TSOM:
R&D 100 Award Winner

Nanoscale Measurements With TSOM* Optical Method

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*TSOM is pronounced as “tee-som” and stands for “Through-focus Scanning Optical Microscopy”
Latest review paper can be found at: http://iopscience.iop.org/0957-0233/22/2/024002/
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Periodically this presentation will be updated with available new results: Exp. TSV results added

Abstract

A relatively new "through-focus scanning optical microscopy" (TSOM) method transforms conventional optical microscopes into 3D metrology tools for nanoscale dimensional analysis. TSOM is not a resolution enhancement method. However, it has a potential to provide lateral and vertical *measurement* sensitivity of less than a nanometer using a conventional optical microscope, comparable to the dimensional measurement resolution of typical SEMs and AFMs and is expected to extend the limits of optical metrology. The TSOM method has the ability to decouple vertical, lateral or any other dimensional changes at the nanoscale with little or no ambiguity and has the potential to analyze target dimensions ranging from a few tens of nanometers to relatively large dimensions (tens or even hundreds of micrometers in the lateral and the vertical directions, beyond the reach of typical SEM and AFM) with similar nanometer scale sensitivity. The method can be used in both reflection and transmission modes and is applicable to a variety of target materials, and shapes.

Applications include defect analysis, inspection and process control; critical dimension, photomask, overlay, nanoparticles, thin films, and 3D interconnect metrologies; line-edge roughness measurement, and nanoscale movement of parts in MEMS/NEMS. Industries that could benefit include the semiconductor industry, MEMS, NEMS, biotechnology, nanomanufacturing, nanometrology, data storage, and photonics.

The method is relatively simple and inexpensive, has a high throughput, provides nanoscale sensitivity for 3D measurements with significant savings and yield improvements in manufacturing. Applications are demonstrated using experiments and simulations.

Introduction

Perceived **optical limitations:**

Optical microscopes are not suitable for features smaller than half the wavelength

Several methods are available to overcome this *perceived* limitation

For the TSOM method sub-wavelength optical microscopy is achieved by

- Going beyond edge-based imaging
- Considering the image as a “signal”
- Using a set of through-focus images instead of one “best focus” image

TSOM: Through-focus Scanning Optical Microscopy

What it is: Optical method for dimensional analysis

What it is not: Not an image resolution enhancement method

What it does: Potentially transforms a conventional optical microscope to 3D metrology tool that provides lateral and vertical measurement sensitivity comparable to a typical Scatterometry, SEM and AFM

How does it do: By analyzing a set of through-focus (out-of-focus) images

Needs a TSOM image for the analysis

Through-focus Scanning Optical Microscopy (TSOM) Imaging : Procedure to construct a TSOM image

❖Acquire a set of through-focus (out-of-focus) images by

- Scanning the target along the focus direction
- Scanning the objective lens along the focus direction
- Scanning the camera along the focus direction
- Any other method

(Even though the images obtained by these methods are not exactly the same, they are very similar)

❖From the set of through-focus images extract the optical intensity profile at the area of interest in the field of view.

❖Stack the profiles at their respective focus positions to construct two-dimensional TSOM images.

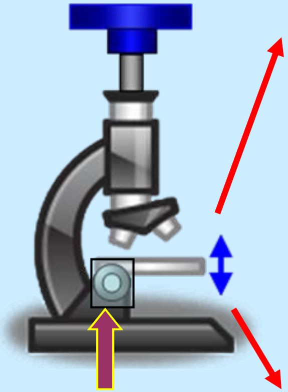
❖Since scanning the target along the focus direction is easily and widely available method to obtain out-of-focus images, it is used in all of the following presentation.

Animation showing the TSOM image construction method using a conventional optical microscope

(a)

Optical Microscope

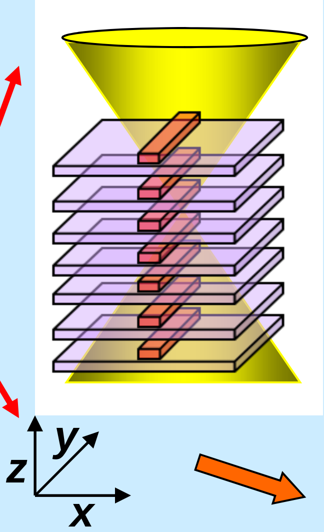
Digital camera



Motor for focusing

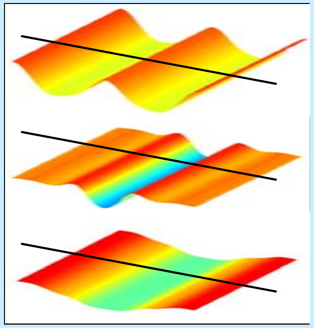
(b)

Schematic showing through-focus scanning of the target



(c)

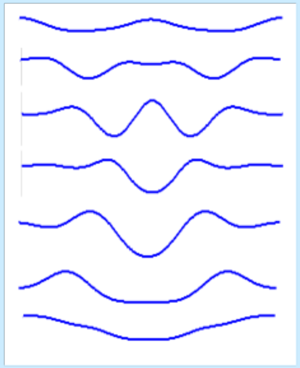
2D optical images at different through-focus positions



Computer acquires multiple digital images of targets

(d)

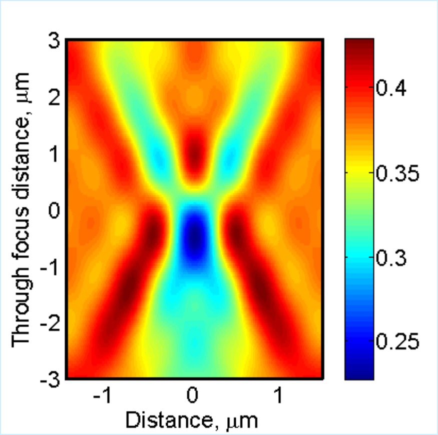
Optical intensity profiles extracted from the optical images



Computer algorithms process the acquired digital images and produce the TSOM images

(e)

