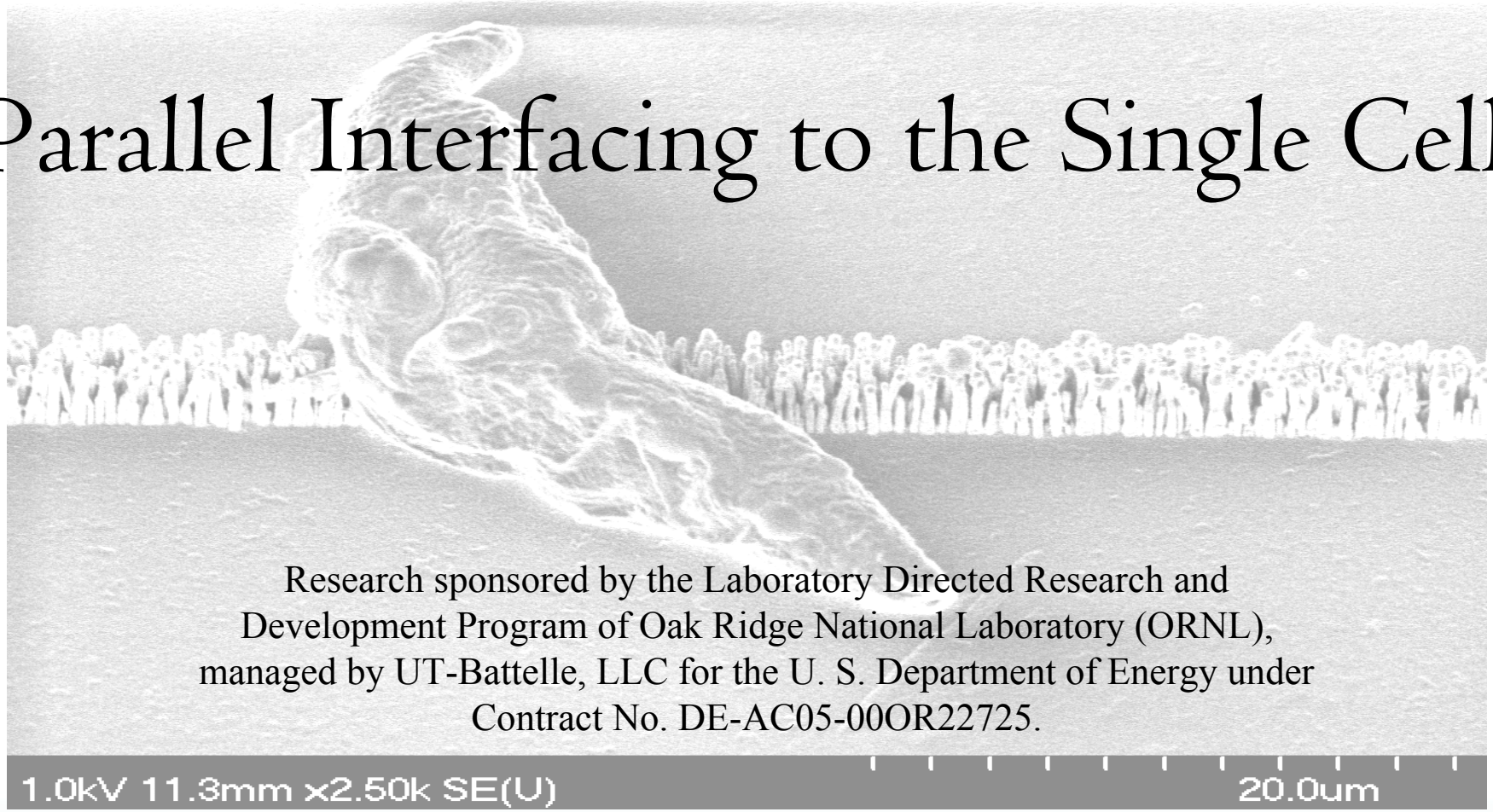
Fabrication of High Aspect Ratio Vertically Aligned Carbon Nanofiber-Based Electrochemical Probes for the Probing of Intact Whole Cells

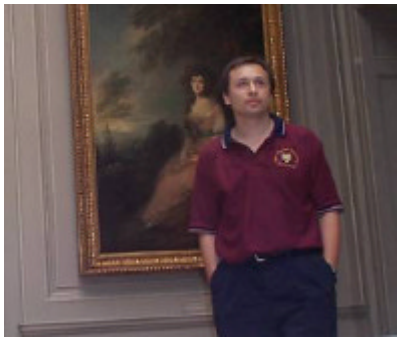


Research sponsored by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory (ORNL), managed by UT-Battelle, LLC for the U. S. Department of Energy under Contract No. DE-AC05-00OR22725.

Mike Simpson

Michael Guillorn

Vladimir Merkulov



Tolik Melechko

Derek Austin

Guy Griffin

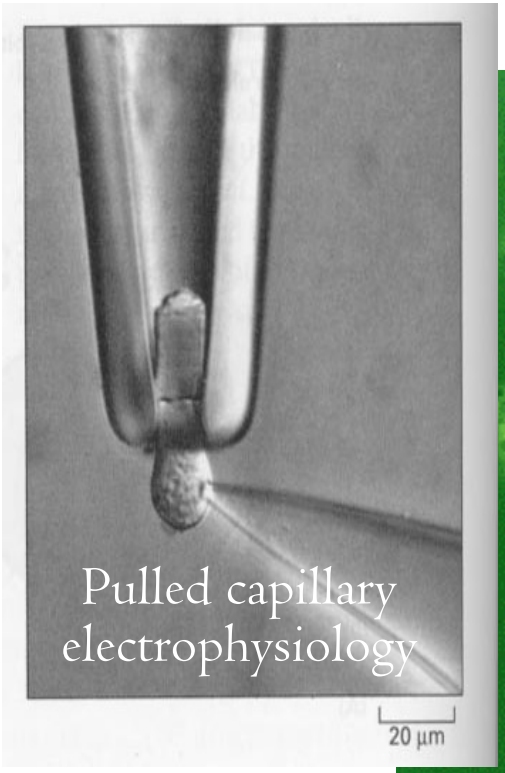
Doug Lowndes

Stephen Jacobson

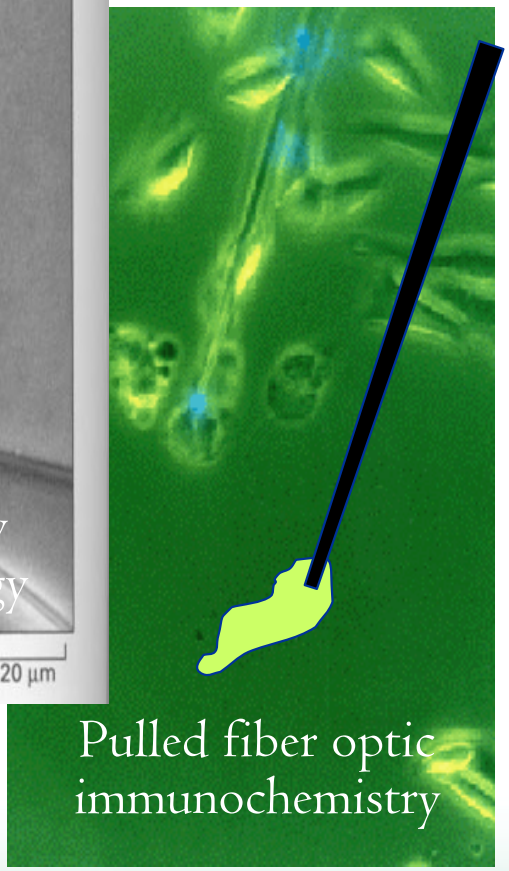
Chris Culbertson

TD Chung

The ability to interface to the cellular world is an integral aspect of basic research and applied biotechnology

