Time-Domain Noise in "per-Decade Spectra" from AFM Images of Mica

Ted J. Davich[1], Bishal Nepal[2] and P. Fraundorf[1*]

[1.] Physics & Astronomy, University of Missouri Saint Louis, St. Louis, Missouri, USA.
[2.] Chemistry & Biochemistry, University of Missouri Saint Louis, St. Louis, Missouri, USA.
* Corresponding author: pfraundorf@umsl.edu

The absolute strength (as opposed to the relative strength) of spatial periodicities is seldom discussed, since Fourier analyses have a wide range of "ways to normalize", and line strengths (unlike in temporal frequencies) are seldom linked to energy flow. However, Parseval's theorem relates those periodicities directly to root-mean-square (rms) roughness, whose size scale is often useful to understand.

In this paper, we illustrate an application for an earlier-proposed strategy [1, 2] to track rms-roughness *per decade* over a wide range of size scales, for any single-valued function of two "translation variables". In particular, in context of a project to characterize the roughness *per decade of spatial frequency* for very flat surfaces (like gigascale integrated-circuit silicon, and cleaved mica or graphite), we here use this strategy, along with a "stationary-tip" [3] atomic force microscope (AFM) "image", to characterize vibration noise in a relatively-new installation site.

Let's begin with 1024×1024 pixel AFM images of freshly cleaved mica, with field-widths of 100, 10, 1 and 0.1 micron. Each was recorded over about 17 minutes i.e. with line scans of 1 second duration. This means that the tip is moving about 100 microns per second for the large field image, but only 100 nm per second for the small field image. The median line-filtered images evidenced little structure shown in Fig. 1 exhibited little structure, except for a likely 1nm mica step in the 1 micron square image.

Although azimuthally-averaged spectral profiles might be of interest in some applications, they contain more line-to-line noise and poorer statistics (at least for isotropic specimens) in that sticking to only fast-scan profiles gives us 1024 instances with no line-to-line noise, and lag-statistics available as well if needed. Hence Fig. 2 shows averaged fast-scan spectral profiles of "rms roughness per decade of spatial period" versus "spatial period", i.e. all in distance units. Taking the root sum of this quantity squared, over each decade, yields a good approximation to the rms roughness of each image as a whole.

As you can see, the three smaller-field images show some evidence of connecting together, and perhaps providing some insight into specimen roughness over a wide range of sizes. The much higher "roughness" seen in the 100 micron field-width image does not connect up, and may well be a result of feedback-loop spikes as the rapidly moving tip's feedback loop over-reacts to oncoming variations. This is consistent with the "spikes on a dark field" nature on the 100 micron field-width image itself.

The smaller-field width image roughness spectra, however, also contain spike-features which seem to be shared in time, rather than in space. The largest, labeled in each of these spectra at about 328 Hertz, is a case in point. To investigate this possibility further, we did a purely time-domain analysis of the 1,048,476 data points in a "stationary-tip image" (feedback loop engaged but scan-width 0) taken earlier on the same microscope site (Fig. 3). As you can see, the "time-domain" spikes in the three smallest-field AFM images

may be showing up in the stationary-tip image as well. This kind of analysis, therefore, opens the door to further exploration of noise sources in the environment of the microscope itself.