Constructed TSOM image using the optical intensities

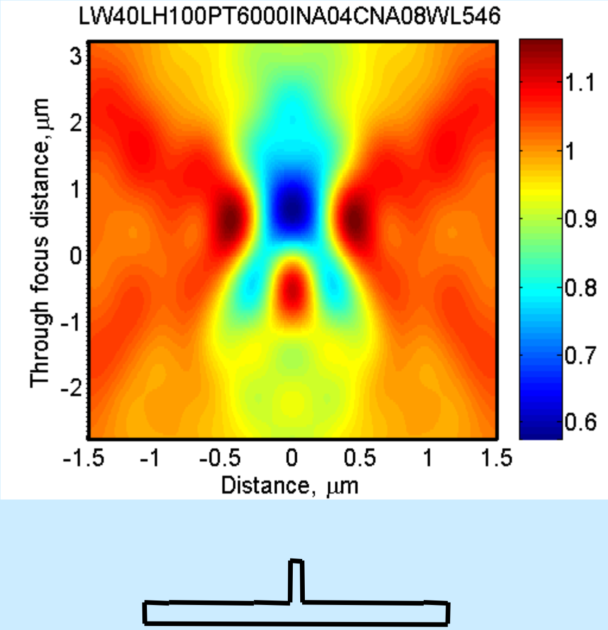


Color scale represents the optical intensity

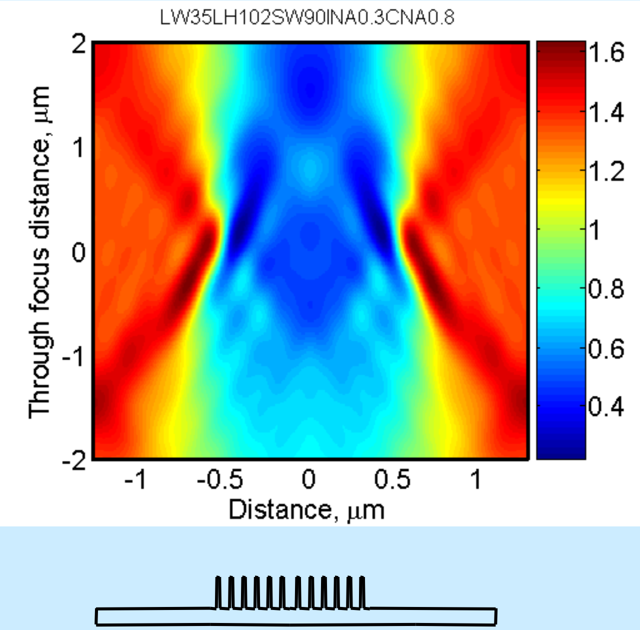
Simulations

TSOM Images: Examples

Isolated line @ 546 nm



Finite dense array @193 nm

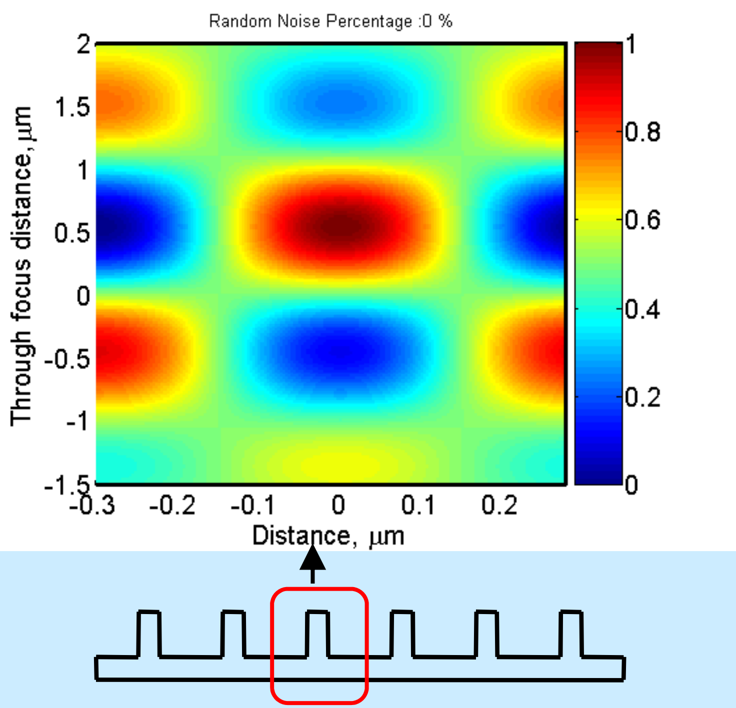


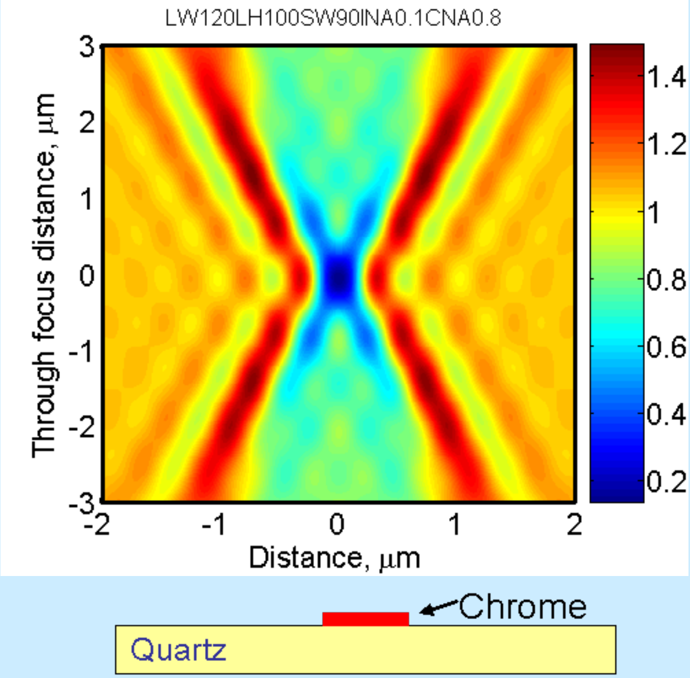
Simulations

TSOM Images : Examples

Line grating @ 546 nm

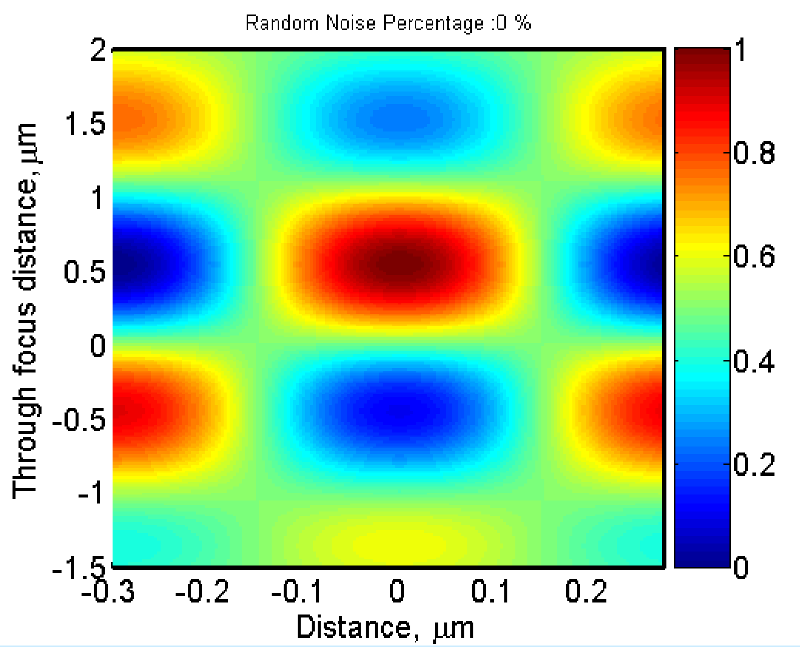
Photo mask (Transmission) @ 365 nm



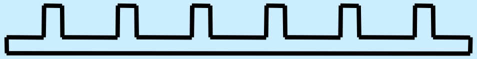


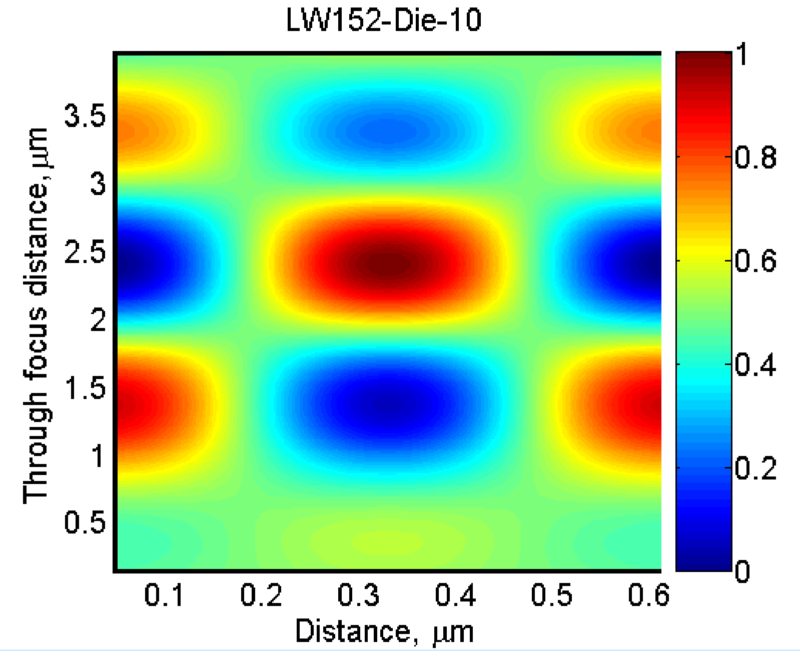
Simulations to Experiment Comparisons

This set of data Showed good agreement between experimental and simulated TSOM Images



Simulation





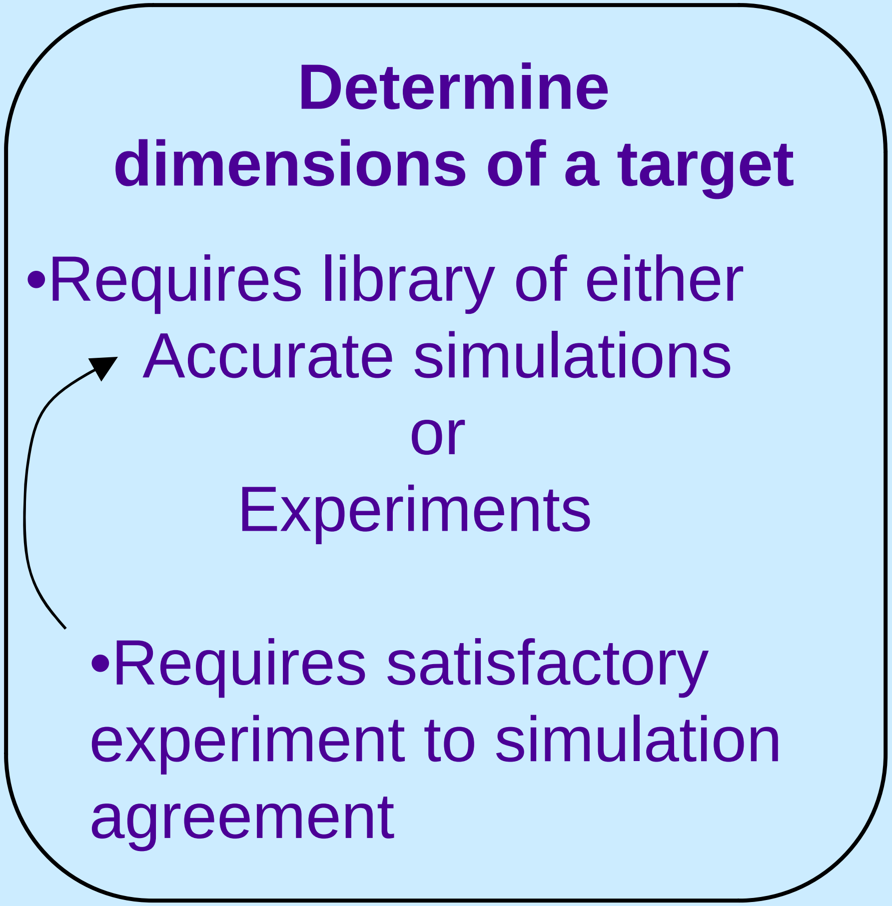
Experiment

Line width = 152 nm, Line height = 230 nm,

Two Methodologies

Evaluate relative changes in dimensions

- Requires two targets
- Simulations are not necessary but useful



Determine dimensions of a target

- Requires library of either

Accurate simulations
or
Experiments

- Requires satisfactory experiment to simulation agreement

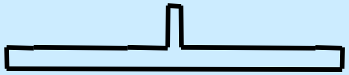
First Method

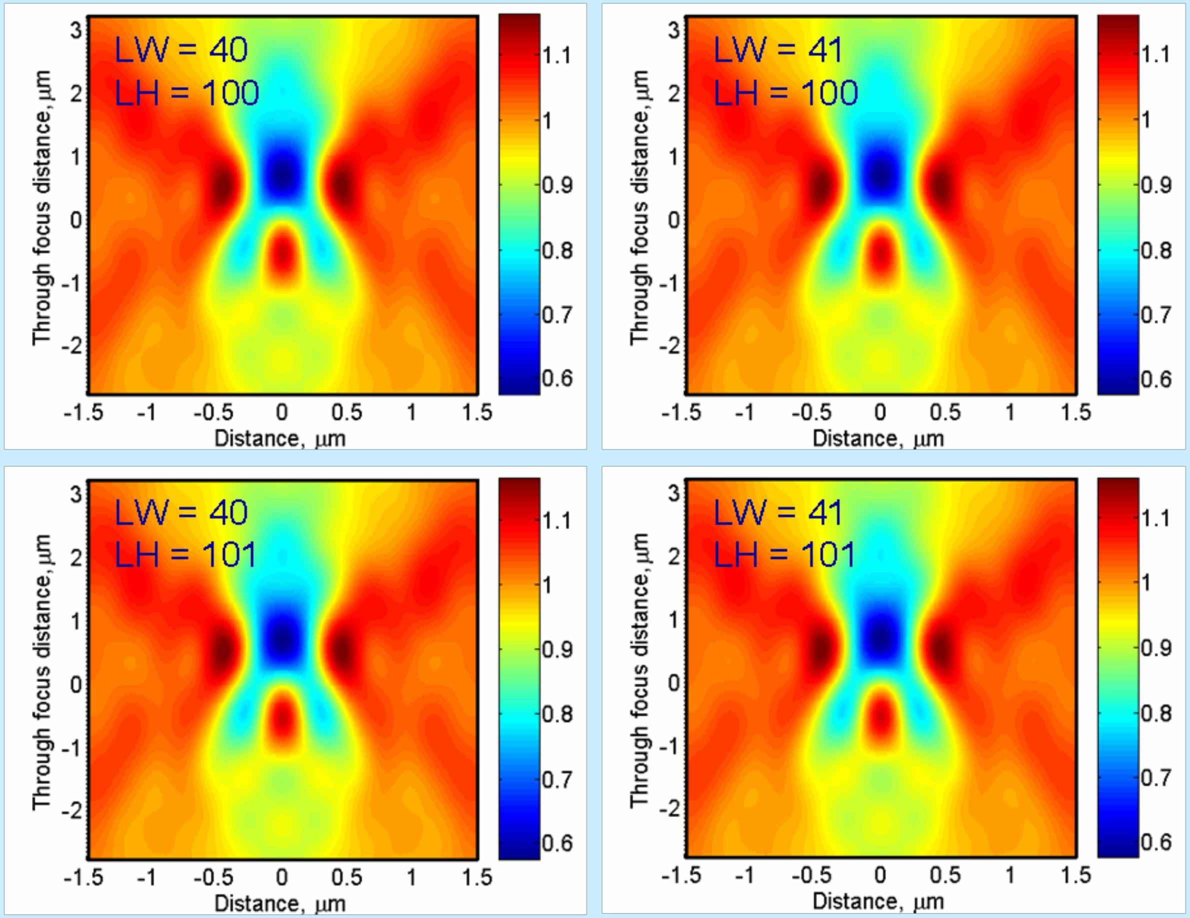
Evaluate relative changes in the dimensions

(For two targets)

The TSOM images are similar for small differences in the targets.

