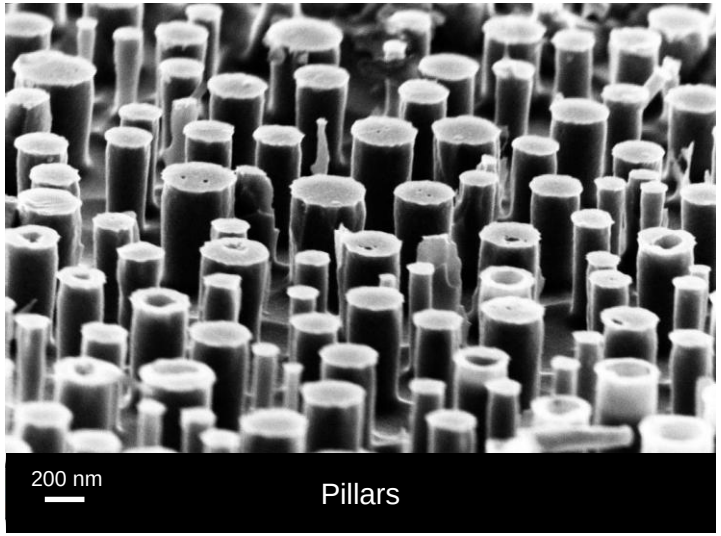
Submicrometric structured silicon surfaces obtained from polymer blend film by silica replication and cryogenic plasma etching



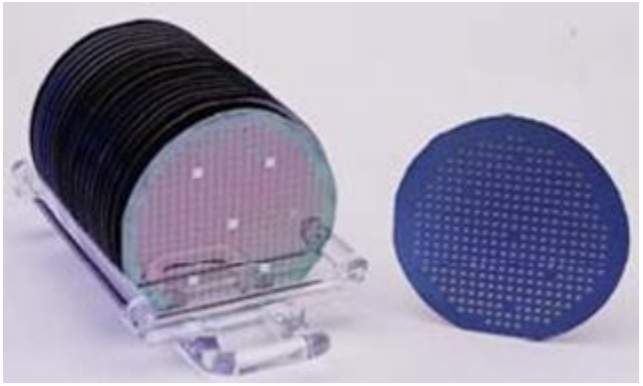
Alexane VITAL

Thomas TILLOCHER, Rémi DUSSART, Marylène VAYER, Christophe SINTUREL

PESM 2014

Context

Develop nanostructured surfaces

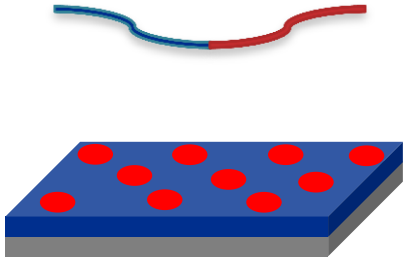


The photolithography is generally used to realize mask for plasma etching in the CMOS technology.

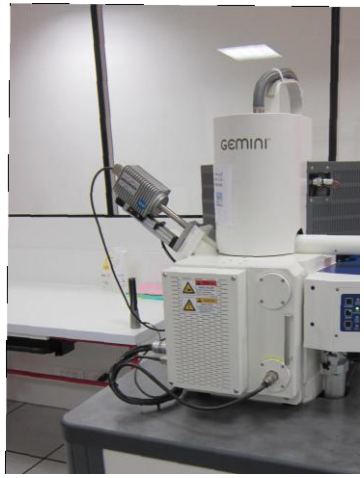
However, this step is limited for small size.

Different solutions:

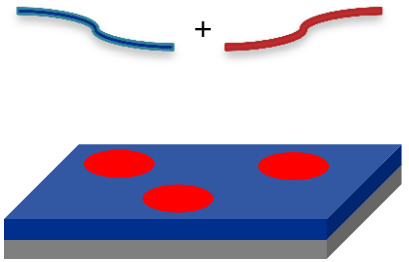
Block copolymer film



E-beam lithography



Homopolymer blend film



Elaboration of polymer mask

Blending of two homopolymers :

- In bulk :

phase separation at macroscopic scale

- In thin film : phase separation at nanometric or submicrometric scale

Conditions:

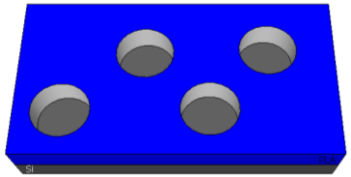
- Incompatibility of the two polymers
- Surface energy of the polymers
- Interaction between the polymer and the surface

Laterally phase separated system

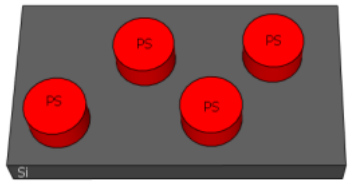
Stratified system

Homogeneous system

Selective extraction of one component :



Selective extraction of the minor component

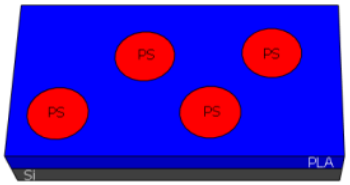


Selective extraction of the major component

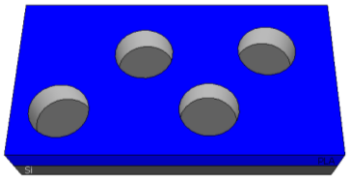
Goal

Develop nanostructured silicon surfaces by cryogenic plasma etching.

