Combination of FIB and Conventional Processes in Microelectronics

Tzipi Cohen-Hyams, Elad Peer, Uri Sivan and Wayne D. Kaplan
Technion, Israel Institute of Technology, Haifa, 32000, Israel

EFUG 2009, Arcachon

Outline

- Introduction
- Fabrication of Nanopillars
- Results
- Summary

Cell Injection System (Nanoinjector)

- Molecular delivery technologies to target cells are fundamental requirements in biotechnology and biochemistry.
- The applications of nanoinjectors:
  - Insertion of probes into cells to observe physical and biochemical interactions.
  - Manipulations of cells; transfection of foreign molecular-scale cargoes into cells (e.g. DNA, RNA, polymers, dendrimers, nanoparticles, etc.)
  - Advanced of the fields of gene therapy, cell-based therapy, and tissue bioengineering

Cell Injection Systems

Common limitations of using larger scale of cell injection system include:

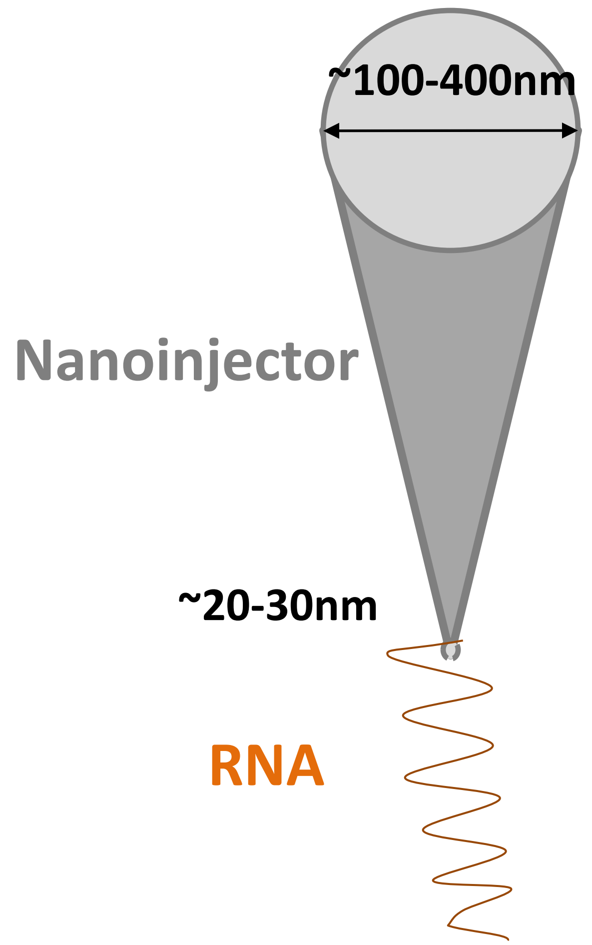
- Restrictions on the size and the biochemical composition of the cargo.
- Limit on the number of cells that can be addressed and also on the number of times a cargo can be introduced into a specific cell (usually once).
- Interference with normal cell metabolism; need for specialized and costly equipment; and need for special training.

ADVANTAGES of Nanoinjectors

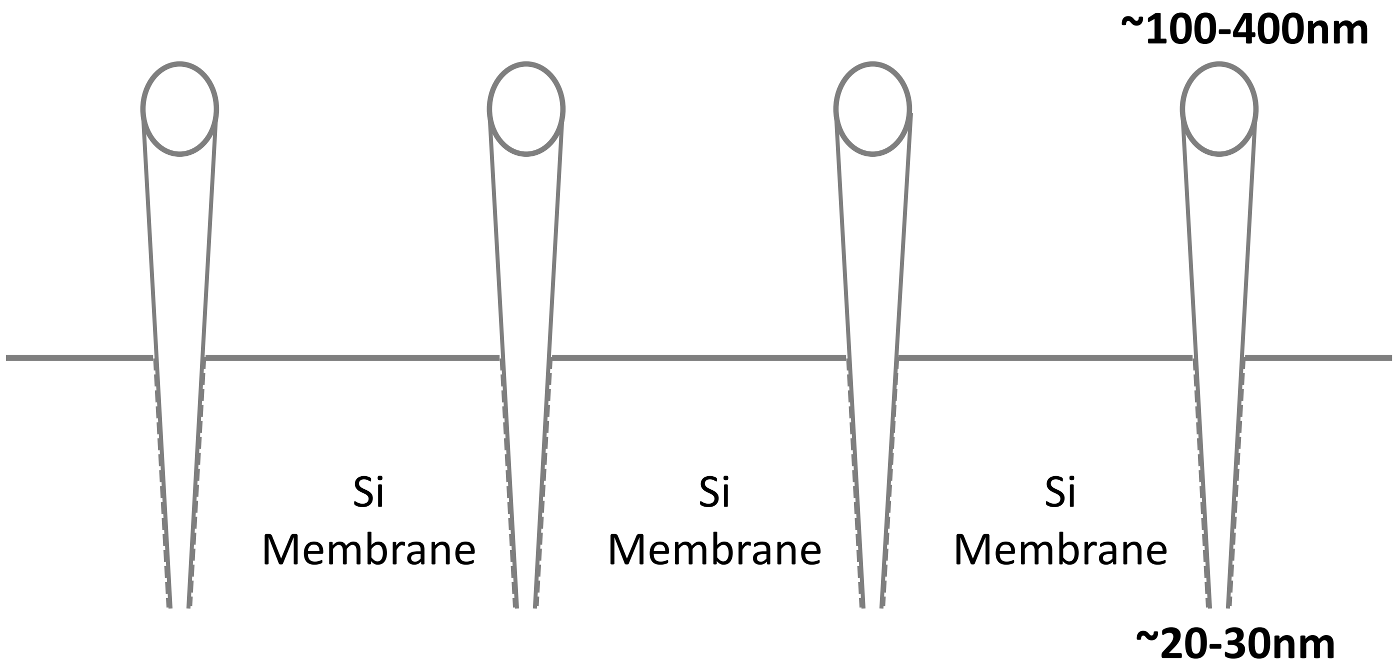
- Do not damage the cell membrane
  - Overcome other limitations associated with microinjection: **Eliminate need for a carrier solvent**
  - Not limited to larger cells
  - Provide nanometer-scale control of nanoneedle position for targeted cargo delivery
- Allow control of the number of cargo released by adjusting incubation time of nanoneedle within the cell
- Enable probing of cell's interior for specific molecules or properties

Nanoinjector

- Currently, we are developing a system for a repeated, long term, injection of macromolecules into vital cells:
- Develop a structure of an array of inorganic hollow pillars on which cells are grown for an extended period of time.
- The inner voids of the pillars will be directly connected to the cytoplasm at one end of the tubes, and to external injectors at the other end.



Pillar Material



Silicon dioxide (SiO_2)- a hydrophilic material with well-established fabrication techniques and readily available for chemical modifications. Dimensions of the pillars should be less than 400nm external diameter and a length of a few µm (i.e., aspect ratio of about 1:100).

Fabrication of Nanopillars

Electron-beam lithography on the oxidized silicon followed by etching in a Deep Reactive Ion Etching (DRIE) machine or the use of FIB combined with DRIE?

What is the maximum aspect ratio from FIB?

- ❖FEI guarantees an aspect ratio of 10:1
- ❖DRIE provides high aspect ratio profile (100:1), but is size limited.

Focused Ion Beam (FIB)

- FIB enables a direct-write technique of high resolution and is a powerful tool for mask less nano patterning.
- Limitation: low aspect ratio of milled patterns in the FIB are around 10:1
- Low etching rates in large dimensions above 100 µm.
- FEI Strata 400-STEM

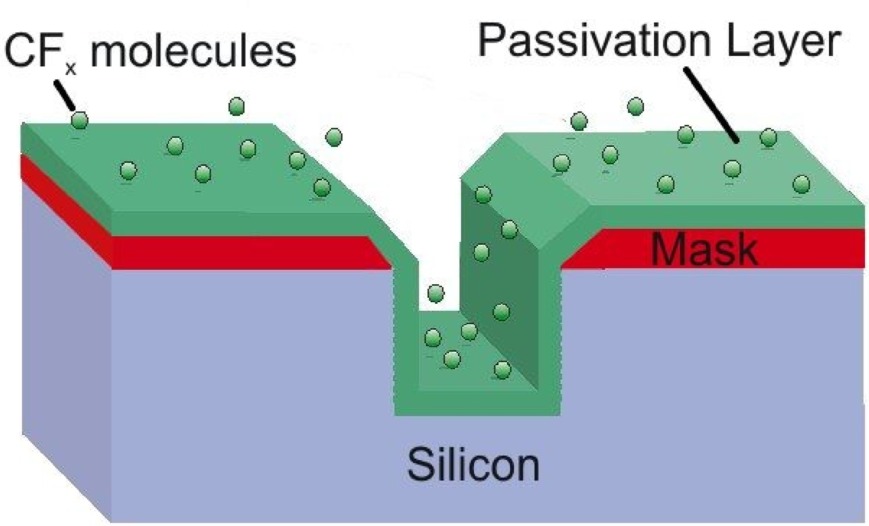
Deep Reactive Ion Etching (DRIE)

DRIE combines both physical and chemical etching techniques. RF energy is applied to the substrates and the material can be removed by both chemical means and ion bombardment of the substrate surface. Greater control over line widths and edge profiles is possible with oxides, nitrides, polysilicon and aluminum

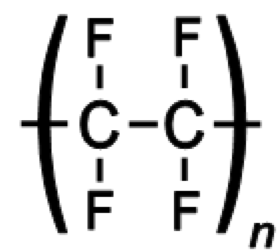
DRIE: Si Etch

Phase 1 - Passivation Step：

- At the beginning of each cycle a C_4F_8-based plasma is used to conformally deposit a few monolayers of PTFE-like fluorocarbon polymer across all surfaces exposed to the plasm.



Teflon-like passivation film

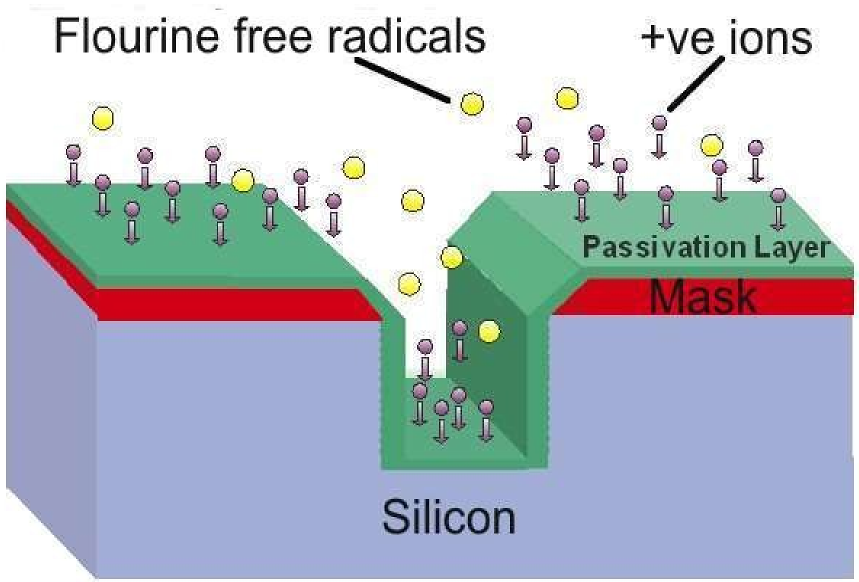


Si Etch

Phase 2 - Etch Step 1:

- The plasma gas is then switched to SF_6 to isotropically etches silicon. Through the application of a d.c. bias to the plate, ions from the plasma bombard the surface of the wafer, removing the polymer.
- Increased ion energy in the vertical direction results in a much higher rate of removal of fluorocarbon from surfaces parallel to the wafer surface.