Isolated line





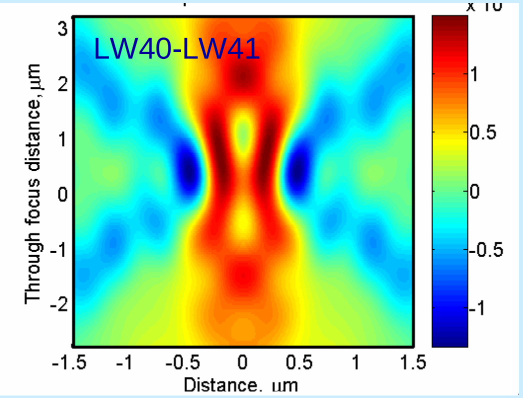
LW=Linewidth; LH=Line height; SW=Sidewall angle

Differential TSOM images uniquely highlight the difference

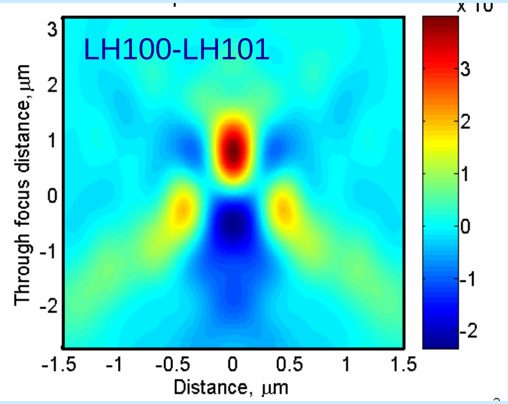
Differential TSOM Image = (TSOM Image1 - TSOM Image2)

Differential TSOM Images

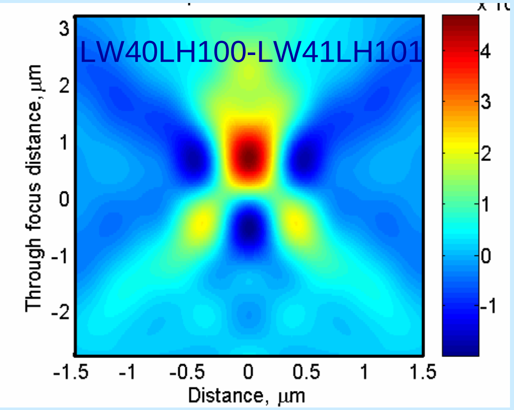
Line width



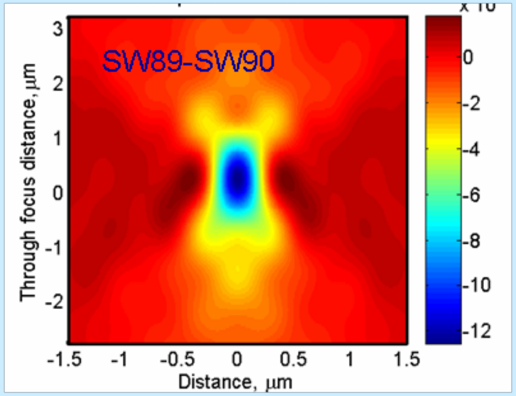
Line height



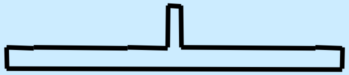
Line width and height



Sidewall



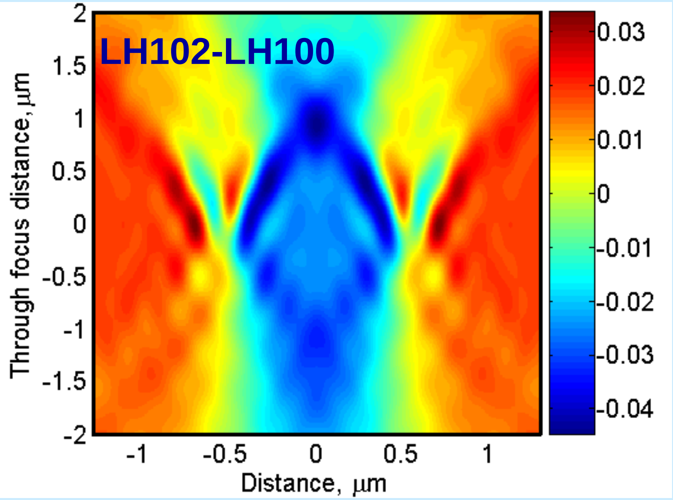
Isolated line



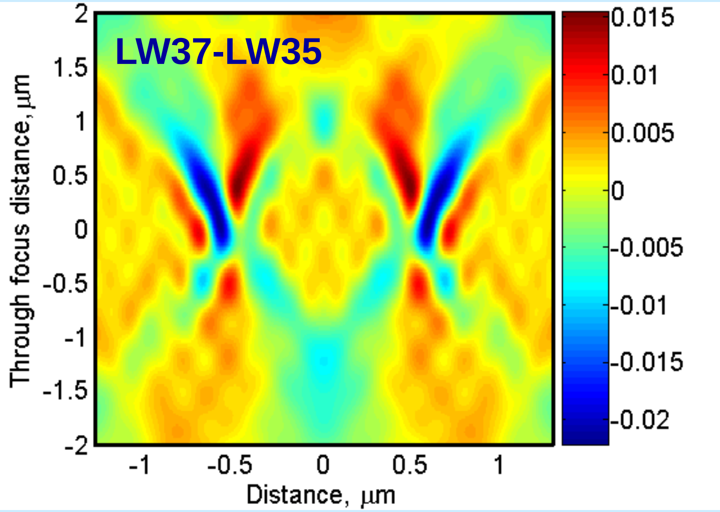
Simulations

Differential TSOM images uniquely highlight the difference

Finite dense array @ 193 nm: 9 lines



2 nm difference in the line height



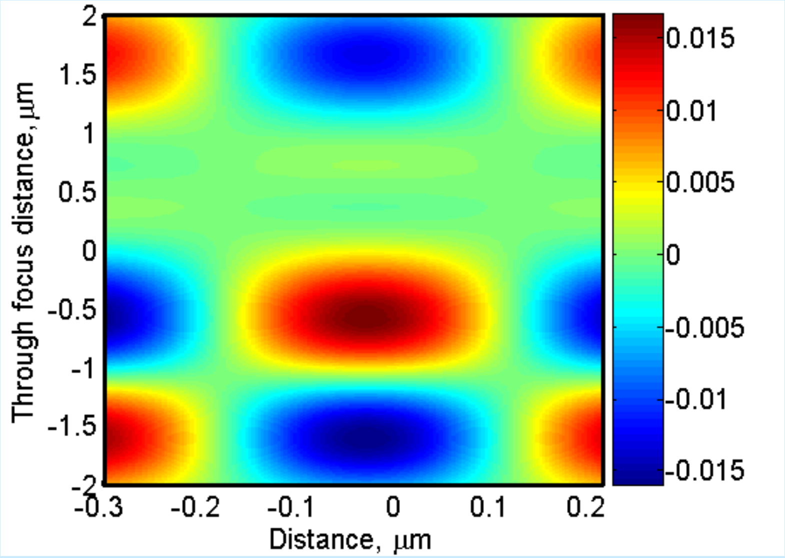
2 nm difference in the line width

Experiment

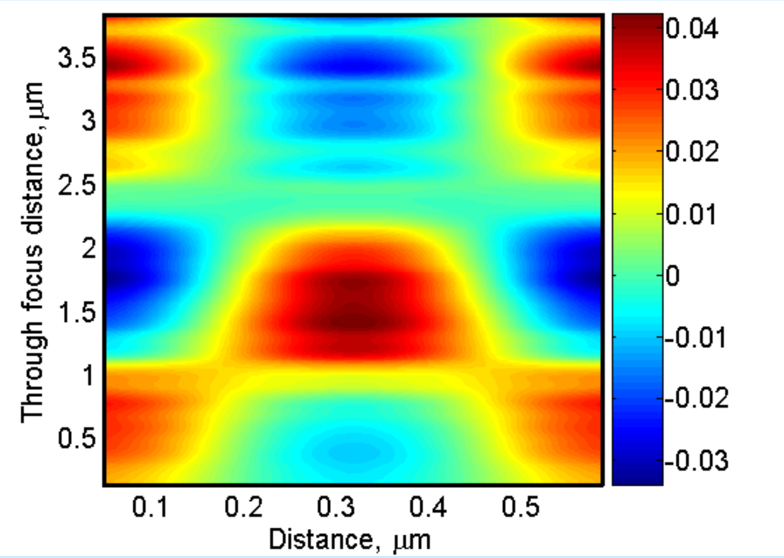
Dimensional Sensitivity: Experiments

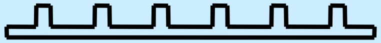
Differential images for **3 nm** difference in line width

