Accurate Endpoint Detection for Ion Beam Nanohole Milling

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A focused helium ion microscope (HIM) (Zeiss Nanofab), equipped with a digital camera, was used to demonstrate accurate process control and spatial endpoint detection during ion beam milling of nanoholes in various free-standing membrane materials, including amorphous (α) and crystalline Si (15 to 50 nm thick). The camera, located on the floor of the vacuum chamber, is underneath the conventional sample tilt and translation stage, with a direct line of sight to the sample through a slit in the stage [1]. The formation of nanoholes was inferred from the decay in the width of the ion transmission intensity as a function of He^+ beam energy (20 keV), focus (8.0 - 8.6 mm), and current (1 – 10 pA).

We found that time to completion of an individual hole formation could be measured with an accuracy of 0.2 s. However, the average value for a repetitive process varied poorly with inverse beam current. Figure 1 shows a plot of milling time through crystalline–Si (50 nm) versus reciprocal beam current (beam energy 20 keV) with nominally a constant sample focus (working distance 8.21 mm). The line is a linear least-squared fit with a slope of 13 pC and a minimum milling time (*y*-intercept) at infinite current, of 7 s. Figure 2 shows SEM images of nanoholes obtained for two of these milling conditions. Despite differences in beam current and spot size, the surface area of the holes are comparable.

Comparisons with theoretical predictions, and previous reports [2-4] indicate that the rate of milling is predicted but not the delay time. A structural analysis of the resulting nanoholes using scanning and transmission electron microscopy will be presented. Problems with competing processes including the growth of contamination layers will be discussed [5-6]. These results are useful for future optimization of nanohole fabrication in ultrathin membranes.

[1] J. Wang, S. H.-Y. Huang, C. Herrmann, S. A. Scott, F. Schiettekatte, and K. L. Kavanagh, *JVST B* **36**, 021203 (2018).
[2] M. M. Marshall, J. J. Yang, and A. R. Hall *Scanning* **34,** 101–6 (2012)
[3] F. Sawafta, A. T. Carlsen, and A. R. Hall *Sensors* **14,** 8150–61 (2014)
[4] D. Y. Xia, C. Huynh, S. McVey, A. Kobler, L. Stern, Z. S. Yuan, and X. S. Ling, *Nanoscale* **10,** 5198–204 (2018)
[5] D. Fox, Y. B. Zhou, A. O'Neill, S. Kumar, J. J. Wang, J. N. Coleman, G. S. Duesberg, J. F. Donegan, and H. Z. Zhang, *Nanotechnology* **24,** 335702 (2013)
[6] X. J. Jiang, W. Cai, W. W. Luo, Y. X. Xiang, N. Zhang, M. X. Ren, X. Z. Zhang, and J. J. Xu, *Nanotechnology* **29,** 385205 (2018)

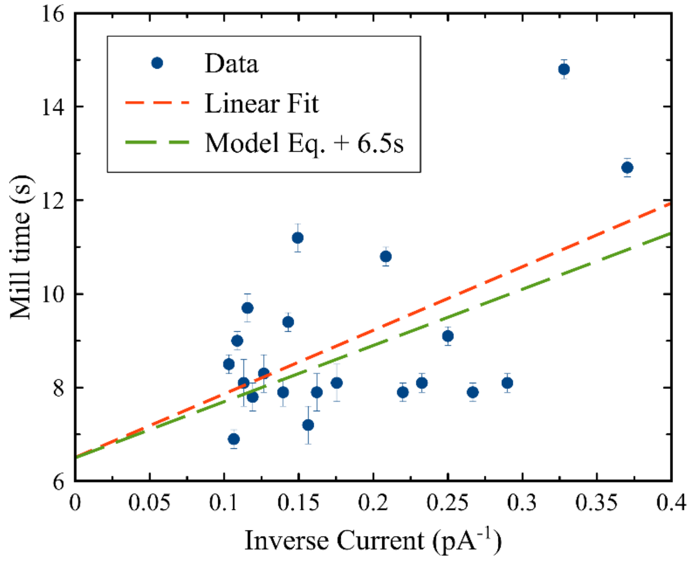

FIG. 1. Milling time as a function of reciprocal focused He ion beam current (He pressure in the gun) for a 50 nm thick crystalline Si sample under constant beam focus and energy 20 keV. Data overlayed with linear fit (red) and modified model equation (green).

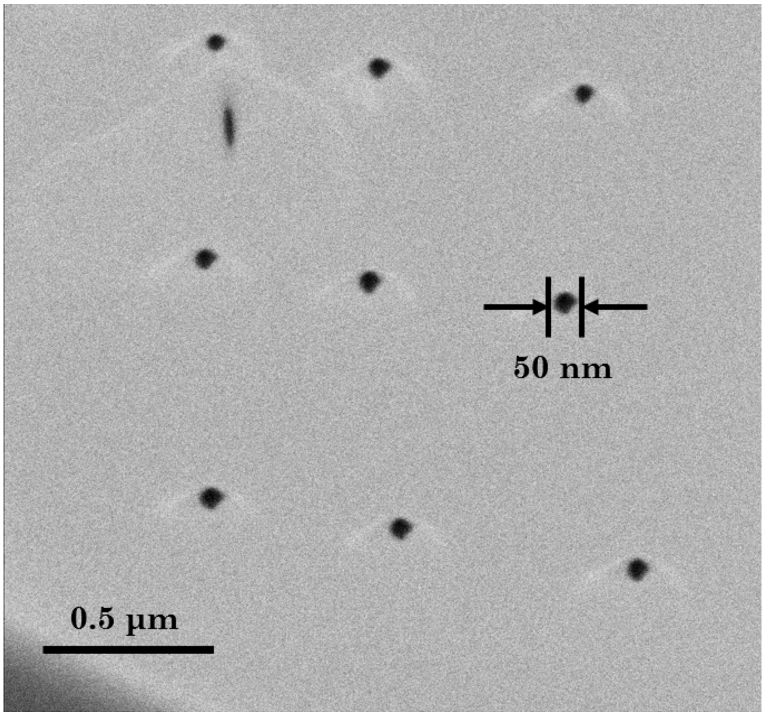

FIG. 2. Secondary electron images of holes milled in an α-Si membrane (15 nm) using a beam energy of 20 keV. The top 6 holes were milled with current 1.5 pA, spot size 3, while the bottom 3 holes, with current 3.16 pA, spot size 2.