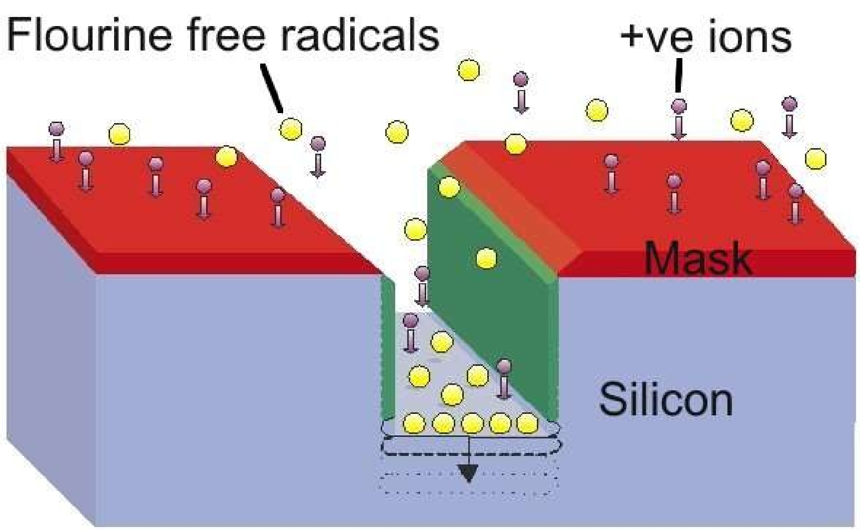
Etching by physical mechanism - spattering



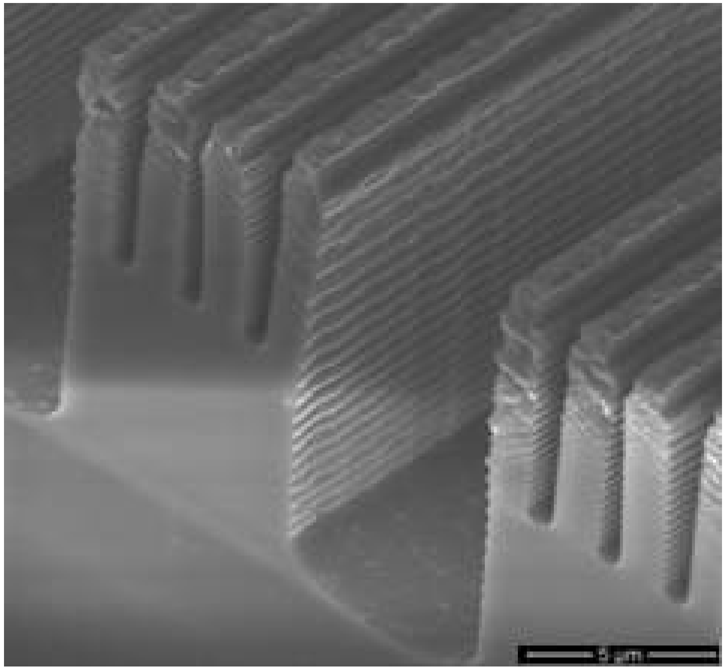
Si Etch

Phase 3 - Etch Step 2 :

- SF_6 based plasma (Ar may be added).
- Isotropic etch of exposed Si.
- The remaining fluorocarbon polymer protects the vertical walls of the trench from etching.



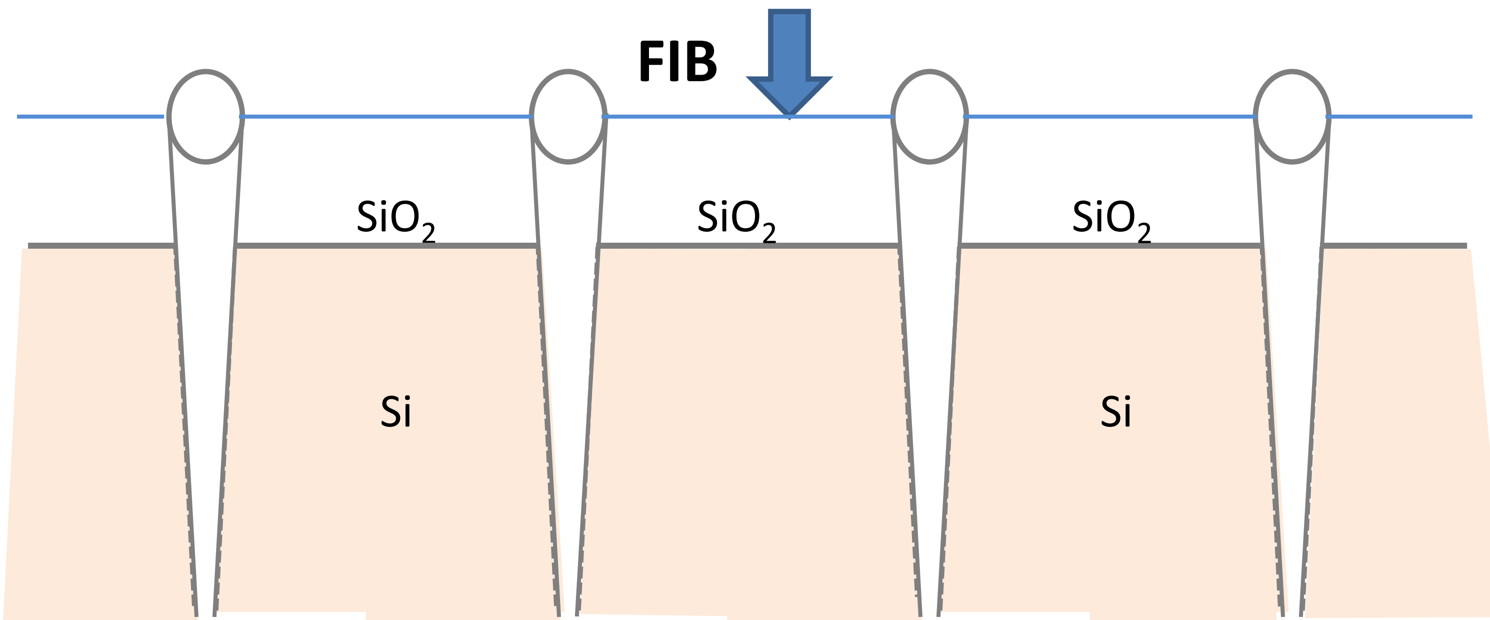
Typical 'wave-like' profile



Deep Reactive Ion Etching (DRIE)

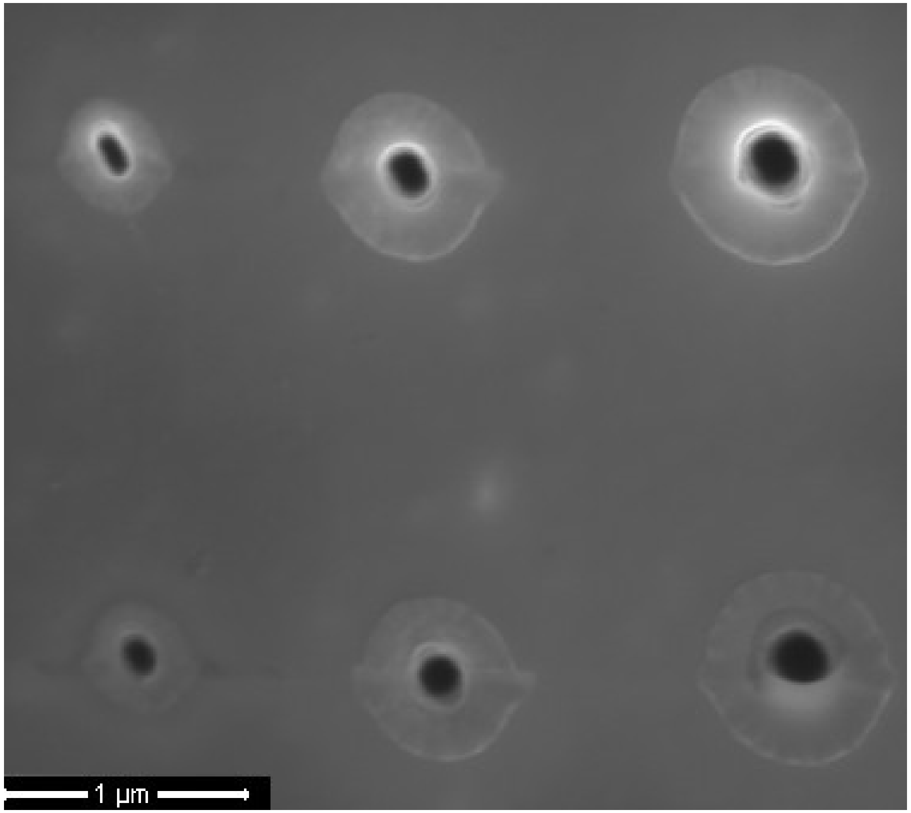
- Deep etch (hundreds of microns)
- High selectivity : Si:SiO_2(CVD) – 1:80
- Vertical profile (near 90^o)
- High aspect ratio profile (100:1)
- Fast - ‘time is money’ (1.7µm/min for Si, SiO_2(CVD) – 0.02 µm/min)
- Controllable, Repeatable and Uniform
- Drawback: hard to remove the Teflon on the wall sides - acts like a passivation film for molecule binding.