Simulation



Experiment

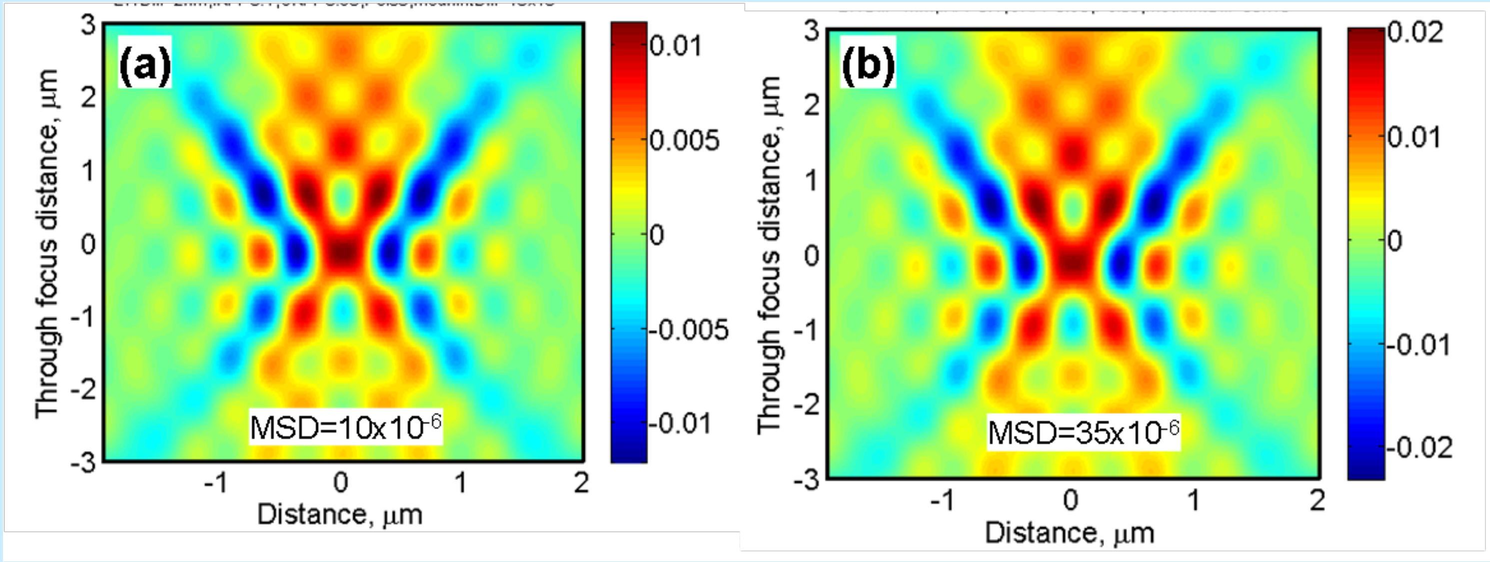




Simulations

Qualitatively the differential images appear similar for changes in the same dimension

Linewidth difference

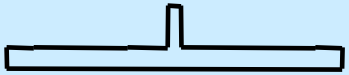


Linewidth difference = 2 nm

LW100-LW102

Linewidth difference = 4 nm

LW100-LW104

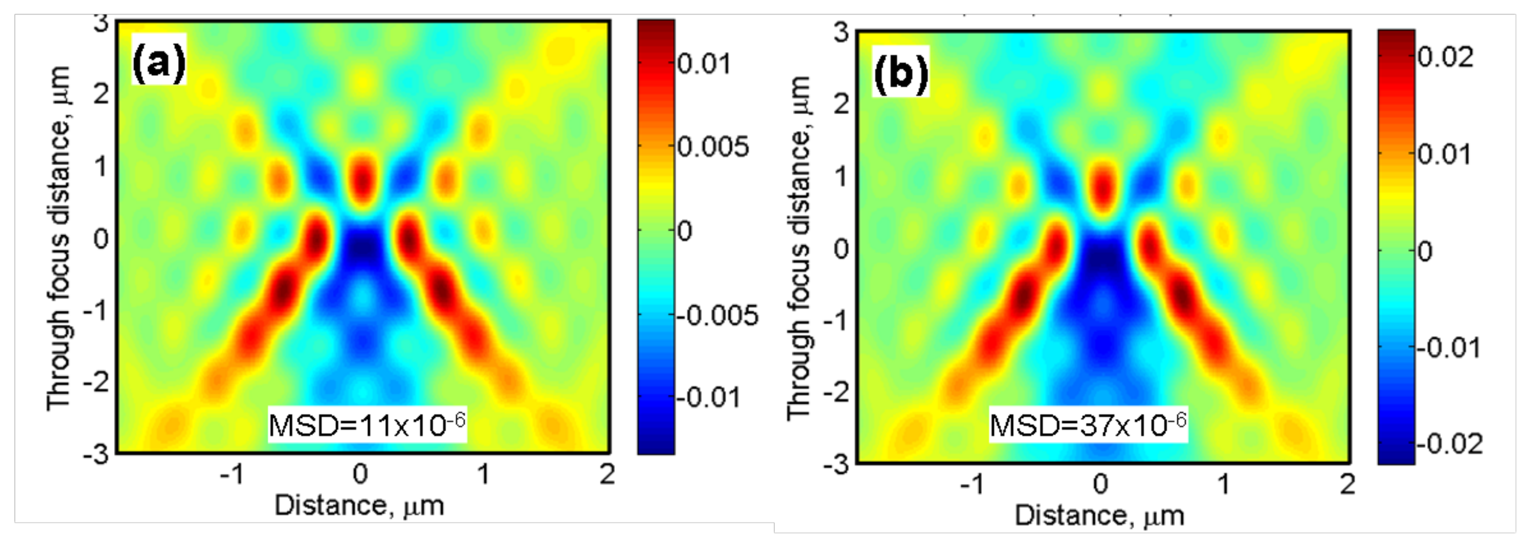


Wavelength = 546 nm

Simulations

Qualitatively the differential images appear similar for changes in the same dimension

Line Height difference

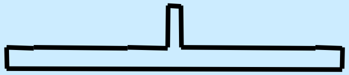


Line height difference = 2 nm

LH100-LH102

Line height difference = 4 nm

LH100-LH104



Wavelength = 546 nm

NIST

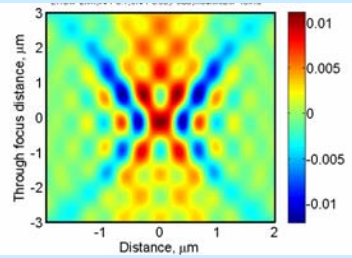
Quantifying Dimensional Differences using the Mean Square Difference (MSD)

Optical intensity of the differential image increases with increasing magnitude of the difference. Integrating the optical intensity of the differential image provides an estimation of the magnitude of the difference. MSD is one of the several such methods to integrate the optical intensity.

$$\text{MSD} = \frac{(\text{TSOM Image1} - \text{TSOM Image2})^2}{\text{Total number of points in the image}}$$

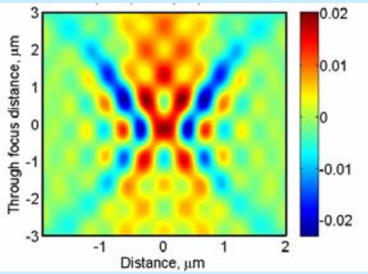
Simulations

MSD provides estimation of the magnitude of the dimensional difference



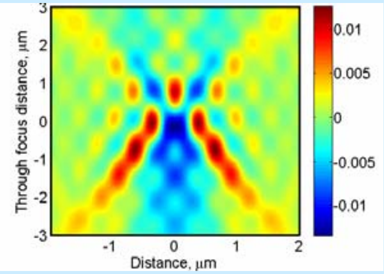
Linewidth difference = 2 nm

MSD = **10** x10^{-6}



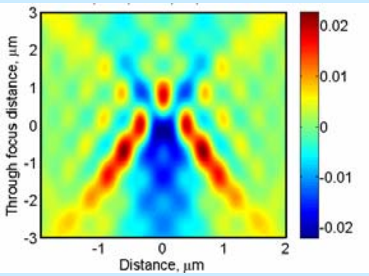
Linewidth difference = 4 nm

MSD = **35** x10^{-6}



Height difference = 2 nm

MSD = **11** x10^{-6}



Height difference = 4 nm

MSD = **37** x10^{-6}

Intermediate Summary

- Differential TSOM images highlight nanometer scale dimensional differences.

- Differential TSOM images appear to be distinct for different dimensional change (breaks the correlation between parameters, e.g., height and width, in the optical signal).

- Qualitatively differential TSOM images appear similar for a change in the same dimension.

- Mean Square Difference (MSD) provides magnitude of the difference.

Second Method

Determine (all) the dimensions of a target

TSOM Image: Second Method

Assumption:

TSOM image is unique for a given target

Experimental TSOM image

Match

Library of Simulations/experiments

Best matched simulation target provides the dimensions of the unknown target

TSOM Image: Second Method

Uniqueness test using simulations

A small library of TSOM images was created for a line grating with the following parameters:

Line width: 145 nm to 155 nm with one nm step (11 values)

Line height: 125 nm to 135 nm with one nm step (11 values)

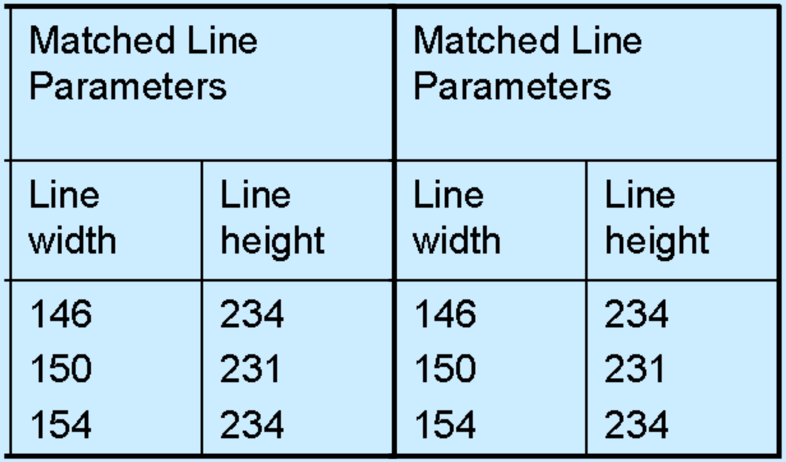
Collection NA = 0.8 Illumination NA = 0.36

