Nanoporous SiN membranes patterned by wafer-scale nanosphere lithography

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Nanoporous SiN membranes are interesting for a number of applications, e.g. stenciling, filtration, or tissue engineering [1-3]. The patterning of the pores requires a high resolution lithographic tool. Focused ion beam milling or e-beam lithography fulfills this requirement. However, they are slow, serial writing techniques and thus wafer-scale writing of nanodot arrays becomes time-consuming and expensive. Alternative parallel, fast and inexpensive tools are, for example, nanoimprint-lithography, interference lithography, block copolymer lithography, or nanosphere lithography (NSL) [4]. For applications where no long-range array order is needed, we show here that NSL using polystyrene (PS) beads provides a fast and efficient tool with sub-µm patterning resolution for the fabrication of large nanoporous membranes. Another advantage is the process flexibility. The size of the PS beads determines the later pore size. It can be changed after the deposition of the beads onto the substrate. The pore density can be controlled by choosing a different original bead size. Thus, within a certain range, the pore size and pore density can be tuned independently of each other.

Fig.1 shows a schematic of the fabrication process. 4" Si wafers with 100 nm double-side low-stress SiN and 200 nm of Al on the backside serve as the base substrate. A monolayer of close-packed polystyrene beads with diameters Ø 428 nm or Ø 535 nm is deposited by spin-coating (Fig. 2 a, b). Then, the size of the beads is reduced by O2-RIE (Fig. 3). This step allows a tuning of the later pore size. After bead size reduction, a thin metal layer is evaporated directionally onto the beads. Subsequent bead removal in organic solvents produces a holey metal etch mask. The holey mask is transferred into the SiN layer by DRIE. The nanoporous SiN layer is released by backside lithography and a combined dry and wet etch procedure.

Nanoporous, 100 nm thick SiN membranes with an area of $(500\ \mu m)^2$ and a pore density of $\sim 5 \times 10^8$ pores/cm^2 were fabricated (Fig. 4 a, b). The use of NSL makes the pore patterning process step fast, cheap and flexible. The pore diameter can be tuned from 200 ~ 400 nm for the bead size used. The pore size distribution is related to the size distribution of the PS beads, and it is typically less than 5% off the mean diameter. This is small compared to the pore size distribution of large-scale, commercially fabricated nanopore membranes (e.g. ~ 10% for polymeric track-etched membranes).

Ti/Au nanodots were deposited onto a SiN substrate by evaporation through a nanoporous membrane (Fig. 4 c). After the evaporation, the stencil was cleaned in a metal wet etch and could be reused with reproducible results. The stencil membranes withstood both the stress induced by the evaporated metal as well as the wet etch cleaning procedure without any damage. This proves the nanoporous membranes applicability as a mechanically stable, reusable stencil shadow mask.

The membranes mechanical properties will be analyzed as a function of membrane and pore size, and pore density. Further applications will be tested, including through-stencil dry-etching, a useful technique for the patterning of substrates with deep grooves or mesa structures [5], and the filtration of nanoparticles.

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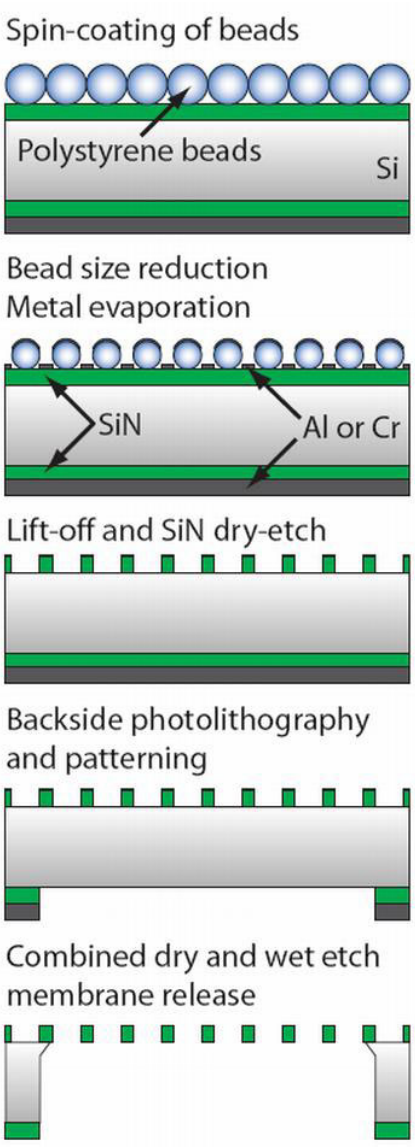

Fig. 1: Schematic fabrication process.

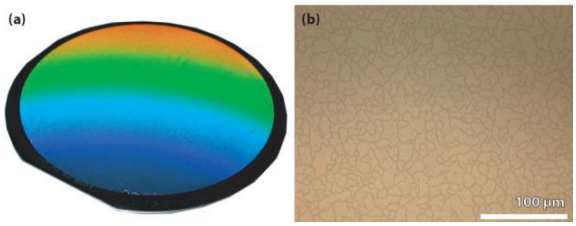

Fig. 2: (a) Photograph of a wafer after spin-coating a monolayer of PS beads (Ø 428 nm). (b) Optical microscope image of a monolayer of hexagonally close-packed beads (Ø 535 nm).

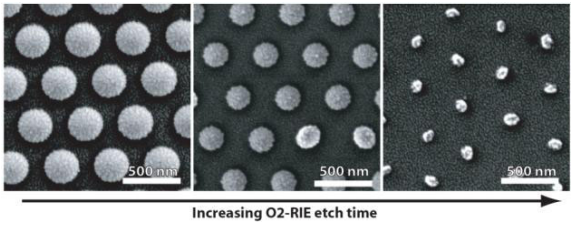

Fig. 3: The bead diameter can be tuned by adjusting the O_2-RIE for etch duration (original Ø 428 nm).

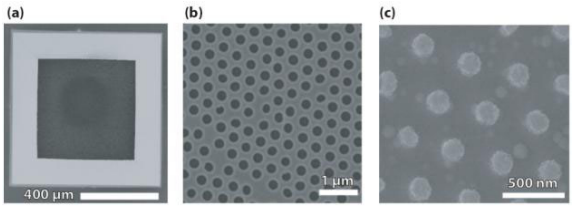

Fig. 4: (a) and (b) SEM images of the holey SiN membrane after backside release; c) Ti/Au nanodots on a SiN substrate deposited using the holey SiN membrane as stencil shadow mask.