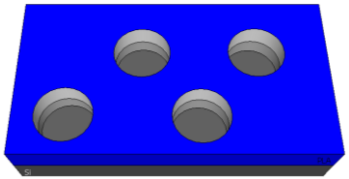
To achieve this goal : 2 ways



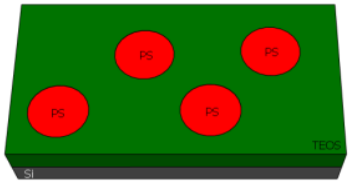
Thin film of polymers blend



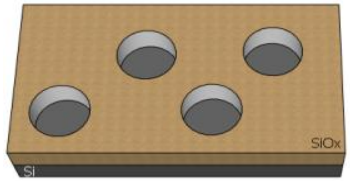
Porous polymer mask



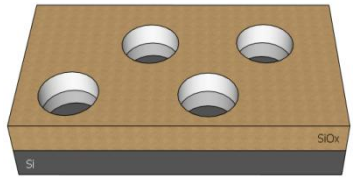
Etched surface



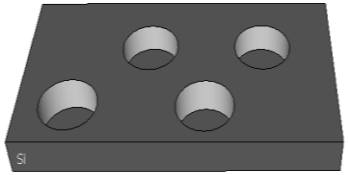
Replication of selectively extracted polymer film



Silica mask

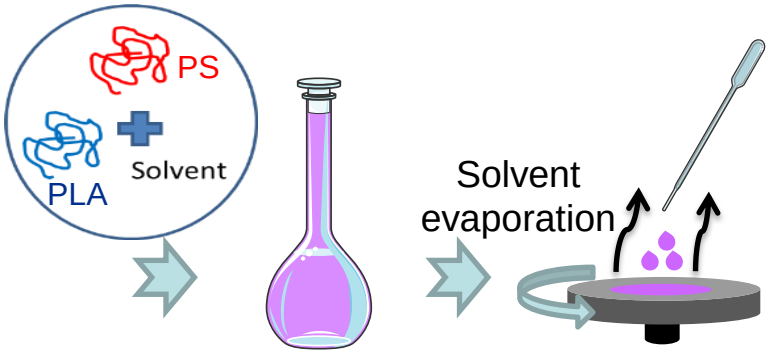


Etched surface



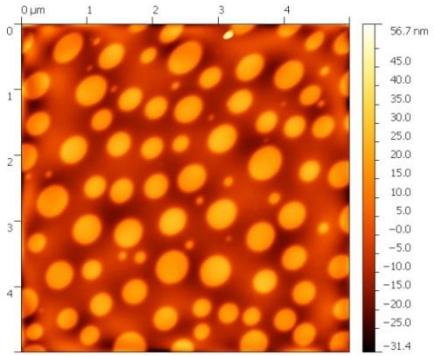
Etched silicon surface

Elaboration of continuous polymer mask

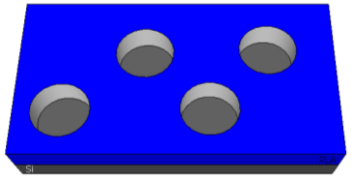


Homopolymers blend in solution

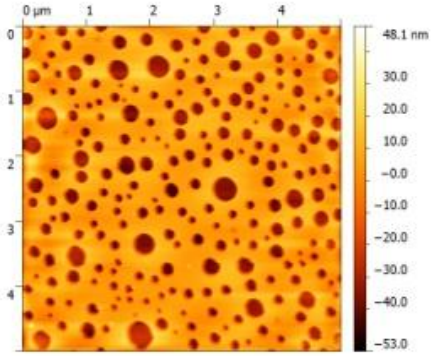
Spin Coating



AFM images

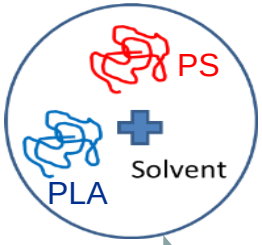


Selective extraction of the minor component



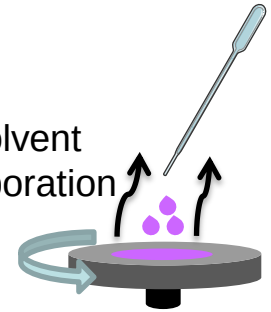
$\overline{\text{Diam}}$ = 500 nm
Thickness = 100 nm