Wavelength = 546 nm

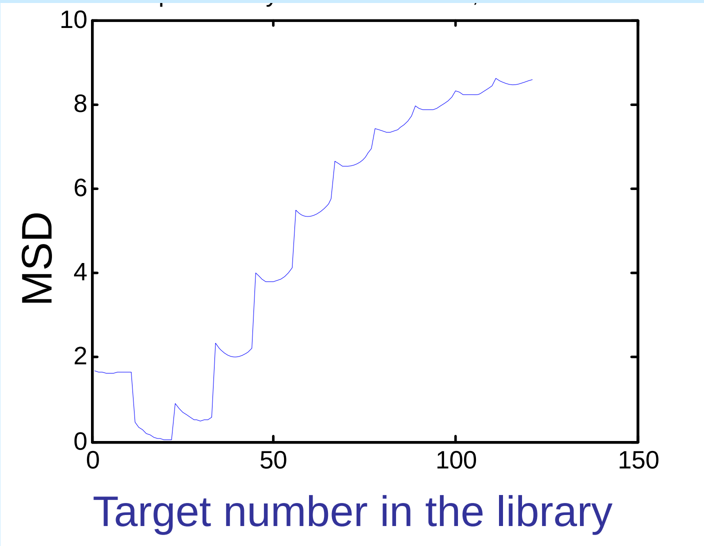
A total of 121 simulations

TSOM Image: Second Method

Uniqueness test using simulations



Matched Line Parameters		Matched Line Parameters	
Line width	Line height	Line width	Line height
146	234	146	234
150	231	150	231
154	234	154	234



Simulations

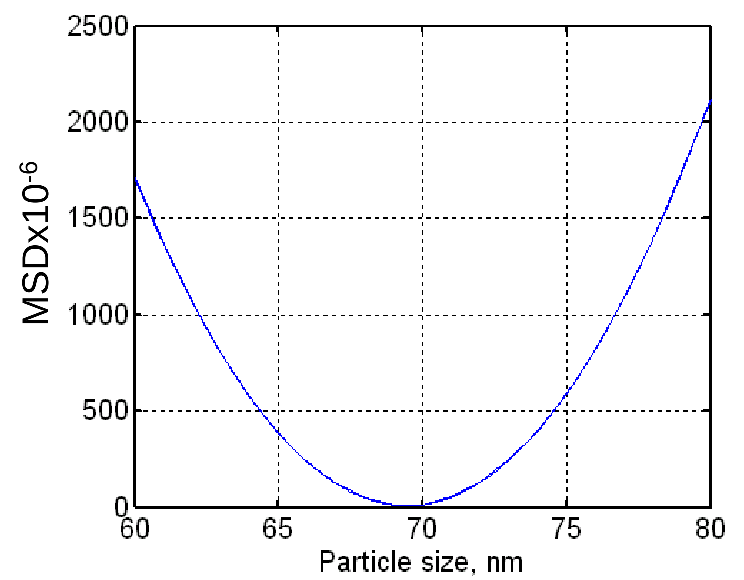
TSOM Image: Second Method

Gold particle analysis

Library: 60 nm to 80 nm

Unknown particle size: 69.5 nm

Best matched size: 69.453

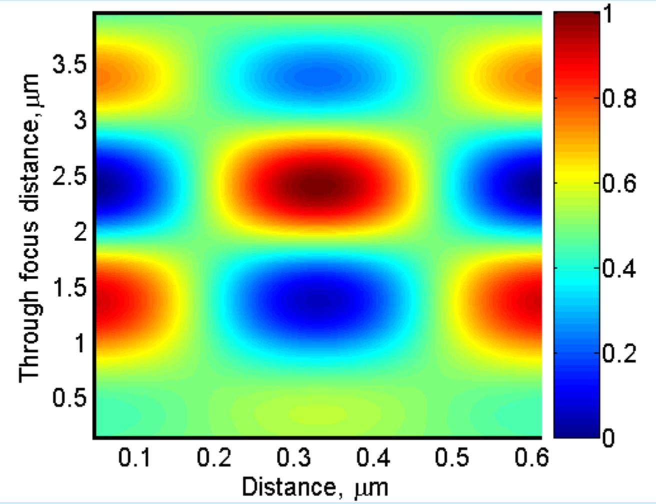


Experiment

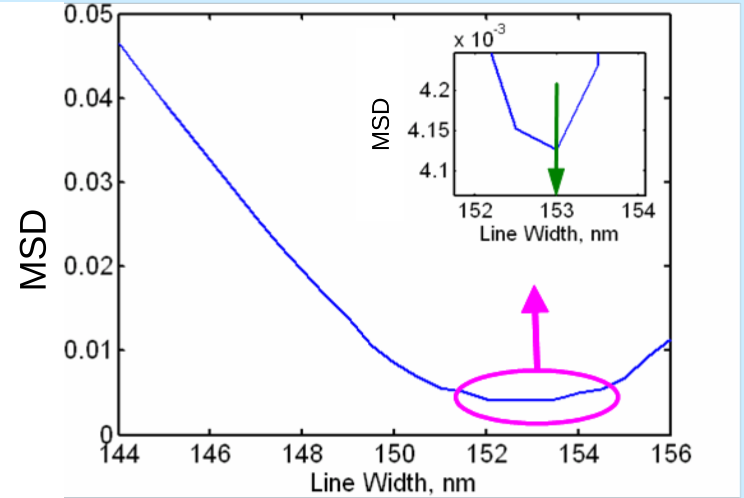
TSOM Image: Second Method

Line width analysis

Experimental TSOM image



Determining the dimension using the library matching method

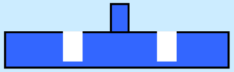


TSOM Matched target line width : 153 nm

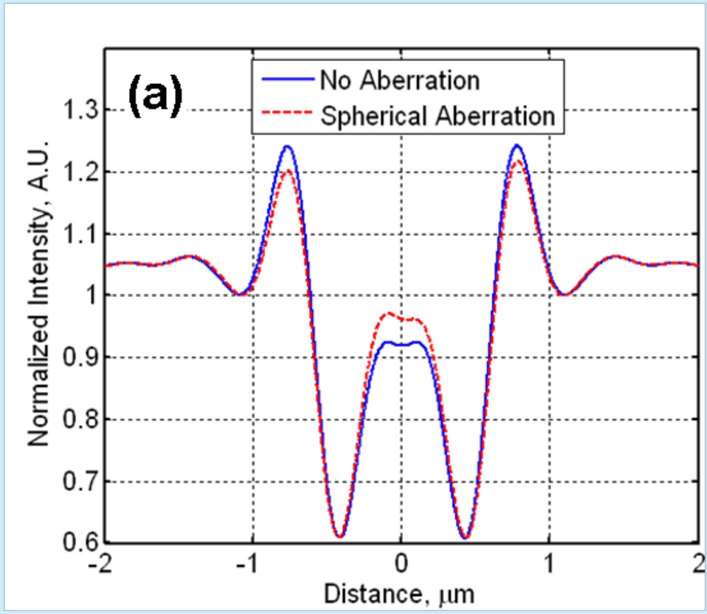
AFM measured line width: 145 nm

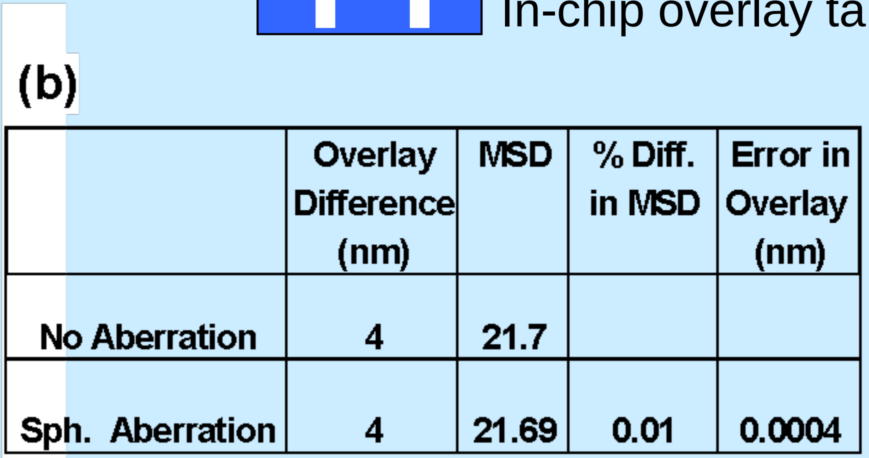
Simulations

Robust to Optical Aberrations



In-chip overlay target





(b)

	Overlay Difference (nm)	MSD	% Diff. in MSD	Error in Overlay (nm)
No Aberration	4	21.7		
Sph. Aberration	4	21.69	0.01	0.0004

Comparison of the intensity profiles at the best focus position

This application is robust to optical aberrations

TSOM Image Sensitivity: Optimization

How can we improve dimensional sensitivity?

(-Larger the MSD – Higher the sensitivity)

Polarization

Unpolarized, TE-polarized and TM-polarized

Experimental conditions

Illumination NA (INA), Collection NA (CNA) , Wavelength and others ??

Simulations

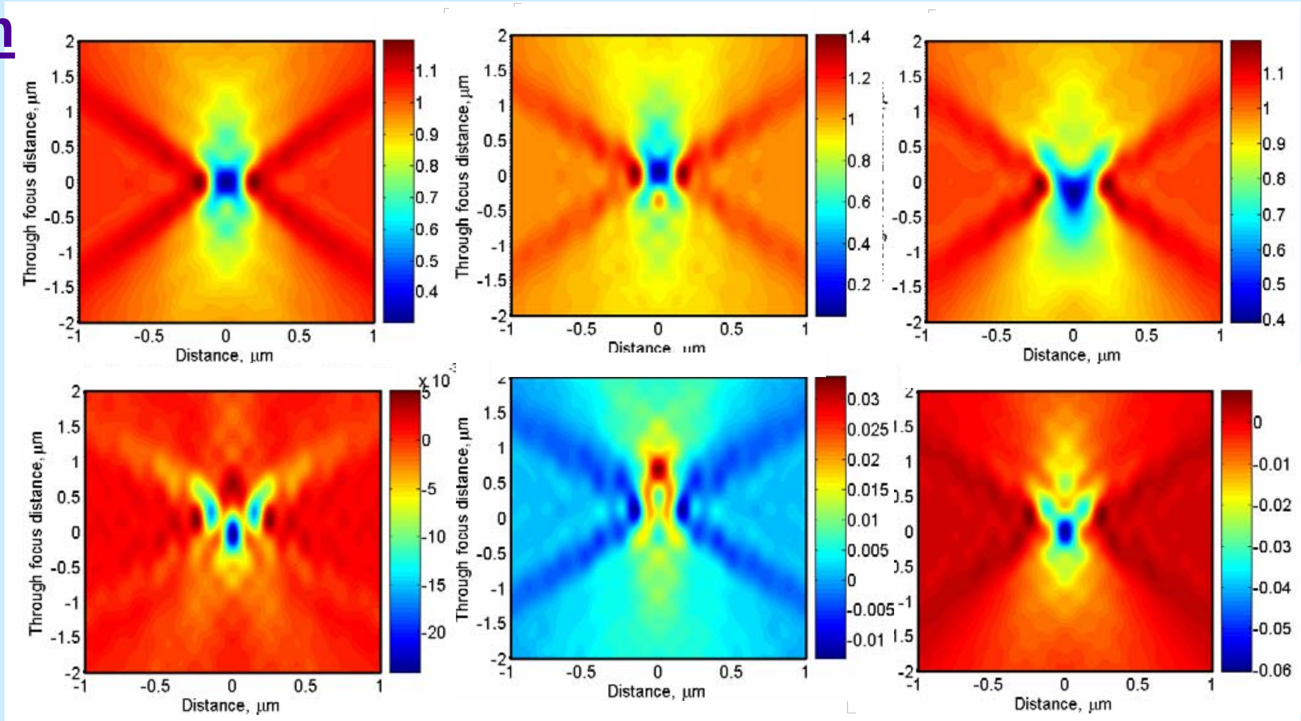
TSOM Image Sensitivity: Polarization

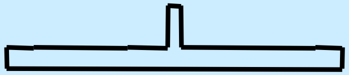
Line height difference = 2 nm

Un-polarized TE-polarized TM-polarized

TSOM Images

Differential TSOM Images





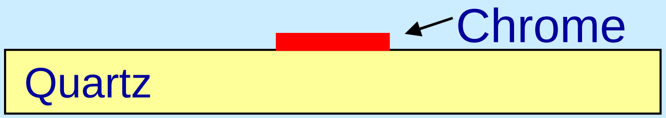
MSDx10^{-6}	3	16	33

In this example TM polarization provides the maximum sensitivity to line height difference