Preliminary Tests



Results

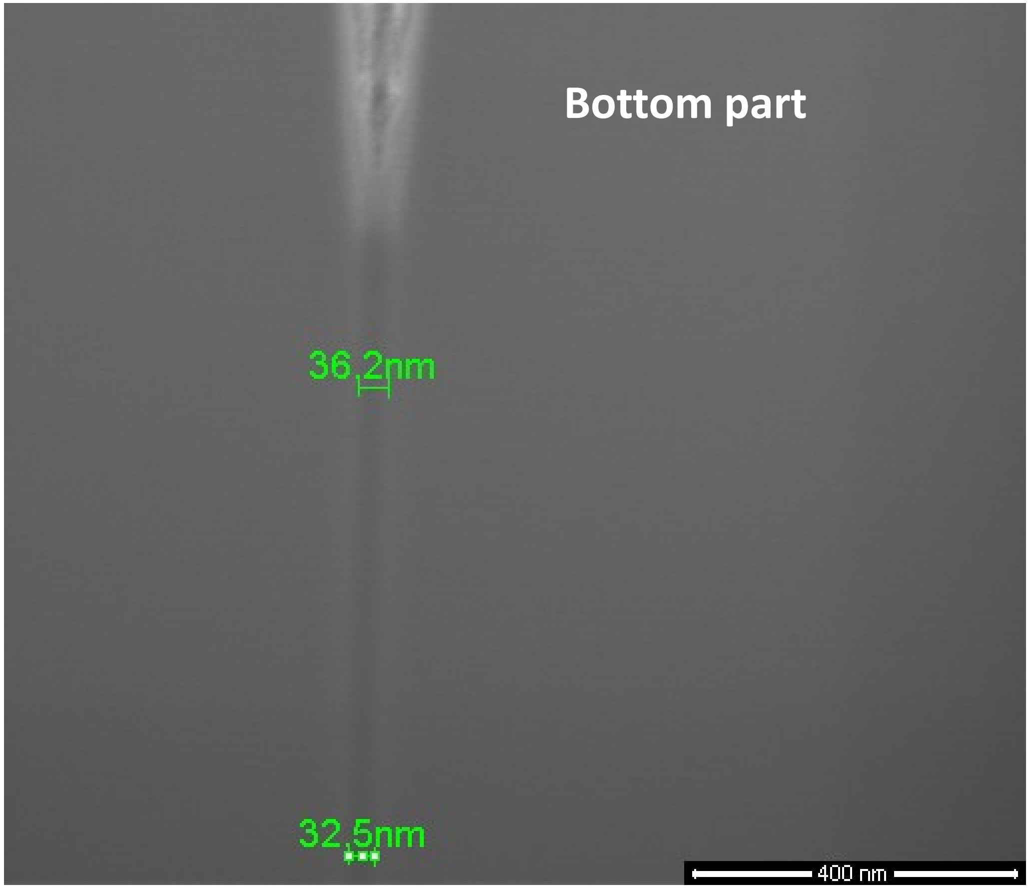
Top View



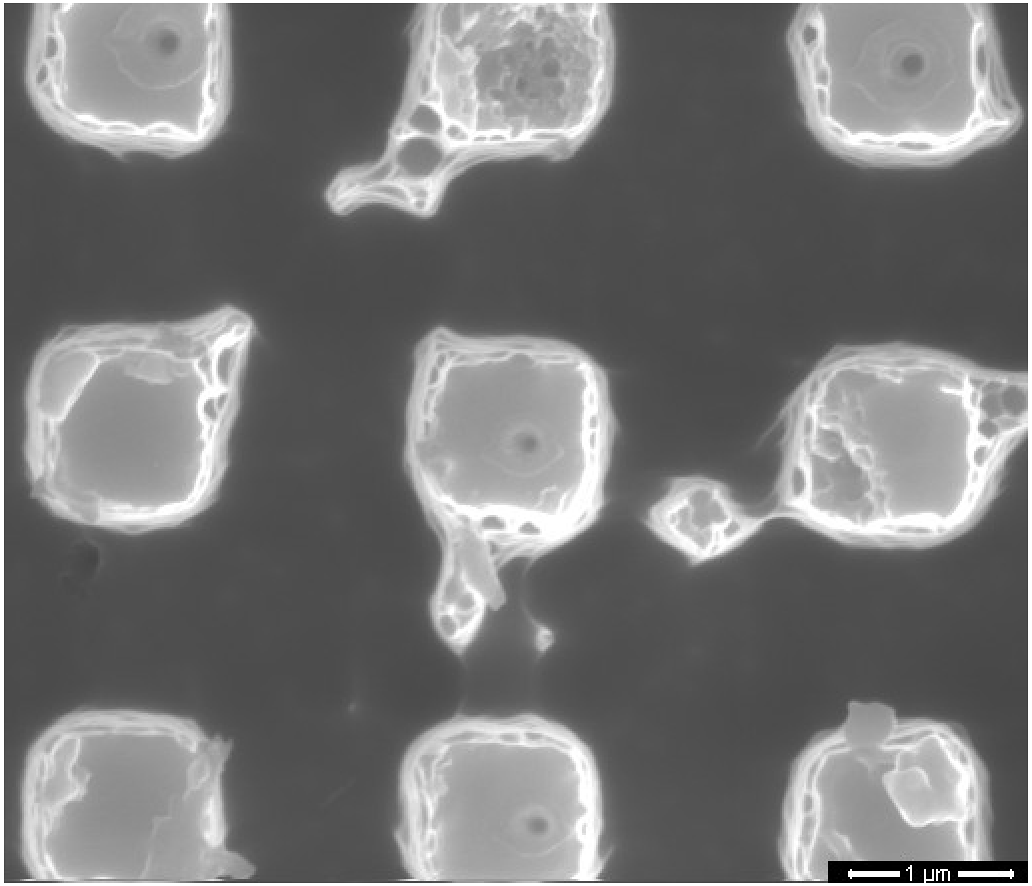
Cross-Section

Cross-Section

The hole milled reached
at least 12µm deep



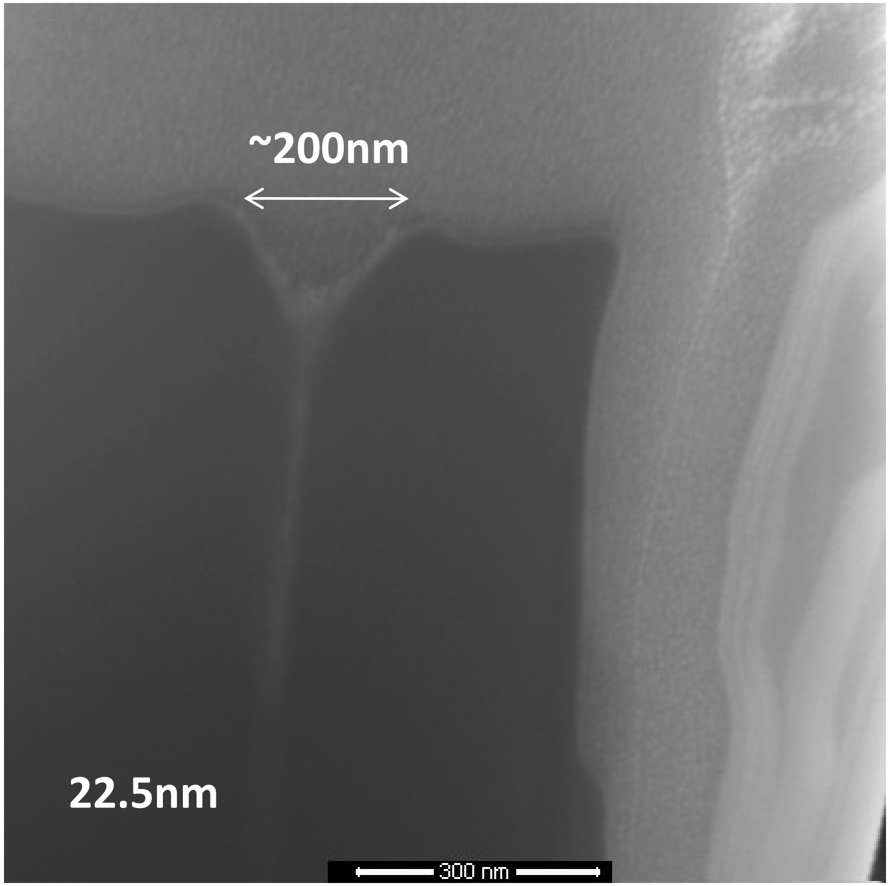
FIB Milling into Pillars



Si Pillars were formed using , Oxidization, Optical lithography, Masking and Etching, followed by milling to form nano holes