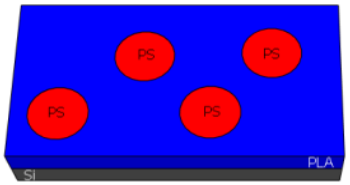
Elaboration of discrete polymer mask



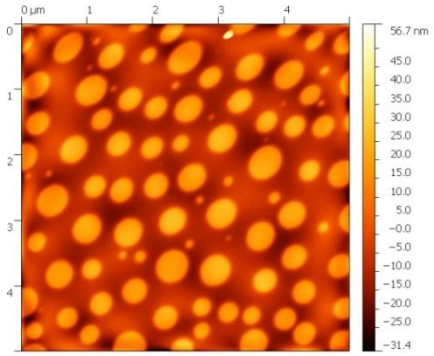
Homopolymers blend in solution

Solvent evaporation

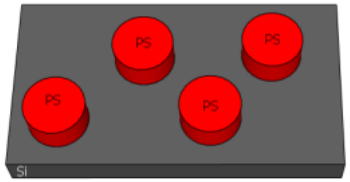




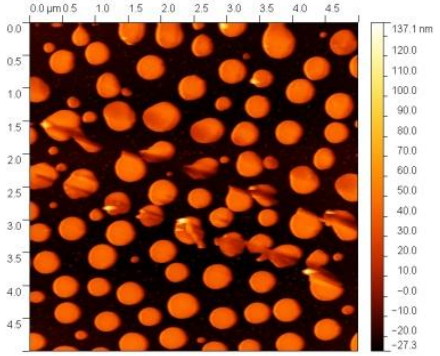
Spin Coating



AFM images



Selective extraction of the major component

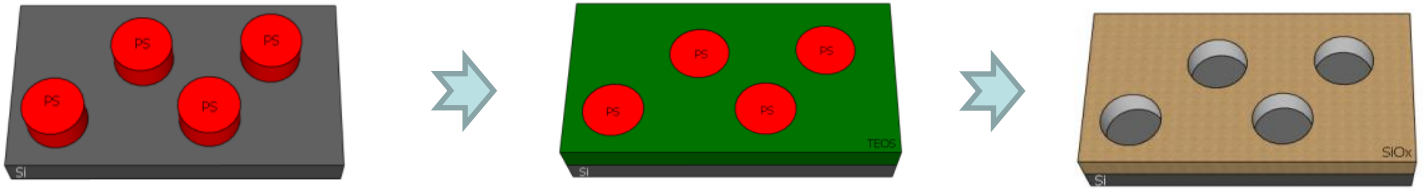


$\overline{\text{Diam}}$ = 500 nm
Height = 100 nm

Important parameter : Concentration allows to modify domains size

Preparation of continuous silica mask

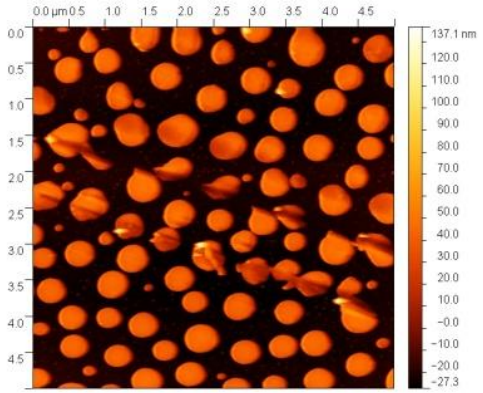
Discrete polymer film

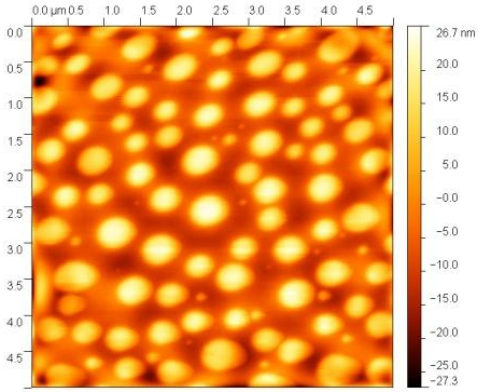


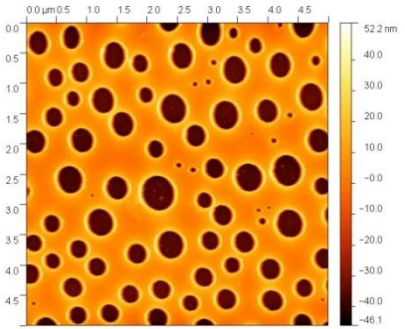
After selective extraction of the major component

