An Economical Process for Templating, Highly-ordered, High-aspect ratio Architectures

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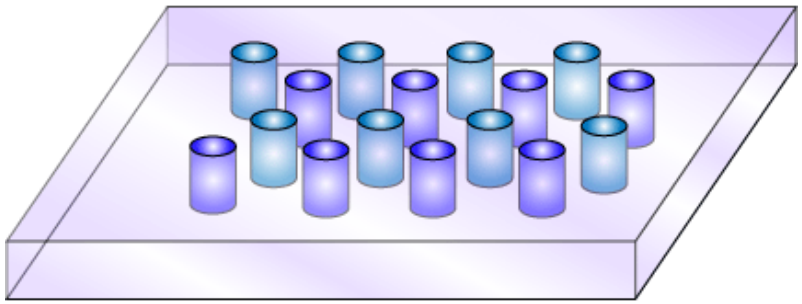
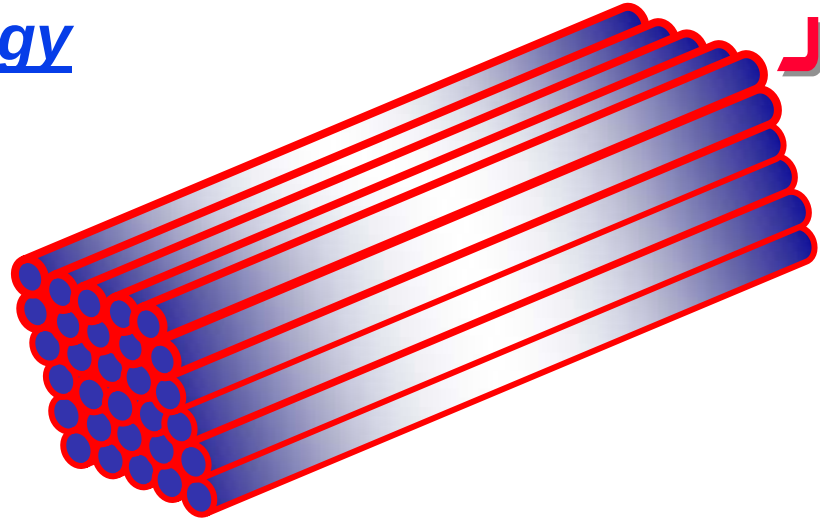
Description of Technology



Fabricating ordered nanowire or nanoconduit arrays on flat substrates:



Fabricating free-standing, ordered nanowire or nanoconduit arrays:

Specifications:

- Wires or conduit diameter ranges from <100nm to millimeters
- Spherical elements form Close-packed arrays
- Spacing between wires or wall thickness between conduits can be closely controlled
- Length of wires or conduits >meters (likely limited by other processes)

Economical Process

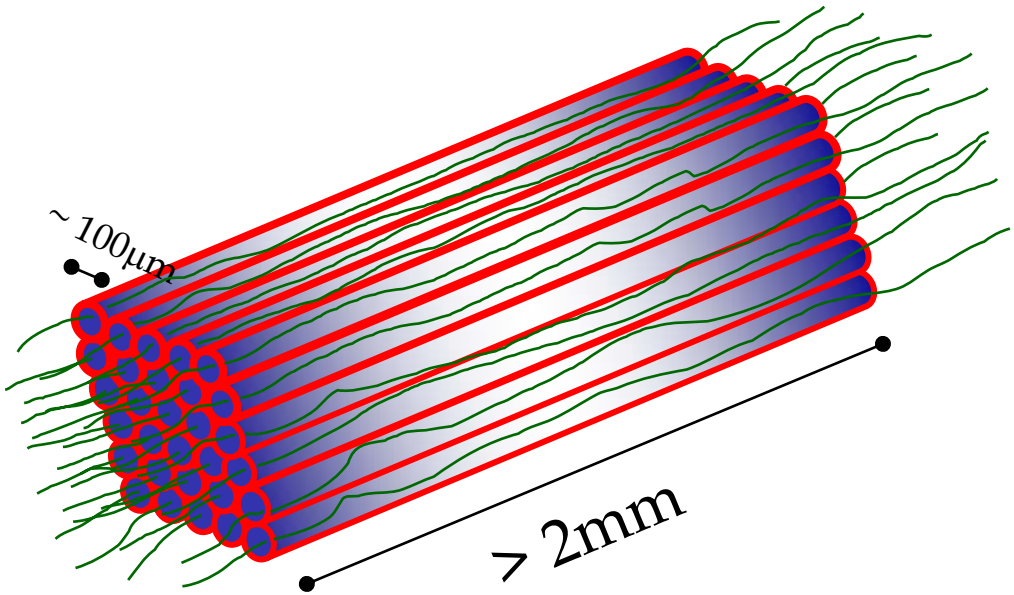
- **Benchtop process for patterning high aspect-ratio elements**
  - **Selective removal of polymer constituents does all the work**
    - **Achieved by immersion in common solvents such as acetone, THF or water**
  - **Involves established fiber optic technology**
    - **Common polymers such as PMMA and polystyrene are used**
  - **Does not involve photolithography**
    - **No cleanroom, stepper, masking, etc.**
  - **From proof-of-concept to implanting *in vivo* in 1 year for $30K**