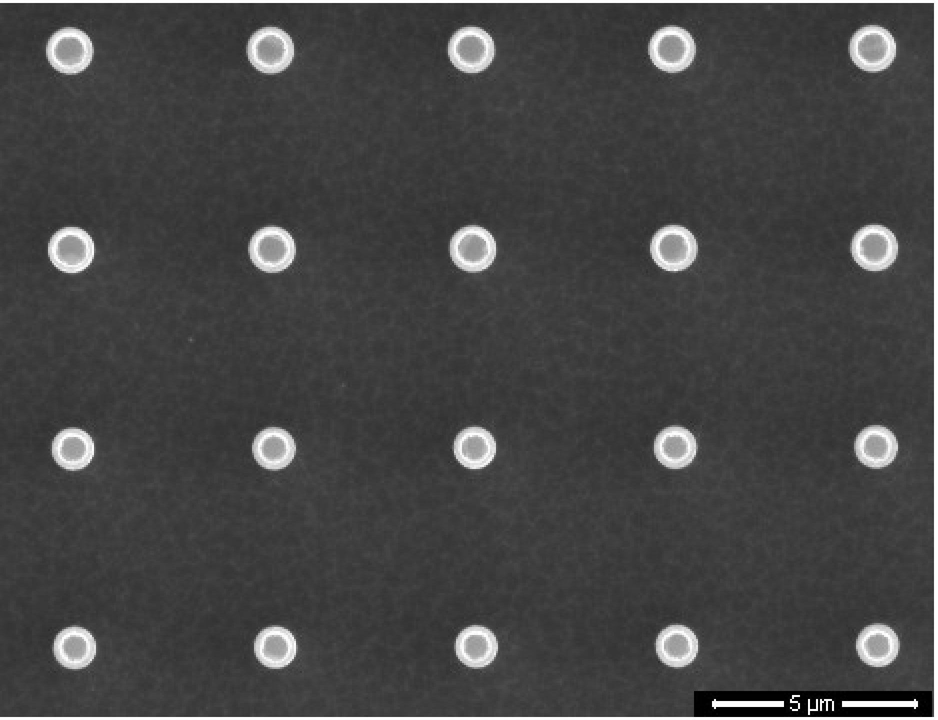
FIB Milling into Pillars

Cross-Section View

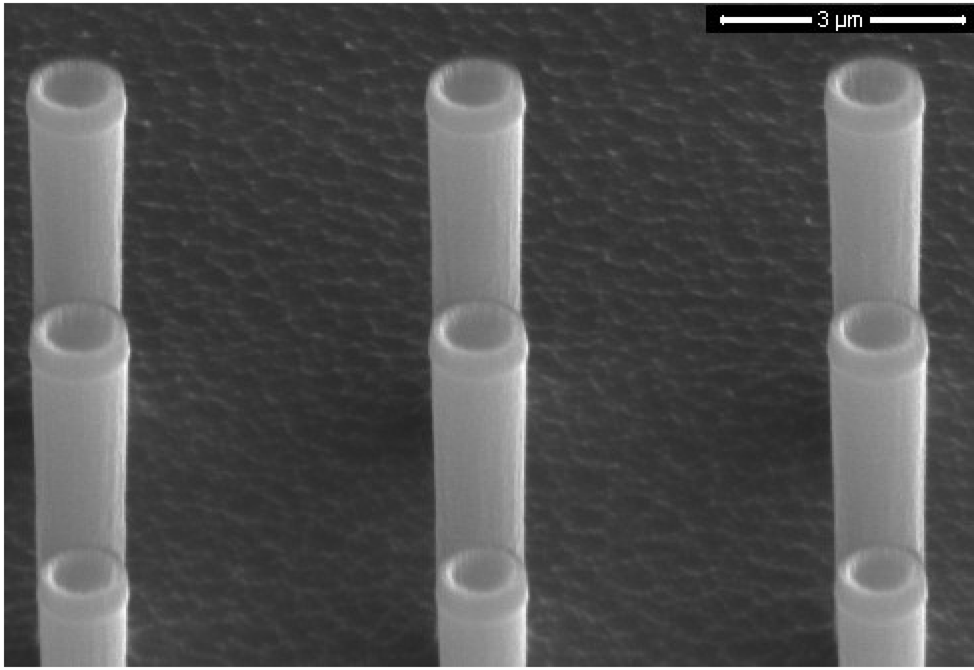


Pillars formed using DRIE

Top View

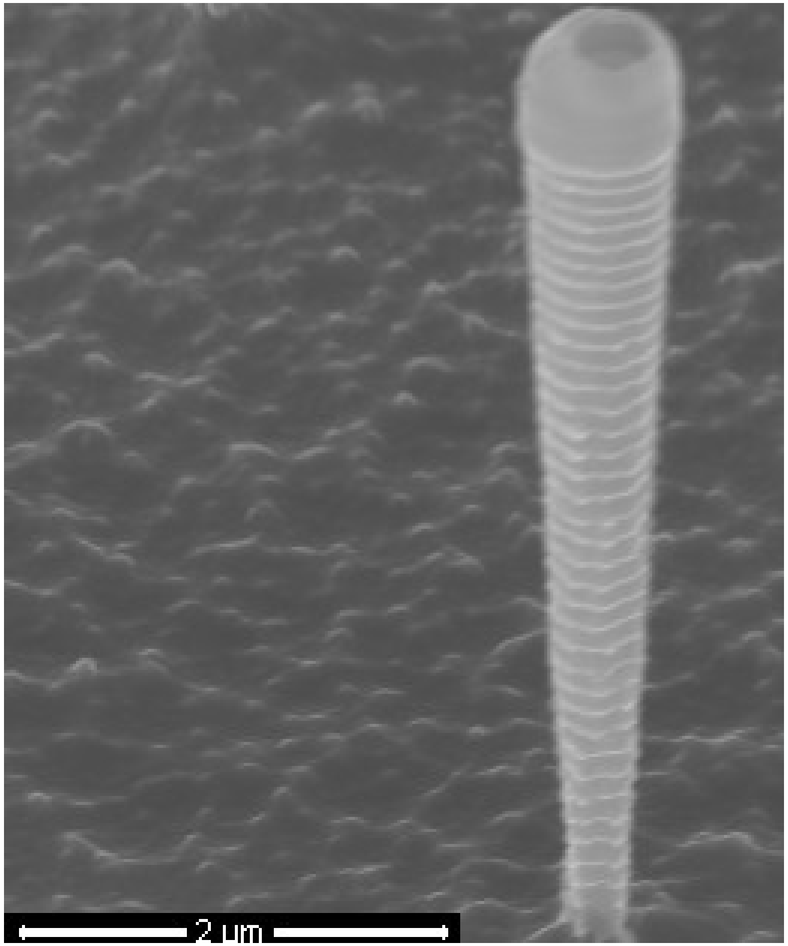


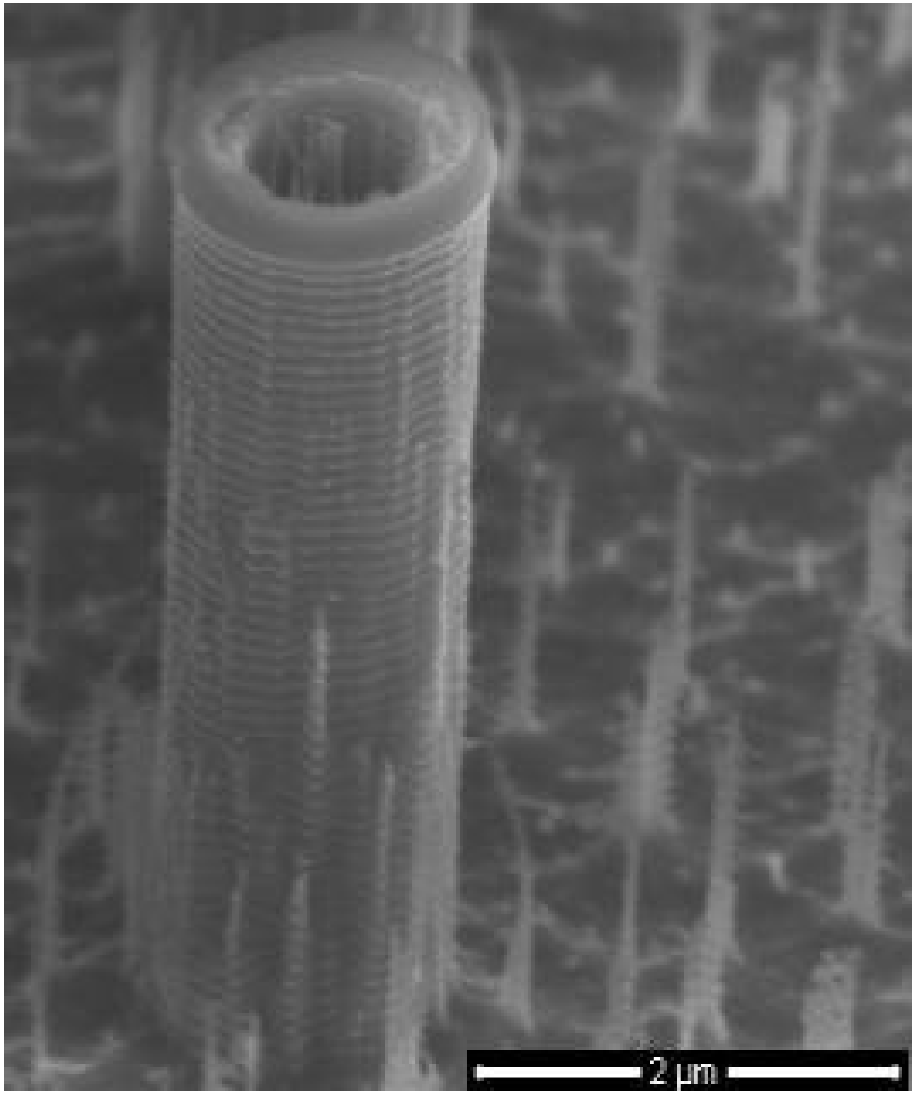
Side View

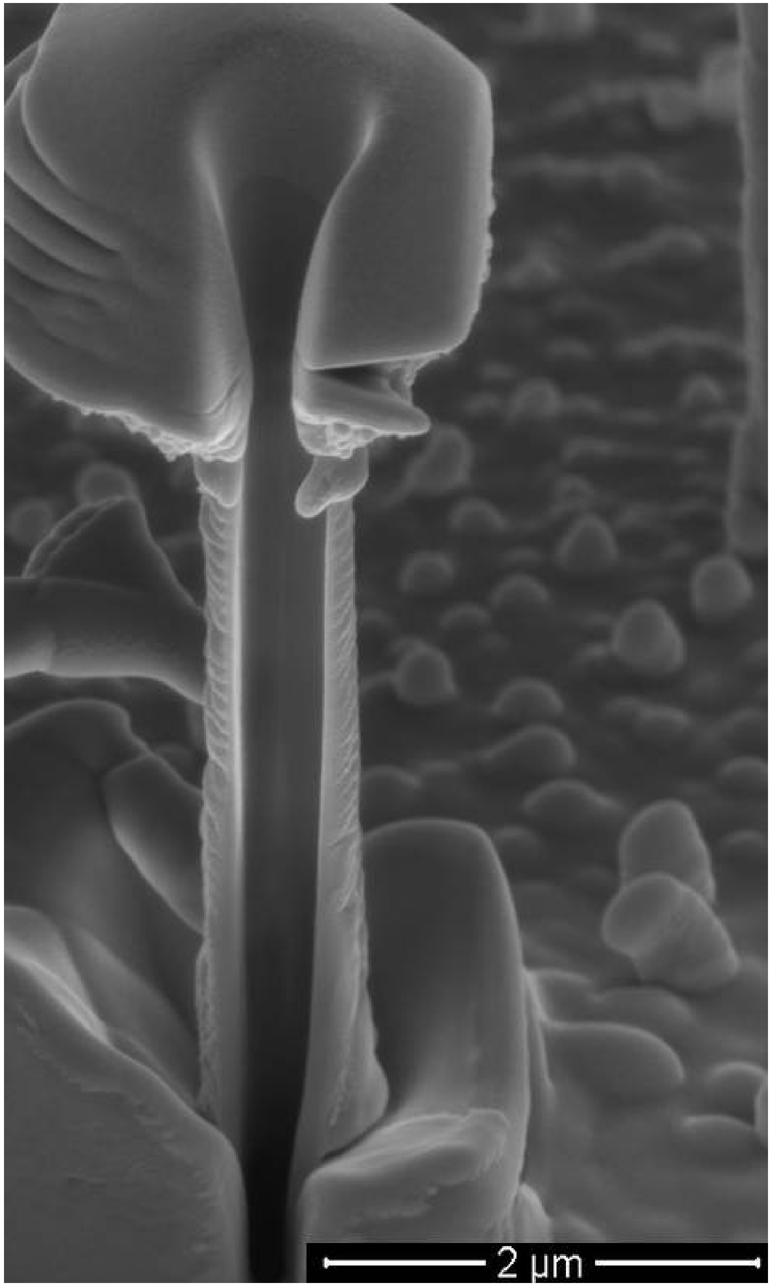
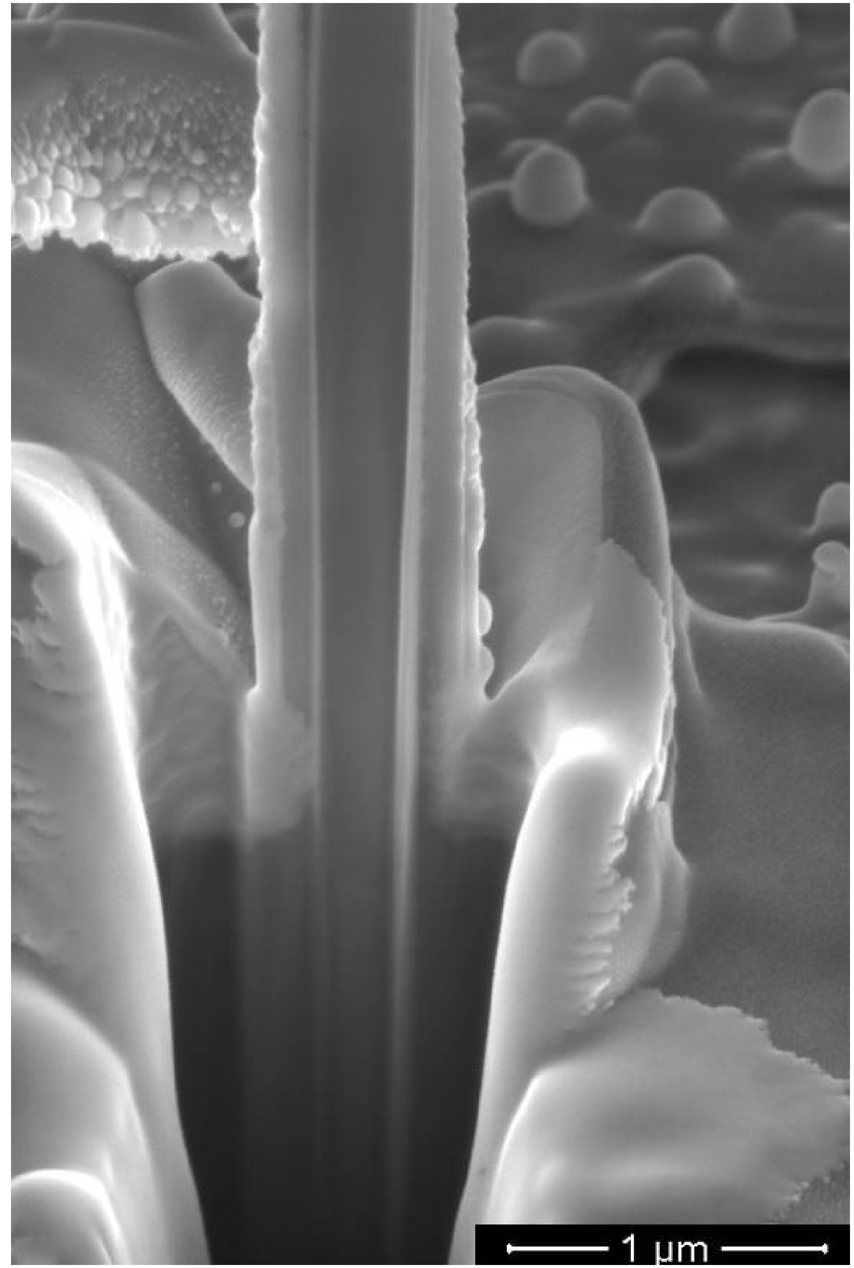