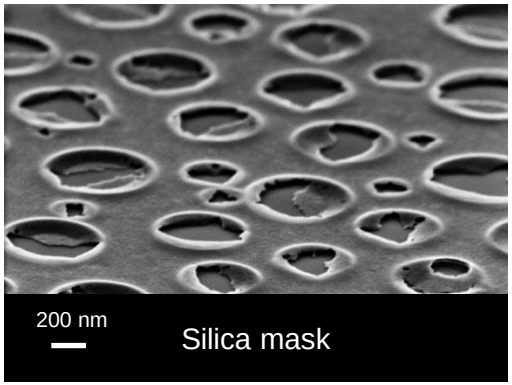
Solution of silica precursor is deposited

Calcination





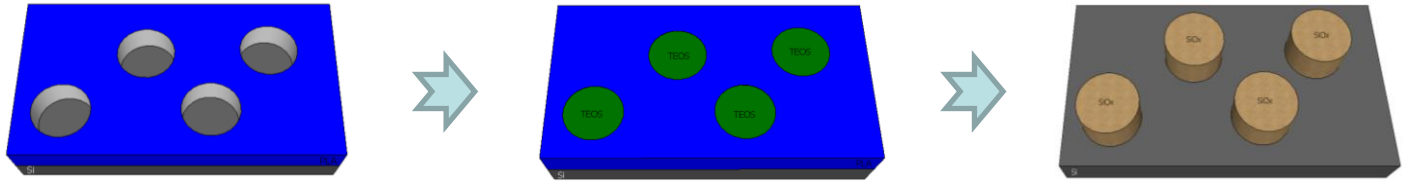




$\overline{\text{Diam}}$ = 500 nm
Thickness = 100 nm

Preparation of discrete silica mask

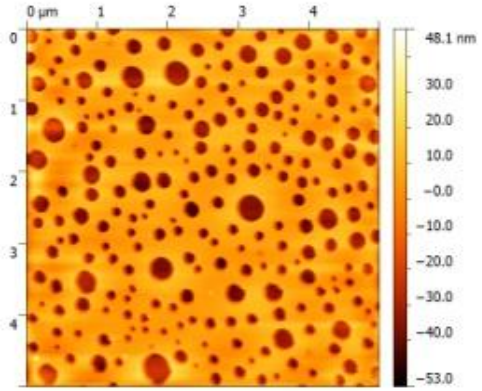
Continuous polymer film

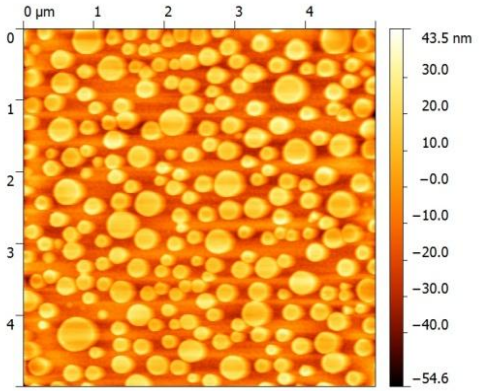


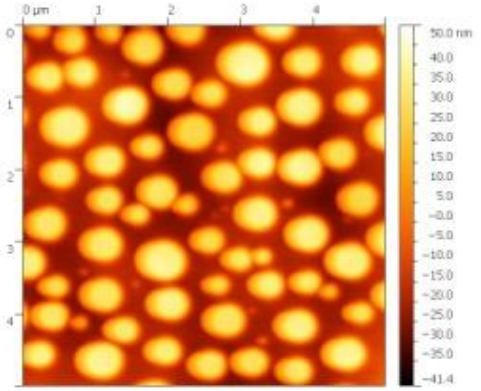
Selective extraction of the minor component

Solution of silica precursor is deposited

Calcination



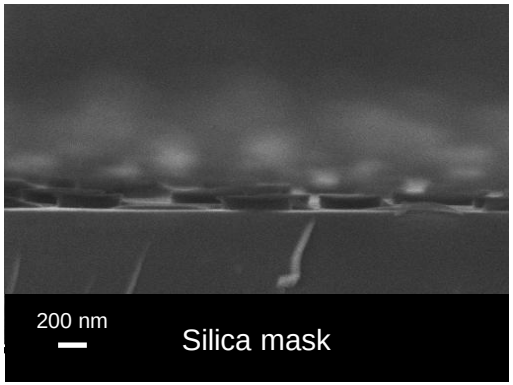




Important parameter :

