
Nanometrology Using Interferometrically-Patterned Fiducial Grids

Personnel

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Sponsorship

DARPA/ARO

The ability to see and measure the results of a process is critical to advancing fabrication technology. Historically, the development of improved microscopy techniques led to rapid progress in microfabrication. Thus, the scanning-electron microscope was essential to the microelectronics revolution. Similarly, the scanning-tunnelling microscope is creating a revolution in the study of interfaces and nanostructures.

In the past, metrology of microstructures and the measurement of workpiece distortion (e.g., a photolithographic reticle or X-ray mask) has been based on point-by-point measurement through an optical microscope using an X-Y table monitored by a laser interferometer. Although this approach enables relative distances in a plane to be measured with 1 nm-level detectivity, it is expensive, tedious, and subject to a number of shortcomings, including the necessity of placing rather perturbative marks on a workpiece. We have initiated a new approach to metrology for the sub-100 nm domain that is based on large-area fiducial grids produced by interference lithography. This new approach is complementary to the point-by-point approach in much the same way that aerial photogrammetry is complementary to ground-based land surveying for the mapping of terrain.

A key element in this effort is the Holographic-Phase-Shifting Interferometer (HPSI), illustrated in Figure 32. This system enables the global measurement of the in-plane distortion of a workpiece, provided one of its surfaces contains a shallow fiducial grid. Ideally, the grid on the workpiece will be created by interference lithography or a derivative thereof, such as near-field holography.

The Semiconductor Industry Association (SIA) roadmap calls for minimum features to shrink below 35 nm over the next 15 years, implying that planar metrology tools with errors below 1.0 nm will be required in the next

decade (see Figure 33). We believe that interferometrically patterned grids are nearly ideal vehicles to this end. As part of our effort in sub-100 nm metrology, we are pursuing a variety of approaches to eliminate the distortion in interferometrically produced grids, decreasing or eliminating the coefficient of the hyperbolic phase progression (a consequence of creating a grid by interfering spherical wavefronts), and increasing the useful area of fiducial grids.

One such approach is Scanning Beam Interference Lithography (SBIL), depicted schematically in Figure 34. The concept here is to combine the sub-1 nm displacement measuring capability of laser interferometry with the interference of narrow coherent beams to produce coherent, large-area, linear gratings and grids. Our ultimate goal is to produce gratings having sub-nm distortion over areas many tens of centimeters in diameter. These would be used to calibrate lithography tools or used directly as optical encoder scales, eliminating the laser interferometer and significantly improving tool performance, while reducing cost.

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 image phase using heterodyne fringe detection, acousto-optic modulator phase locking (see Figure 35), and a high-speed Digital Signal Processor (DSP) controller (see Figure 36).

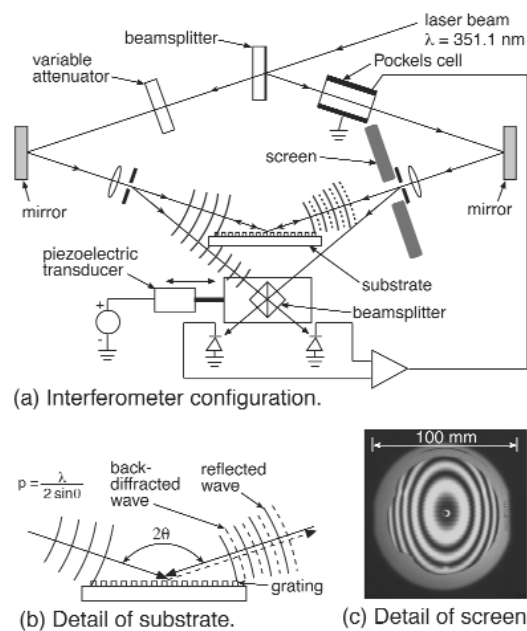


Fig. 32: Schematic of the Holographic-Phase-Shifting Interferometer (HPSI). A spherical wave back-diffracted from a shallow substrate grid, and a second wave specularly reflected, interfere on a fluorescent screen at the spatial filter. The fringes are imaged onto a CCD. By shifting the beam splitter with a piezo, a computer generates an X-Y map of phase error.