Pillars formed using DRIE

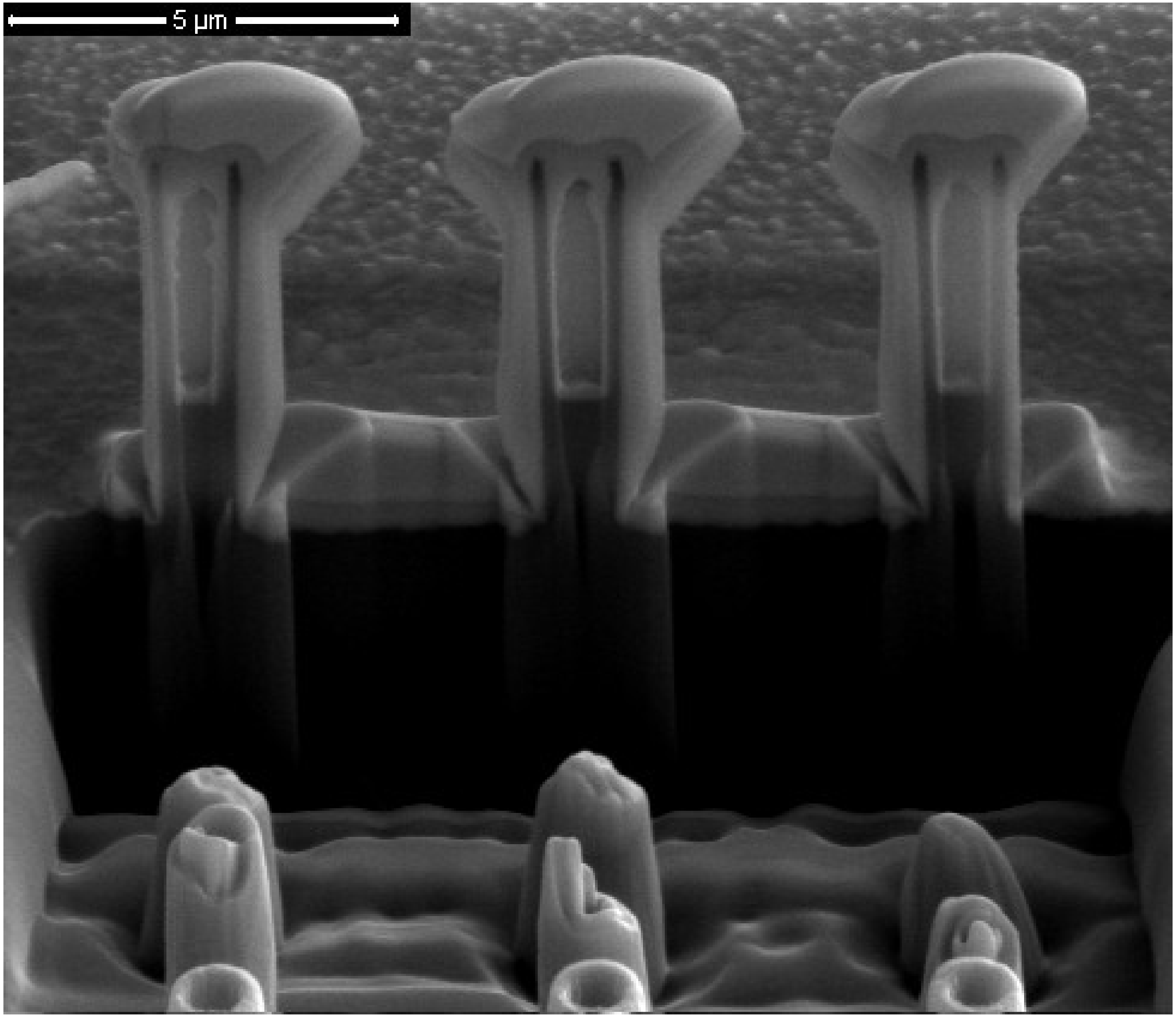
Side View



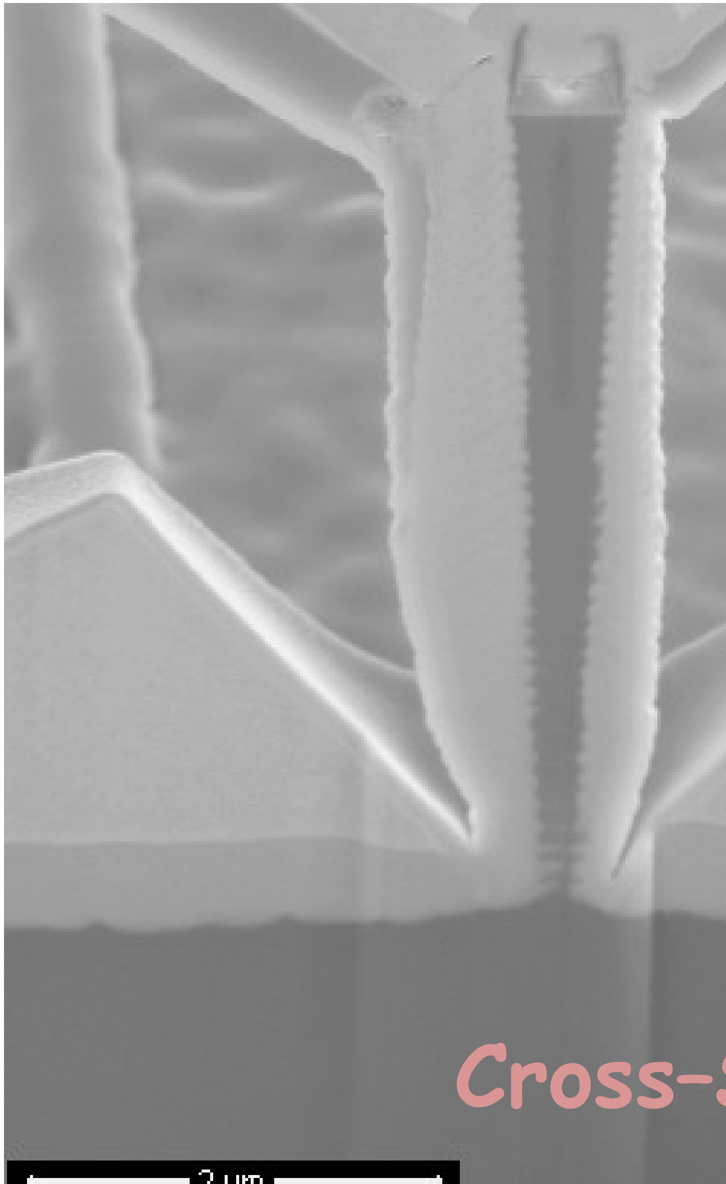


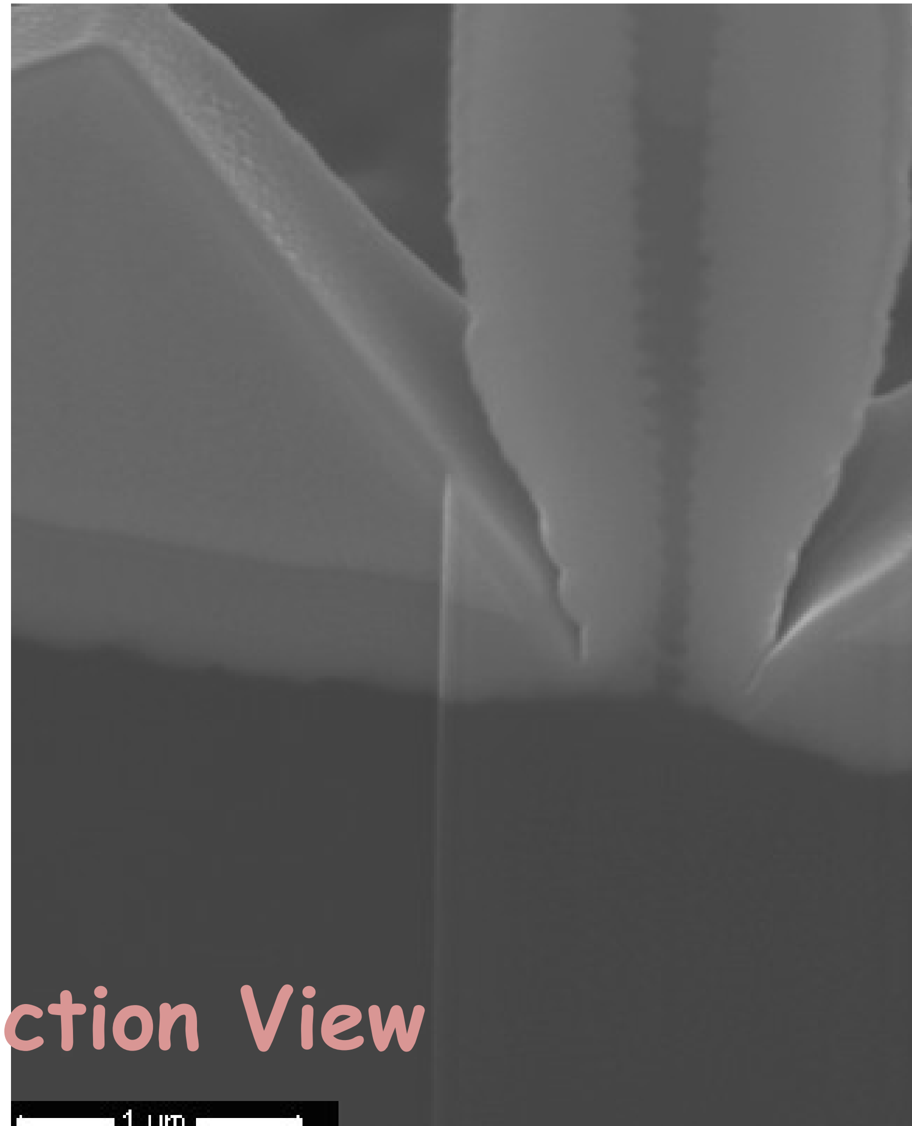

2 µm

1 µm

Cross-Section View



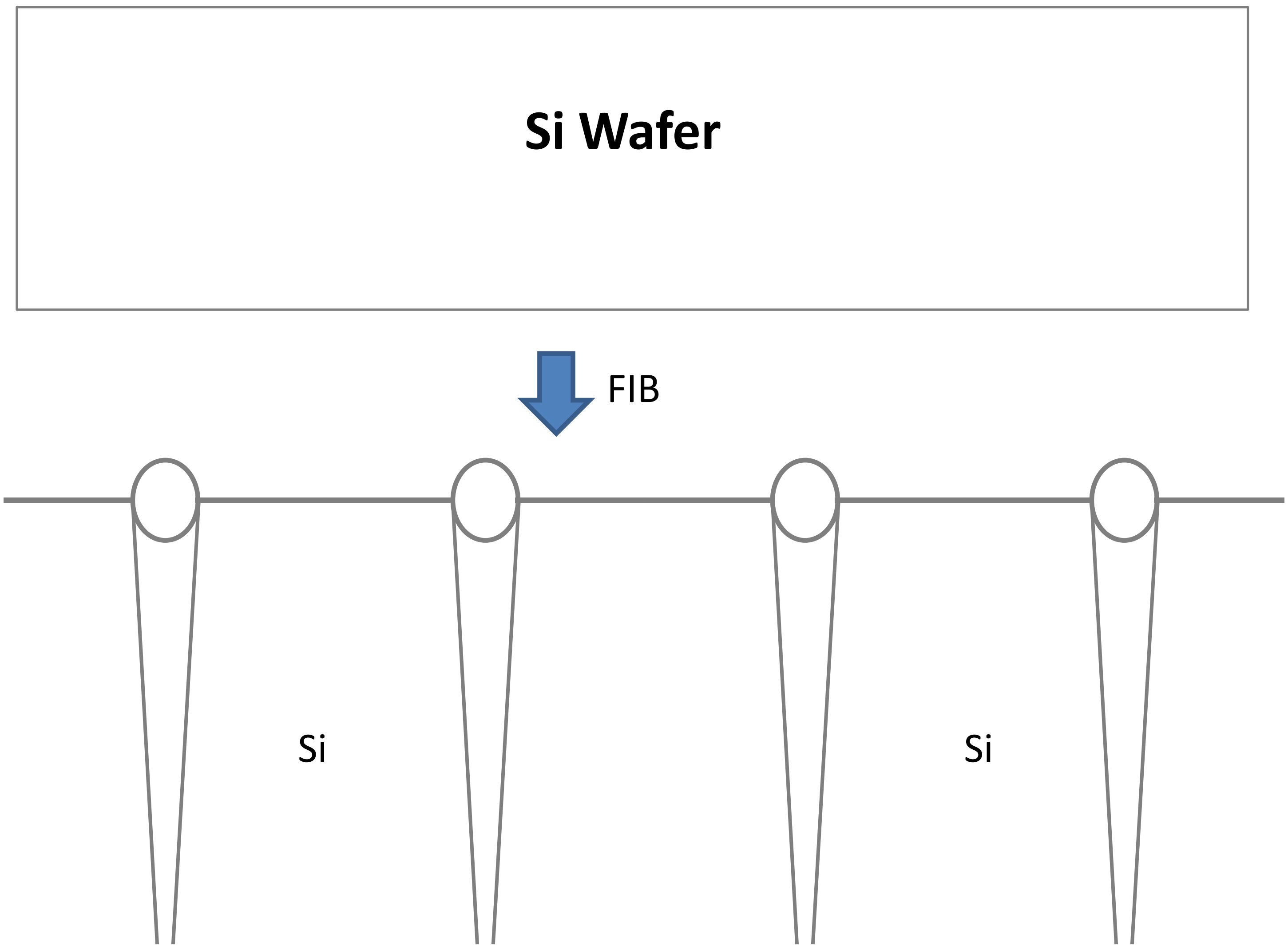
Pillars formed using DRIE