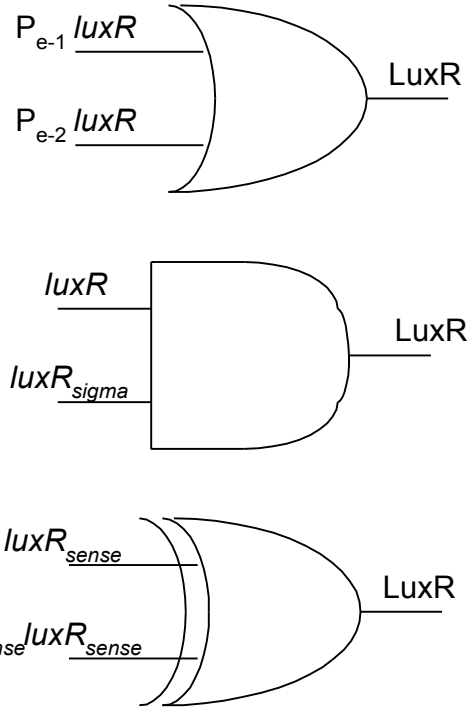


Pulled capillary electrophysiology



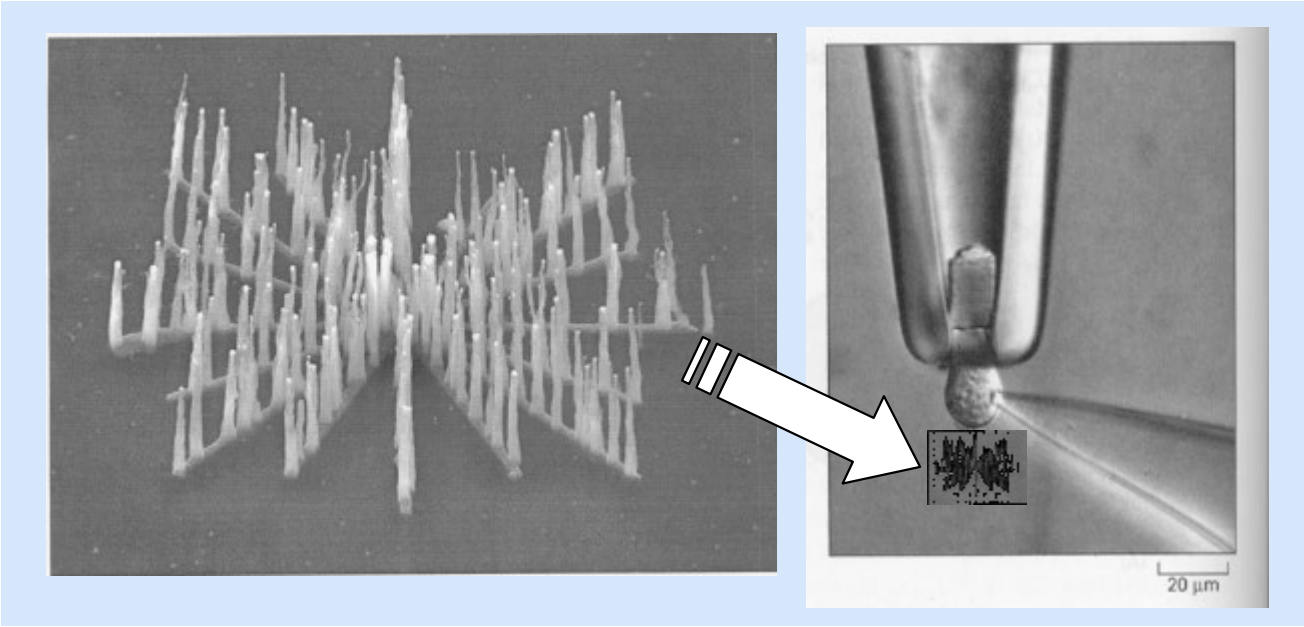
Pulled fiber optic immunochemistry

Environmental Monitoring



Transcriptional Logic Advanced Computing

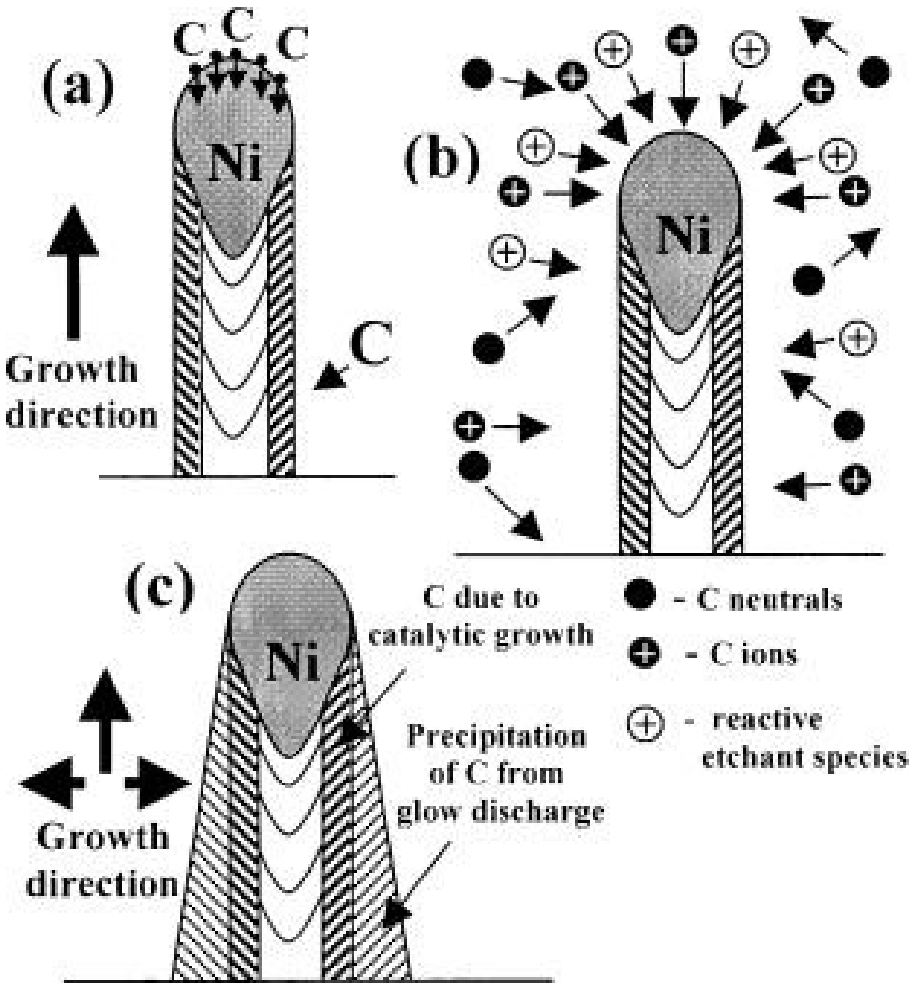
The carbon nanofiber provides an approach for massively parallel integration with the cell



Based on the development of techniques to generate vertically aligned carbon nanofiber arrays.

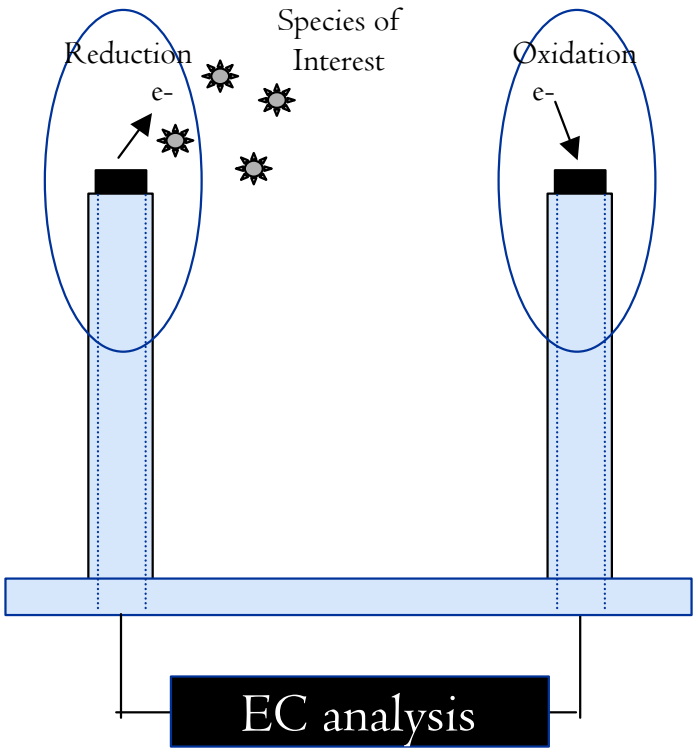
The Carbon Nanofiber...