Background: Technology derived from Spinal Cord Repair Research

- **Problem:**

  The Neuroscience Department at UC San Diego was interested in a process for fabricating nerve guidance conduits to guide nerves in central nervous system (spinal cord)

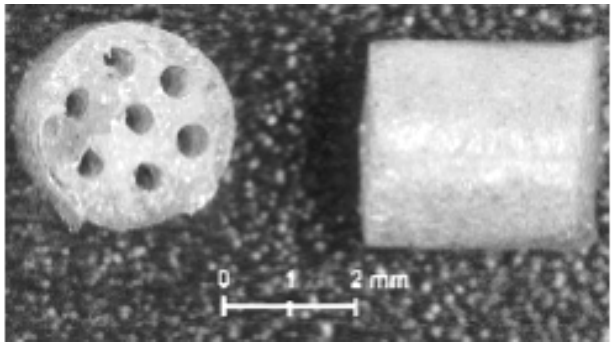
  - **Process had to produce close packed (>50% pore volume) >2mm long, ~1μm to >100μm diameter conduits**
  - **Process had to be compatible with biopolymer gels**
    - **Biopolymer is a liquid >83C and gels <40C**
    - **Gel is 97% water**

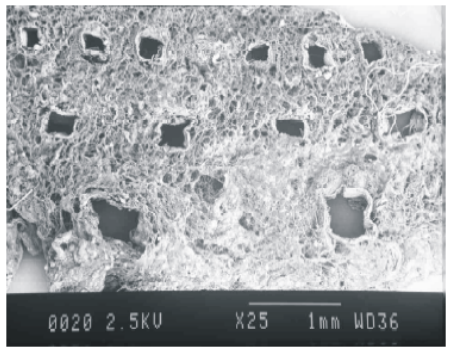


Possible Approaches

- **Mechanical removal (drilling):** not gentle enough to fabricate structures with thin walls, can not achieve <100μm
- **Photolithography:** Not capable of producing stand-on-end features >2mm; limited by spin-on photoresist thickness ~<50-80 microns
- **Laser drilling:** not compatible with ablating biopolymer gels (97% water), difficult to achieve high intensity at <100μm spot size
- **Extrusion through a die:** biopolymer liquid-to-gel transitions are not compatible with extrusion

State-of-the-art

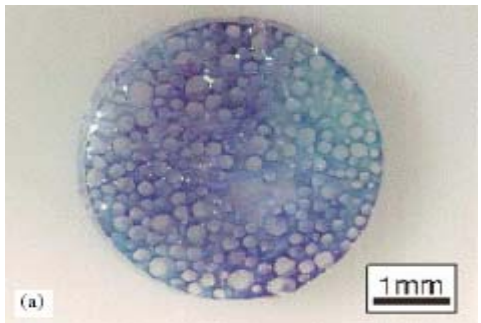


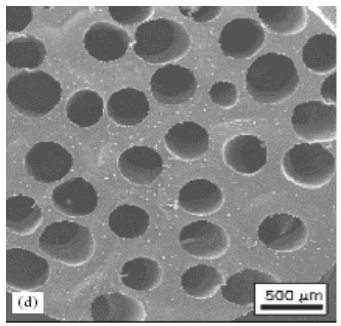


Ink jet printing (Agarose):

Pores ~500μm- resolution not quite adequate.