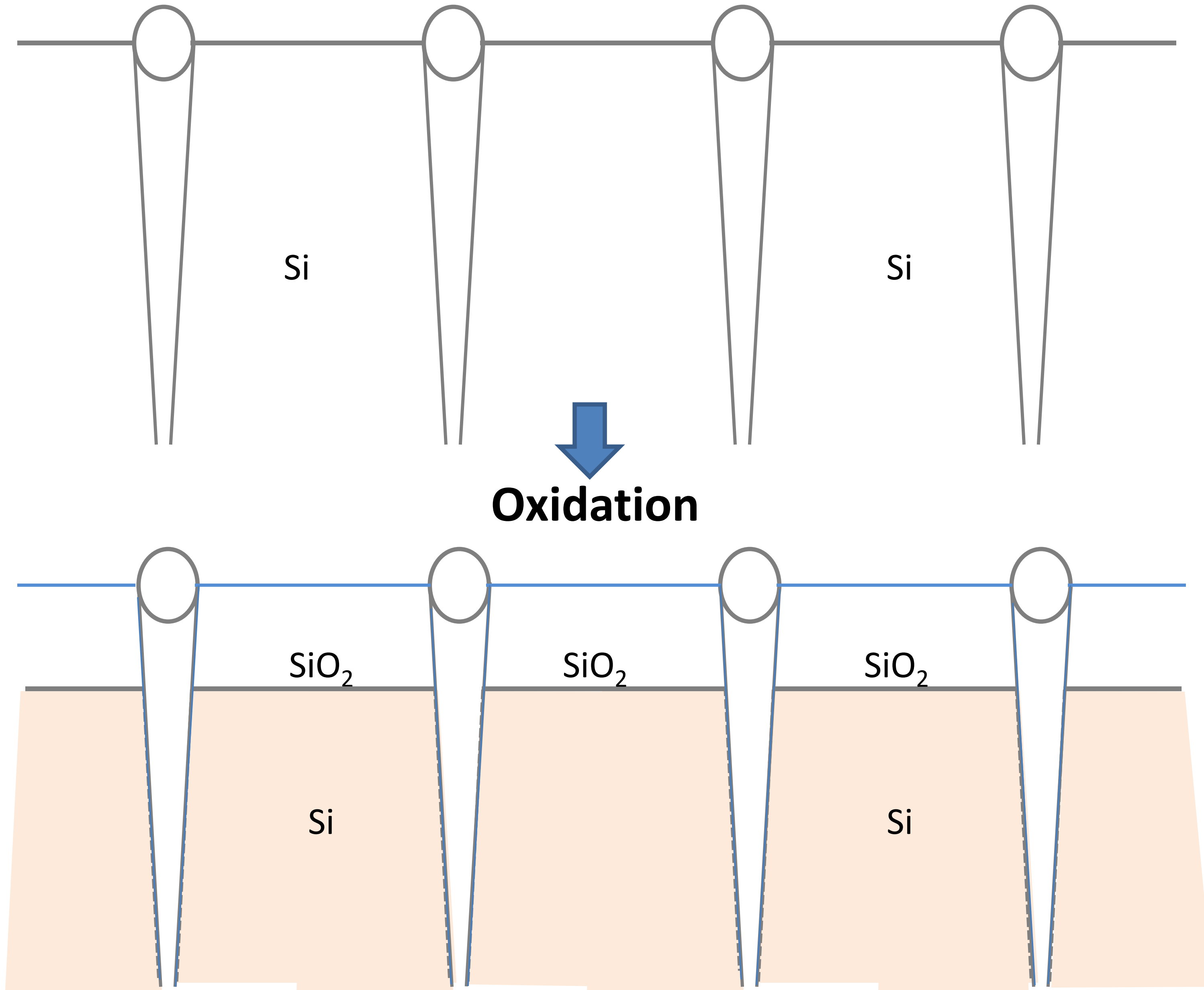


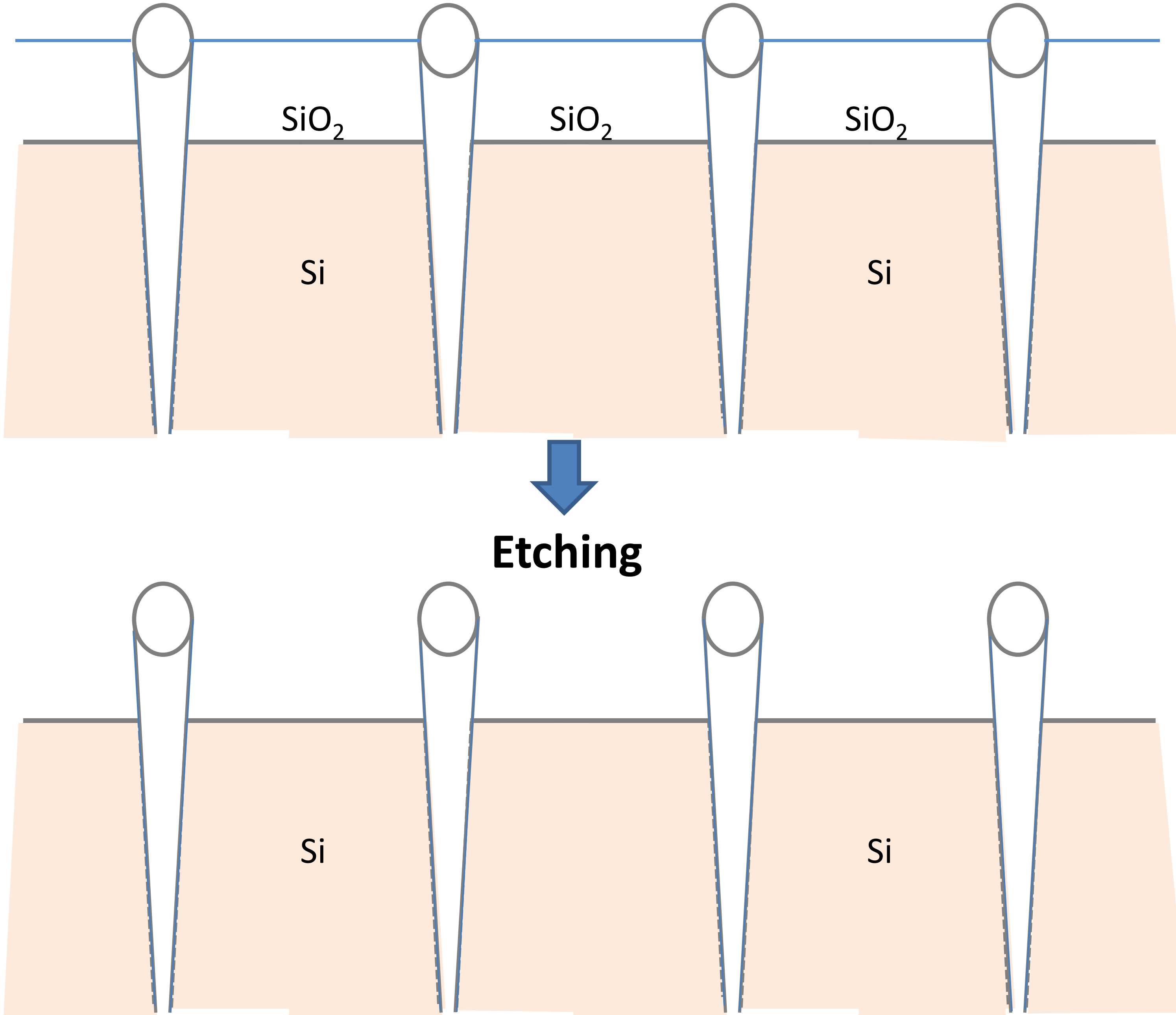


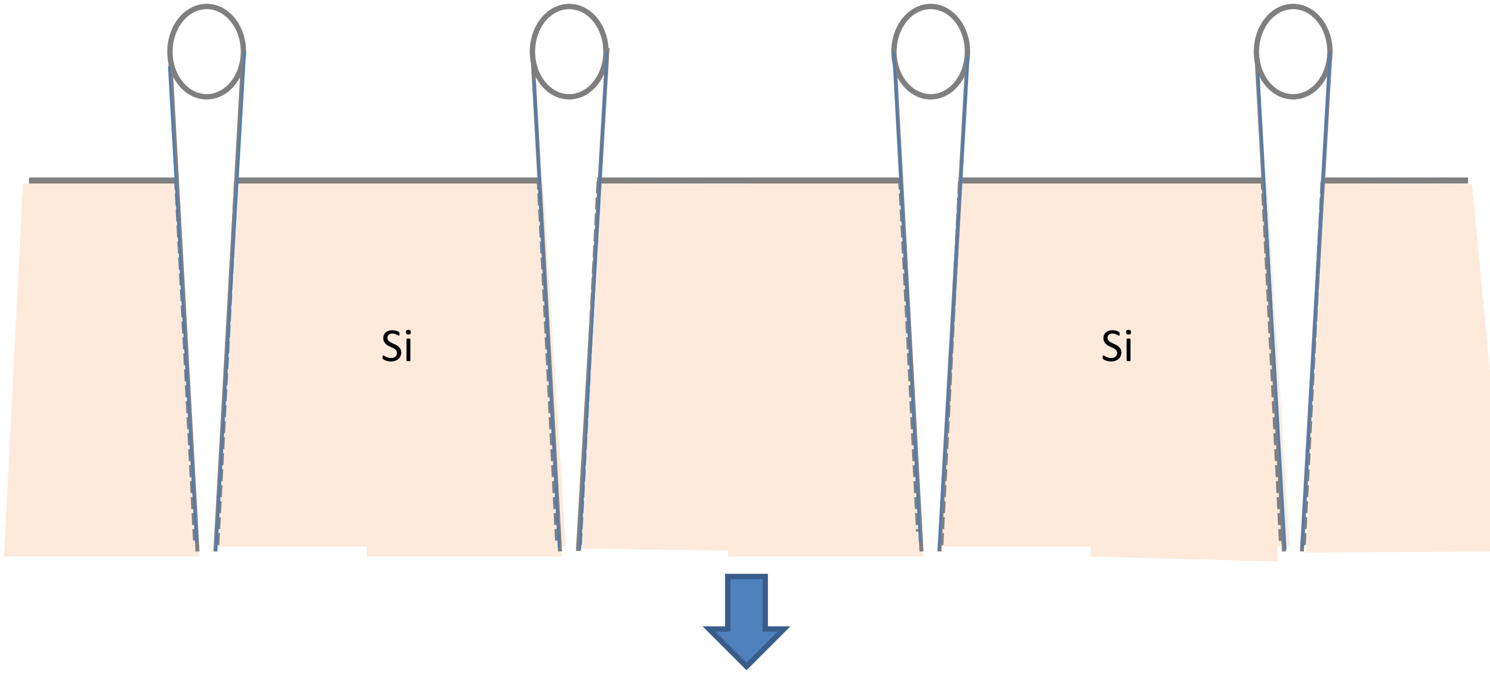
Cross-Section View

Fabrication of Nanoinjectors

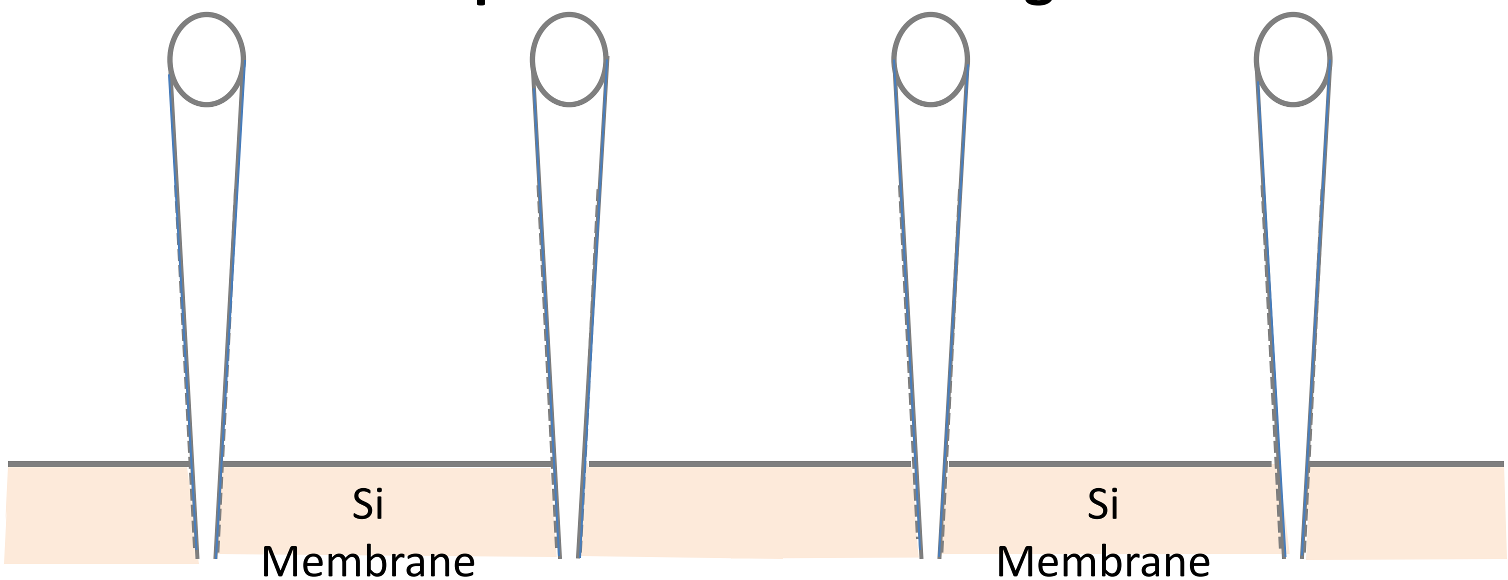


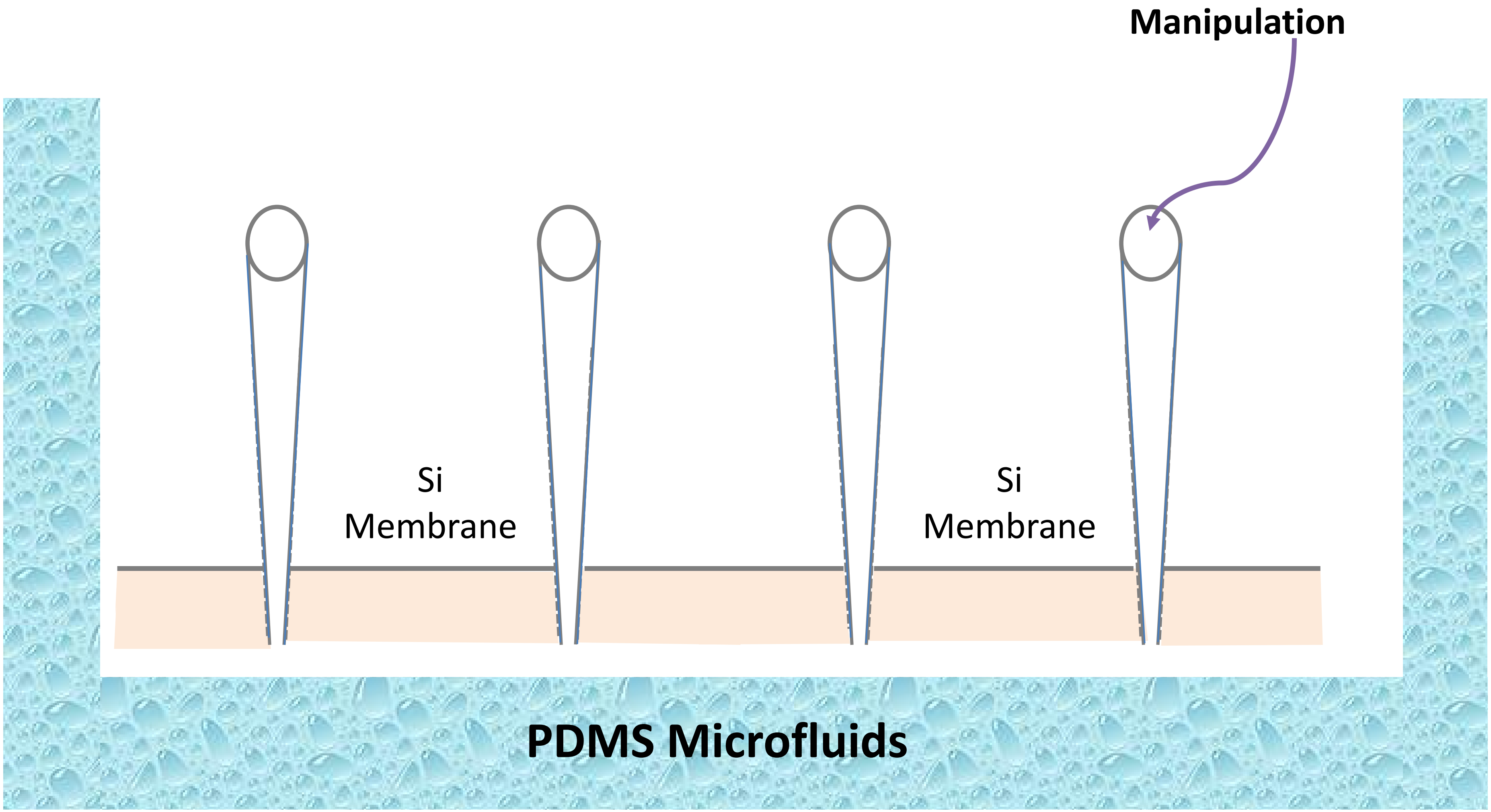

Si
Si
