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FIB MICRO/NANO FABRICATION OF SILICON MASTER FOR BIOMEDICAL APPLICATIONS

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Instrumentation

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CrossBeam® 1540XB by Zeiss

❑**Scanning Electron Microscopy** (FE-SEM)

*Resolution **1,1 nm***

❑**Focused Ion Beam** (FIB)

*Resolution **7 nm** – Ga^+ Ion Energy **5 ÷ 30 KeV***

❑ **Gas Injection System** (GIS)

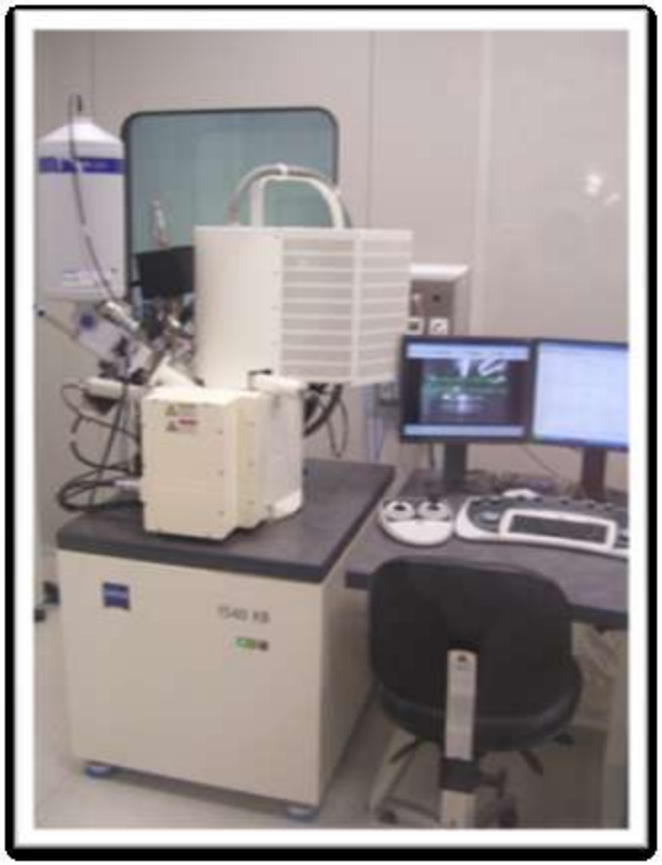
5 gas: Pt – W – Insulator – Water - F

❑**EDS Microanalysis**

Energy resolution **127 eV** at Mn K_α

❑ **STEM**

.