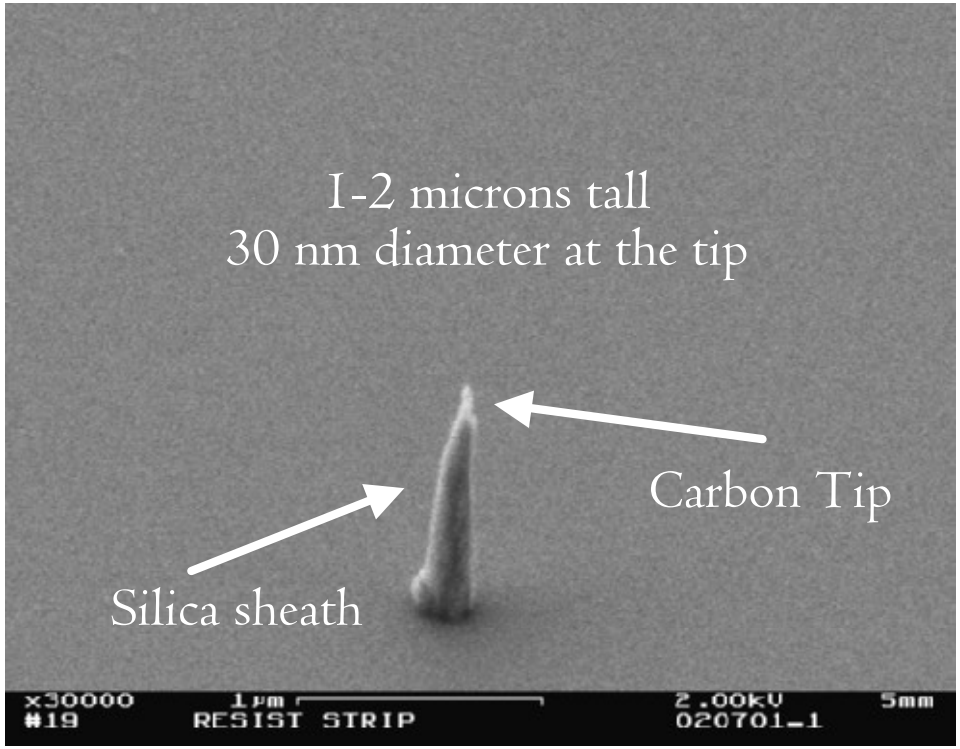
High aspect ratio nanoscale electron conductors that may be synthesized in highly deterministic patterns.



Merkulov, et al, Applied Physics Letters, Vol. 79, No. 8, pp. 1178–1180, 20 August 2001

Fiber array structures may be fabricated specifically for application as subcellular-scale electrochemical probes





7 microns - typical diameter of mammalian cell

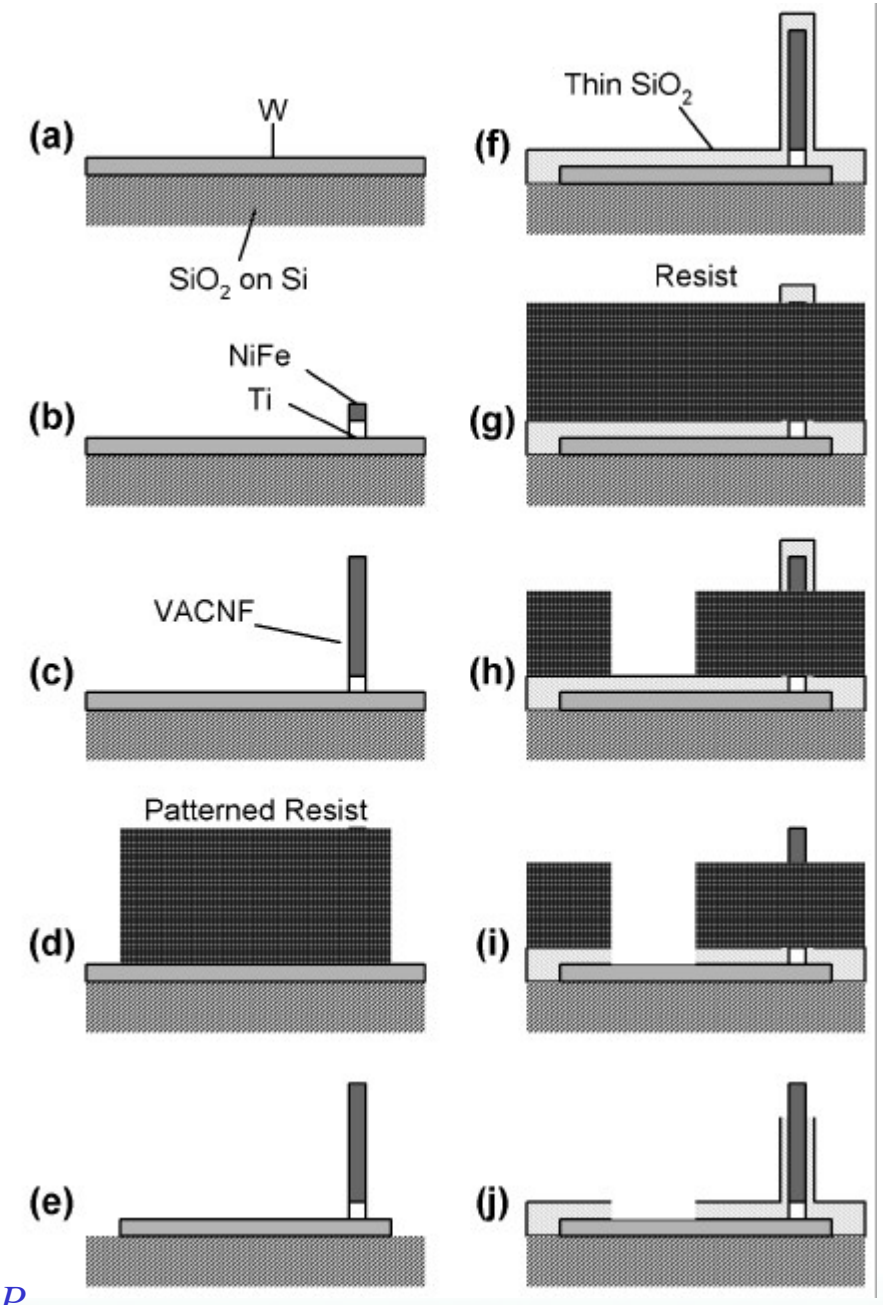
Devices may be fabricated on transparent substrates, enabling integration with optical microscopy