Concentration of silica precursor allows to modify the filling ratio

$\overline{Diam}$ = 500 nm
Height = 100 nm



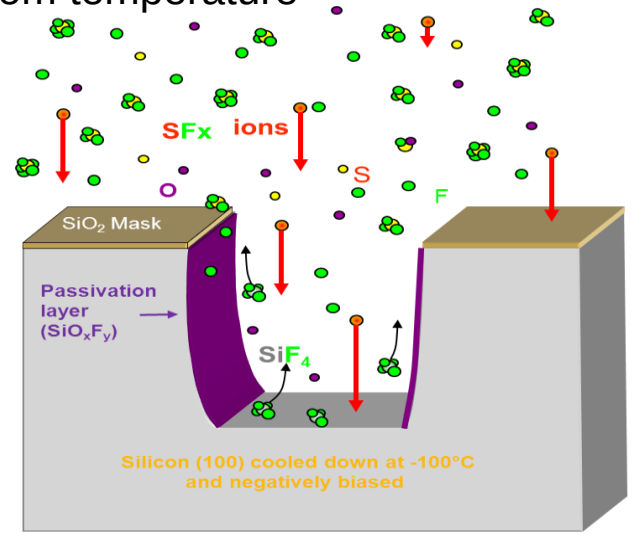
Cryogenic Plasma Etching

In a standard process, silicon substrate is :

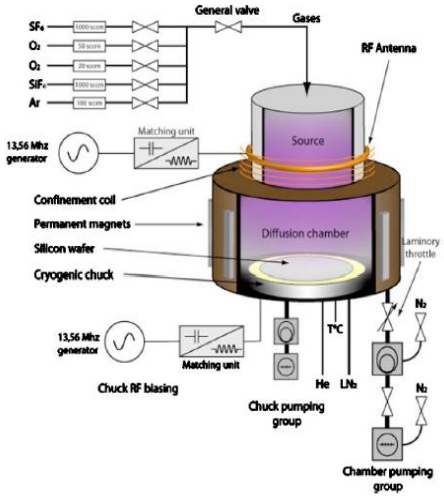
- cooled down at a cryogenic temperature (-120°C)
- exposed to a monocyclic SF_6/O_2 plasma

Passivation layer : SiO_xF_y

- prevents lateral etching and so promotes vertical etching
- is stable only at low temperature and is desorbed when heated to room temperature

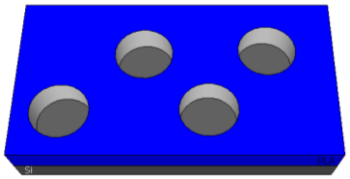


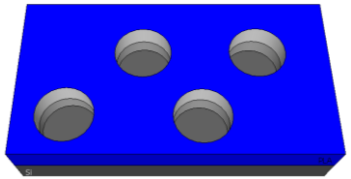
Equipement : Alcatel 601E



The standard cryogenic process allows to obtain high etch rates with smooth sidewalls

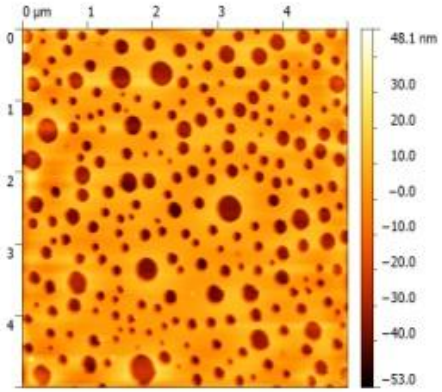
Cryogenic Plasma Etching with continuous polymer mask





-120°C

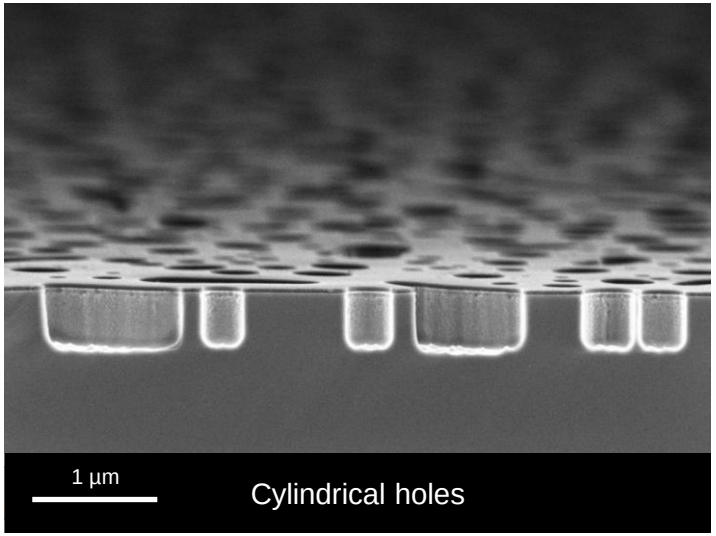
After selective extraction of the minor component



$\overline{\text{Diam}}$ = 500 nm

Thickness = 100 nm

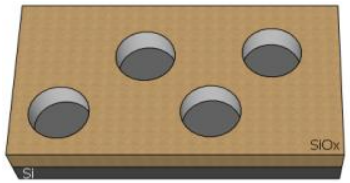
Plasma etching (45 s)