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NanoMolecular Sieves

E. Angeli, G. Firpo, et al ,*Lab Chip*, 2011,**11**, 2625-2629

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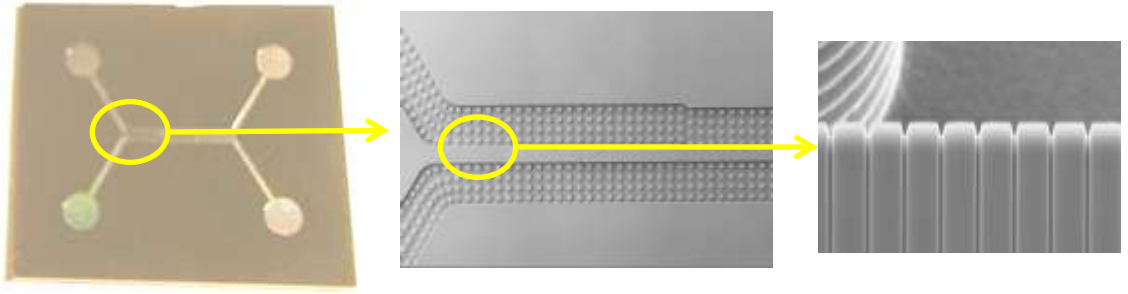
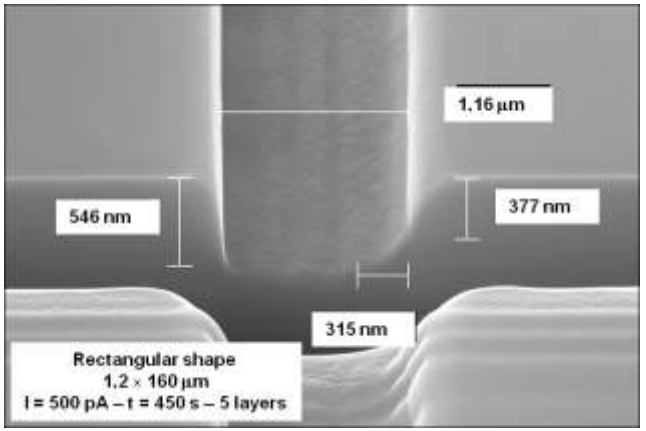
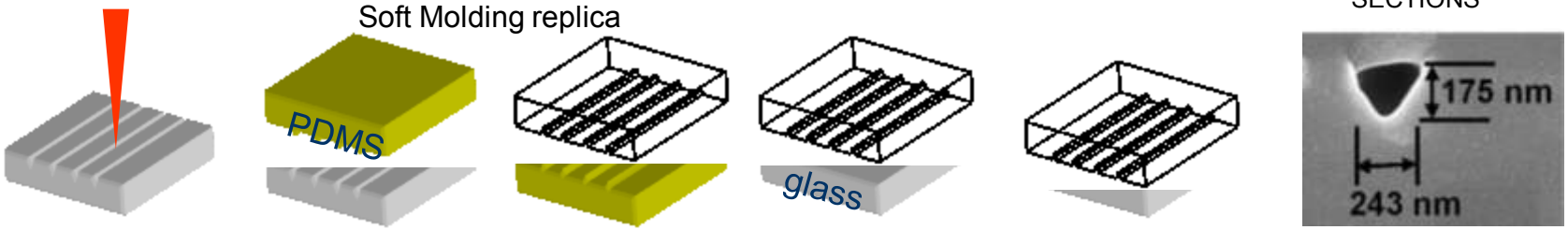
CHANNELS FABRICATION





