SNL-5 The MIT Nanoruler: A Tool for Patterning Nano-Accurate Gratings.

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Historically, the ability to observe and measure the results of processes has been critical to advancing fabrication technology. Thus, improvements in optical microscopy (e.g., Nomarski differential interference contrast) were a key enabler of the microelectronics revolution. In turn, the scanning-electron and atomic-force microscopes are essential tools as we move into the nanotechnology era. While the ability to print or resolve a particular feature size is a necessary condition for the successful lithographic manufacturing of nanosystems, it is, by no means, the only requirement. Equally important is the ability to measure and control the size and placement of lithographic features with very high accuracy

All modern lithographic production and inspection tools, and all precision tools for that matter, are based on the notion of a *metrology frame*. Such a frame is composed of three components: (1) a rigid mechanical structure, (2) means to measure the motion of a workpiece with respect to the metrology frame, and (3) means to project, image or detect patterns on the workpiece, such as by use of an optical or electron lens. The preferred means for measuring workpiece motion has been the laser interferometer. The accuracy of a lithographic tool is critically dependant on the accuracy of its metrology frame, which, in turn, is dependant on the accuracy of the interferometer. Due to a number of factors, however, interferometer accuracy is not keeping pace with the shrinking tolerances as called for by the semiconductor industry roadmap, and is inadequate for many integrated optoelectronic patterns and the future nanotechnology revolution.

To address this problem, we are developing a lithographic tool called the *Nanoruler* that is designed to pattern gratings of such high accuracy that they may serve as the means for detecting workpiece motion in precision tools, using a method known as optical encoding, with an accuracy that is some 10-100X better than laser interferometers. The Nanoruler utilizes a patterning method called *scanning-beam-interference lithography* (SBIL), developed in the Space Nanotechnology Laboratory (SNL), that is capable of rapidly patterning large gratings (>300 mm diameter) in only a few minutes with unprecedented accuracy (see Fig. 5.1). Such super-accurate gratings can serve as optical encoder plates. Another important application for the Nanoruler is the patterning of nano-accurate gratings necessary for locking an electron beam using a novel technique called spatial-phase locked electron beam lithography (SPLEBL) that is under development in the NanoStructures Laboratory (NSL) and described elsewhere.

High fidelity gratings are also critical for advanced instrumentation and optics such as laboratory and astronomical spectrographs, high-bandwidth optical communications and fusion energy research. Conventional means of fabricating gratings, such as diamond ruling, holography, or beam writing, can take many hours or weeks to complete, and typically produce gratings of poor spatial-phase fidelity.

The concept of SBIL is to combine the sub-1 nm displacement-measuring capability of laser interferometry to control a high-performance air-bearing stage, with the interference of narrow coherent beams, to produce coherent, large-area, linear gratings and grids. Our ultimate goal is to produce gratings with sub-nm distortion over areas many tens of centimeters in diameter. SBIL requires sophisticated environmental controls to mitigate the effects of disturbances such as acoustics, vibration, and air turbulence, and variations of temperature, pressure, and humidity. The system also features real-time measurement and control of optical phase using heterodyne fringe detection, acousto-optic modulator phase locking and a high-speed digital signal processor (DSP) controller (see Fig. 5.2).

An important feature of SBIL is the ability to both write and read gratings with nanometer control of grating phase. We have demonstrated ~2 nm 3σ repeatability of the writing and reading process. Fig. 5.3 shows a photograph of a 300 mm-diameter wafer patterned with the Nanoruler.

