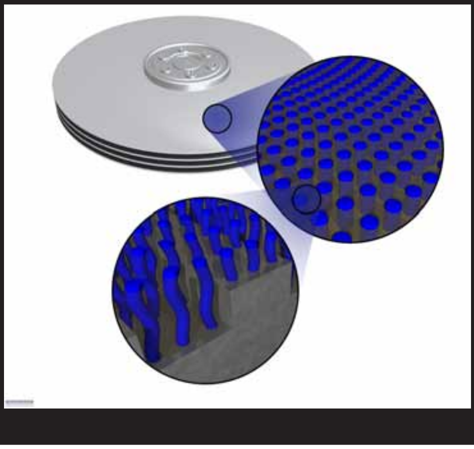
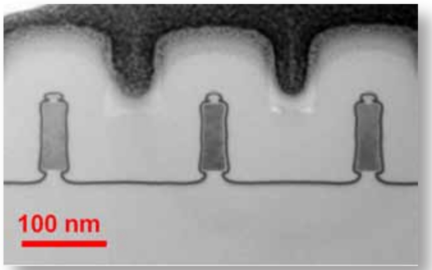
Dimensional Metrology for Nanomanufacturing

Objective

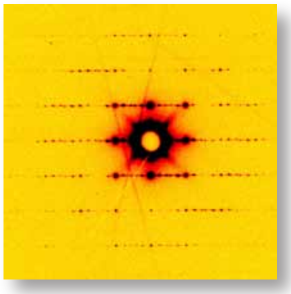
Our goal is to develop measurements that quantify pattern shape, size, and orientation as a tool to quantitatively evaluate nanofabrication and assembly processes. Our customers range from the semiconductor fabrication community, where the dimensional metrology needs are well-documented by industry roadmaps and critical to quality control, to emerging technology sectors, such as bit patterned magnetic data storage media, where quantitative feedback is critical to developing and optimizing nontraditional nanofabrication routes. Our unified approach is to develop nondestructive scattering and reflectivity measurements using X-rays and neutrons as a high-resolution and quantitative pattern shape metrology.



Impact and Customers

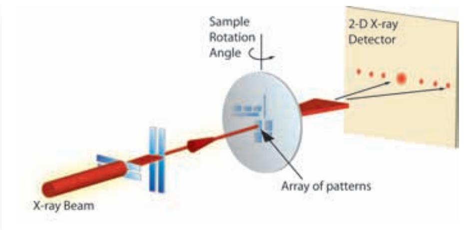


- Directly addressing the "Grand Challenges" of the International Technology Roadmap for Semiconductors, a document that articulates the lack of measurement solutions for pattern uniformity and placement in dense arrays of sub-50 nm structures which are the foundation of next generation electronics and data storage devices.
- Critical Dimension Small Angle X-ray Scattering (CD-SAXS) achieves the first example of 3D metrology for interconnects. Preliminary measurements on FINFET structures demonstrate the feasibility of application to these buried structures. Such measurements are not possible with current methods.



- A NIST collaboration with IBM and Hitachi Global Data Storage has provided the distribution of orientation of self-assembled structures, a key indicator of pattern quality necessary for technology development, using Rotational Small Angle Neutron Scattering (R-SANS).
- CD-SAXS is included on the 2007 ITRS Update as a candidate next generation critical dimension pattern metrology technology for the semiconductor industry.
- Customers include Intel, SEMATECH, IBM, and Hitachi Glabal Data Storage.

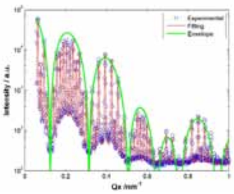
Approach



Scattering and reflectivity techniques, i.e., measurements in reciprocal space, are employed to measure, with sub-nm precision, pattern shape, physical dimensions, and orientation for periodic arrays of nanostructures. Critical Dimension Small Angle X-ray Scattering (CD-SAXS) utilizes the transmission scattering from a small beam size (100 x 100 μm) to provide detailed shape and dimensional data for 10 to 500 nm structures placed with high uniformity in pitch. A lab scale prototype at NIST complements the current optical scatterometry, CD-AFM, and CD-SEM methods that are widely used in the nanofabrication community. CD-SAXS can easily quantify the pattern shape in arrays of nanostructures with periodicities in the range of 10 to 500 nm with sub-nm precision, is nondestructive, is capable of quantifying buried or free-standing patterns, and is straightforward to interpret via scattering theory. Rotational Small Angle Neutron Scattering (R-SANS) is a complementary technique capable of measuring the distribution in orientation for patterning methods based on directed self-assembly. These unique dimensional measurements are applied to evaluate emerging nanofabrication processes including extreme ultraviolet lithography, electron beam lithography, and block copolymer directed self-assembly.