MA STER CROSS SECTIONS

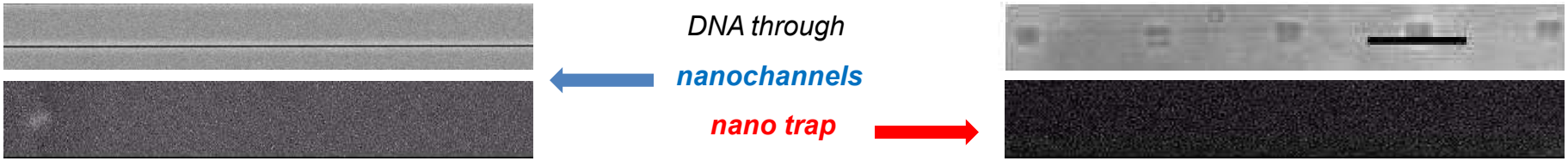
DEVICE FABRICATION – SOFT MOLDING



FIB | Negative | Positive | Glass bonding | Device

DEVICE CROSS SECTIONS

FIRST RESULTS



DNA through

nanochannels

nano trap

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Nanopore Technology

V. Mussi, G. Firpo et al, *Nanotechnology* 2010, **21,** 145102

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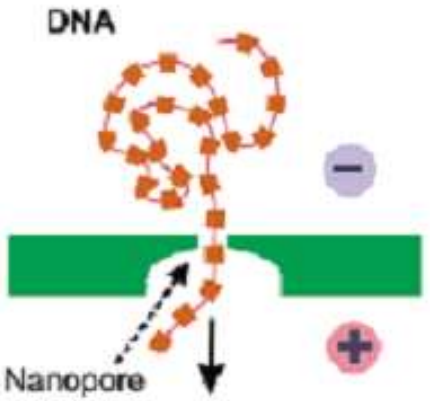
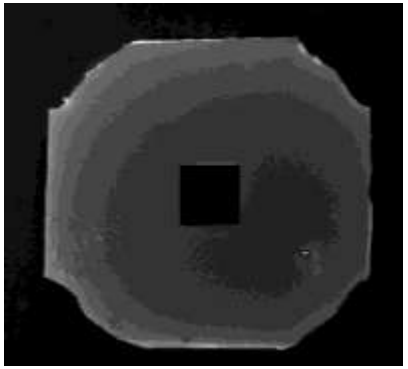
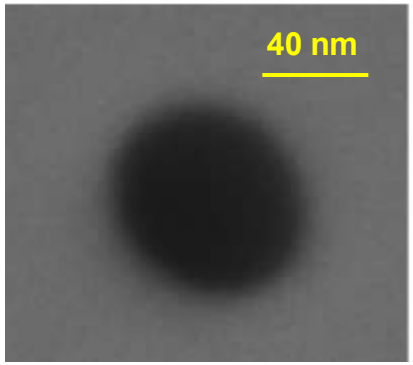
TRANSLOCATION EXPERIMENT



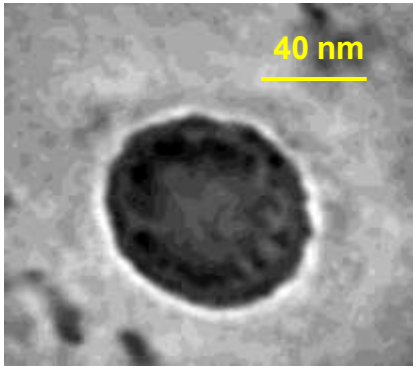
NANOPORE FABRICATION



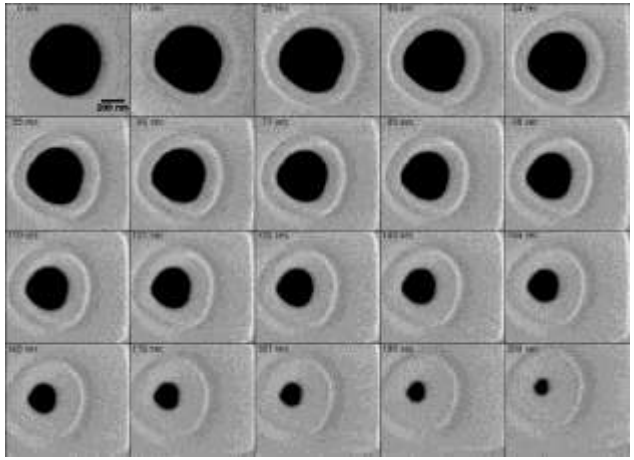
Si_3N_4 membrane
100 nm - thick



FIB spot
1 pA @ 30 keV - t = 1 s
∅ 30 ÷ 40 nm



Pore Functionalization



SEM rastering @ 200 V – WD 2 mm

AN OPEN QUESTION . . .

Reduce the pore size is possible with

SEM rastering

✓ Si_3N_4 pore shrinkage ?
(*Appl. Phys. Lett.* **90**, 163102 (2007))

✓ Carbon deposition?

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Nanochannel device

P. Fanzio, G. Firpo, et al, *Lab Chip,* 2011, **11**, 2961

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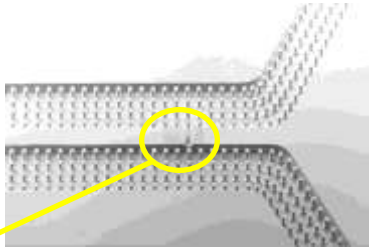
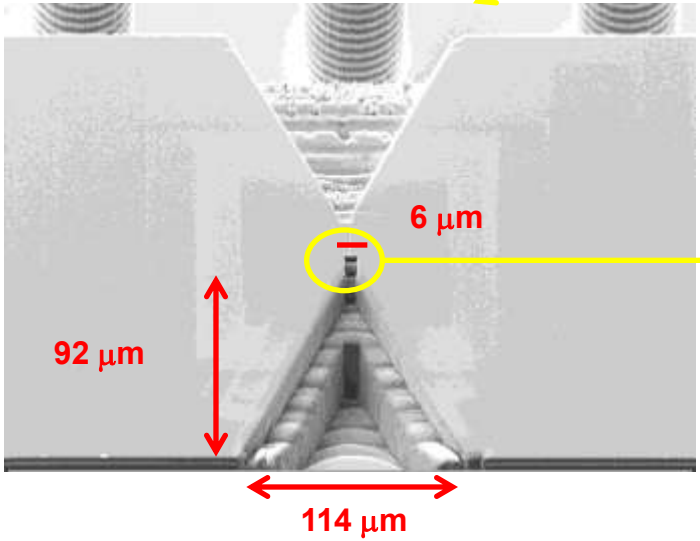
POLYMERIC NANOCHANNEL DEVICE

