Real-time Spatial Phase Locking for Vector-Scan Electron Beam Lithography

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Spatial-phase locked electron beam lithography (SPLEBL) provides feedback control of electron-beam position by monitoring the signal from a fiducial grid on the substrate. Continuous, or "real-time," spatial-phase locking has been investigated for raster-scan Gaussian-beam[1] and for shaped-beam[2] systems. Discontinuous feedback, or "look-then-write," techniques have been implemented for vector scan systems.[3-6] However, it would be advantageous to provide real-time spatial-phase locking for vector-scan systems because of their wide adoption for research, prototyping, and specialty device production. Here we present a phase-locking algorithm, performance simulations, and initial experimental results for real-time, vector scan SPLEBL.

During a vector scan exposure one builds up a two-dimensional signal from the fiducial grid as shown in Fig. 1(a). As this figure illustrates, the grid need not be aligned to the beam deflection axes. Information about the beam position is contained in the phases of the fundamental spatial frequencies that can be observed in the 2D Fourier transforms shown in Fig. 1(b,c). The order in which samples are acquired does not affect the actual phase or frequency; therefore, the signal can be acquired while exposing one or more arbitrary shapes using any desired shape filling strategy (raster, serpentine, or spiral fill).

In practice, the exposed pattern represents a complicated and time dependent signal windowing function that impacts the precision and accuracy of the phase estimates. This raises a number of issues concerning the ultimate performance of vector-scan SPLEBL, the optimal grid configuration, and the best exposure strategy. Here we consider the more important of these issues including the time required to achieve acceptable estimates of beam location. As shown in Fig. 1(d,e) a high signal-to-noise ratio grid signal with a practical periodicity (200 nm) allows one to estimate beam location with nanometer precision after sampling relatively few pixels. We also show that the grid should be rotated with respect to the deflection axes and spiral shape filling should be used to rapidly achieve accurate position estimates. Fig. 2 shows the experimental x- and y- position error estimates from spiral shape filling using the signal from a rotated, coarse (1μm) period fiducial grid. Finally, we address the pattern dependent performance of vector-scan SPLEBL and identify certain pattern-grid combinations that should be avoided.

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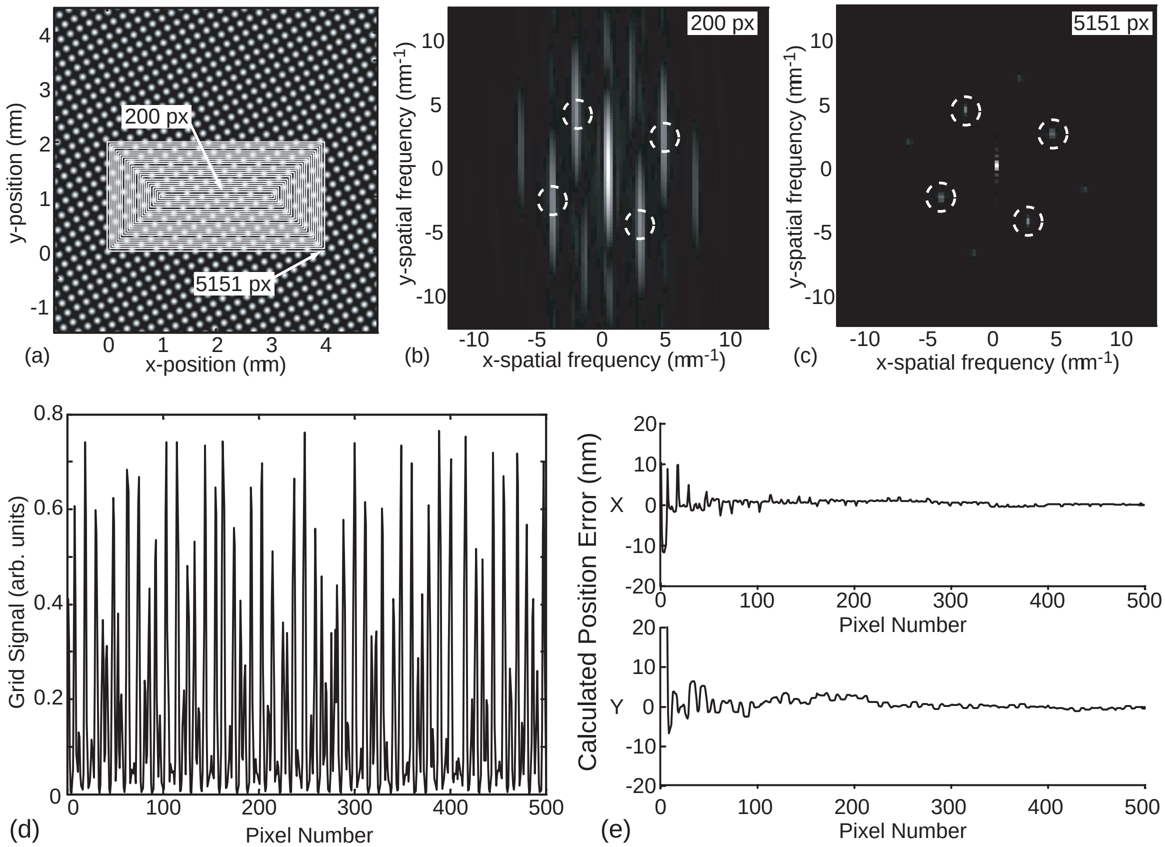