Pore area <<30%





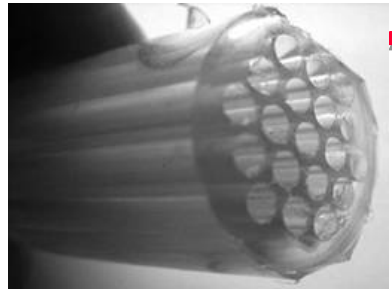
Dissolvable fiber templating (pHEMA)

Pores ~200-500μm

Pore area ~30%

Inadequate control over wall thickness

Solution



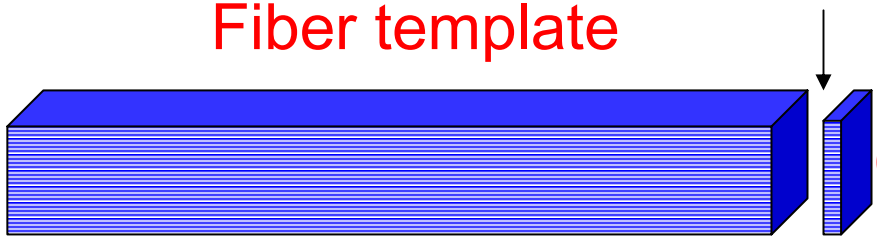
- Develop a polymer-fiber-based templating process
- Collaborated with Paradigm Optics Inc.
  - Developed highly-ordered, two-component polymer fiber matrices

- Cross-section is close-packed array of cylinder, hexagons or squares
- Two dissimilar polymers enables selective removal to obtain template
- Fiber diameters ranged from 50 to 200μm and could control spacing (from 33 to 100 μm)
- Length of templates >10cm

Fabricating nerve regeneration scaffold

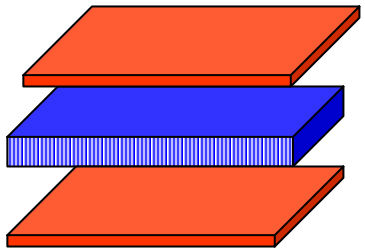
Fiber template

1)



Cut to desired length (~2mm for SCR)

2)



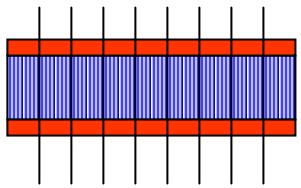
Polymer sheet

Fiber template

Polymer sheet

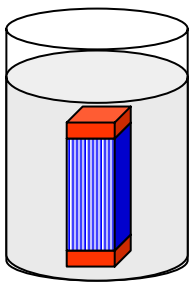
Bond endcaps

3)

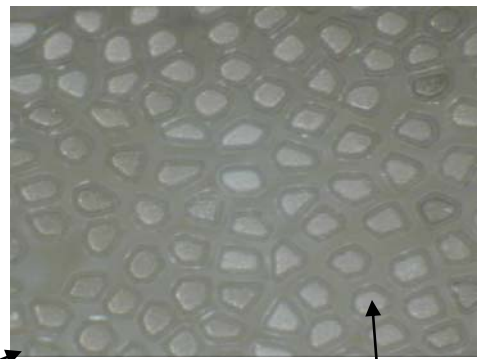


Cut into columns, which are close to the final dimensions

4)



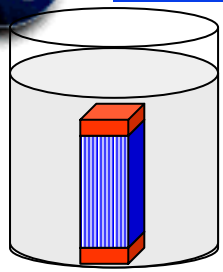
Selectively dissolve fiber cladding leaving only fibers and endcaps intact



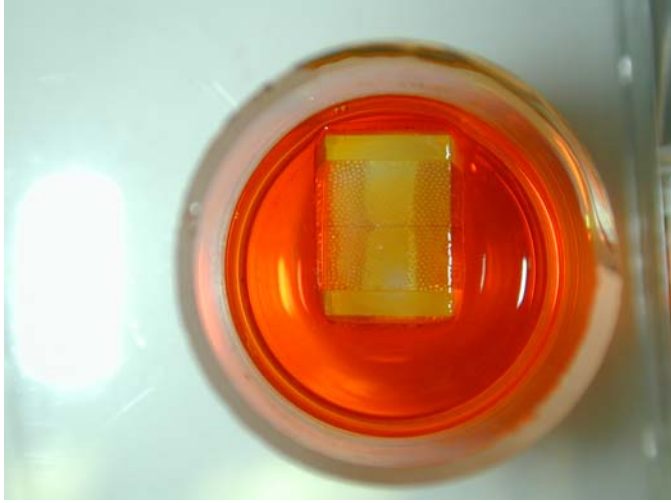
Cladding etched away leaving only fibers