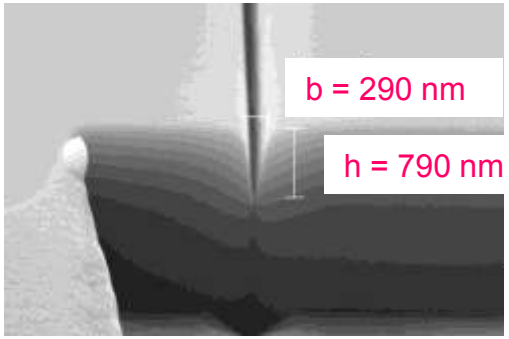
A LOW NOISE alternative to nanopore technology to DNA detection

FIB is used to fabricate two facing trapezoidal excavations (the depth decreases gradually from 20 μm to 2 μm) to reduce the distance between the two microchannels till 15 μm



The microchannels are connected by a FIB drilled nanochannel, with length L = 15 μm





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Nano Patch-Clamp

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CLASSICAL PATCH CLAMP

Performing with glass pipette with tip end diameter in the range of 15 micron

PLANAR PATCH CLAMP

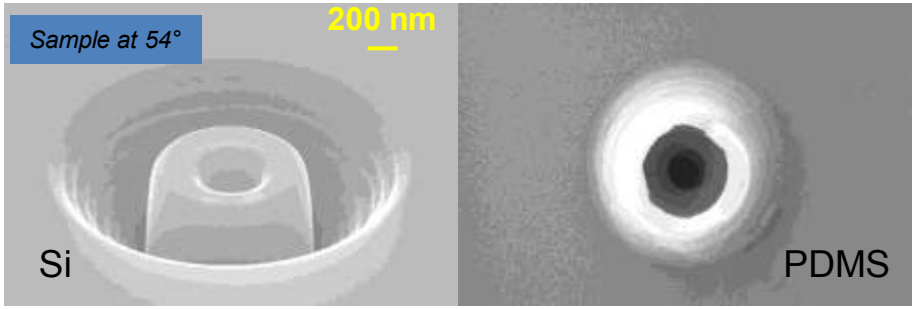
The glass pipette is replaced by a microopening in a planar substrate

FABRICATION OF PLANAR SUBSTRATE

With **air moulding technique**: from silicon master to PDMS biocompatible polymer substrate

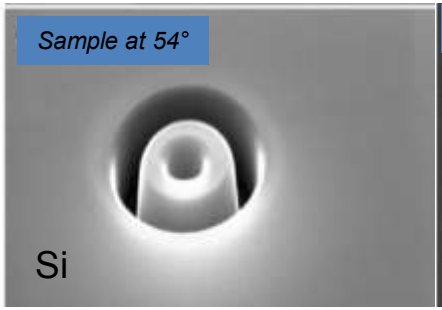
J Eur J Physiol **449** p.56 (2005)

FIB has been used to prototype masters with different morphologies for the creation of polymeric micro-nozzle pipettes similar to the glass pipette traditionally used for patch clamp.