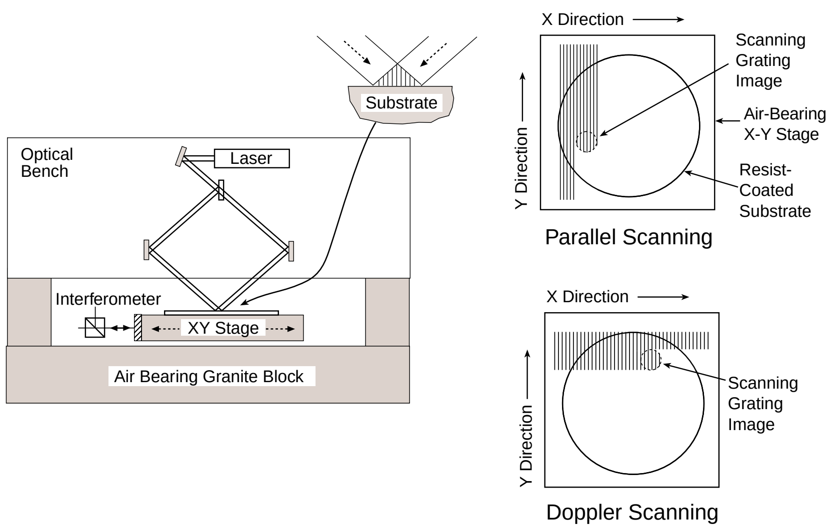

Figure 5.1. *Schematic of the scanning-beam-interference lithography (SBIL) system under development in the SNL. A pair of narrow, low-distortion beams overlap and interfere at the substrate, producing a small grating "image." The substrate is moved under the beams, writing a large area grating. Tightly overlapped scans ensure a uniform dose.*

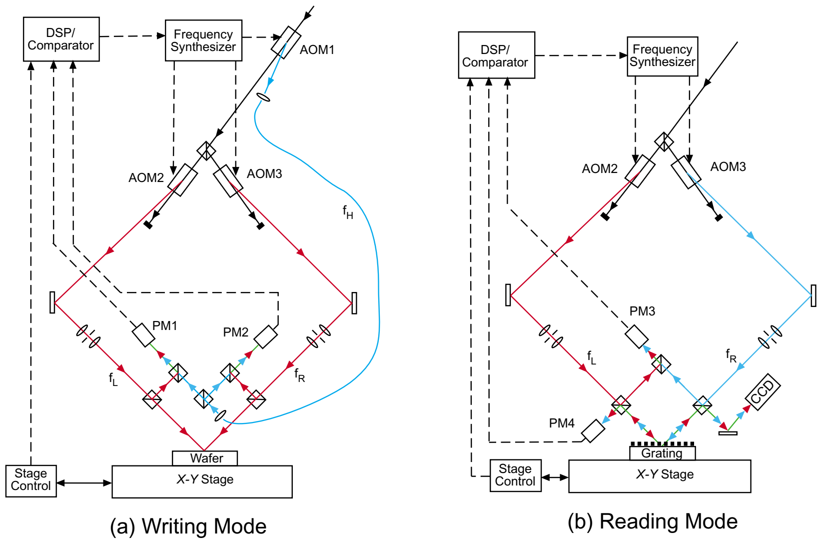

Figure 5.2. *Schematic of SBIL acousto-optic (AO) modulator phase locking system. Both writing and reading modes are depicted. The phase of the grating image is measured by a small interferometer close to the writing surface. The AO modulators Doppler shift the beams into the mega-Hertz range, providing high-accuracy heterodyne measurement of phase. This information is processed by a digital signal processor and used to control RF frequency synthesizers which drive the AO modulators, thus locking the image phase to the moving substrate.*

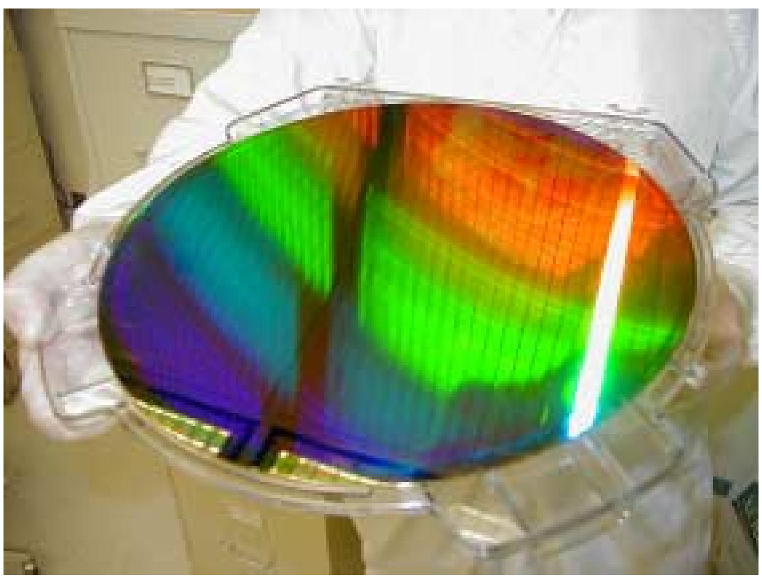

Figure 5.3. *A 300 mm-diameter silicon wafer patterned with a 400 nm-period grating by the Nanoruler. The grating is diffracting light from the overhead fluorescent bulbs.*