Templating agarose

5)



Permeate liquid biopolymer gel at 80C



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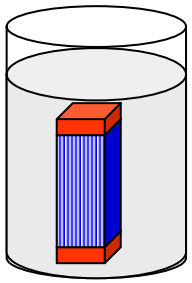
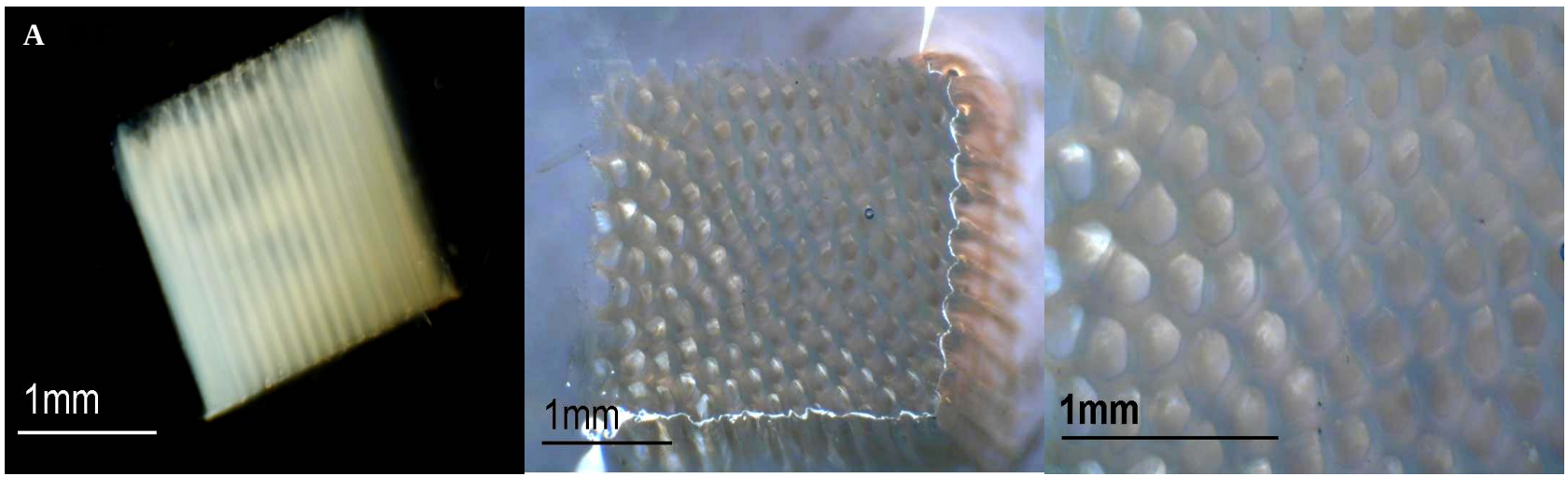
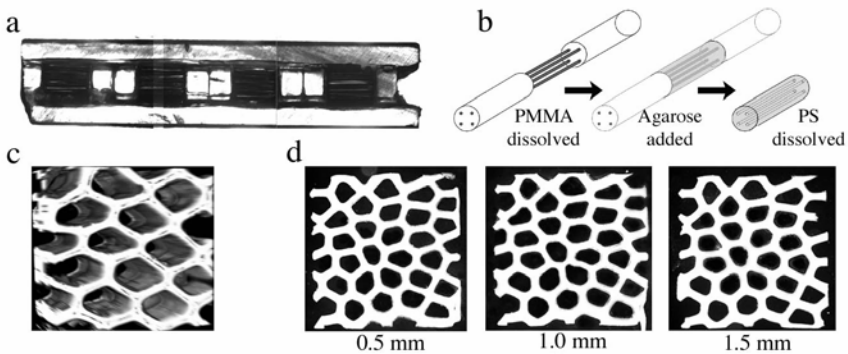


Selectively dissolve fibers by immersing in solvent that only a dissolves fibers and leaves the biopolymer intact.