High Aspect Ratio Structures

Transparent Substrate

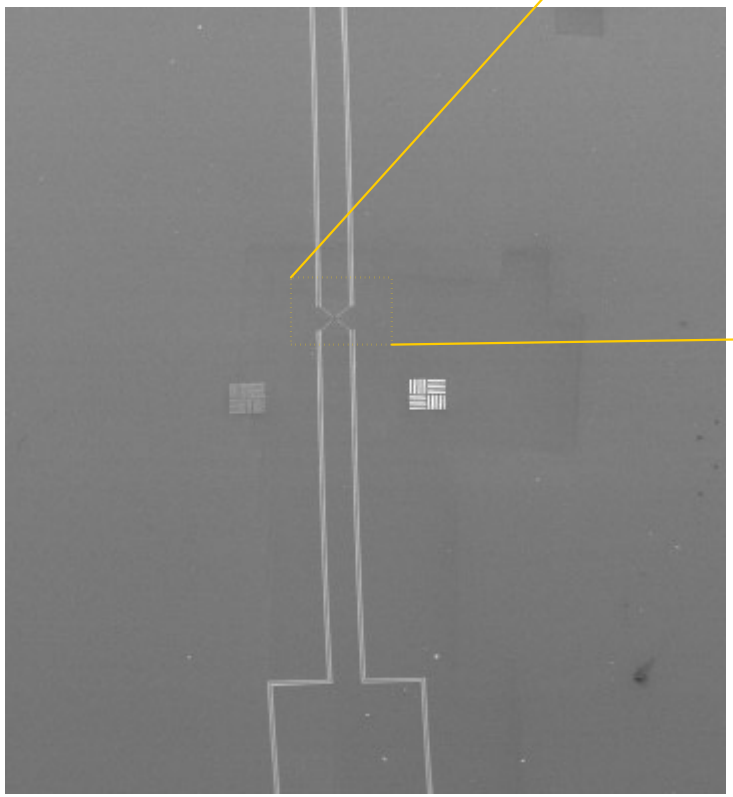
Individual Addressability

Controlled Exposure of Tip

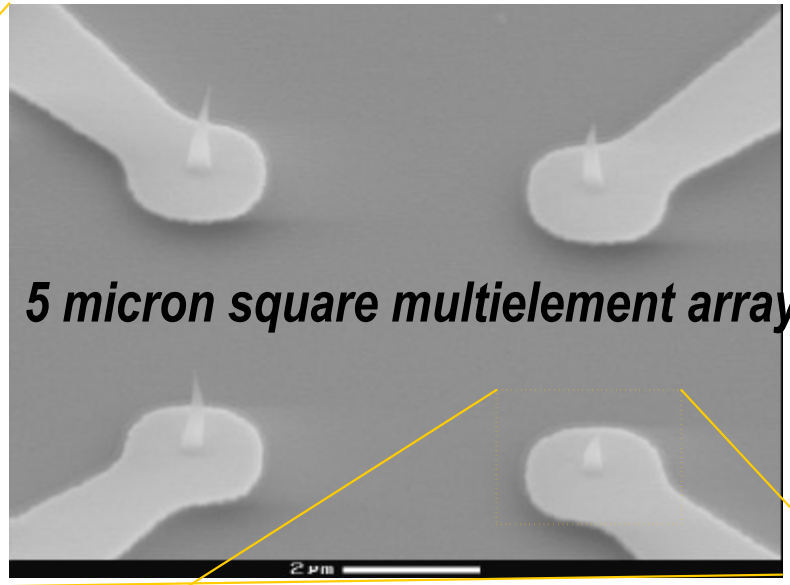


M.A. Guillorn, T.E. McKnight, et al, submitted to JAP

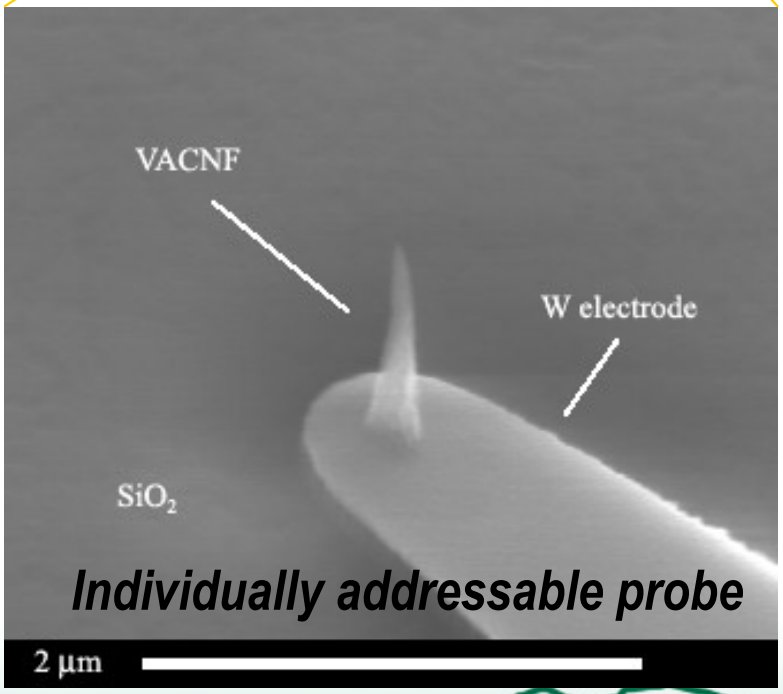
Individually addressable, multielement nanoarrays



4-element nanofiber array with tungsten leads to periphery of chip

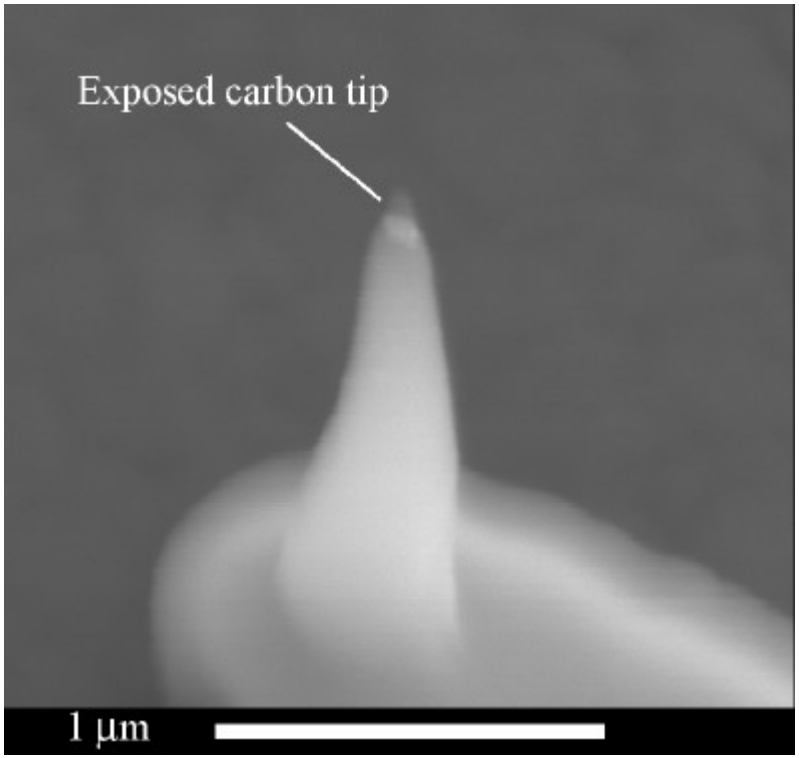


5 micron square multielement array

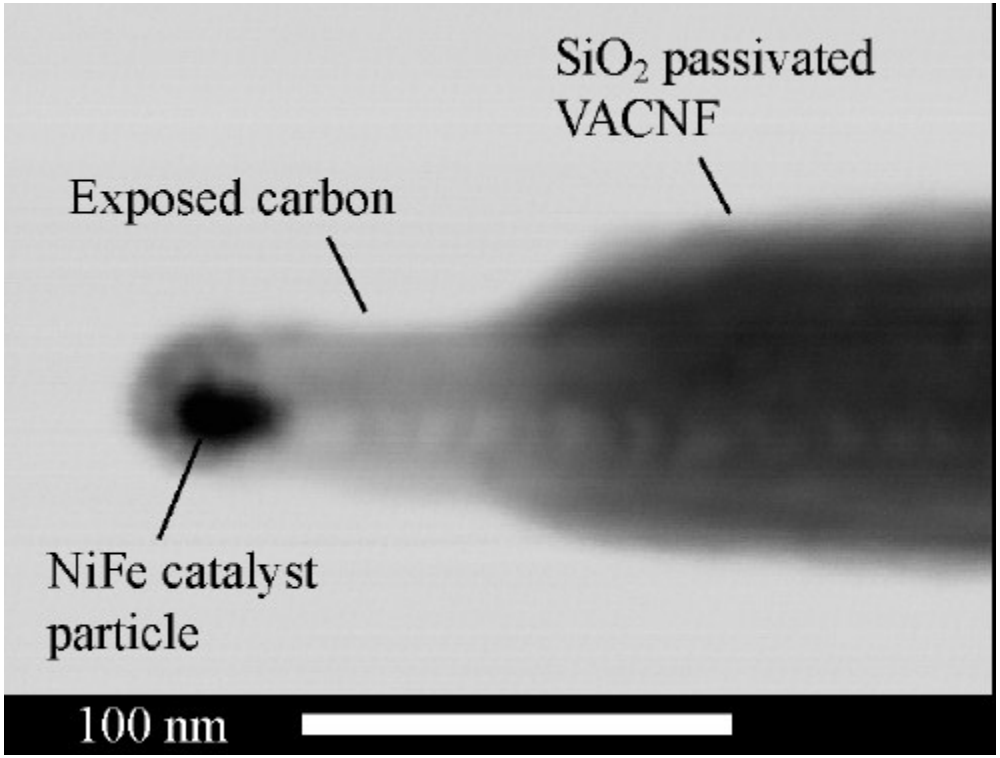


Individually addressable probe

The electrochemically-active surface area can be selected by controlling the depth of protective photoresist