SEMICONDUCTOR INDUSTRY ASSOCIATION (SIA) ROADMAP 2000

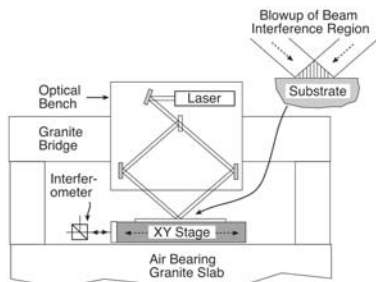
YEAR	1999	2000	2001	2002	2003	2004	2005	2007	2010	2013
CD (nm)	180	150	130	115	100	90	80	65	45	33
OVERLAY (nm, mean +3 sigma)	65	52	45	40	35	31	28	26	19	13
MASK IMAGE PLACEMENT (nm)	39	31	27	24	21	19	17	15	11	8
METROLOGY ERROR (nm)	10	7.8	6.8	6.0	5.3	4.8	4.3	3.8	2.8	2.0

Solutions Exist
 Solutions Being Pursued
 No Known Solutions

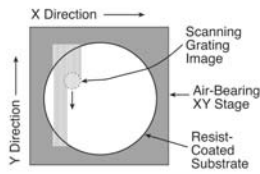
METROLOGY STANDARD (nm)	2.4	1.9	1.7	1.5	1.3	1.2	1.1	0.94	0.69	0.50
SRII INTERNAL ERROR (nm)	0.61	0.48	0.42	0.38	0.33	0.30	0.27	0.23	0.17	0.13

MIT Effort

Fig. 33: Semiconductor Industry Association (SIA) roadmap tracking critical dimension (CD) or minimum feature size, overlay error, mask image placement error, and metrology tool error. The MIT effort seeks to produce grating metrology standards with sub-nm errors, which would be used as planar metrology length scales or optical encoders in lithographic equipment, eliminating the laser interferometer.



(a) Interferometer configuration.



(b) Grating scanning method.

Fig. 34: Schematic of the Scanning Beam Interference Lithography (SBIL) system under development in our laboratory. A pair of narrow, distortion-free 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.

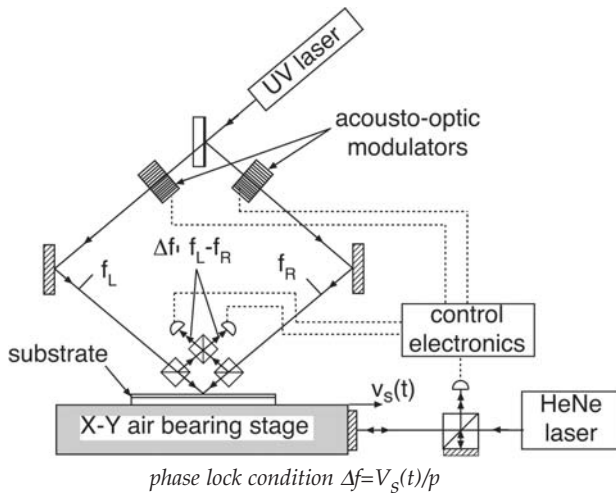


Fig. 35: Schematic of SBIL Acousto-Optic (AO) modulator phase locking system. The phase of the grating image is measured by the small inner interferometer close to the writing surface. This information is processed by a digital signal processor and used to control RF frequency synthesizers which drive the AO modulators, thus locking the image phase to the moving substrate.

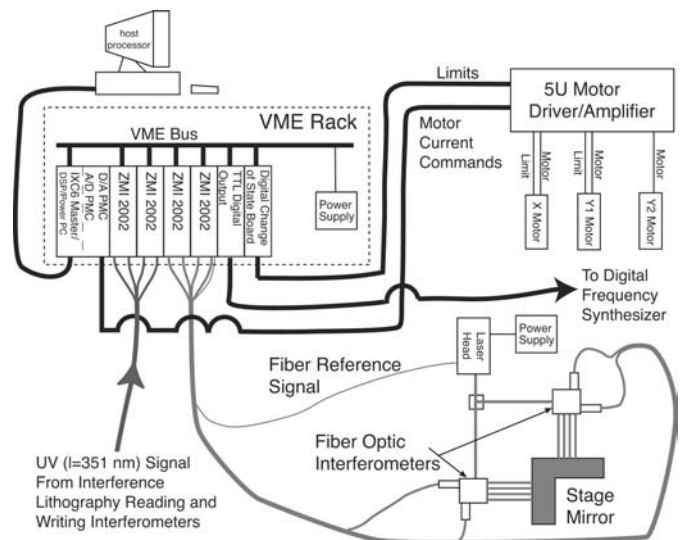


Fig. 36: Schematic of SBIL system architecture. The system utilizes a frequency stabilized HeNe laser ($\lambda=632.8$ nm) and heterodyne interferometry to measure substrate position, and argon ion ($\lambda=351.1$) heterodyne interferometry to measure image fringe phase. Phase error signals are processed by an IXTHOS 4x167 MHz DSP board, which then drives the stage DC motors and the RF digital frequency synthesizer that controls the fringe-locking AO modulators.