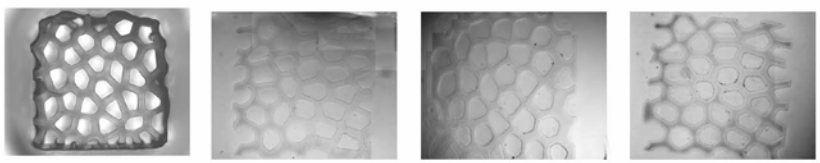


Templates/nerve regenerations scaffolds: 100μm walls/200μm pores

100μm walls/200 μm pore scaffolds

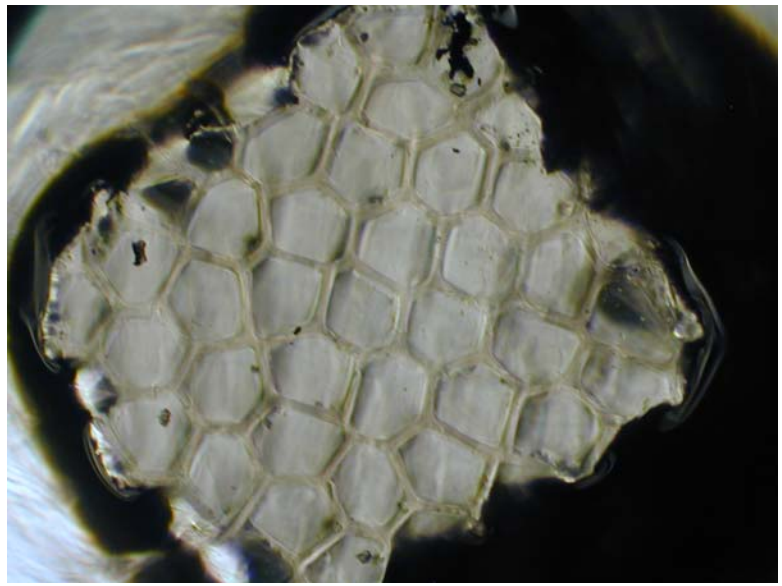


3d-reconstruction reveals uniform pore structure from end-to-end

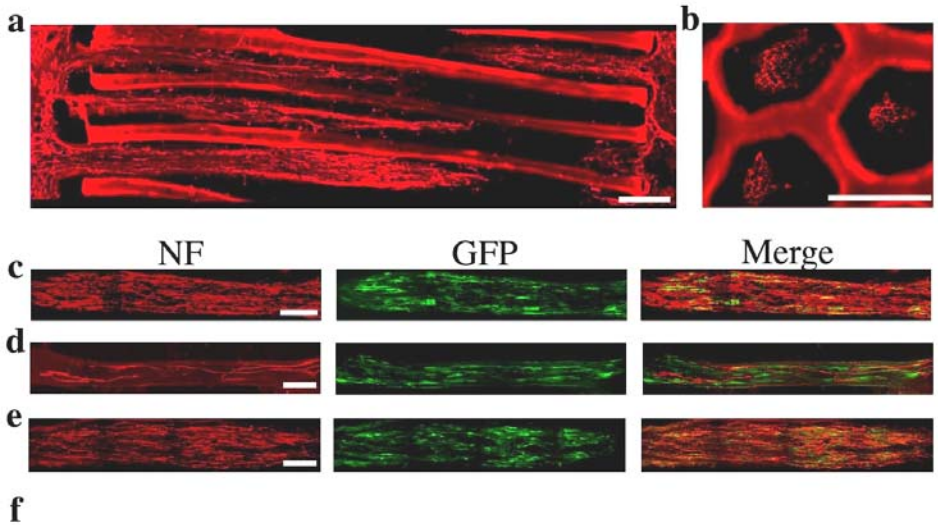


First generation: 44% porosity

33μm walls/200μm pore scaffolds



Second generation: 60% porosity!


a
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NF
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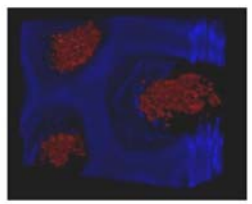


