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Formation of a few nanometer wide holes in membranes with a dual beam FIB

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The ability to form holes with diameters of only a few (1 to 10) nanometers is important in areas such as nano-fluidics [1] and proximity lithography with ions and atoms [2, 3]. Here we present a simple method for the controlled formation of holes with arbitrarily small diameters, down to sizes below probe beam diameters. At first, holes are drilled in thin (~200 nm thick), low stress silicon nitride membranes with the Ga^+ ion beam in a dual beam focused ion beam system (Figure 1). Membranes were coated with a thin (a few nm) layer of Au/Pd to reduce charging. Following ion beam drilling, the area with the holes is imaged with the electron beam in SEM mode. The pressure in the FIB vacuum chamber is typically in the mid 1E-6 torr range. We found that holes close during imaging over a scanning period of several minutes. The holes close with a rate which depends on the scan rate and the background gas pressure. Typically closing rates were linear with time and diameters were reduced by about 0.3 nm/s. Measurements of film thicknesses are in progress. In figure 2 we show a set of holes prior to extended e-beam scanning, and after hole closing. Choosing SEM contrast based on backscattered electrons shows that the holes are closed with a low Z material that appears dark compared to the Au/Pd coating. TEM imaging of the same holes confirms the presence of small holes with diameters of 5 to 10 nm in low Z material. Here, the Au/Pd layer appears dark, the silicon nitride light, and the hydrocarbon layer lightest. We conclude that the hole close through the built-up of contamination resist [4].

Alternatively, holes can also be closed with metal or silicon oxide, which are available for controlled deposition in the FIB system. Deposition can be mediated by either the ion or electron beam. In figure 3, we show a series of SEM images from a hole that was closed through the deposition of Pt from an organometallic gas during e-beam scanning. One SEM image was taken following gas injection and e-beam scanning for a few seconds. The diameter of the hole was found to close with a rate of 7 nm/s.

Combining FIB drilling and electron beam assisted thin film deposition in a dual beam FIB offers a simple method for controlled *in situ* engineering of structures with sizes below dimensions that are accessible with the direct beams alone.

Acknowledgments

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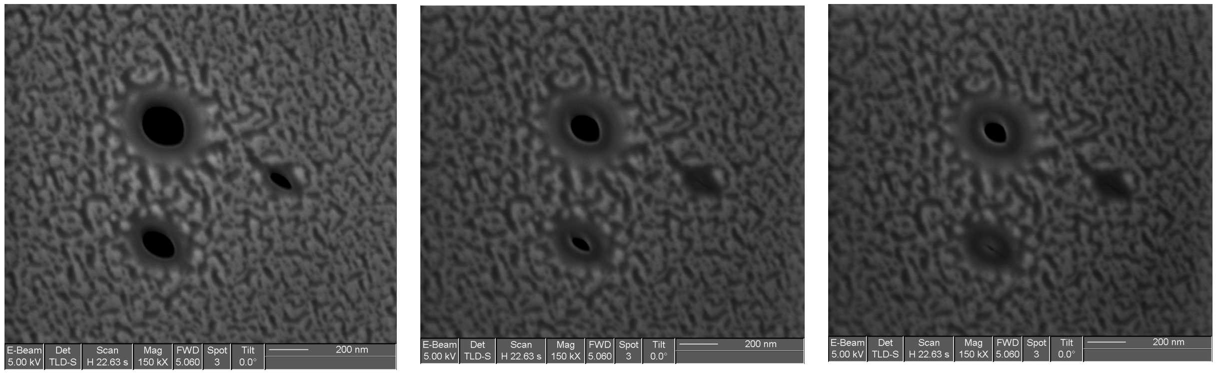

Fig. 1: Series of SEM images taken over a period of several minutes of electron beam scanning over the area with three holes. The holes were formed by drilling with a 30 keV Ga^+ beam. The target is a 200 nm thick silicon nitride membrane coated with a thin (few nm) layer of Au/Pd.

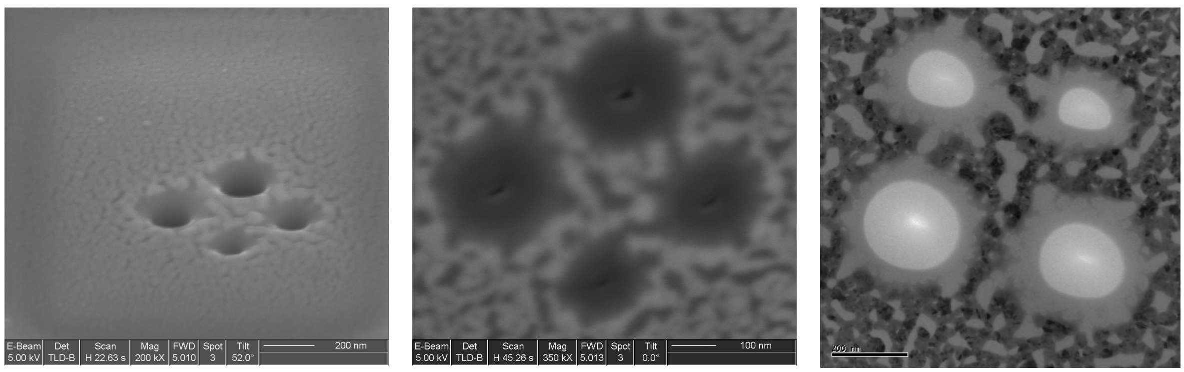

Fig. 2: Left: SEM image of a set of four holes prior to extended electron beam scanning. Middle: SEM image of the same holes following electron beam scanning of the area for several minutes. Contrast is from backscattered electrons. Left: TEM image of the same holes.

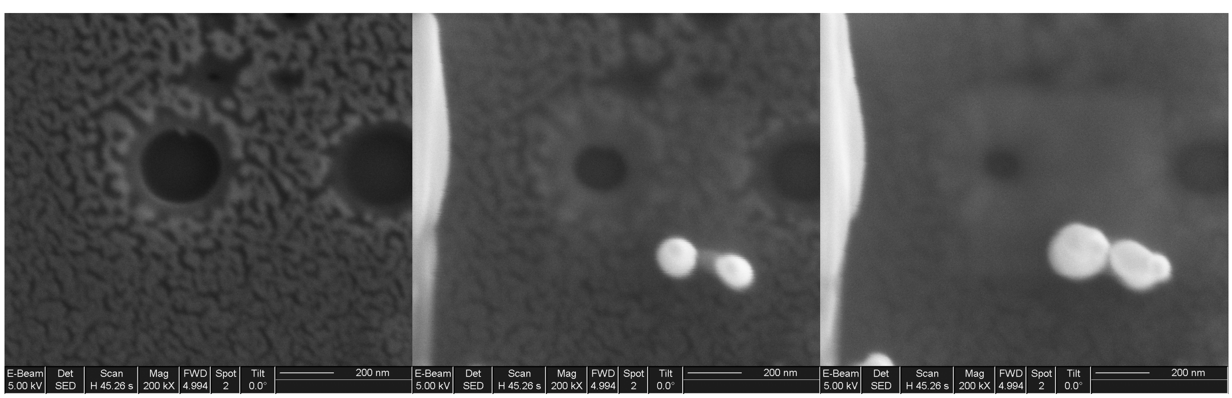

Fig. 3: Series of SEM images taken over a period of several minutes of electron beam scanning over an area with a hole. Following each scan Pt containing organometallic gas was injected over the scan area for a few seconds.