doi:10.1017/S1431927610062471
Microsc. Microanal. 16 (Suppl 2), 2010

"Methodologies for Quantifying Milling Acuity in Focused Ion Beam Systems"

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Focused Ion Beam (FIB) systems are widely used for a broad range of nano-machining applications. Many different commercial FIB systems are available, and the various models are optimized to perform a wide variety of tasks. In order for users to fairly evaluate the milling performance of a specific system, universal milling performance metrics are needed. Historically, FIB performance has been characterized by minimum spot size and imaging resolution. However, both of these metrics have limitations. For example, imaging resolution can be defined in different ways, and manufacturers are not always consistent (or forthcoming) in the techniques they use to measure image resolution. Minimum spot size measurements using knife-edge techniques are difficult to perform, and can be difficult to interpret. Samples with finely-pitched features (such as graphite) provide an abundance of data in a single image, but it can be difficult to deconvolute the distribution of feature sizes on the sample from the distribution of experimental edge width measurements. Additionally, sample erosion by the ion beam can complicate the data analysis. Finally, and perhaps most seriously, measurements of imaging resolution and minimum spot size are almost always performed under ideal experimental conditions, such as lowest possible beam current and lowest possible vacuum background pressure. The results from these types of experiments tell us relatively little about how a FIB system will perform its intended daily tasks, especially when beam chemistry is involved.

In this work, we propose a new metric for FIB performance, which we call "Milling Acuity" [1,2]. Several experimental techniques are presented, and methods for quantifying milling acuity from these experiments are discussed. Line burn series on chrome-on-glass samples are performed, and the line width is plotted as a function of ion dose. These experiments are performed over a range of background gas pressures, to observe the rate of peripheral erosion outside the intended repair zone. An example of this type of experiment is shown in Figure 1. Beam broadening due to gas-scattering effects is an important phenomenon in applications such as circuit edit and fault isolation, which utilize high local pressures of various gas precursors to assist etching and deposition processes. However, the phenomenon has not been adequately quantified, and conventional FIB metrics do not address it. High-aspect ratio (HAR) via milling is also examined in detail. HAR via milling is of great interest to many customers, but it is a strenuous application that demands high milling precision and tool stability. The effect of various milling parameters on HAR via profiles is described, and a numerical scoring convention is introduced to quantify the cross-sectional profile of the HAR via. An example of a HAR via analysis is shown in Figure 2.

[1] C. Rue, Proceedings of the *European FIB User's Group* (2009).
[2] C. Rue, R. Hallstein, and R. Livengood, *FIB User Group Meeting, ISTFA* (2009).

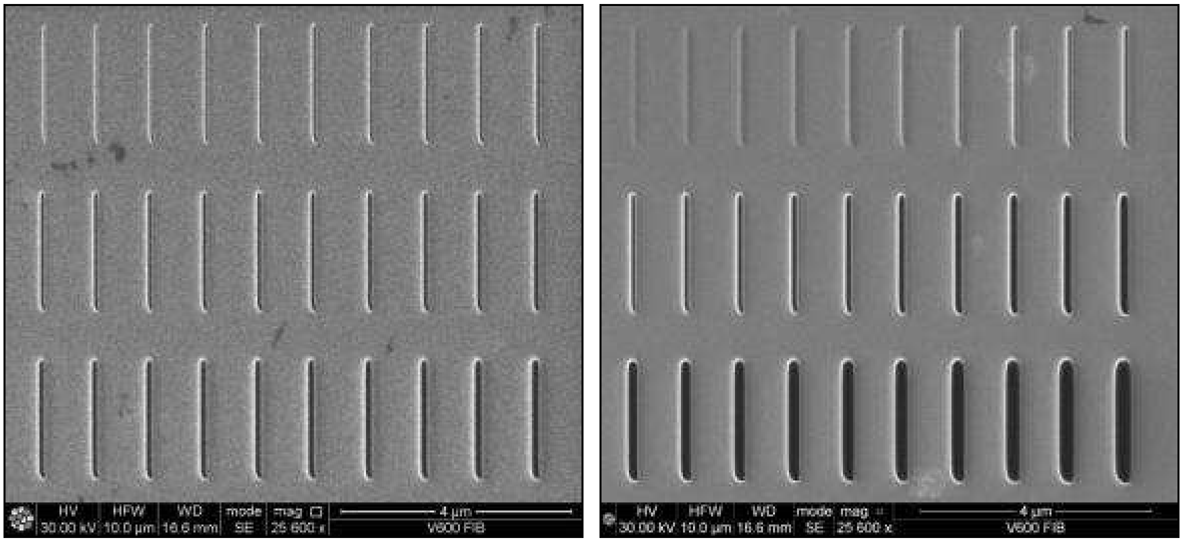

Figure 1: Line burn series on a chrome-on-glass sample, in which the ion dose increases from left-to-right and from top-to-bottom. The image on the left was performed without background gas, at a base vacuum pressure of 1.3e-6 Torr. The image on the right was performed with a XeF_2 chamber pressure of 1.0e-5 Torr. Note that the presence of the XeF_2 gas causes beam broadening, and the line burn features are wider in the image on the right.

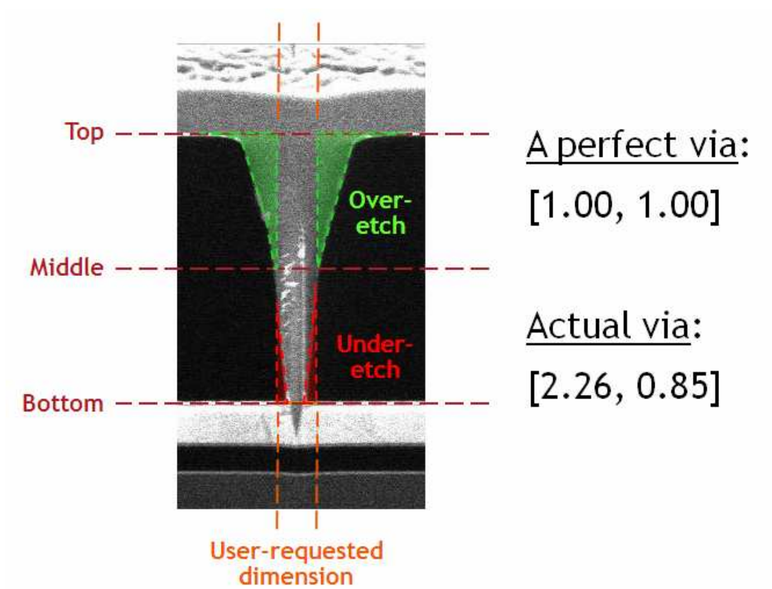

Figure 2: Cross sectional image of a High-Aspect Ratio (HAR) via. The cross-sectional areas of the upper and lower halves of the via are expressed as fractions of the ideal (user-requested) dimensional area. The first number of 2.26 indicates the upper half of the via is overetched, resulting in an area 2.26 times larger than the ideal size. The lower half score of 0.85 indicates that the via is tapering closed at the bottom, such that the actual area is only 0.85 times the ideal size.

https://doi.org/10.1017/S1431927610062471 Published online by Cambridge University Press