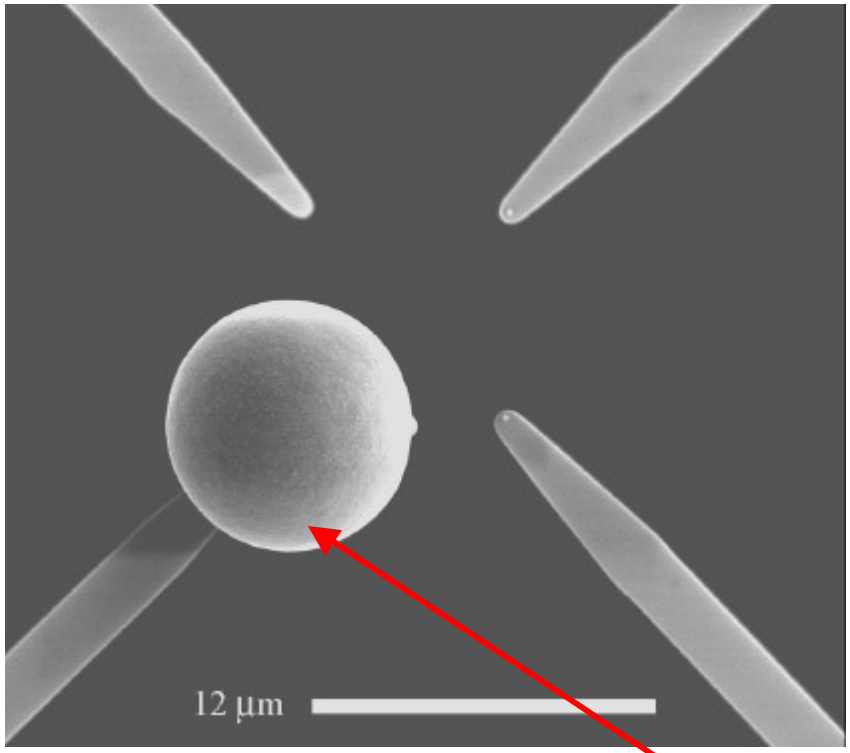
SEM image showing a completed device

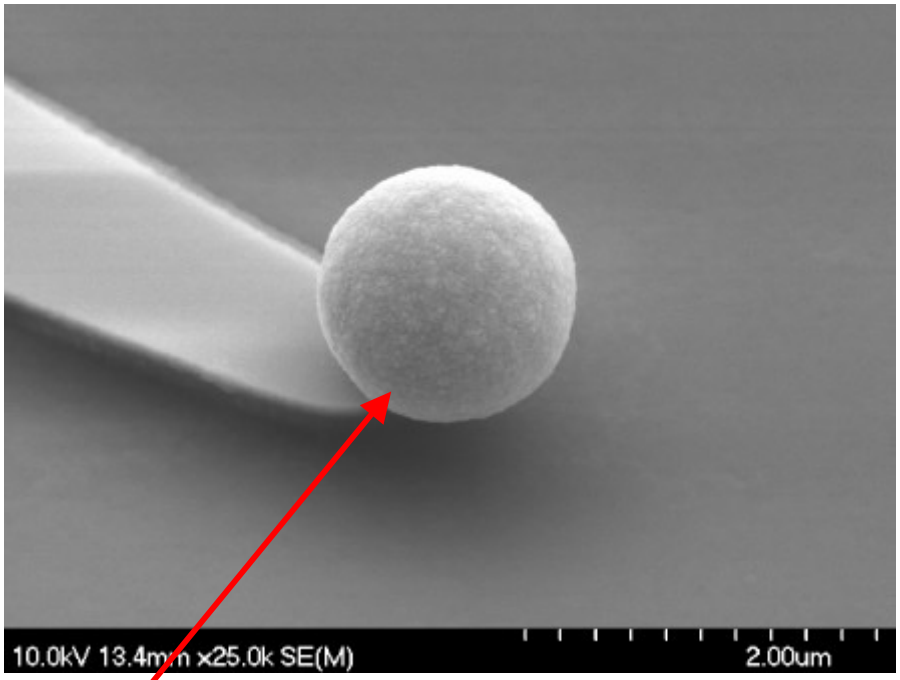


STEM image showing a completed VACNF probe tip that was removed from the substrate. The oxide layer has been removed from the tip.

Quality of the PECVD oxide

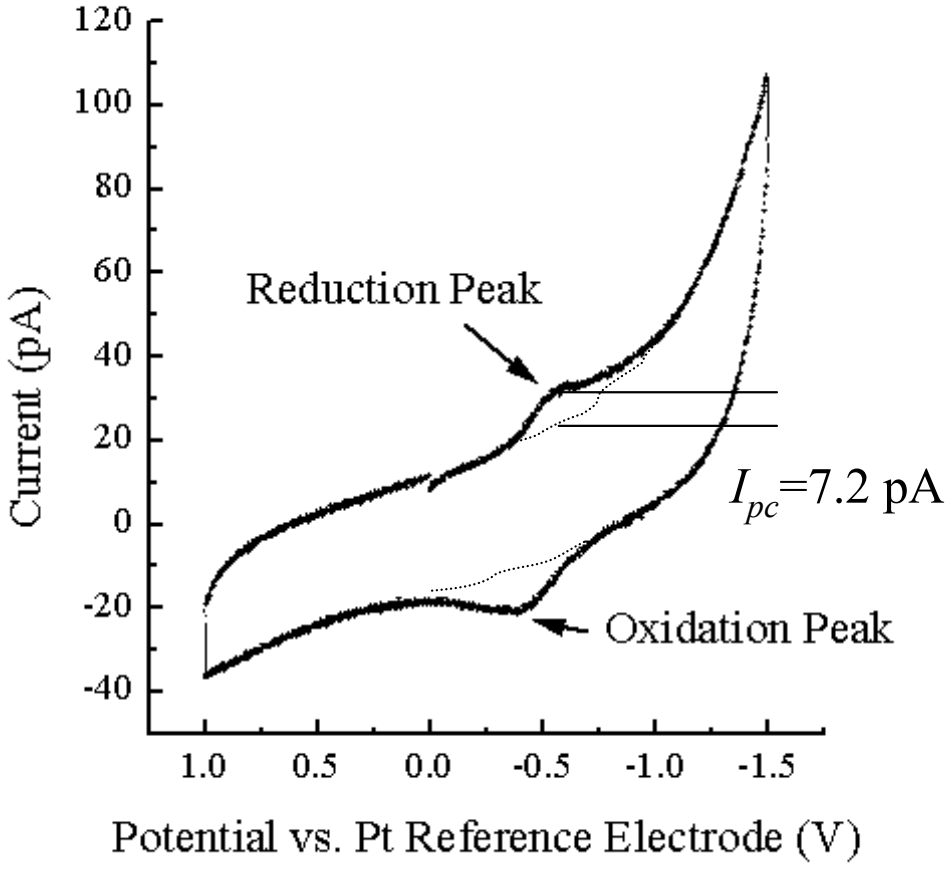
Device passivation (leads and probe shaft) must be pinhole free, such that electrochemical activity is limited to the probe tip. This was demonstrated using gold electrodeposition.