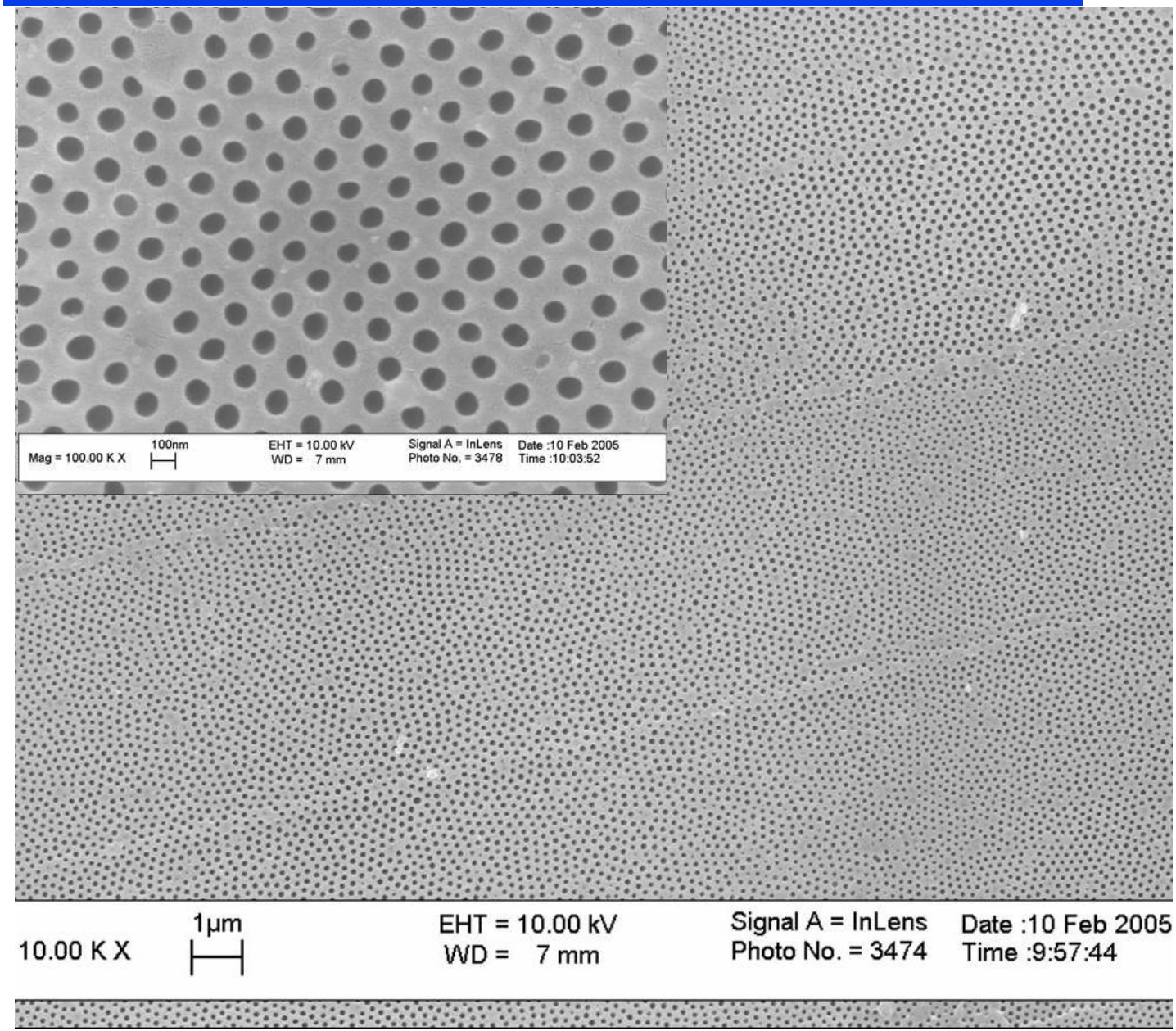
Future Spinal Cord Repair Work

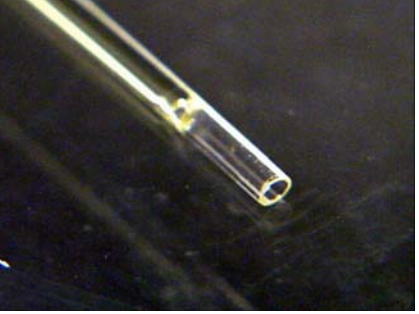
- Pursue paradigm that focuses on functional recovery
- Scale up scaffolds
- Employ same technology in peripheral nerve regeneration