Figure 1. (a) Simulated 2D signal from a 200-nm period fiducial grid rotated 30.6 degrees with respect to the beam deflection axis. A spiral fill feature exposure is shown as well. (b,c) 2D Fourier tranforms of the grid signal after sampling 200 pixels and 5151 pixels respectively. Note the improved resolution of the fundmental frequency components (circled). (d) 1D signal as it is acquired from the sprial scan. (e) Estimated x- and y- beam poistion errors as a function of number of sampled pixels.

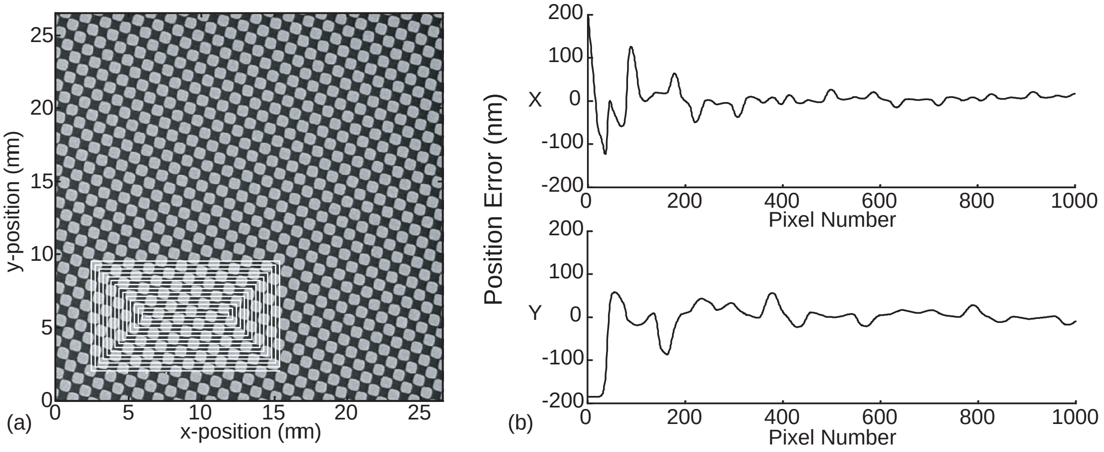

Figure 2. (a) Experimental secondary electron signal from a 1-µm period Cr-Au on Si grid and a spiral scan representing a 500x300 pixel feature. The primary beam energy was 30keV. (b) X- and Y- error estimates from the spiral scan signal as a function of number of exposed pixels.