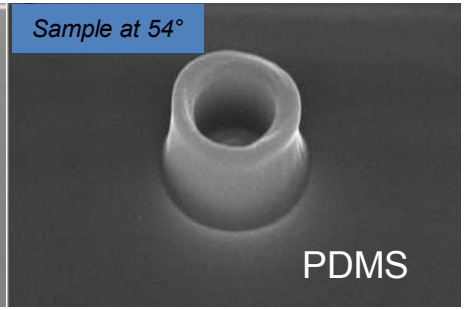


Silicon master with conical morphology and 500 nm pore

Air moulding replica



Silicon master with cylindrical morphology and 500 nm pore



Air moulding replica

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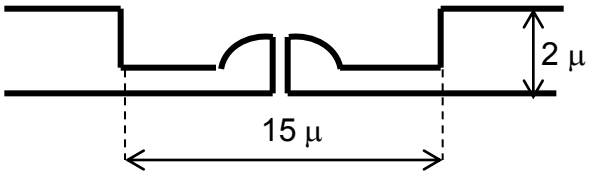
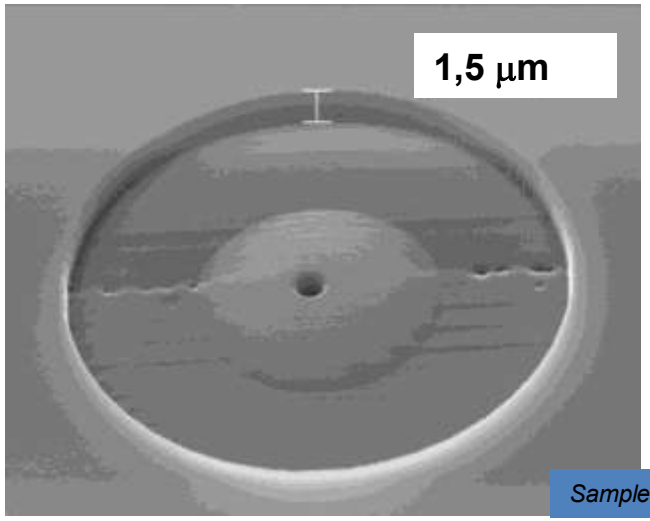
FIB Artefacts

Another type of profile for master morphology for planar patch clamp.

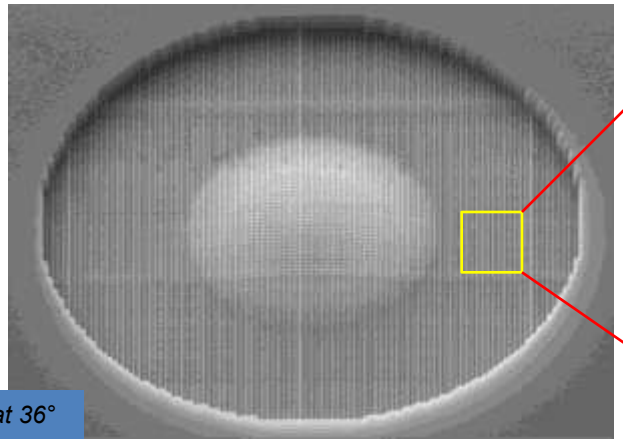


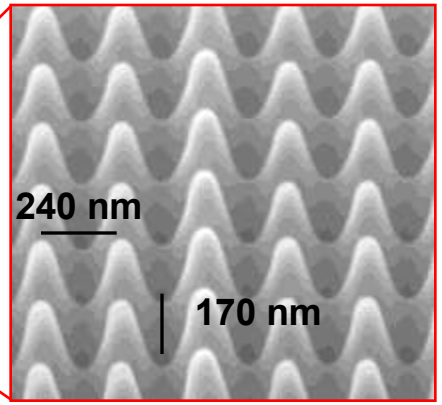
We create a txt file containing a matrix 2D with dwell time such that to realize the profile.

Load txt file on FeatureMill SW of the FIB



ROUGH SURFACE





TOO ROUGH FOR CELL ADHESION
BUT
FAST METHOD TO FABRICATE HYDROPHOBIC SURFACES

FIB parameters

I = 500 pA
T = 4500 s
pixel size 130 nm (M = 2800)

I = 500 pA
T = 4500 s
pixel size 243 nm (M = 1500)