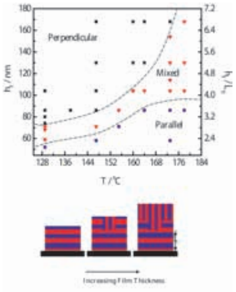
Accomplishments

Non-Planar Electronics: In order to meet future challenges from thermal and power efficiency requirements of sub 32nm technology nodes, transistor architecture is migrating from planar to non-planar structures. These structures, such as the tri-gate and FinFET devices, feature increased complexity in pattern shape and nanoscale conformal coatings. Current measurement platforms are challenged by the small dimensions inherent in these structures, where diminishingly small variations in composition and dimensions will reduce or eliminate device functionality. Critical Dimension Small Angle X-ray Scattering (CD-SAXS) is a metrology platform with the potential capability to quantify 3-dimensional non-planar structure with sub-nm precision. Specifically, CD-SAXS has the potential to non-destructively characterize the thickness and, to a limited extent the uniformity of the thickness, of the conformal high-k dielectric layer.



CD-SAXS data from a model tri-gate structure patterned in a line/space array (top) and the resulting model used to fit the data (bottom). Dimensions resolved include the pitch, line width, line height, sidewall angle, and dielectric thickness.

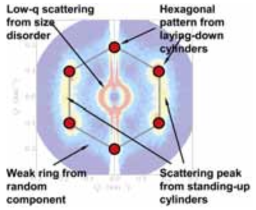
In FY08, we have demonstrated this capability of X-ray based scatterometry by measuring high-k dielectric layers deposited from 0 to10nm in thickness over grating patterns with a nominal critical dimension of 20 nm. For these patterns, CD-SAXS provides high precision data on average high-k dielectric thickness, line width (CD), and pitch. In addition, the measurement has the capability to measure the average top layer thickness and the dielectric thickness on the pattern sidewall independently, providing a measure of uniformity.



Block copolymer orientation as measured by top-down microscopy. The processing conditions, in this case the annealing temperature and film thickness, dictate the orientation of nanoscale cylindrical phases. However, microscopy does not reveal the structure below the top surface indicated in the cross section schematic.

Orientation in Directed Assembly: Di-block copolymers are polymeric chains composed of two covalently linked sub-chains that can assemble into nanoscale domains. Morphologies achieved to date include spherical, cylindrical, lamellar, and bicontinuous phases. The capability to assemble these polymers within a thin coating to achieve phases with narrow size disparity makes them attractive as sacrificial resists as well as functional materials. However, control over orientation requires external guides and control over processing conditions.

A wide array of strategies have been employed to date to create large area films with nearly single crystalline order including solvent annealing, chemical pattern templates, topological templates, and electric fields. Challenges still exist in the precise measurement of block copolymer orientation, particularly in thick films and during early stages of processing, where electron microscopy is frequently destructive and X-ray contrast is often low. To address this challenge for block copolymer (BCP) films and other nanoscale soft matter systems, we are developing Rotational Small Angle Neutron Scattering.



R-SANS data collected for a block copolymer film during directed self-assembly. Shown is a Fourier space image of diffraction from nanoscale cylindrical phases, where two orientations co-exist.

Rotation Small Angle Neutron Scattering, in conjunction with specular neutron reflectivity, can measure the relative fractions of perpendicular and parallel components. Shown are data from a "mixed" state film, where one phase is perdeuterated, measured along the Q_x-Q_z plane. The hexagonal diffraction spots are indicative of several layers of ordered cylinders parallel to the substrate. Neutron reflectivity reveals these cylinders as located near the bottom substrate. These data indicate the perpendicular cylinders become more dominant as film thickness increases, providing a detailed picture of coexisting orientations with the relative fractions varying with thickness and annealing temperature.

Learn More

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Publications

Zhang X, Berry BC, Yager KG, Kim S, Jones RL, Satija S, Pickel DL, Douglas JF and Karim A *Surface Morphology Diagram for Cylinder Forming Block Copolymer Films* ACS Nano, 2: 2331 (2008)

Wang CW, Choi KW, Jones RL, Soles CL, Lin EK, Wu WL, Clarke JS, Villarrubia, JS and Bunday B *Linewidth Roughness and Cross-sectional Measurements of Sub-50 nm Structures with CD-SAXS and CD-SEM* SPIE Proceedings: Metrology, Inspection, and Process Control for Microlithography XXIII, 6922: 69221Z (2008)

Wang CW, Choi KW, Fu WE, Ho DL, Jones RL, Soles CL, Lin EK, Wu WL, Clarke JS and Bunday B *CD-SAXS Measurements Using Laboratory-based and Synchrotron-based Instruments* SPIE Proceedings: Metrology, Inspection, and Process Control for Microlithography XXIII, 6922: 692212E (2008)

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