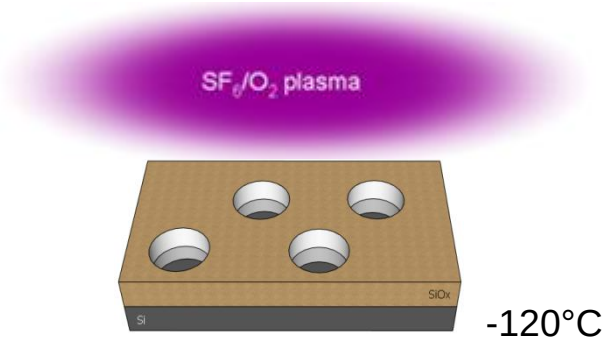
Depth : 800 nm

ER_{Si} : 1.6 µm.min^{-1}

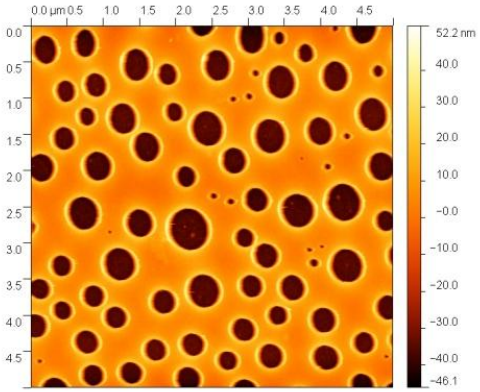
Cryogenic Plasma Etching with continuous silica mask



After calcination

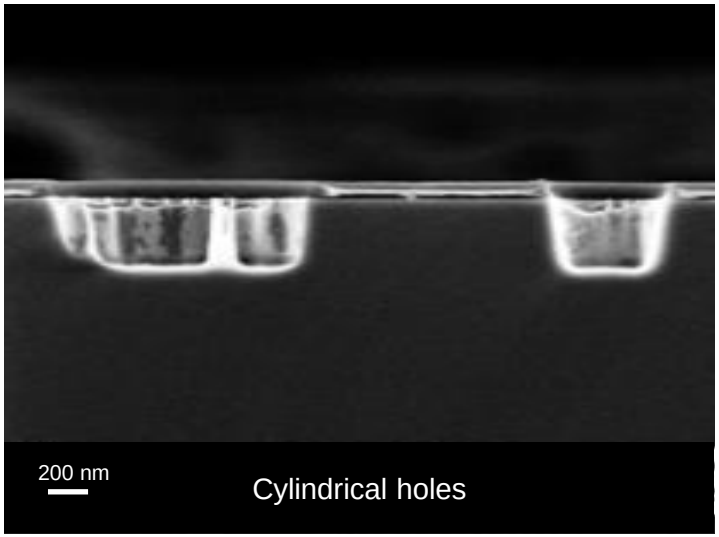


Plasma etching (45 s)



$\overline{\text{Diam}}$ = 500 nm

Thickness = 100 nm



Depth : 800 nm

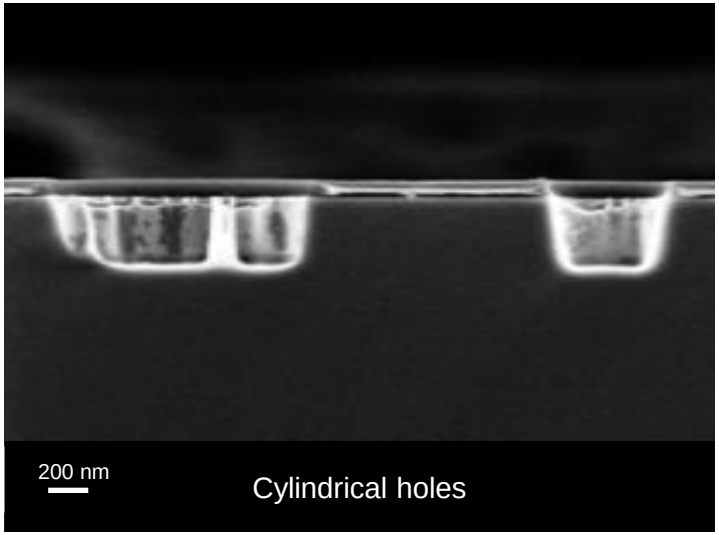
ER_{Si} : 1.6 µm.min^{-1}

Concentration influence of polymer solution

The concentration of polymer solution is divided by two :

