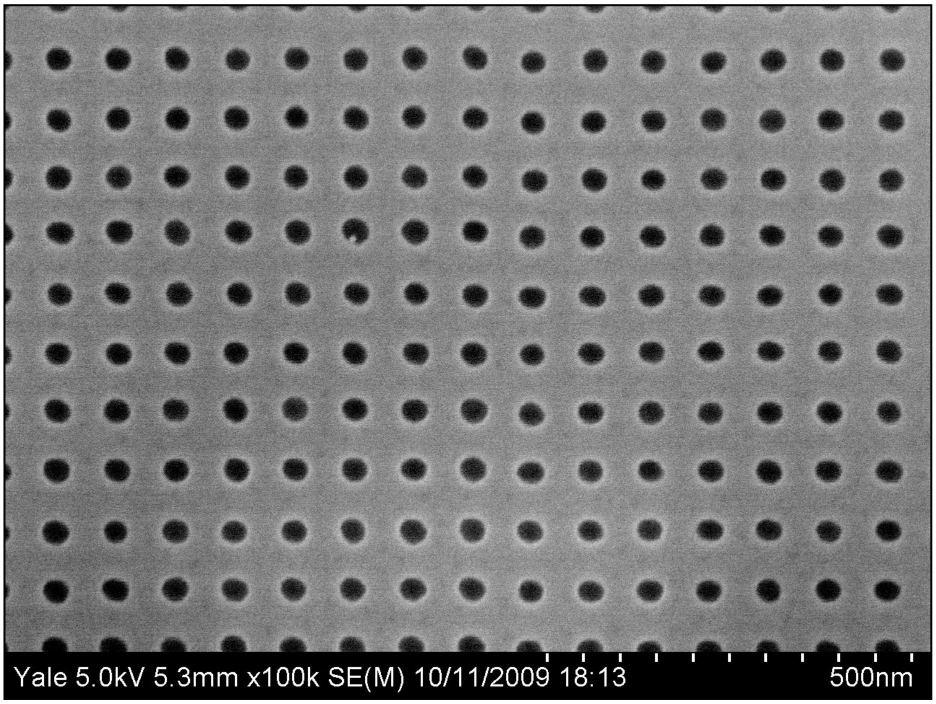
Analysis of electron-beam deflection noise with open-source software

Michael Rooks
Yale Institute for Nanoscience and Quantum Engineering
55 Prospect Street, New Haven CT 06520
Richard Tiberio
Geballe Laboratory for Advanced Materials, Stanford University
McCullough Hall, Stanford CA 94305

Deflection noise in an electron-beam lithography system is often inferred by measuring line-edge roughness, a quantity that is the convolution of deflection noise and process-induced roughness. To decouple process noise from electronic noise one can expose an array of dots and then measure the displacement of those dots from an ideal grid. To eliminate ambiguous effects from the blanking system, a simple array of dots can be written by underexposing a large rectangle while using a pixel spacing greater than the beam diameter. By exposing low-sensitivity resist (e.g. PMMA, ZEP or HSQ) with ~ 1 nA current and ~ 1 μs dwell time, the beam position is recorded in the resist film. This technique of writing "dots on the fly" is not new, but analysis of the resulting patterns is often subjective, due to the lack of easily accessible software. In this brief "shop notes" paper, we demonstrate the use of open-source software, developed at Yale, which fits horizontal and vertical gratings to an image of dots, automating the process of extracting the average jitter in an electron beam. The program is written in Python, and relies on a simplex fitting routine which is included in the SciPy package. Our program and all the required modules are available as free downloads. In addition, we provide the source code for a program which analyzes line-edge roughness.

We have used the "dot noise" program to analyze patterns from several commercial e-beam systems, using images of resist, etched holes and lifted-off metal. SEM imaging conditions have a significant effect on the analysis, and so this paper outlines the best techniques for collecting data. If the pattern of dots is written all in one deflection subfield, without pausing between rows, then a temporal noise spectrum can also be inferred from the data. This can be very useful when diagnosing equipment malfunctions.

(a)



(b)

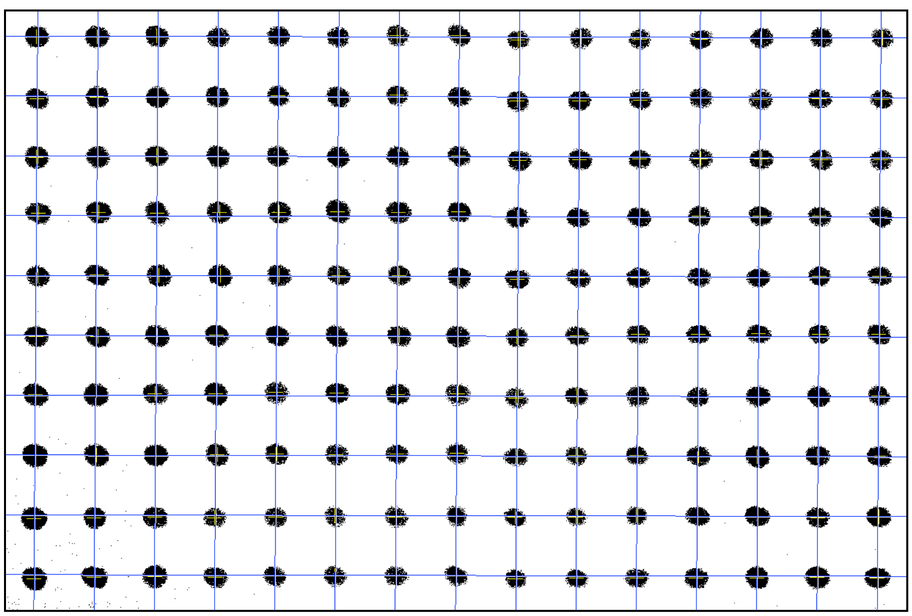


Figure: (a) Unretouched SEM image a dot array. Dots were written on-the-fly by choosing a pixel pitch of 80 nm and then underexposing a single rectangle. The pattern was exposed in PMMA resist and then etched 15 nm into a film of silicon nitride. (b) After manual cropping and thresholding, the algorithm searches for dark regions, calculating each "center of mass". Dot locations are fit first to a horizontal grating and then to a vertical grating.