Direct Ga and Si Ion Beam Lithography for Nanopore Fabrication with High Resolution and Reproducibility

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DNA sequencing, molecular analysis or biological filtering is both from a scientific and a commercial point of view a high interest topic [1]. Requirements for appropriate nanopores are small feature size (diameter <20 nm), symmetric, high aspect ratio and reproducible shape as well as minimal damage or contamination around them. Given the large number of devices needed for research and development and commercial screening applications, small batch but wafer scale production is a must have with additional stability and reproducibility constrains on the process and instrumentation.
Membrane based solid state nanopore devices have been fabricated by different instrumental approaches (e.g. FIB-SEM, TEM, HIM [1]) with varying degrees of quality, precision, repeatability and yield. Here we used direct milling Focused Ion Beam Lithography (IBL) which has proven to fabricate high resolution nanopores [2] and is capable of automated nanopore device production at the (4") wafer scale.

We investigated the feature size and reproducibility (intrinsic and large area process related) of nanopores using an IBL nanofabrication instrument based on a focused Ga ion beam as well as the utilization of non-Ga ion species like Si from newly developed alloy ion sources. For Ga we have achieved 20 nm to 12 nm diameter pores (see Figure 1) with a reproducibility of 1-2 nm on membranes over a 4" wafer. This has been established using the automated scanning electron microscope metrology capabilities of an Electron Beam Lithography system (see Figure 2). Employing the multi-species IBL system nanopores below 20 nm can be achieved with Si and other ion species (see Figure 3). In addition to the motivation for potentially minimizing chemical contamination by using a Si focused ion beam, we also work towards 10 nm feature sizes with Si and other ion species.

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[1] J. Edel, T. Albrecht, Nanopores for Bioanalytical Applications: Proceedings of the First International Conference (ROYAL SOC OF CHEMISTRY, 2012).
[2] B. Schiedt, L. Auvray, L. Bacri, G. Oukhaled, A. Madouri, E. Bourhis, G. Patriarche, J. Pelta, R. Jede, J. Gierak, Microelec. Eng. 87 (2010) 1300–1303.

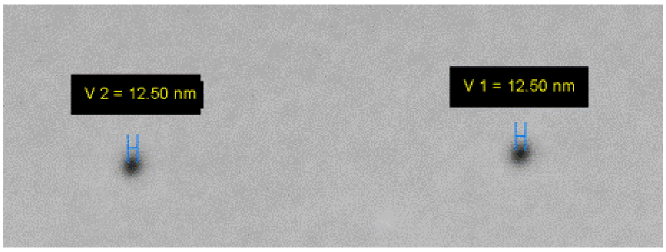

Figure 1: Nanopores fabricated by Ga on a 30 nm thick Si_3N_4 membrane (SEM micrograph).

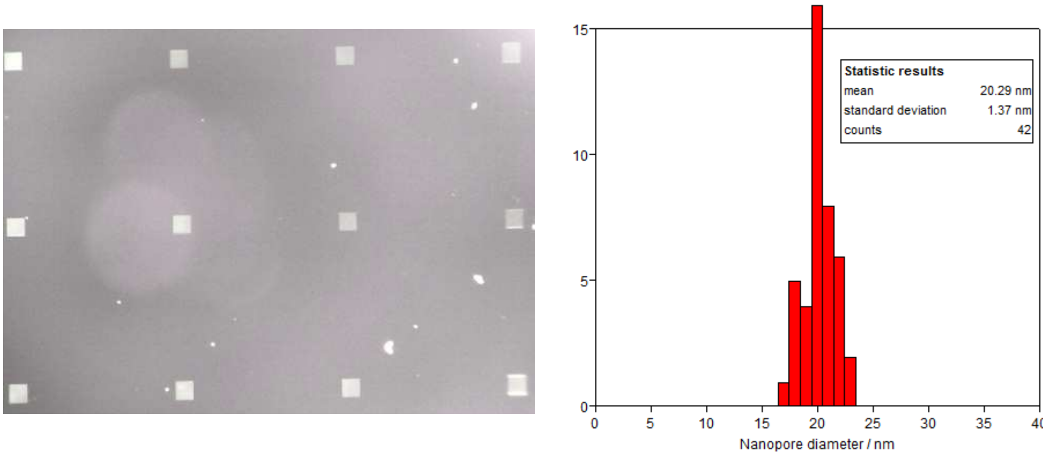

Figure 2: Reproducibility of the nanopore diameter over 42 Si_3N_4 membranes on a sample of 30 mm in total size (left, optical image showing part of the sample). At the thickness of 100 nm a pore size of 20 nm with a reproducibility of 1.4 nm (right, standard deviation) has been found.

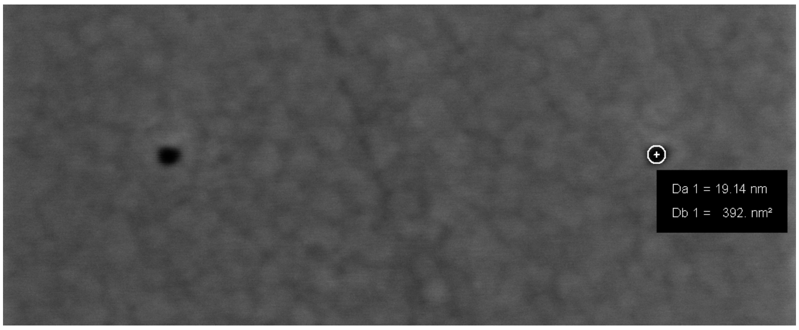

Figure 3: Dots drilled by a sub-10 nm focused Si ion beam into a 20 nm thick gold layer on glass (SEM micrograph).