Oxidation
SiO2
SiO2
SiO2
Si
Si


SiO2
SiO2
SiO2
Si
Si
Etching
Si
Si



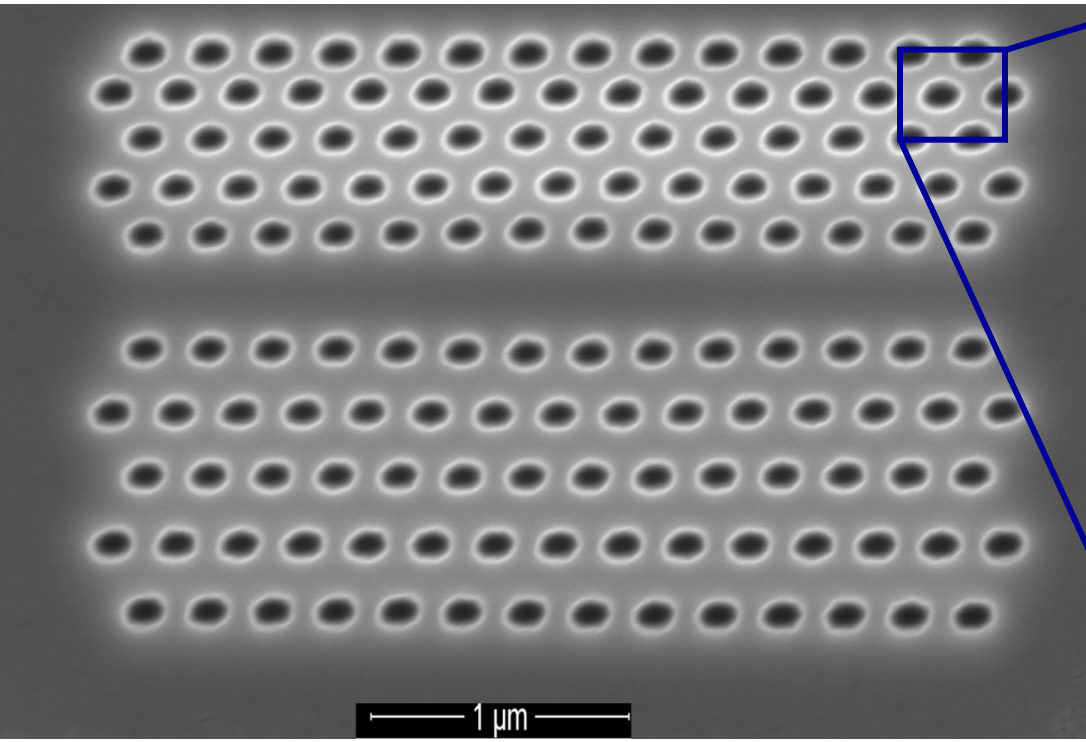
Deep Reactive Ion Etching



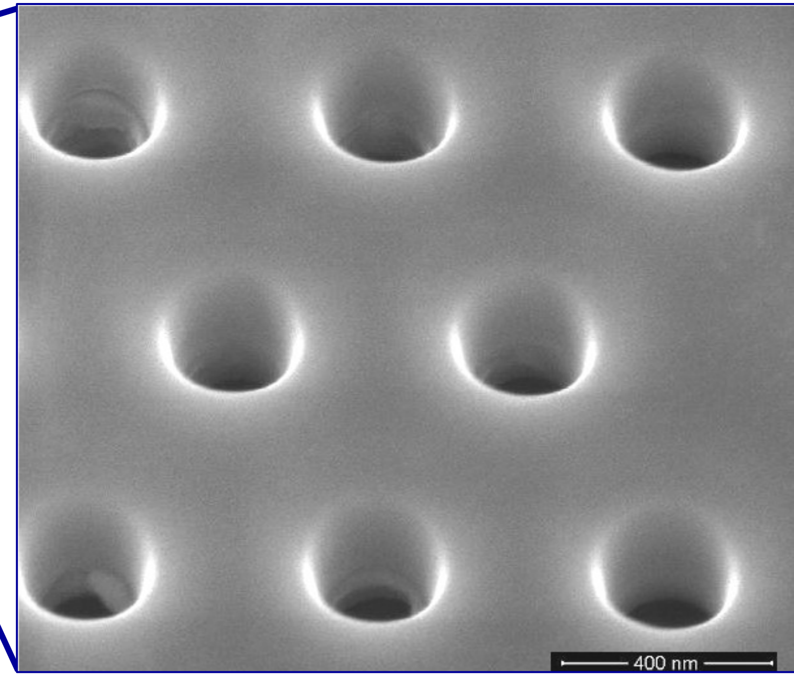


Introduction of external solutes to the nanoinjectors will be done via a PDMS