Au ball formed during electrodeposition

Electrochemical characterization of individual probe elements



For a hemispherical microelectrode, the radius of curvature, r_c, is given by

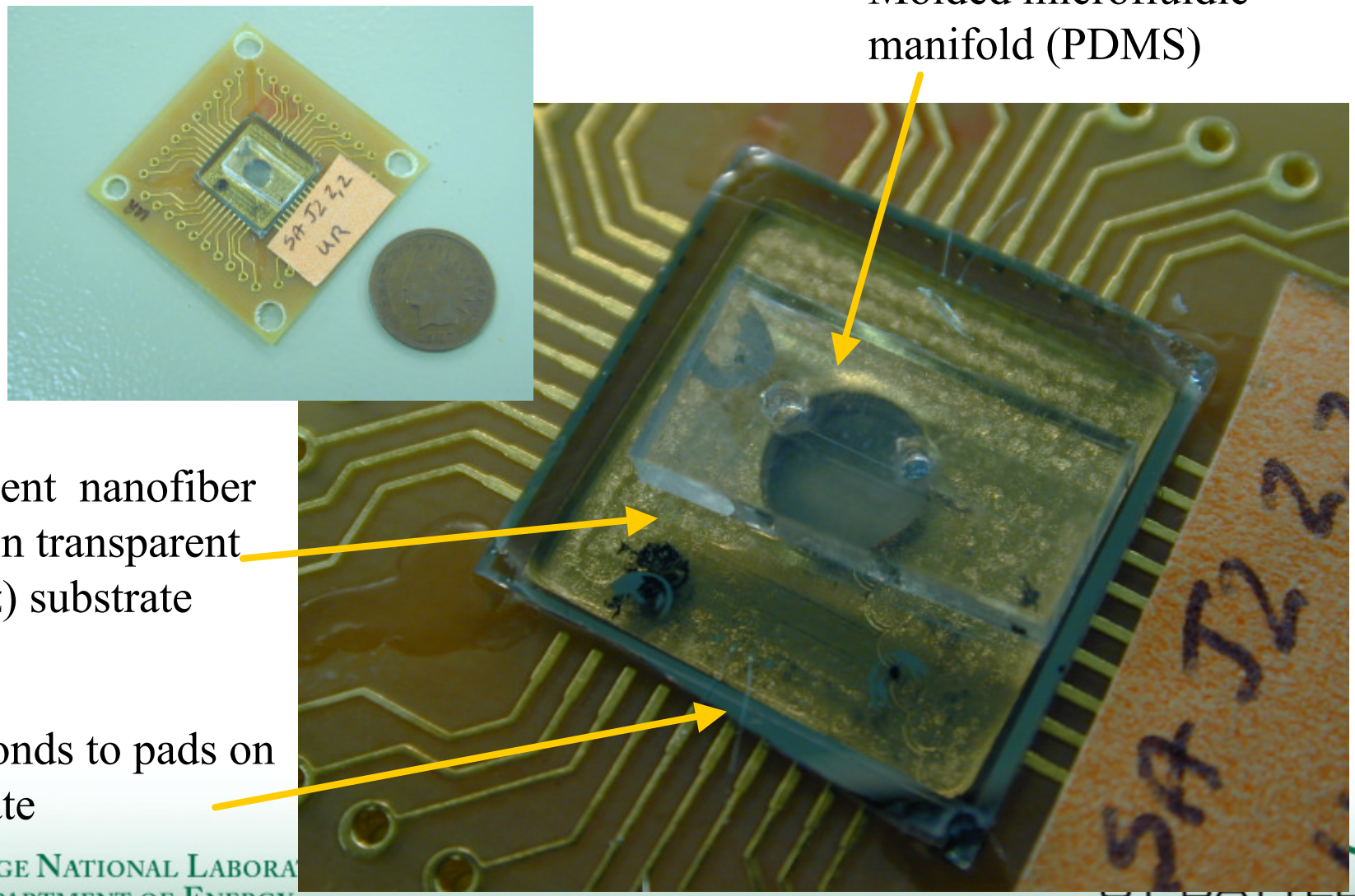
$$r_c ? \frac{I}{anFDC}$$

Thus,

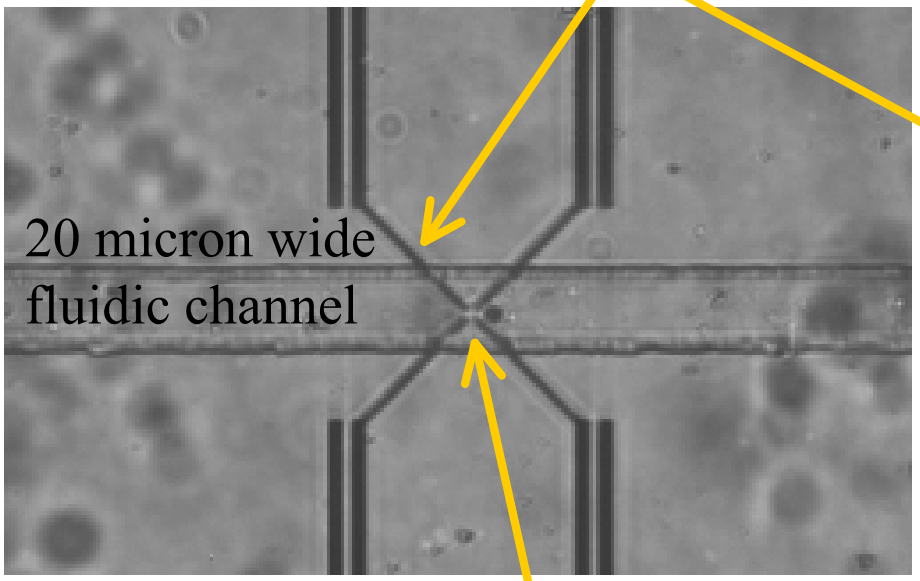
$$r_c ? 18.8\,\text{nm}$$

Agreeing with the observed r_c for the VACNF probe tip

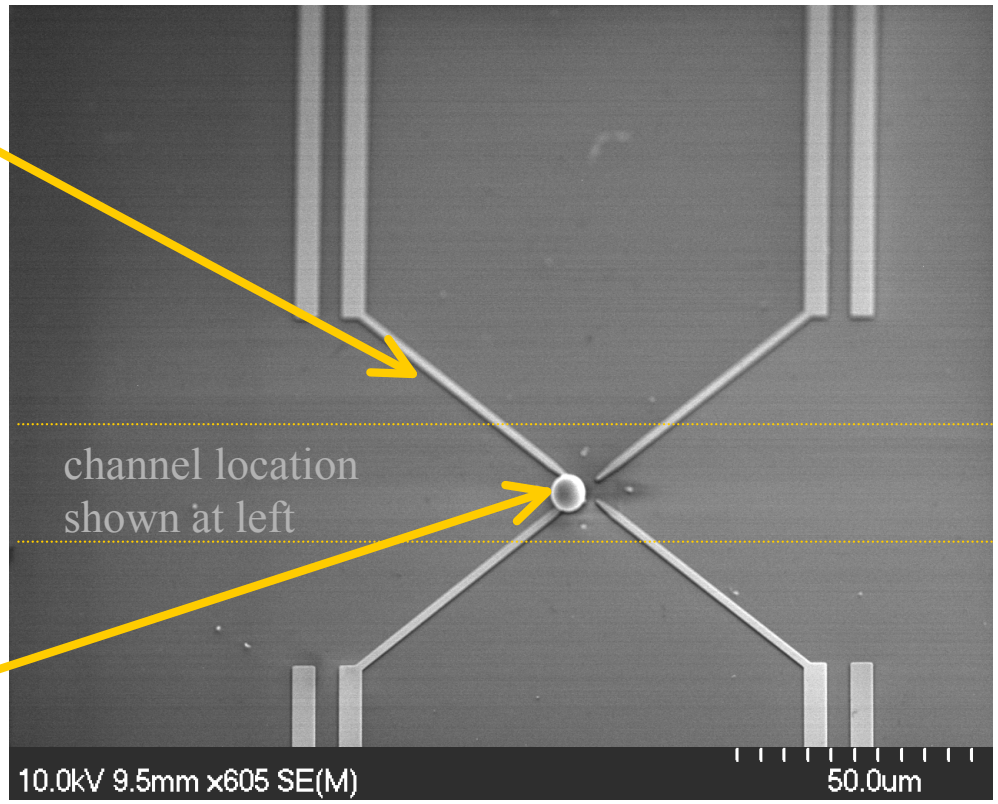
Individually addressable 4-element fiber array integrated with a 20 micron fluidic channel



Integration with microfluidics enables improved control over analyte delivery



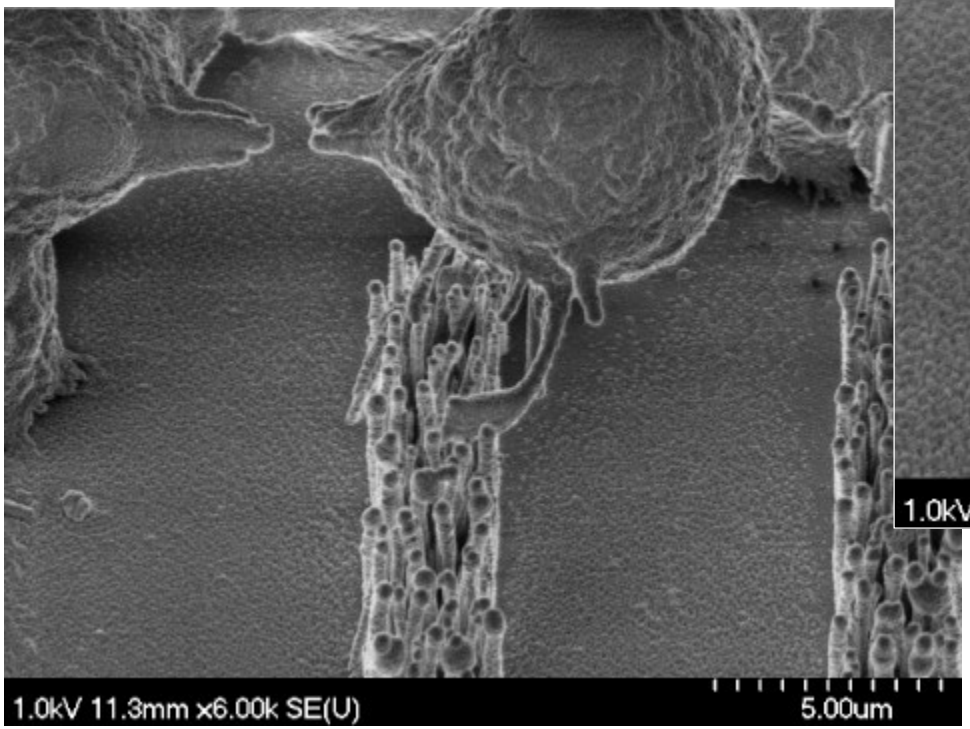
Optical micrograph of array in a 20 micron channel

