Microfabricated Diffractive Optical Ruler for Tip Based Nanofabrication and Metrology

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Abstract:

The transition from research level to wafer scale manufacturing using tip based nanofabrication methods will require improvements in the serial fabrication speed while increasing the placement precision. Current methods use massive, low mechanical bandwidth stages and metrology systems whose high precision and accuracy extend to sub-millimeter ranges. We aim to resolve these challenges using an atomically-stabilized optical field to generate a precise 3-D ruler. The system generates a microfabricated diffractive optical ruler, whereby the scanning probe moves in space and positions itself both precisely and accurate.

We have demonstrated 10^-5 precision over a region extending 65 mm.

Summary of Research:

An external cavity laser is locked to the Rb D2 line (780 nm). A microfabricated diffractive grating consists of aluminum on low pressure chemical vapor deposition (LPCVD) silicon nitride. The bulk Si is removed from the backside by a potassium hydroxide (KOH) etch to the nitride. A 1 mm hexagonal lattice of 3 µm holes is etched by a chlorine reactive ion etch (see Figure 1). Such a grating generates a hexagonal lattice diffraction pattern. The diffraction pattern effectively generates a precise three dimensional optical field which can be used to position a nanofabricating tip with a photosensitive element (see Figure 2). In this case, we use a quad photodetector which locks to a high intensity point in the diffraction pattern in a proportional-integral loop. The detector is mounted on a PC board with a scanning

Figure 1: Hexagonal lattice diffraction grating of chlorine RIE etched aluminum. Bar shows 20 µm.

Figure 2: Schematic of diffractive ruler setup.
tunneling microscope (STM) tip. These are mounted on a piezo stage, which is mounted on a large stepper stage to allow for long travel across a three inch wafer. The photodetector is positioned within the optical ruler by locking its center to a point in the hexagonal lattice diffraction pattern in a proportional-integral control loop. The optical system had 190 nm position error ($10^{-6}$ over 100 mm): see Figure 3. To demonstrate the precision of the system, indentations were made in PMMA with the STM tip while it was positioned relative to the optical ruler. Twenty seven indentations in a region 66 mm by 28 mm were made. The marks were measured in an SEM and the position read out from the stage in the SEM was used to measure the precision of the system. Accounting for errors, we have shown a precision of $1.5 \times 10^{-5}$.

We are now fabricating quasiperiodic gratings in the device layer of an SOI wafer. With the increased complexity of the optical ruler and an image array to cross correlate theoretical data to the image, we are heading towards the expected maximum precision of $10^{-8}$, or a nanometer over 100 mm.

Figure 3: Noise of quadrature photodiode, showing 190 nm standard deviation in position.