10. Interference Lithography

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Interference lithography (IL) is the preferred method for fabricating periodic and quasi-periodic
patterns that must be spatially coherent over large areas. IL is a conceptually simple process
where two coherent beams interfere to produce a standing wave, which can be recorded in a
photoresist. The spatial-period of the grating can be as low as half the wavelength of the
interfering light, allowing for structures of the order of 100nm from UV wavelengths, and features
as small as 30-40 nm are possible using a DUV ArF laser.

The NanoStructures Lab has been developing IL technology for close to 20 years, and
we currently operate 4 different IL systems for a wide variety of applications. One system, shown
schematically in Figure 1, is run in cooperation with the Space Nanotechnology Lab. This system
is specially designed for high stability and repeatability and is capable of producing metrological
quality gratings and grids up to 10 cm in diameter at spatial periods down to 200nm. Used
primarily for satellite applications, gratings produced with this tool have flown on numerous missions, most notably, the Chandra x-ray astronomy satellite launched in August of 1999 included hundreds of matched, high-precision gratings.

![Schematic of one of the MIT interferometric lithography systems. This system occupies a 2x3m optical bench in a class 100 clean environment. The beamsplitter directs portions of the two interfering spherical beams to photodiodes. A feedback locking is achieved by differentially amplifying the photodiode signals and applying a correction to the Pockels cell which phase shifts one of the beams in order to stabilize the standing wave pattern at the substrate.](image-url)
We operate another system similar to the one shown in Figure 1 based around the 325 nm line of a HeCd laser. This system functions both as an exposure tool with capabilities comparable to those described above as well as an analysis tool. Using a technique known as holographic phase-shifting interferometry (HPSI), the linearity and spatial phase of gratings produced in this system can be quantitatively measured and mapped with an accuracy on the order of parts per million. Known hyperbolic distortions in the spatial-phase of gratings printed using IL are responsible for changes in periodicity of a few angstroms (for a 200 nm period grating) over a 10 cm wafer. Although seemingly small, distortions of this scale can be highly significant, especially in metrological applications such as the fiducial grids for spatial-phase locked electron beam lithography. Using the HPSI, we have been able to investigate innovative techniques for reducing these distortion levels. One method, based on the controlled bending of the substrate during exposure, has demonstrated a reduction of the distortion pattern from 2 dimensions to 1 dimension as well as reducing the magnitude of the distortions by about a factor of 5.

Figure 2 Schematic of a Lloyds-mirror interferometer. The substrate and mirror are fixed at a 90˚ angle to one another, and centered in a single incident beam. Rotating the substrate/mirror assembly about its center point varies the spatial-period of the exposed grating. The micrograph shows a grating with 70 nm lines on a 170 nm pitch exposed using the Lloyds-mirror.
Also utilizing a 325 nm HeCd laser is the Lloyds-mirror interferometer, shown schematically in Figure 2. The primary advantage of the Lloyds-mirror is that the spatial-period of the exposed gratings can be easily and continuously varied from many microns down to ~170 nm simply by rotating the stage without realigning the optical path. This has opened the door to new possibilities such as varied aspect-ratio grids (different periodicities in the two axes of the grid) for patterned magnetic media and MRAM (magnetic random access memory) devices. Among the many other applications of IL supported by the Lloyds-mirror are alignment templates for semiconductor quantum dots, and other self-assembling structures. Distributed feedback (DFB) structures for quantum dot lasers and photonic bandgap devices have also been made using the Lloyds mirror.

For spatial periods of the order of 100 nm, we use a 193 nm ArF laser. To compensate for the limited temporal coherence of the source, we utilize an achromatic scheme shown in Figure 3. In this configuration the spatial period of the printed grating is dependent only on the period of the parent gratings used in the interferometer, regardless of the optical path or the wavelength and coherence of the source. Thus, gratings and grids produced with this tool are extremely repeatable. Figure 4 shows a 100 nm-period grid of 13 nm-diameter posts etched into Si, produced using achromatic interferometric lithography (AIL) and a sequence of etching steps. Other applications AIL include patterned magnetic media, gratings for atom-beam interferometry UV polarizers, and templated self-assembly.

A new generation of achromatic interference lithography tools is currently being developed to produce 50 nm period gratings and grids, or 25 nm lines and spaces. Because of the limited availability of sub-100nm wavelength sources, all of the possible implementations for making 50 nm period gratings are based around the achromatic scheme described for 100 nm period gratings. Among the possibilities are free-standing gratings etched in a thin membrane for use with soft x-rays, or use of reflection gratings in an analogous AIL scheme with a 58.4 nm helium discharge.

The fourth type of interference lithography is scanning-beam interference lithography (SBIL). Such a system, which is also called the Nanoruler, has been constructed in the Space Nanotechnology Laboratory, and is described in another section.

![Figure 3. Achromatic interferometric lithography (AIL) configuration employed to produce 100 nm-period gratings and grids.](image)
100nm-period posts in Si

Figure 4: Scanning electron micrograph of a 100 nm-period grid, exposed in PMMA on top of an antireflection coating, and transferred into Si by reactive ion etching.