20 mg.mL^{-1}

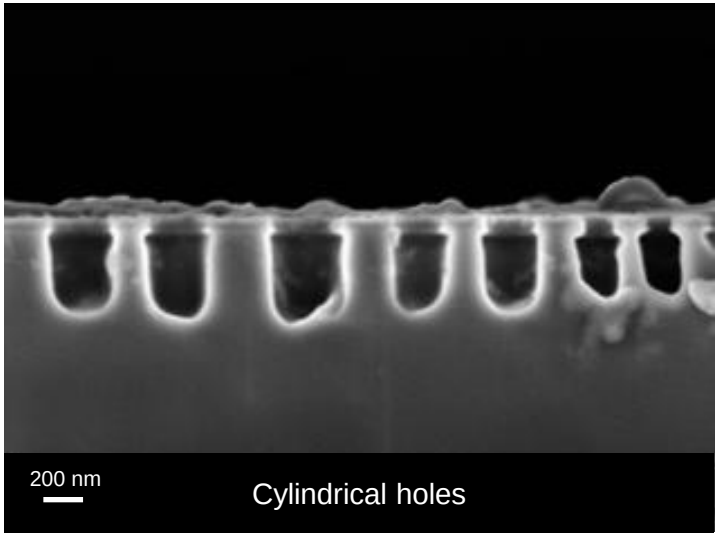
Thickness of mask = 100 nm



Holes size : 500 nm

10 mg.mL^{-1}

Thickness of mask = 50 nm



Holes size : 250 nm

Etch holes with the same :

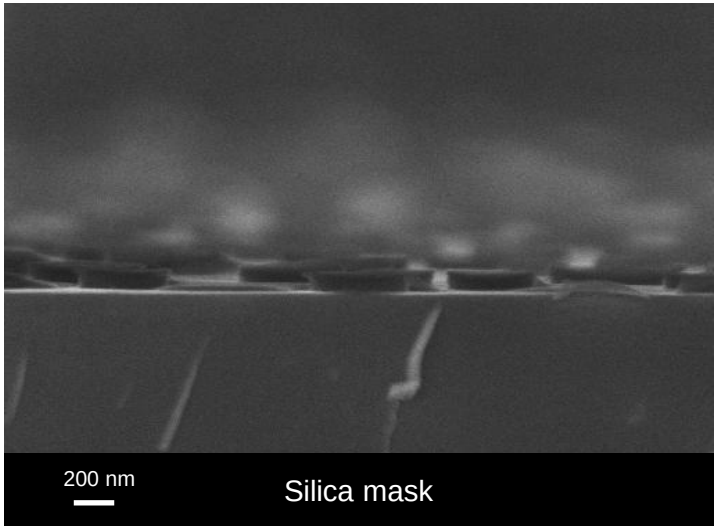
- Depth : 800 nm
- ER_{Si} : 1.6 µm.min^{-1}

Influence of the choice of extracted component

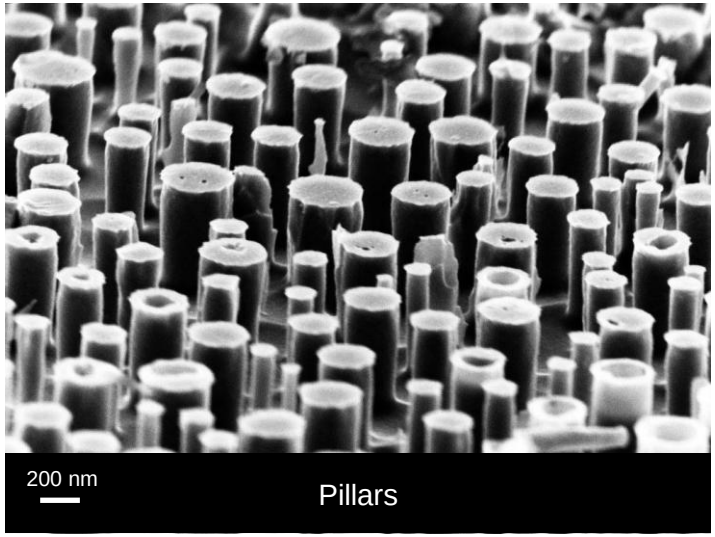
During the preparation of the polymer film, selective extraction of the minor component.

After calcination

Plasma etching (45 s)



