Dual Exposure Glass Layer Suspended Structure (DEGLaSS):

A novel approach to making suspended glass nanostructures for sensors and microfluidic devices.

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Abstract:

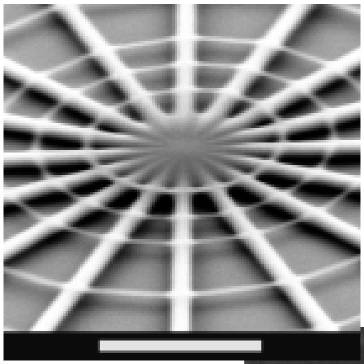
Nanomechanical and microfluidic systems that can be easily integrated with microelectronics are generating a variety of new sensors and separation technologies. We demonstrate a new approach to fabrication of glass nanomechanical and microfluidic systems based on cross linking of Hydrogen Silsesquioxane (HSQ) with variable energy electron beams. The DEGLaSS process eliminates the need to do reactive ion etching or anodic bonding and can be performed on any planar substrate, even above existing integrated circuits, in a single layer additive process.

Project Summary:

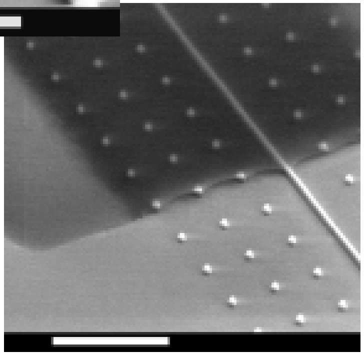
The DEGLaSS process uses a single layer of spin on glass (SOG) material with two negative tone exposures at two different exposure energies to define the suspended and support structures respectively. A low energy exposure has a very short penetration depth, similar to a top surface imaging process, and defines the suspended features. A second exposure is performed with a higher energy that penetrates through the entire glass layer thickness, resulting in support structures. There is no processing between the exposures, and the order of the exposures does not matter. Both patterns are developed simultaneously in TMAH removing all the unexposed material, including the material inside open-ended channels or under suspended features. Samples can be transferred through an ethanol bath to a critical point CO_2 dryer to prevent collapse due to surface tension in the drying of large open cavities. After development the three-dimensional cross-linked SOG structures can be densified converting them to an amorphous glass structure**.** Any two dimensional pattern can be used for both the support structure and the suspended structure, as long as the suspended structure does not contain isolated unsupported regions which will either wash away or fall flat to the substrate. Channels can be patterned with irrigation holes or supported underneath by pillar arrays to enhance structural rigidity or to create artificial sieves. Nanoscale mechanical oscillators can be tailored to have specific resonance frequencies.

We have demonstrated the DEGLaSS process using low energy electron beam exposures of Hydrogen Silsesquioxane (HSQ). HSQ was chosen for its high resolution and sensitivity in negative-tone electron beam lithography. Variable energy electron beam lithography allows control of the electron penetration depth over three orders of magnitude, from 10 nm to 10 µm with a single exposure tool. We have demonstrated the process in HSQ films with a thickness between 200 nm and 1.2 µm. We have used 1-2 keV electrons to define our suspended structures, and 3-10 keV electrons to define our support structures. The 1 (2) keV exposures produce suspended ceilings 40 (110) nm-thick. Microfluidic channels with a cross sectional area of ~5 μm^2 have been demonstrated with lengths up to 2 mm. The channels are optically transparent and dye molecules flowing in the channels can be easily observed. Glass beams, cantilevers, and torsional paddle oscillators have been fabricated with lateral dimensions as small as 100 nm and thicknesses down to 40 nm. We measured the mechanical resonance using a piezoelectric driving force and optical interferometric detection. A series of oscillators from 4 to 9 µm long were observed to have frequencies from 7-30 MHz, with quality (Q) factors over 1000. Higher frequency devices have been fabricated, but are difficult to measure in the current system. The HSQ structures can be converted to SiO_2 using thermal annealing in an oxygen ambient or an exposure to an oxygen plasma.

The DEGLaSS process can be expanded to include more exposure energies allowing more intricate structures to be fabricated, such as those needed for separation technologies, flow sensors, valves, etc. The process eliminates the need to do reactive ion etching or anodic bonding and can be performed on any planar substrate, even above existing integrated circuits, since the ceiling and walls are fabricated from the same SOG in an additive process.



- *Figure 1: Glass rings are suspended above radial supports. The rings are 40 nm thick, 100 nm wide. The scale bar is 2 µm.*



- *Figure 2: The end of a pair of microfluidic channels supported by pillars and separated by a solid wall that continue out from under the ceiling of the channel. The scale bar is 10 µm.*