

**Direct fabrication of sub-20 nm nanopores using focused ion beam, and further closure with electron beams.**

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**ABSTRACT**

Molecular-scale pores are promising as new ways of detecting and characterizing tiny molecules, such as DNA ribbons. Actually there are several ways of achieving nanometer-sized pores, by choosing a specifically thin membrane and using ion beam milling, dry etching or electrochemical etching. The pores can then be further reduced with a TEM beam, an ion beam or by surface coating.  
Here we report the direct fabrication of 20nm-wide pores in ultrathin silicon nitride membrane using focused ion beam etching with a very small aperture. Using scanning electron microscopy, we then further reduced the pores to sub-8nm holes within minutes. This phenomenon may be due to a change in atom’s mobility induced by the electron exposure, and could be used to build other kind of structures, such as bridges or cantilevers.

For all experiments with ion beam we used a Raith-IonLine device with a Ga+ Column. Experiments were conducted either with a 10µm aperture and a beam current of 1pA, or a 20µm aperture and a 6pA beam current. The number of loop can also be changed, which is the number of time a design is milled. On previous experiments we observed that a higher loop provides more uniform pores, with better circularity. As a counterpart, the necessary dose to mill a through hole increase and the range, in which we can directly mill a small pore is reduced and becomes hard to reach precisely:

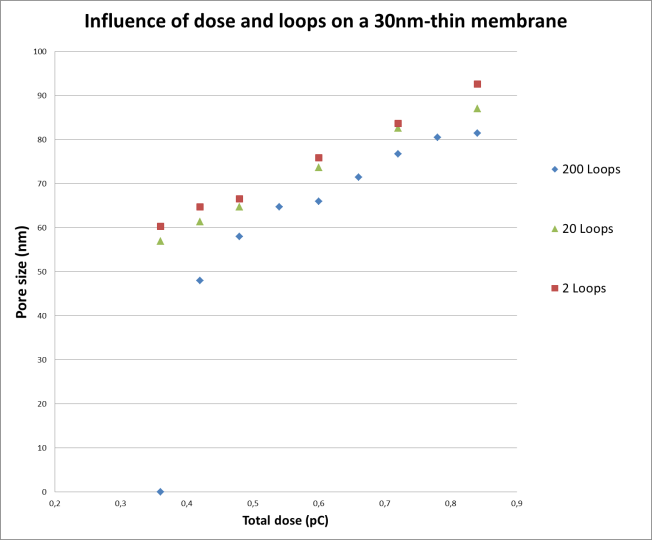


Figure 1 Pore size depending on dose and number of loop. For high loop we quickly reach a range where the hole is not milled anymore.

Hole ratio.  
Coupe ?

To mill the smallest holes we used a focused beam with a beam current of 1pA, which provide a beam of aperture around 10µm. This beam pierced through a 10nm-thin SiN membrane, previously coated with 6nm of Au in order to improve imaging and to avoid charge accumulation.

By spreading the total dose of 32fC on 20 loops, we get slightly more uniform holes.

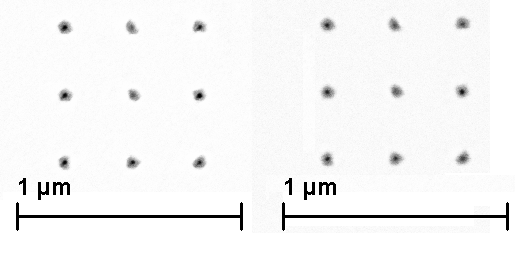
20 loops proved to be a good balance between pore’s uniformity and repeatability of our experiments.  
SEM images then enable us to observe the array of pores:  


Figure 2 Front (left) and backside view of an array of holes. Right image has been mirrored to ease comparison.  
Pores are between 15 and 25nm wide. Those of the front side are slightly bigger than those of the back, with a ratio around 0.8.

The fact that an electron beam can expand or shrink holes is not new (<http://www.nature.com/nmat/journal/v2/n8/full/nmat941.html>) but it has mostly been achieved with TEM.

We used an E-Beam 150-TWO (Raith) Device at Voltage 5 or 10kV. This device achieve faster shrinking rate as with TEM: about 0.3nm/minute) but as a counterpart we achieve a smaller final resolution (~5nm). We never observed the expansion of holes due to electron beam exposure and could shrink pores as wide as 200nm.

Closure

Bridge

3D ? not observed