Height = 100 nm

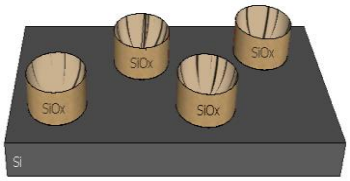


Height : 1 µm

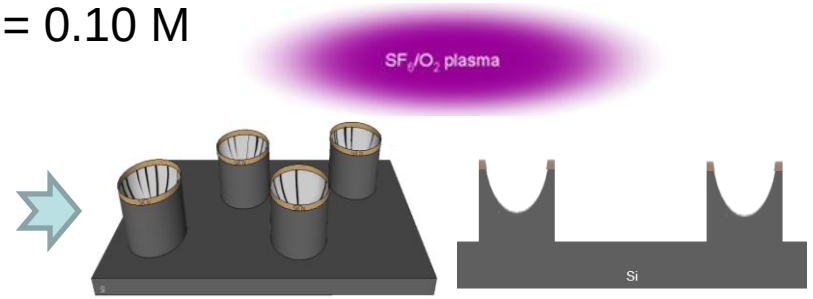
ER_{Si} : 1.9 µm.min^{-1}

Concentration influence of silica precursor solution

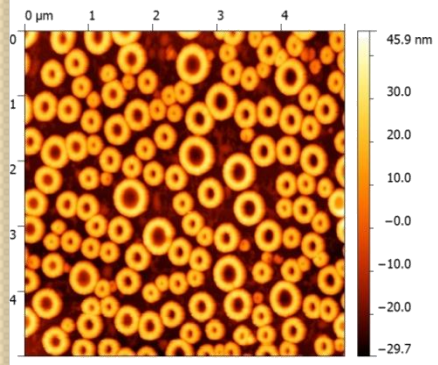
During the step of replication, lower concentration of the silica precursor solution = 0.10 M

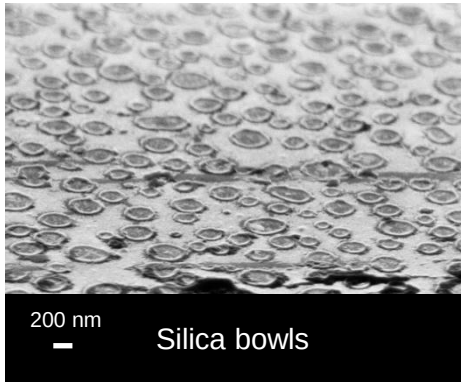


After calcination



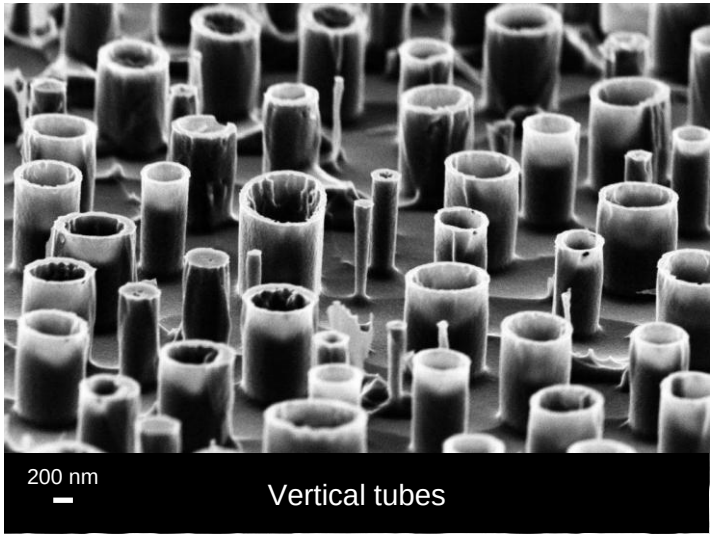
Plasma etching (45 s) -120°C





Height for the edge = 100 nm

Height for the center = 20 nm



Height : 1 µm

ER_{Si} : 1.9 µm.min^{-1}

Conclusion

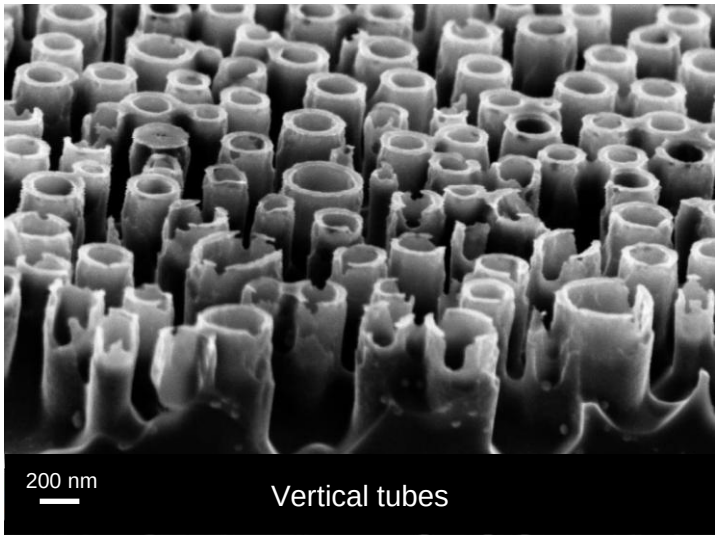
Elaboration of continuous or discrete masks:

- Polymer mask
- Silica mask

Different silicon structures are obtained:

- Cylindrical holes
- Pillars
- Tubes hollow in the upper part

A wide range of etched structures can be prepared with such procedures.



Thank you for your attention

Alexane VITAL