Simulations

TSOM Image Sensitivity: INA

Photo mask target


Chrome

Quartz

Dimension	Diff.	INA	MSD x10^{-6}		
	(nm)		UP	TE	TM
Line width	2	0.1	9.5	**15.7**	6.6
Line width	2	0.6	2.0	2.9	1.5
Line height	2	0.1	4.3	4.0	**5.8**
Line height	2	0.6	0.6	1.0	0.5

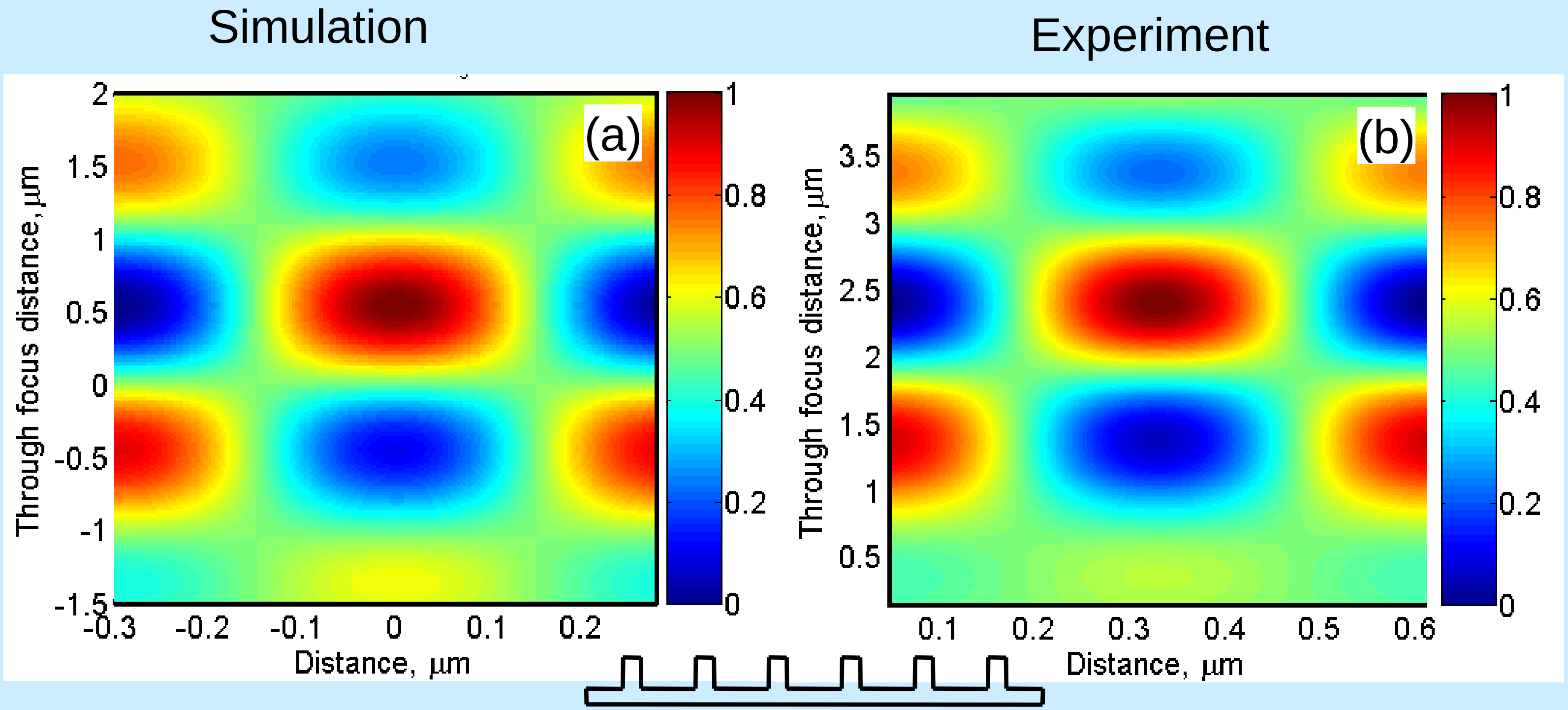
For line width measurements select low INA and TE polarization

For line height measurements select low INA and TM polarization

Some Applications of the TSOM method

Experiment

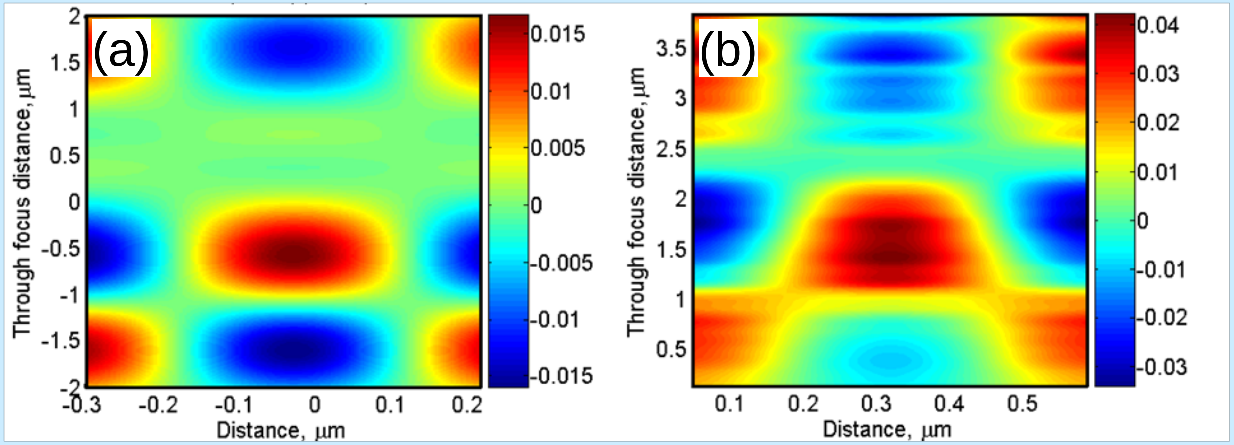
TSOM image comparison of simulation and experiment of <u>gratings</u>



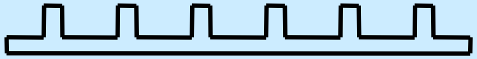
Comparison of (a) the simulation, and (b) the experimental TSOM images for a line grating. Line width = 152 nm, Line height = 230 nm, Pitch = 601 nm, Illumination NA = 0.36, Collection NA = 0.8, Wavelength = 546 nm, Si line on Si substrate. Only one pitch distance is shown in the figure.

Experiment

Differential TSOM image comparison of simulation and experiment showing 3 nm difference in the line width (CD) of <u>gratings</u>


Simulation

Experiment

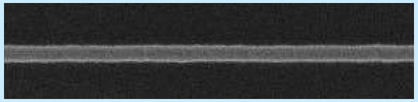


Comparison of (a) the simulation and (b) the experimental differential TSOM images. The differential images were obtained for the two targtes with line widths of 146 nm and 149 nm. Line height = 230 nm, Pitch = 601 nm, Wavelength = 546 nm, Si line on Si substrate.

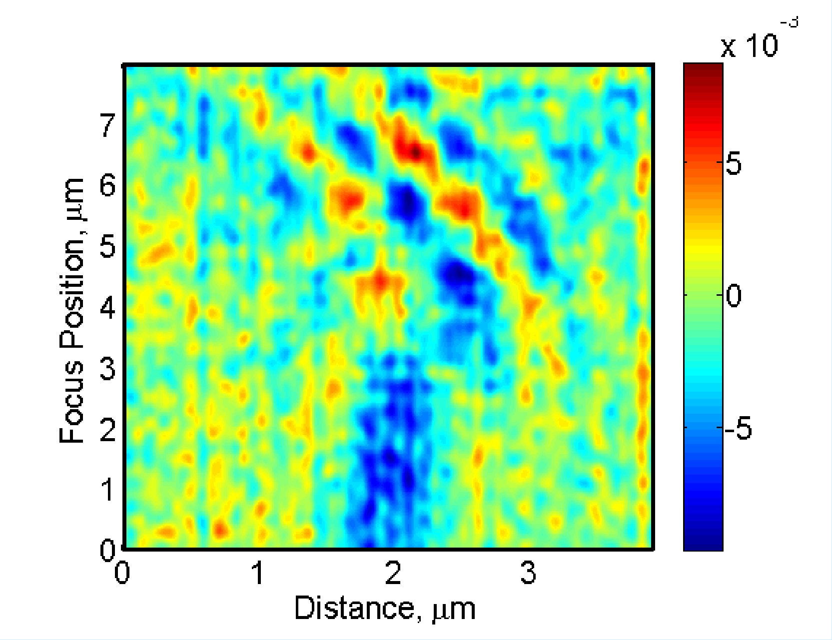
Experimental Line width analysis of isolated lines

Nominal linewidth = 45 nm, Line height = 70 nm; Wavelength = 546 nm;

The line widths were measured with calibrated CD- AFM at NIST



SEM Image of the
45 nm wide line



Experimental differential TSOM image showing about a nanometer difference in the line width

