Real-Time Drift Correction of a Focused Ion Beam Milling System

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Focused Ion Beam (FIB) milling systems are attracting increasing attention outside of their traditional role as semiconductor inspection tools, and many researchers are now using FIB systems for nanofabrication. Although the commercial instruments will run for several hours, executing various automated procedures such as preparing TEM sections and milling nano-structures, they invariably suffer from some form of slow and systematic drift in the beam position over the specimen. Use of a FIB outside of a temperature controlled environment makes this effect much more noticeable, so the traditional applications have either been short in duration (including manual inspection) or have used a carefully chosen milling procedure to deal with the problem.

We are working towards the nano-fabrication of large periodic optical structures, known as photonic crystals. These structures must have extremely smooth and reproducible holes, on a lattice with nm position tolerance [1]. To achieve this we have developed our own custom pattern generation software. For example, we required a lattice of around 50,000 holes, 300 nm in diameter, to be milled over 100×100 μm^2, taking more than three hours to complete. Unfortunately, systematic drift over this long milling time prevented the structures from being fabricated to within the required positional tolerance. Typically, the system could be expected to drift 200-1000 nm depending on the time of day, plus an additional 200 nm periodic component due to the air-conditioner cycling on and off.

To overcome this challenge, we have developed a real-time drift correction system. By milling an array of reference marks and then imaging them periodically with the FIB, we are able to detect the apparent motion of the specimen under the beam to within a few nm, and update the beam shift to greatly reduce its impact. We demonstrate the measurement of drift in our FIB system and its effective compensation, leading to a striking improvement in the optical quality of our structures. See Fig. 1 for an example of recorded drift data, Fig. 2 for a drift-corrected lattice, and Fig. 3. for a close-up view of a reference mark and lattice.

Aside from our use in nano-fabrication, FIB drift correction has also recently found an application in FIB tomography [2], the reconstruction of a sample volume by successive cross-sectioning and imaging. By improving the accuracy of sectioning, thinner slices can be used. Recognition of arbitrarily shaped reference marks also enables the milling to be indexed to existing structures, such as those produced in earlier lithography or milling steps. The technique also compensates for the unknown beam shift normally encountered when changing lens conditions, enabling the use of multiple beam currents without sacrificing positional accuracy.

1. D. Freeman, S. Madden and B. Luther-Davies, “Fabrication of planar photonic crystals in a chalcogenide glass using a focused ion beam,” Opt. Express **13**, 3079-3086 (2005).
2. L. Holzer, F. Indutnyi, P.H. Gasser, B. Munch and M. Wegmann, “Three-dimensional analysis of porous $BaTiO_3$ ceramics using FIB nanotomography,” J. Microscopy **216**, 84-95 (2004).

TOPIC AREA: Nano Fabrication - E-beam, Laser, STM, Ion Beam Lithography

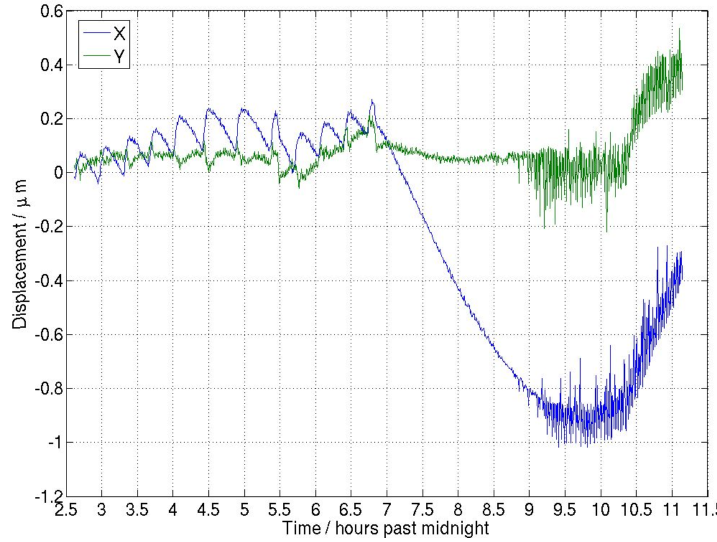

Figure 1. Detected drift during early morning. The reference marks were too badly degraded by around 9AM, leading to excessive noise. At 7AM, the thermal environment changed for an unknown reason.

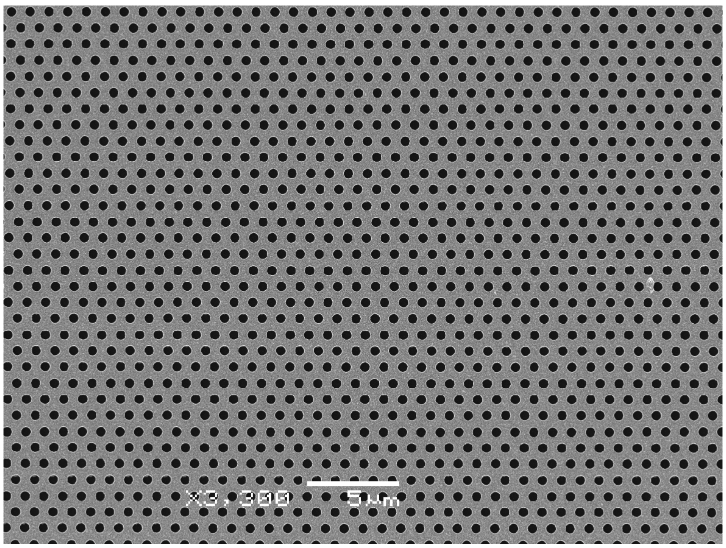

Figure 2. Photonic crystal lattice milled with automatic drift correction enabled.

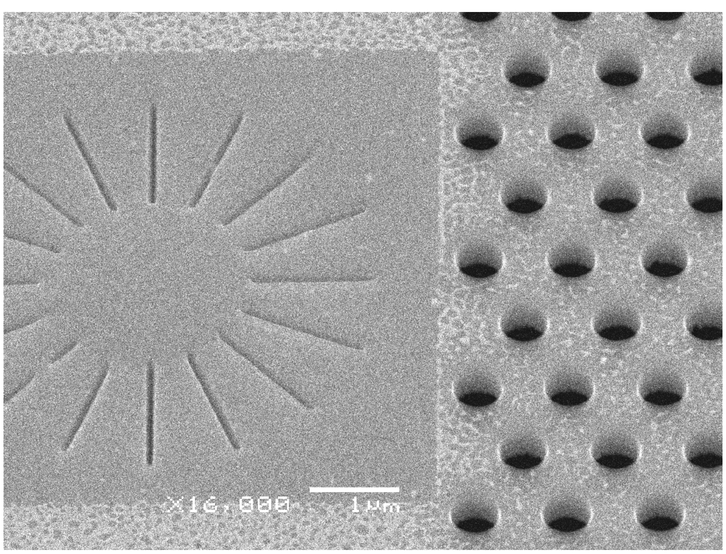

Figure 3. Photonic crystal lattice with a slightly-used reference mark beside it. The structure was milled into a thin Au-coated membrane and the SEM image was taken at 30°.