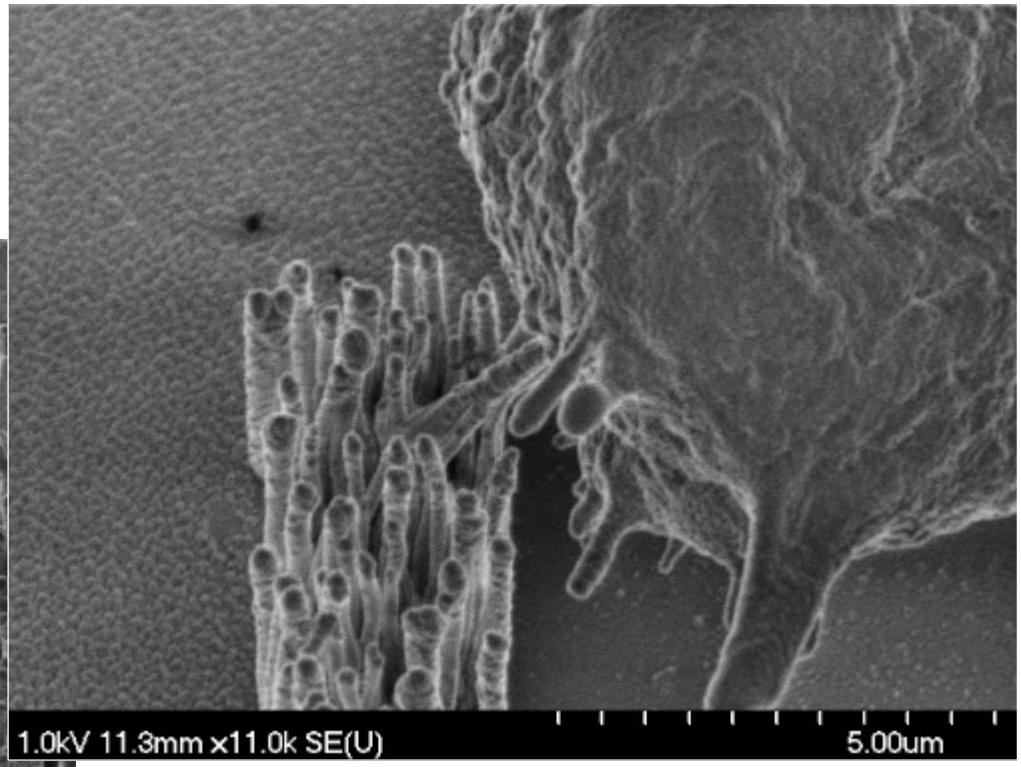


SE micrograph of a 4 element fiber array

The interaction of carbon fibers with cells

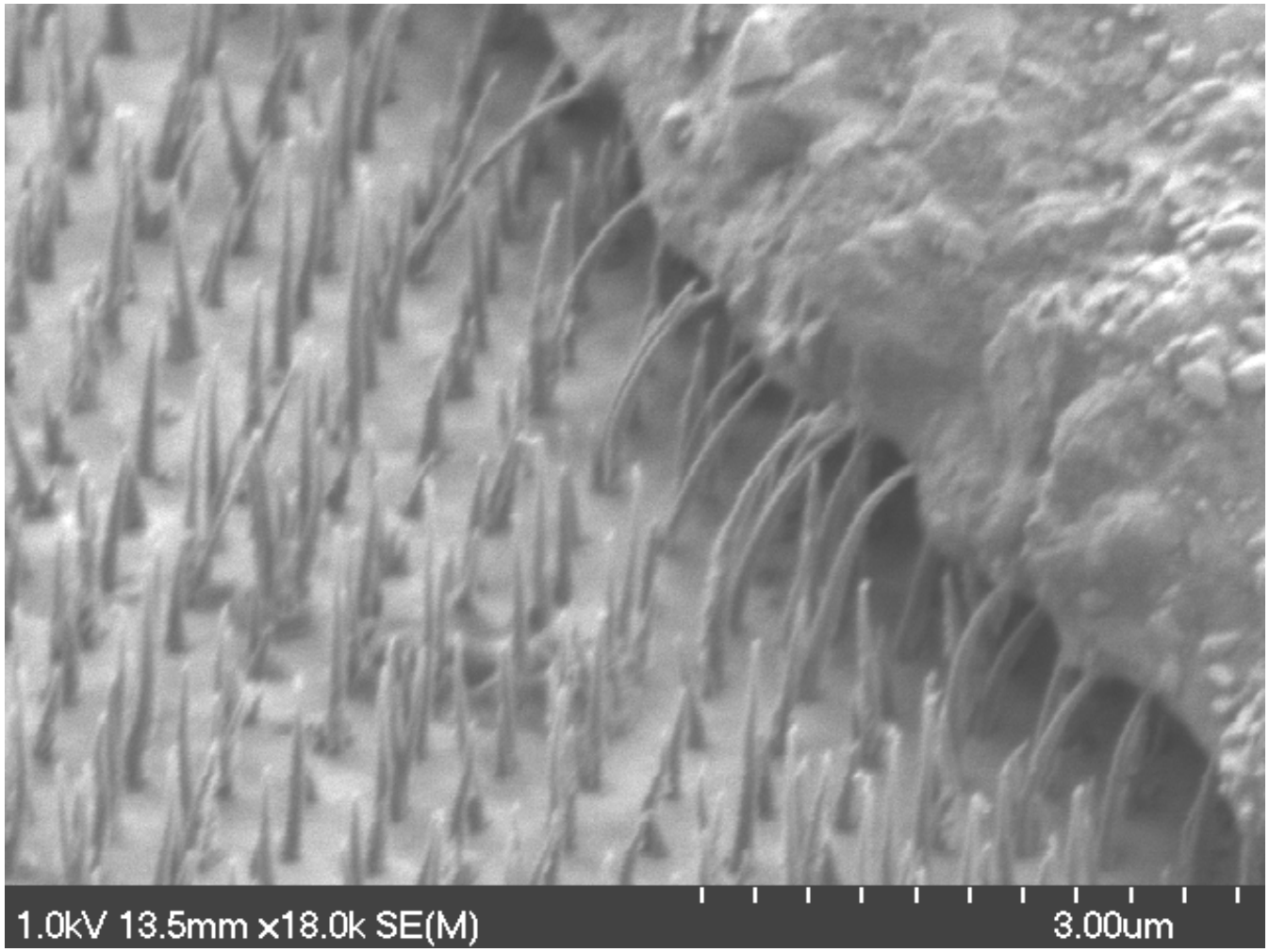
Cryo-SEM imaged of CHO cells impaled on VACNF forests.





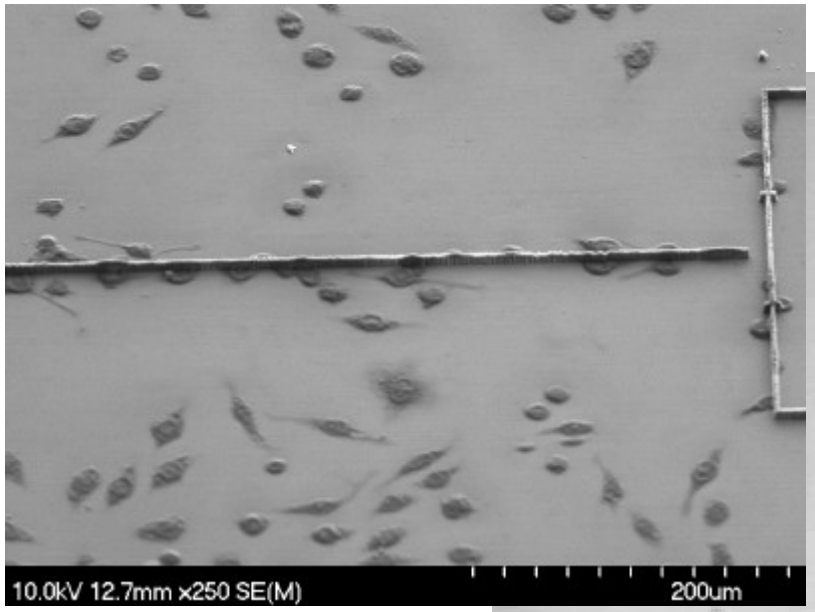
Samples were flash frozen in liquid N_2. Following the removal of ice crystals by a sublimation process the samples were sputter coated with Au and imaged