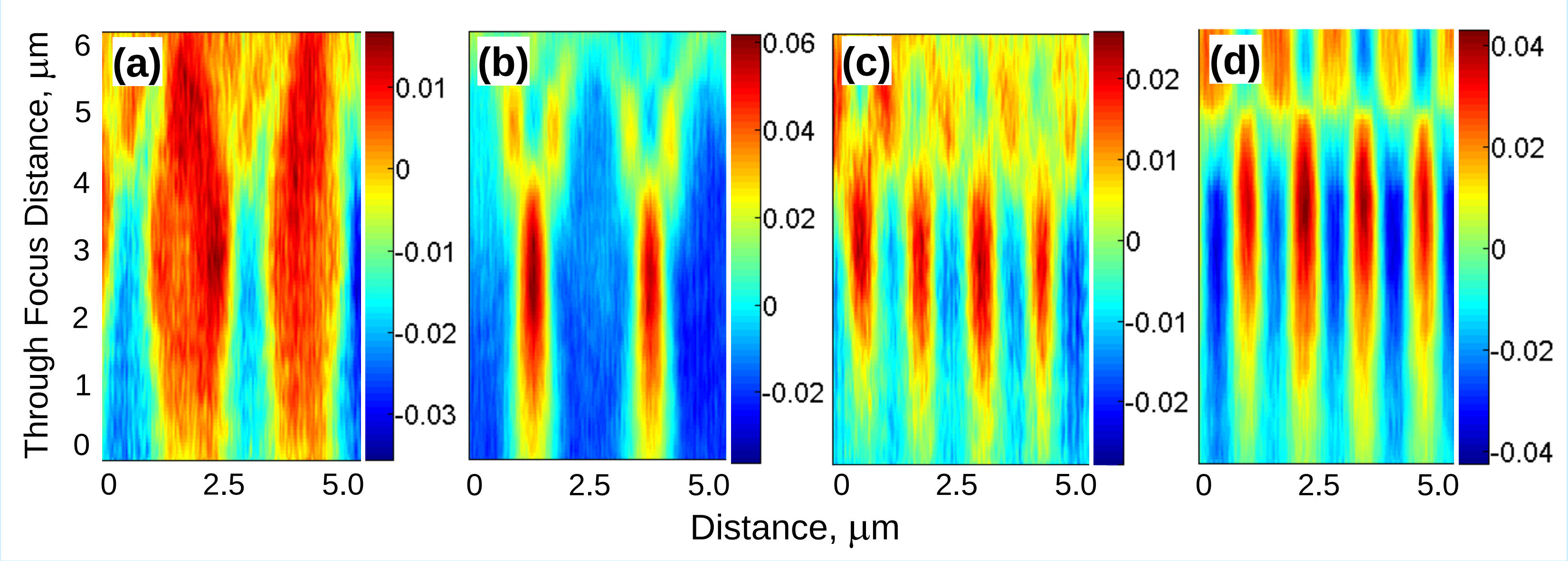
Experimental defect analysis showing four types of 10 nm defects in dense gratings : Pitch = 270 nm, Width = 100 nm

Every 10th line **smaller** by 10 nm

Every 10th line **larger** by 10 nm

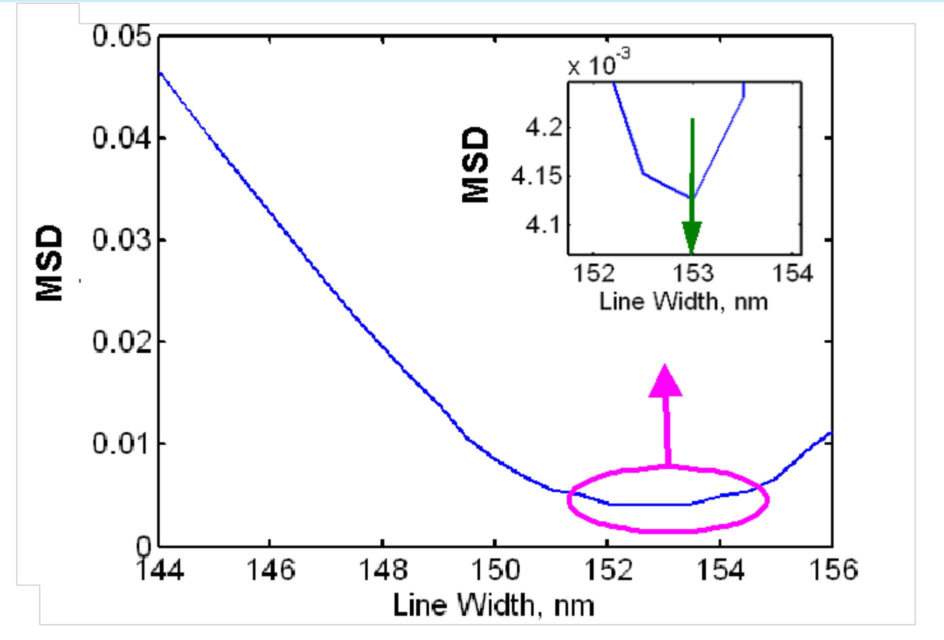
Every 5th line **smaller** by 10 nm

Every 5th line **larger** by 10 nm



Experimental TSOM images for dense line gratings fabricated with intentional defects. Every tenth line is (a) smaller, or (b) larger by 10 nm; or every fifth line is (c) smaller, or (d) larger by 10 nm. [lambda= 546 nm, nominal line width = 90 nm, nominal **pitch = 270** nm]

Experimental determination of line width (CD) using the library matching method

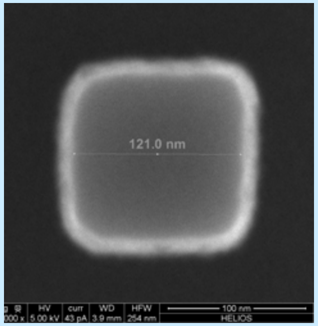


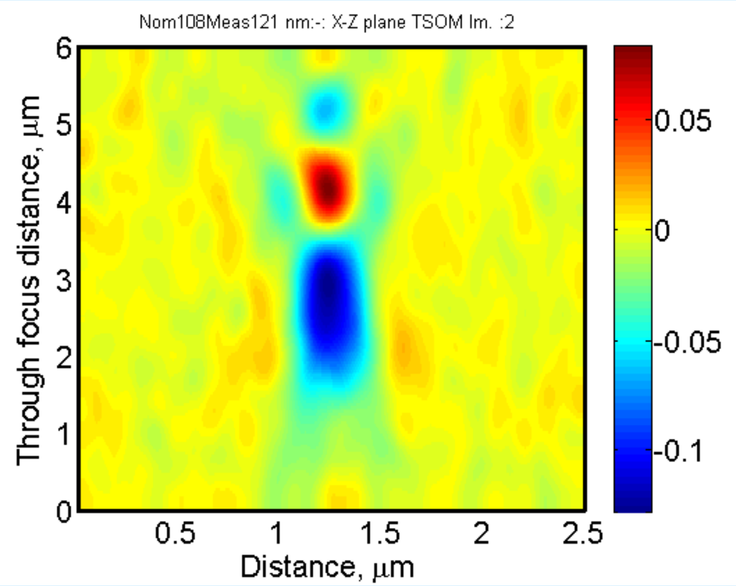
A plot of the MSD values evaluated using the experimental ‘unknown’ target with the library of simulations. The inset shows the magnified portion of the highlighted curve.

Wavelength = 546 nm

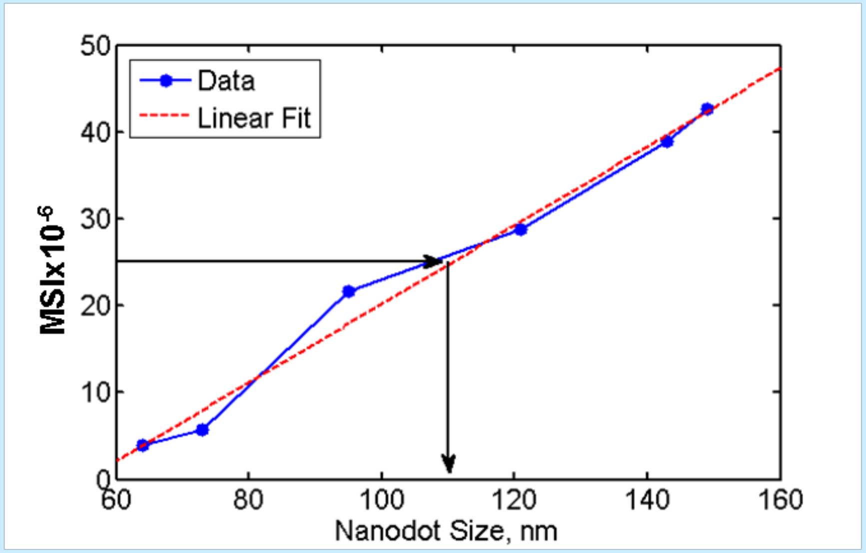
Experiment

Experimental determination of 103 nm square nanodot using the experimental library matching method





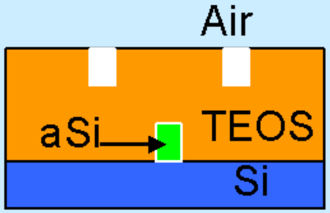
Experimental, intensity normalized TSOM image of 121 nm nanodot. Wavelength = 546 nm, Si nanodot on Si substrate.



Experimental size determination of 103 nm nanodot using the experimentally created library.