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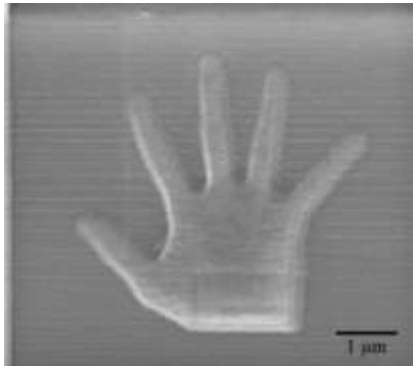
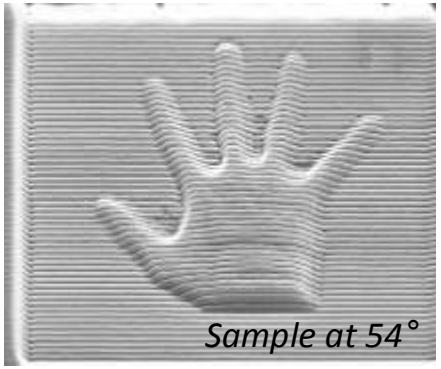
3D Reconstruction

L. Repetto, G. Firpo et al, *Ultramicroscopy* 2009, **109,** 1338–1342

GEOMETRICAL CHARACTERIZATION OF 3D STRUCTURES by FIB-SEM



Scaled copy of hand obtained by optical profilometry milled on silicon



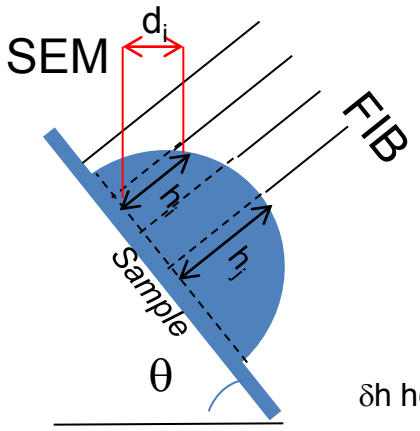
Milling equispaced parallel lines
40 nm wide, 15 nm deep, 100 nm spaced
1 pA, 30 keV, normal incidence
L = 10 μm t = 5 s, Total time 5 min.

The grooves appear deformed

Extraction of geometry of the lines

SW

PRINCIPLE OF OPERATION



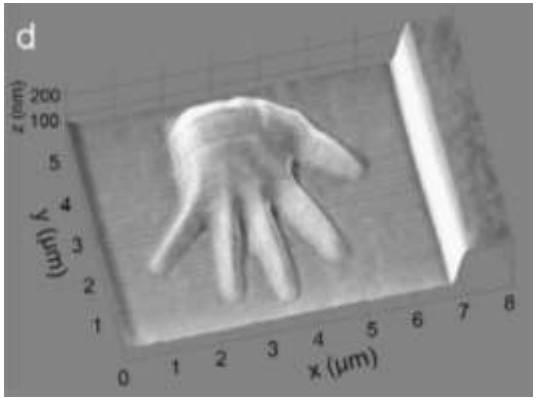
Taking into account tilt correction of SEM view:

$$h_k(x) = \frac{d_k(x)}{\tan\theta} \quad (1)$$

$$\delta h = \frac{\Delta}{\tan\theta}$$

δh height resolution - Δ pixel size

Topography retrieved by applying Eq. (1) to the pattern of lines. The pixel size of the starting SEM image was 10 nm, and according to Eq. (2) this implies a nominal height resolution of 7nm



Giuseppe Firpo

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Leak detection

G. Firpo et al, *J. Vac. Sci. Technol. B* 2009, **27**, 6

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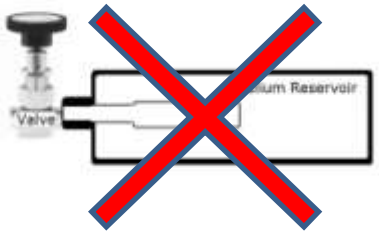
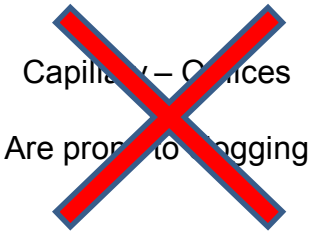
PERMEATION LEAK