The interaction of carbon fiber arrays with biomatrices

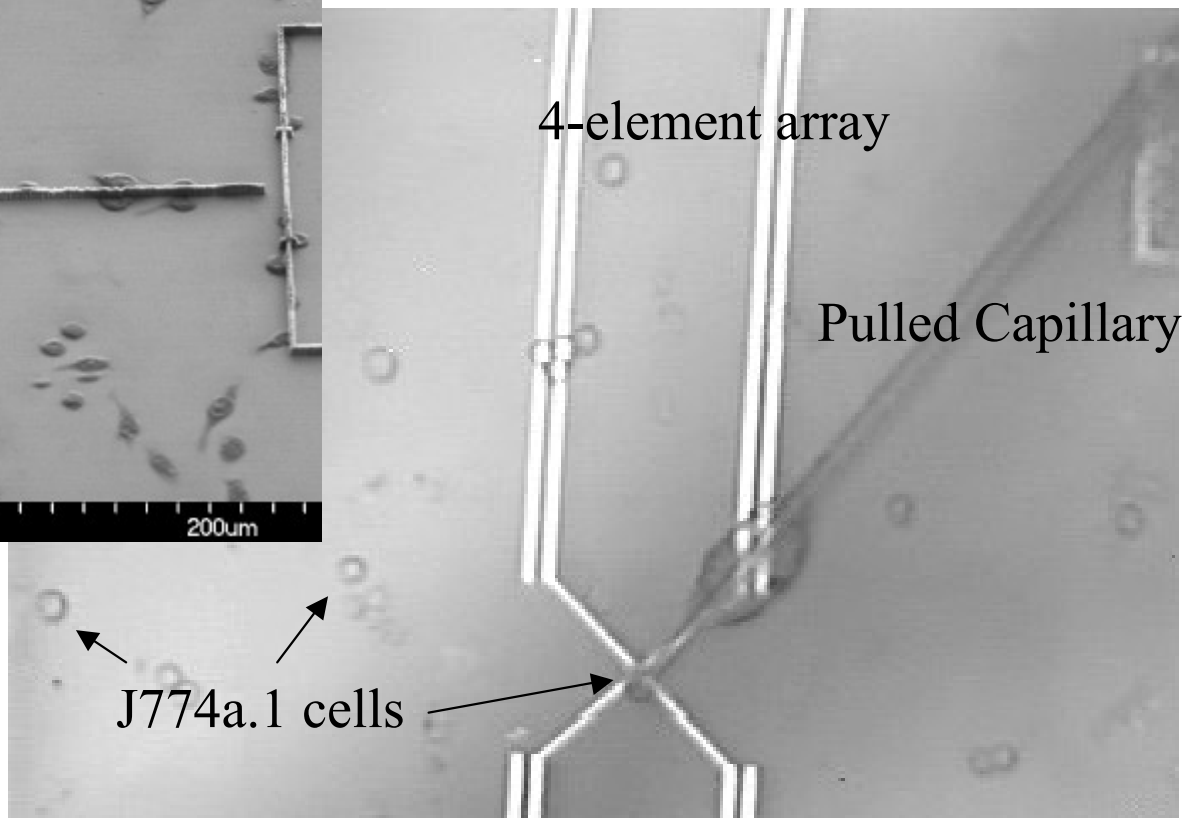


Integration of CNF Array with possible P. fluorescens biofilm

Direct culture and manipulation of a single cell onto a multipoint electrochemical array

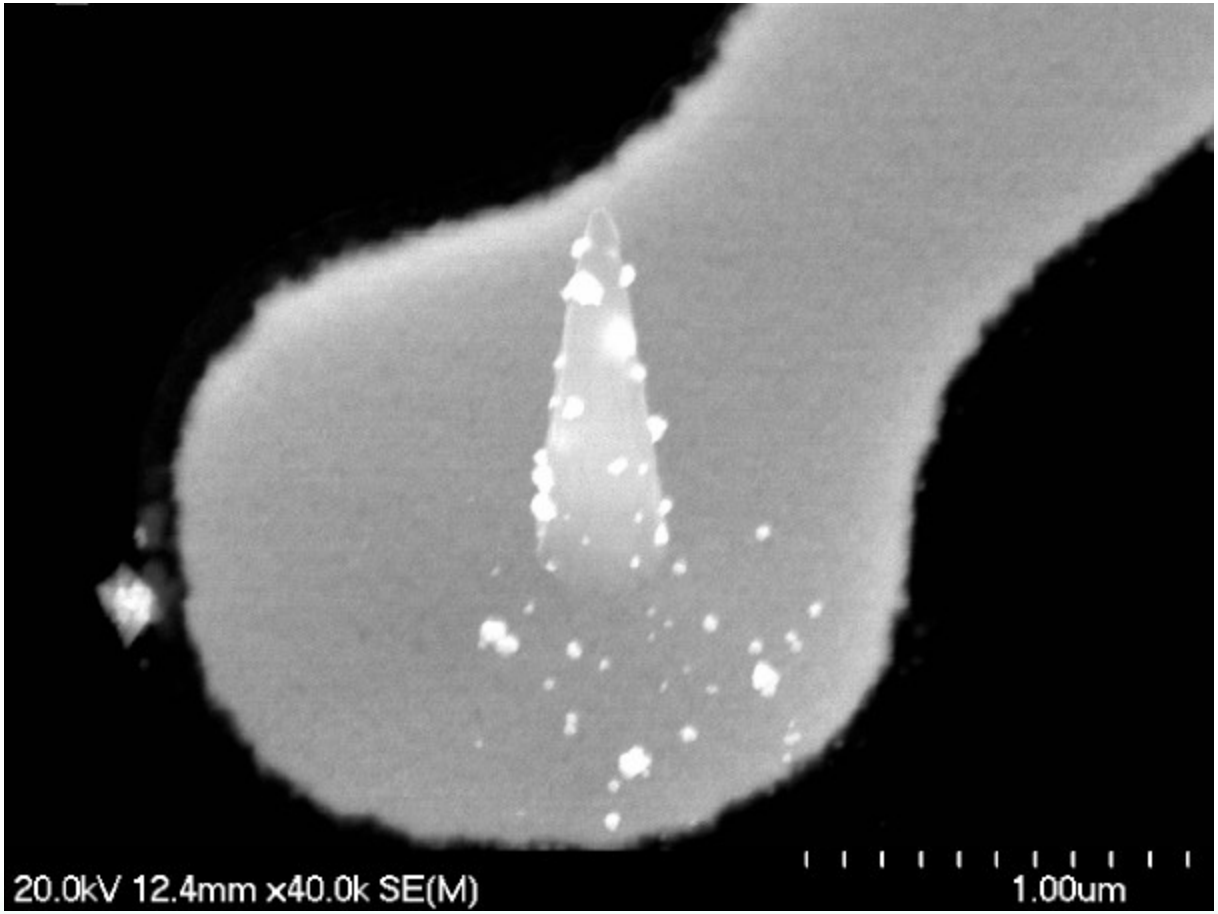


J774a.1 direct cultured on fiber arrays



micromanipulation of single cells onto multielement fiber arrays

Perhaps our most exciting finding…
we've discovered Whoville and their Christmas tree is decorated.



We gratefully acknowledge the following for support and use of facilities.

Laboratory Directed Research and Development Program

CNF Cornell Nanofabrication Facility

Related Talks...

Anatoli Melechko
Control of Carbon Nanofiber Growth: "Base" versus "Tip" Growth Regimes
Thursday, November 1, 2001, 8:20am, Room 133

Michael Guillorn,
Integrated Field Emission Devices with Single Carbon Nanofiber Cathodes
Friday, November 2, 2001, 11:00am, Room 133

Derek Austin
Contacting Carbon Nanotubes by Electrodeposition of Metal
Wednesday, October 31, 2001, 11:00am, Room 133

John Caughmann,
Patterned Growth of Vertically Aligned Carbon Nanofibers by High Density Plasma Enhanced Chemical Vapor Deposition
Tuesday, October 30, 2001, 9:00am, Room 133

Survival rate of fiber elements through spin-coat processing steps is exceptionally high