microfluidics, produced separately. The PDMS cavity contains flow channels and connections to the external chemical reservoirs.

Fabrication: Initial FIB Patterning

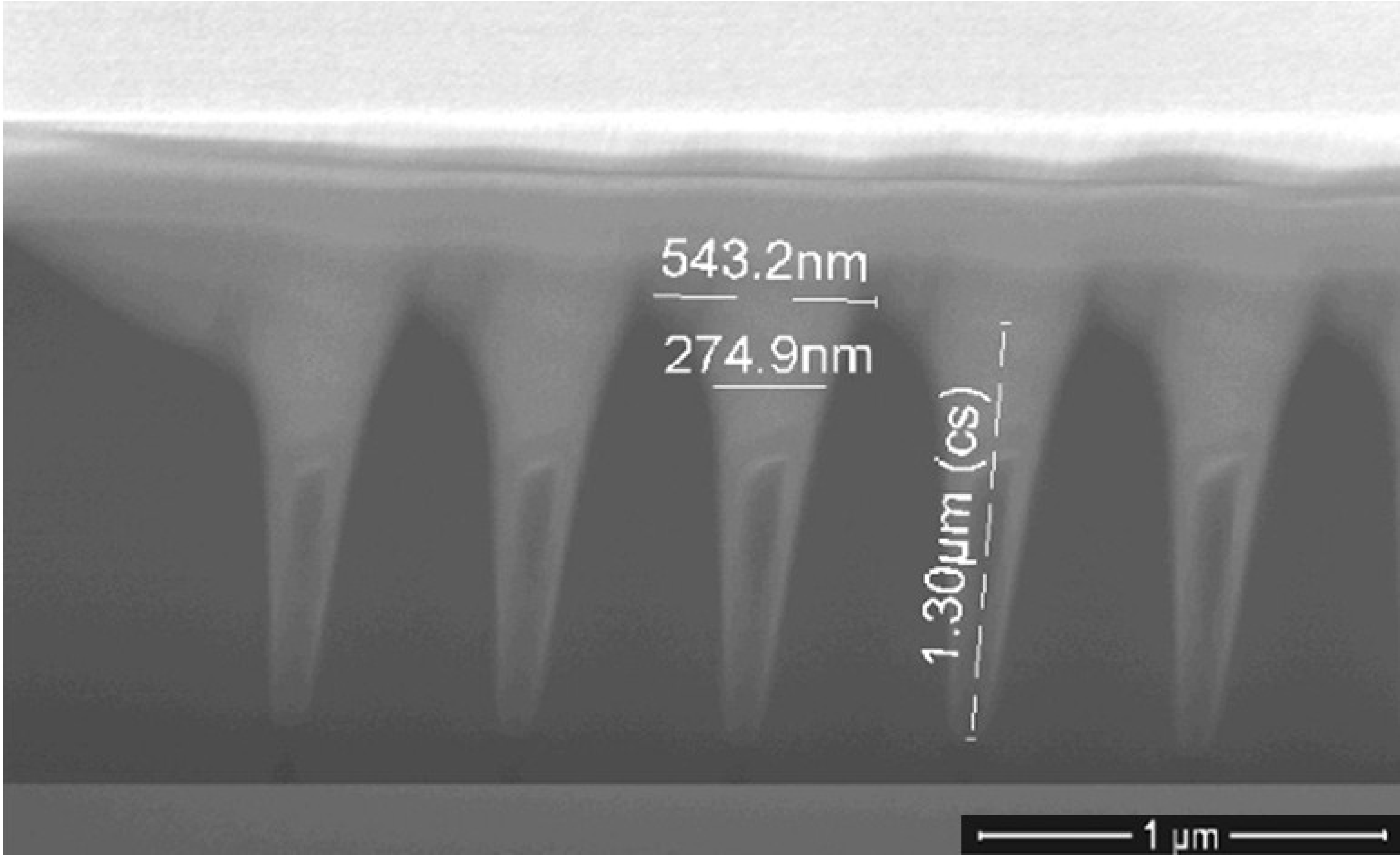


Top View



Side View

Cross-Section View



Thank You!

Questions?