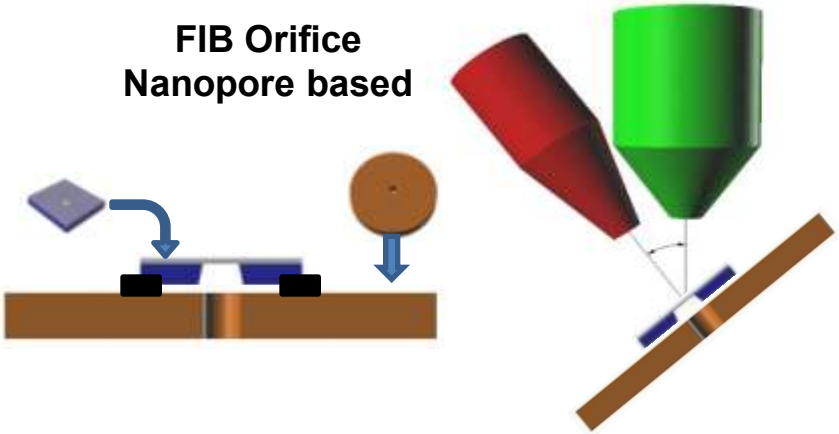
PHYSICAL LEAK



Capilla – Orifices

Are prone to clogging

FIB Orifice Nanopore based

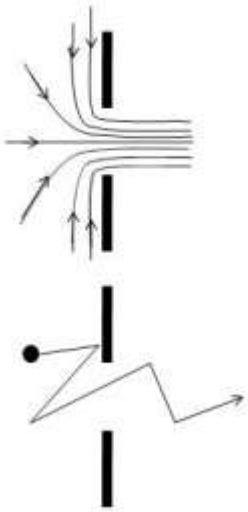


d = orifice diameter - λ = mean free path gas particels **λ(helium) = 170 nm @ 1 atm**

IF d < 200 nm (easy and fast with FIB)

WORK IN MOLECULAR FLOW REGIME UNTIL ATMOSPHERIC PRESSURE

STABLE WITH RESPECT TO THE CLOGGING



d>>λ (viscous flow)

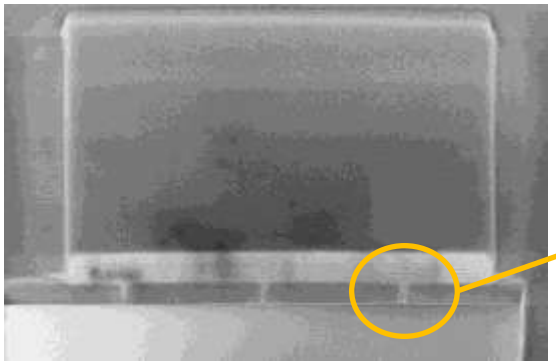
d≤λ (molecular flow)

Patent: TO2008A000683 - PCT IB2009/054039
Licensed to Agilent in 2009

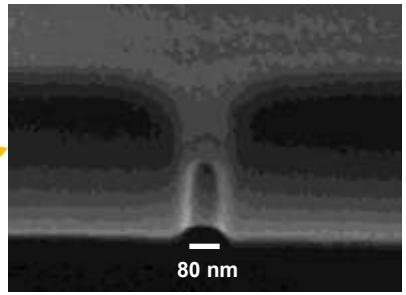
Leak detection

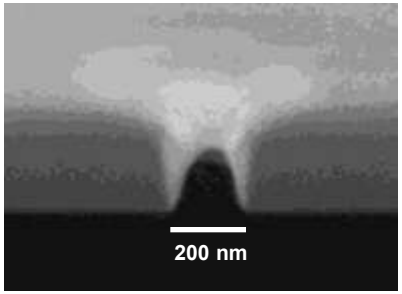
ORIFICE PROFILES

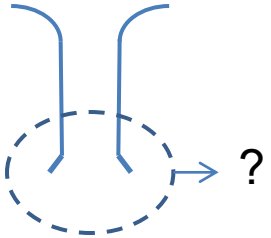
How to obtain the profiles



FIB nano holes at PTB, Germany







It's a real shape or FIB artefact due to milling?

See mini-poster session