Extending process to the nanoscale

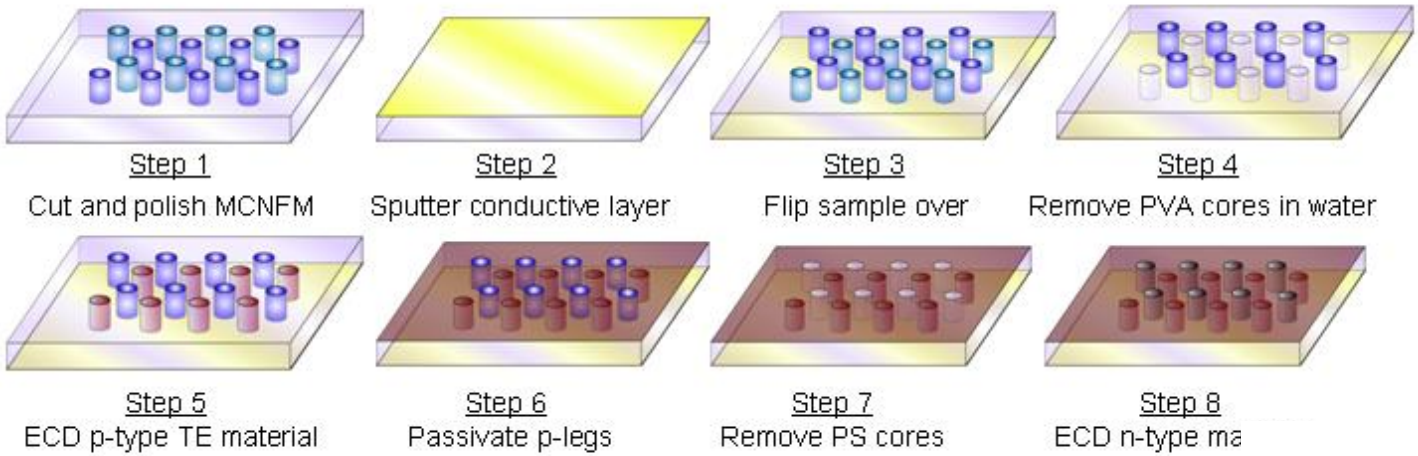
- Ability to fabricate ordered arrays of nano scale features may enable fabrication of nanodevices
- Nanowire-based thermoelectric coolers and power generators
  - Nanoscale “blocks” phonon thermal conductivity, thus improving material/device efficiency.
  - Several templating processed for fabricating nanowire arrays
  - -Alumina
  - BCP
  - Track-etched
  - Nanochannel glass

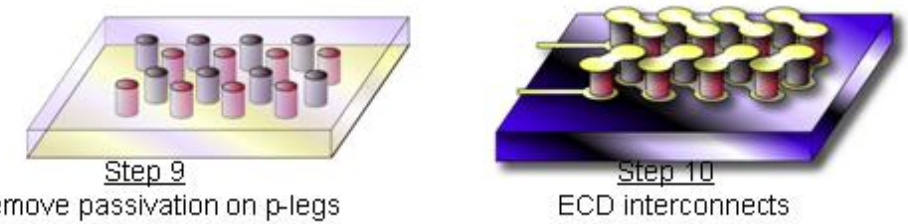
Solution: use polymer nano-fiber templates

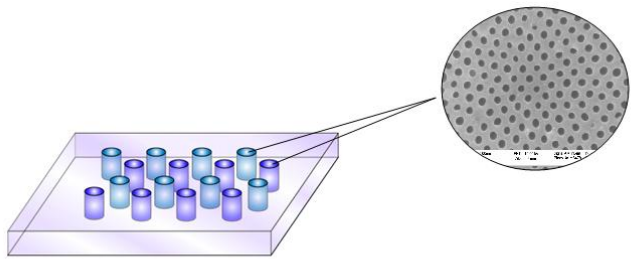




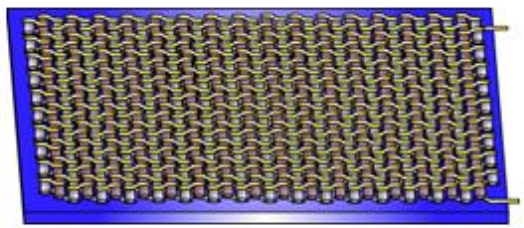
Articulated process for fabricating nanowire-based TE devices







MCNFM is comprised of ordered arrays of dissimilar nanofiber cores.



Envisioned device: 1.5mm by 1.5mm Nanowire Thermoelectric Device for Power Generation or Cooling

Summary

- Developed a process for fabricating high-aspect ratio, highly ordered features
- Dimensions range from millimeters to <100nm
- Process is economical and simple
- JPL is interested in partnering to develop nanoelement-based technologies