Optical Holographic Microscopy for Inspection and Metrology of Photolithographic Masks

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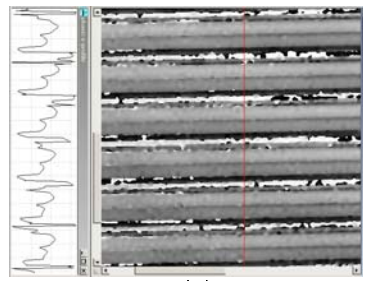
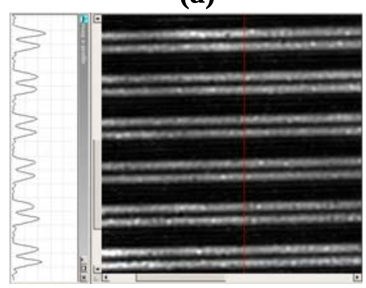
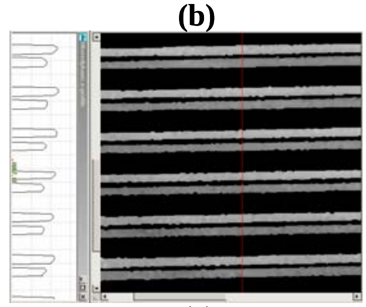
Optical lithography, also known as photolithography, uses light to print patterns on semiconductor devices to create integrated circuits (IC). For many generations of IC printing, the methods of photolithography have incorporated lithographic masks composed primarily of chrome-based blocking regions on a quartz substrate. These are known as binary masks due to their on/off response in a photolithographic system. The mask pattern is projected through a lithography stepper system onto a photoresistive chemical layered onto a silicon wafer. Once exposed, the photoresist (either positive or negative) is removed to provide a pattern for subsequent processing [1]. The fundamental limitation of photolithography is primarily a function of the illumination wavelength and the diffraction limit of the optical lithography system. As device geometries continue to shrink it has become necessary to decrease the wavelength of the illumination source and to develop new phase-shifting mask materials that use destructive and constructive interference to print smaller device features.



(a)



(b)



(c)

Example of a transmission (a) phase (with noise) and (b) amplitude measurement of an AAPSM. (c) Phase result after amplitude filtering.

New advances in the production of photolithographic masks are enabling useful extensions of optical lithography techniques into the 90nm technology node and beyond [2]. These techniques have taken mask technology from simple chrome and quartz configurations to the addition or removal of phase shifting materials to produce constructive and destructive interference through phase shifts. The types of masks being investigated today include attenuating phase shift masks (AttPSM) and alternating aperture phase shift masks (AAPSM). With these new materials and formats comes new issues related to mask inspection and metrology that must be addressed to guarantee adequate availability and function. Due to the inherent nature of photolithography, methods for measuring and inspecting masks that also use optical techniques are desirable since they are non-contact, afford potentially high-throughput and easy mask handling, and characterize the mask with similar wavelengths as those used to perform lithography. Optical techniques also provide the potential to characterize the phase-shifting elements of these masks in terms of a direct measurement of the induced phase shift, not just the image magnitude.

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At the Oak Ridge National Laboratory (ORNL), we have developed an imaging technique called Spatial Heterodyne Interferometry (SHI), also known as optical holography, that captures mask images containing both phase and amplitude information at a high rate of speed [3]. By measuring the phase of a wavefront reflected off or transmitted through a surface, the relative surface heights can be determined. Since surface topology of a phase shift mask (PSM) provides a measure of the phase shift differences between regions, SHI allows phase shift metrology [4] and detection of phase shift structures and defects [5]. The sensitivity of an SHI system for phase-based metrology and inspection will depend on the wavelength in two ways. First, the spatial resolution is limited by the illumination wavelength of the inspection system. Secondly, the phase contrast for different surface depths will depend on the inspection wavelength. The figure shows examples of transmission through an AAPSM using a 532nm interrogation wavelength. The AAPSM in this example has 0^o and 180^o induced shifts in conjunction with opaque chrome regions. Metrology of these devices involves the development of methods to directly measure the phase shift of the wavefront that it induced by the mask during the photolithographic process.

In this presentation we will describe the state of the SHI research that is ongoing at ORNL with regards to both reflection and transmission measurements on PSMs. We will also describe some of the existing challenges associated with direct phase measurements and with optical metrology and inspection in general, especially related to shrinking mask features, assist features, and the potential to extend spatial measurement capabilities through an integration of modeling, analytical, and physical methods.

References

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Biography

Dr. Kenneth W. Tobin is a Corporate Research Fellow and Group Leader of the Image Science and Machine Vision Group at the Oak Ridge National Laboratory, Oak Ridge, Tennessee. He has been performing research with the semiconductor industry since 1991 for rapid yield learning that includes image defect classification, wafermap spatial signature analysis, content-based image retrieval, and holographic microscopy for inspection and metrology. He has authored and co-authored over 120 publications and he currently holds seven U.S. Patents with two additional patents pending in the areas of computer vision, photonics, radiography, and microscopy. Dr. Tobin is a Fellow of the International Society for Optical Engineering (SPIE) and a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE). He has a Ph.D. in Nuclear Engineering from the University of Virginia, Charlottesville, Virginia, and an MS in Nuclear Engineering and a BS in Physics from Virginia Tech., Blacksburg, Virginia.