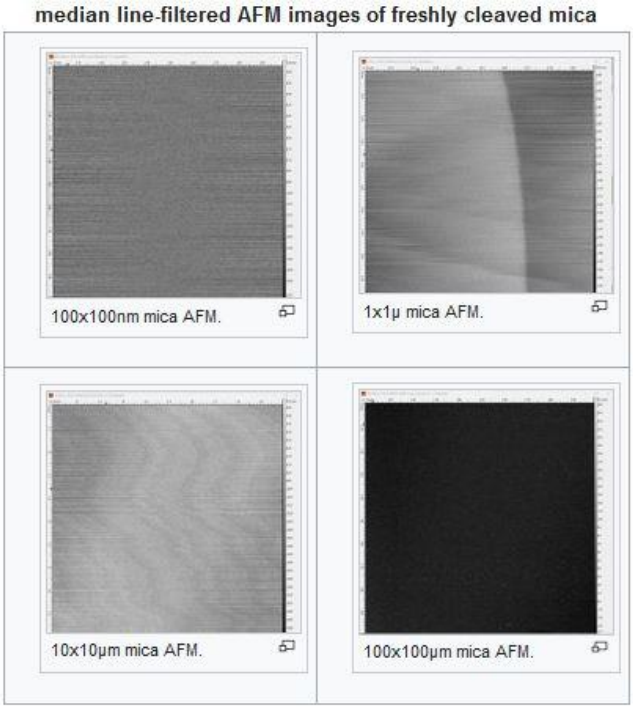


Figure 1. Thumbnails of the four AFM images being analyzed, going from smallest field-width (upper left) to largest (lower right)..

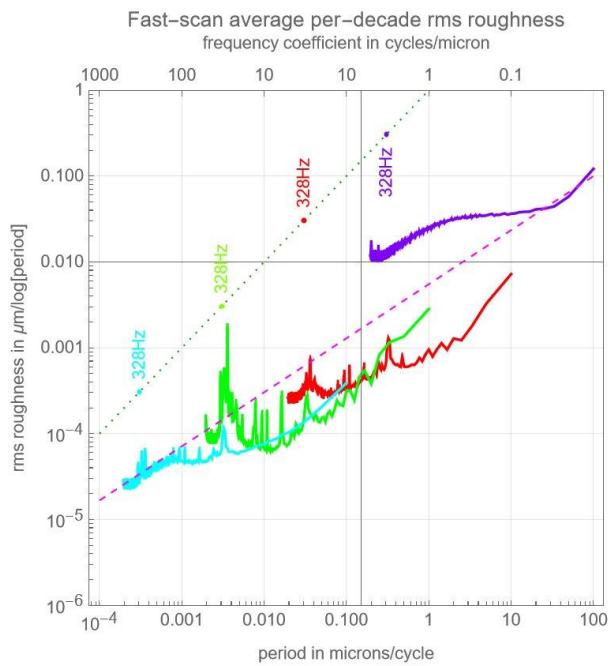
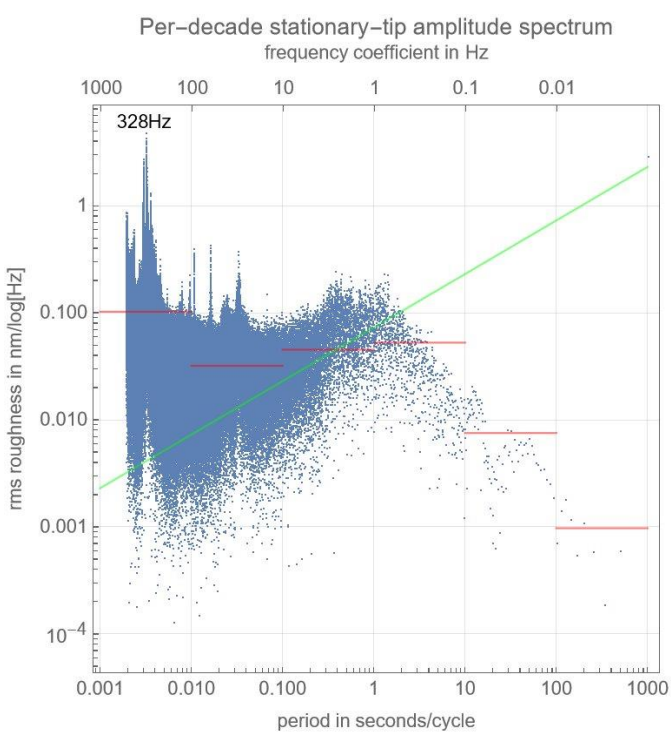


Figure 2. Per-decade roughness spectra, as discussed in the text.

Figure 3. Stationary tip spectra from the same system.



References:

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