

Evaluation of Gallium Ion/Xe Plasma Beam for Patterning of Suspended Silicon Nitride Membranes

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Free-standing ultrathin silicon nitride SiN_x windows suspended on silicon frames have become a key platform for many scientific and technological endeavors such as fabrication of micro-electro-mechanical systems (MEMS), single molecule sensing, ultrafast spectroscopy and electron microscopy. Suspended SiN_x membranes with their excellent optical properties (high refractive index and ultralow loss in the visible and near-infrared range) and mechanical properties, are highly effective window materials for a range of state-of-the-art characterization and sensing systems. They are utilized as electron and photon transparent sample supports in instruments operating in vacuum, ambient or liquid environments; single-molecule sensors for genomics, proteomics, and glycomics; micro/nano-filtration systems, for filtration and controlled sample introduction and formation in nano-fluidic channels [1]–[4].

SiN_x membranes provide a great basis for fabrication of more sophisticated nanostructures. However, their very beneficial mechanical and electrical properties for support applications create various technical problems for patterning these films for the applications discussed above. Among nanofabrication techniques, focused ion beam (FIB) milling is a well-established nanofabrication technique in materials science for modification of structures at the micro-nanometer scale. With the flexibility in pattern dimensions and geometries, FIB is a valuable tool to machine suspended SiN_x membranes. Despite the merits FIB poses, modification of the SiN_x membrane is still challenging. The insulating nature of the membrane makes it difficult to use the electron beam for microscopy to align and visualize the structures during milling/deposition. Moreover, charging during the operation might create stress and break the membrane. Recently, it has been shown that the presence of metallic structures near the milling area neutralizes the charges and reduces the stress during perforation of the 100 nm-thick membrane by FIB [5].

Moreover, MEMS-based microheater chips are rapidly becoming the popular choice to perform in-situ heating and biasing experiments in the transmission electron microscope (TEM) [6], [7]. Hence, deposition of biasing electrodes with low resistance on or near SiN_x membranes to connect the TEM sample with the contacts on MEMs based microchips has become an important objective in in-situ investigations of functional materials. FIB is shown to be an effective technique for fabrication of the electrodes. However, processing parameters need to be strictly controlled not to damage the membrane during deposition. In addition, Ga ion incorporation and the presence of C impurities affects the resistance of the deposited electrodes.

In this work, we focus on the optimization of the process parameters for patterning ultrathin suspended SiN_x membranes (15–30 nm) without the need for additional metallic structures and fabrication of biasing electrodes with low resistivities on MEMs chips. Our effort is to fabricate structures with controlled dimensions without harming the ultrathin membrane through surveying the parameters such as acceleration voltage, beam current, dwell time, pixel spacing, and pattern size by using Xe plasma and Ga ion-based FIB systems. Figure 1 represents a set of experiments performed on silicon nitride membranes. The insulating nature of the silicon nitride makes the deposition harder on the suspended membrane. Ion beam parameters for milling are optimized to mitigate the damage to the membrane. The quality of Ga-ion and Xe-plasma deposited electrodes in terms of ion implantation artifacts is analyzed using a combination of transmission electron microscopy and electron energy loss spectroscopy (EELS) experiments. In this presentation, the effects of the operational parameters, such as the ion

source used in the FIB instrument and the various beam configurations, on the resistance of the electrodes and the degree of the beam damage will be discussed.

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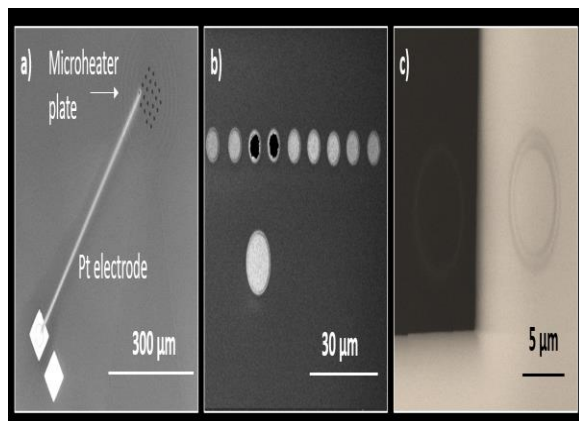


Figure 1 Scanning electron microscopy images of a) Pt electrode deposited by Xe-plasma-FIB on a MEMS based microheater, b) Gallium ion beam milled patterns with varying beam parameters on suspended silicon nitride membrane, some parameters induce stress and damage the membrane, c) Pt microstructures deposited on the suspended (on the left) and silicon supported (on the right) silicon nitride membrane with same beam parameters (falsely colored)

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