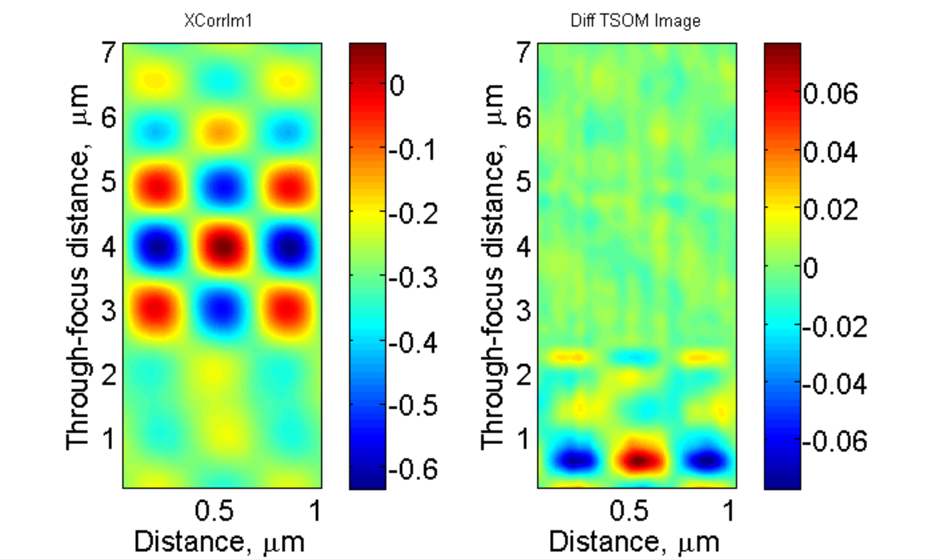
Experiment

Overlay analysis with target designed for Scatterometry



TSOM Image

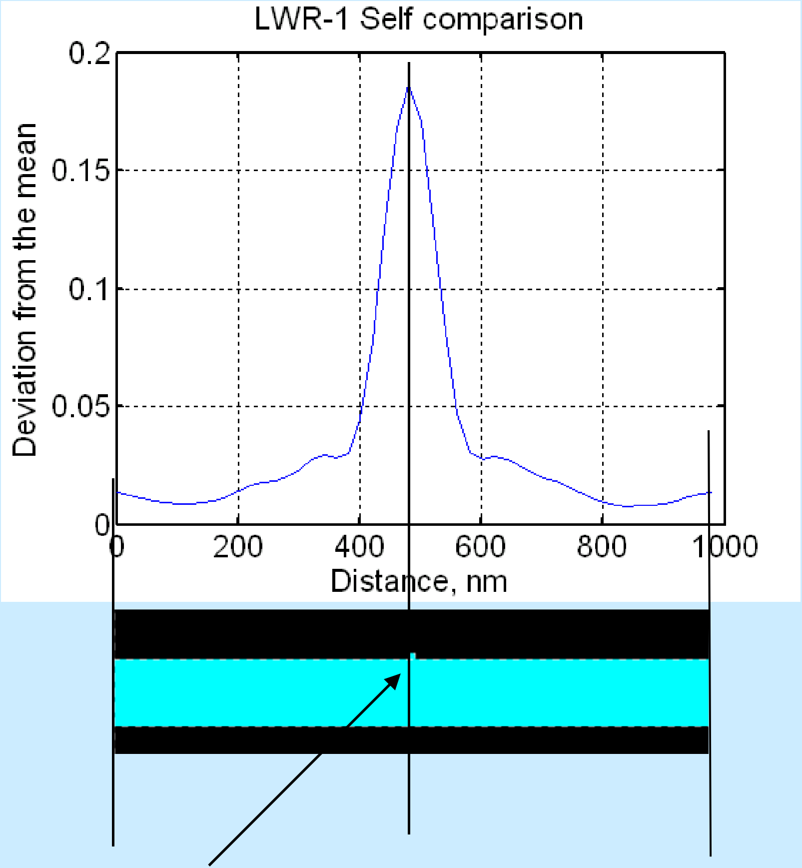
Diff. TSOM Image



Line Width = 150 nm
Overlay = 30 nm
Pitch = 700 nm
Wavelength = 546 nm

Simulations

Defect analysis showing the presence and location of a 5 nm x 5 nm defect on a line. This type of analysis could be extended to line edge roughness.

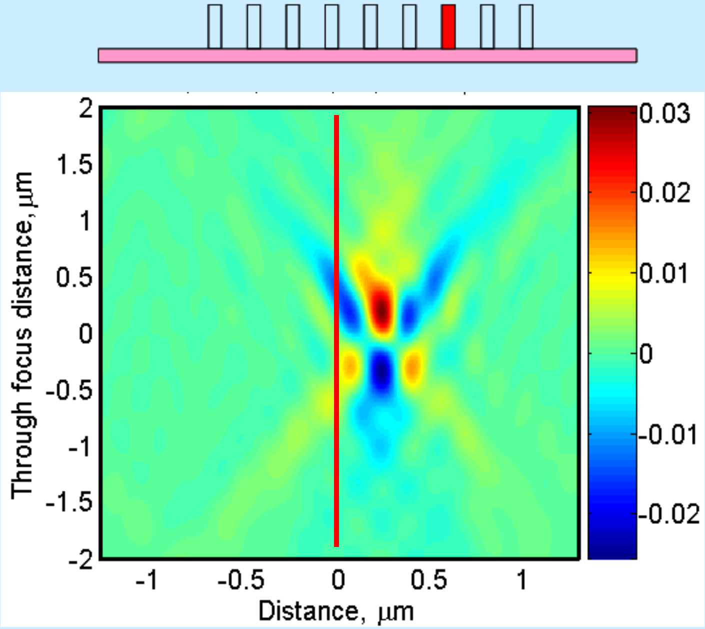


5 nm x 5 nm defect, Line width = 40 nm

Wavelength = 546 nm

Simulations

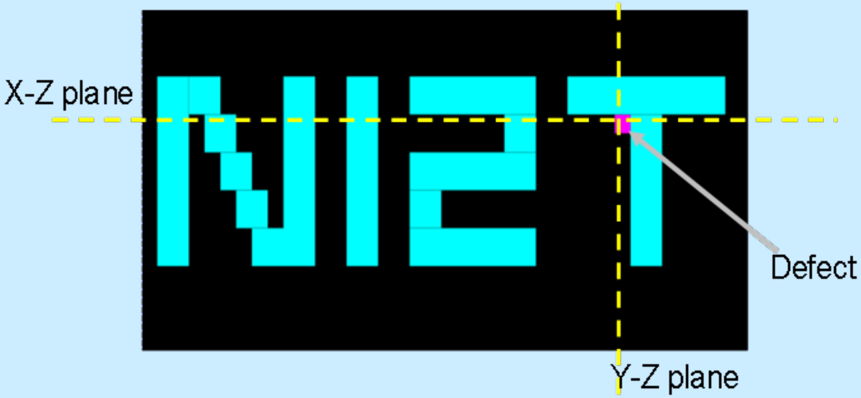
Identifying the presence and location of 2 nm defect in the line width for finite dense grating

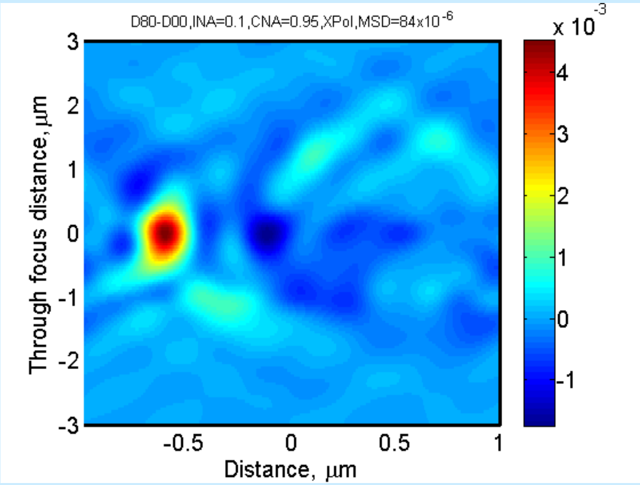


The differential TSOM image showing the presence of a single line defect that is 2 nm smaller then the other line widths in a dense finite grating. LW=35 nm, LH=100 nm, Pitch=105 nm, Total number of lines simulated=9, Illumination wavelength = 193 nm, Si line on Si substrate.

Defect analysis: Random structure

Differential image showing the presence of 30 nm defect that is 25 nm tall, (one fourth the height of the features)

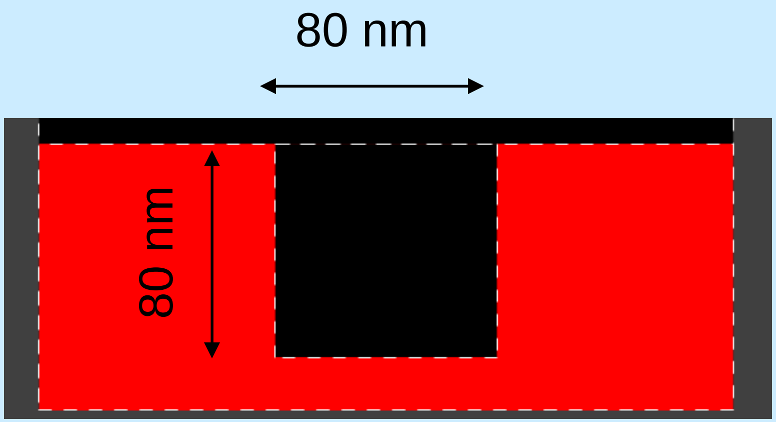




(XZ-plane reversed)

Defect sizes: 30 nm, Defect height = 25 nm;
Line width of the features= 100 nm, Line height =100 nm
Wavelength = 365 nm, Si features on Si substrate

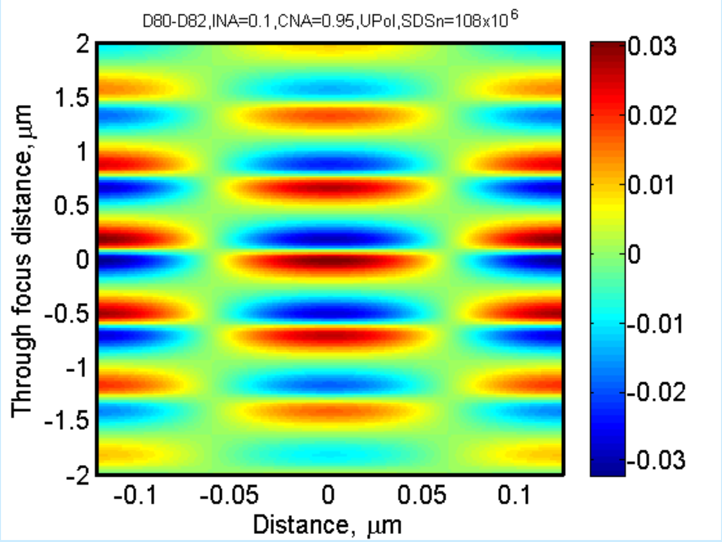
Depth analysis of Vias (circular holes)



A Via

Wavelength = 193 nm
Pitch = 250 nm
Diameter = 80 nm
Depth = 80 nm, and 82 nm

Differential TSOM image showing 2 nm difference in depth
(Depth 80-82)

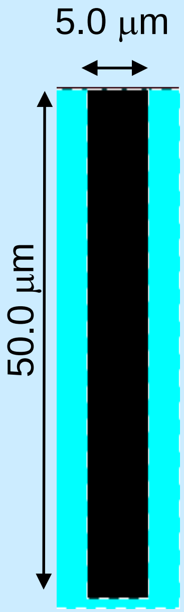


Simulations

Large scale dimensional analysis of deep trenches

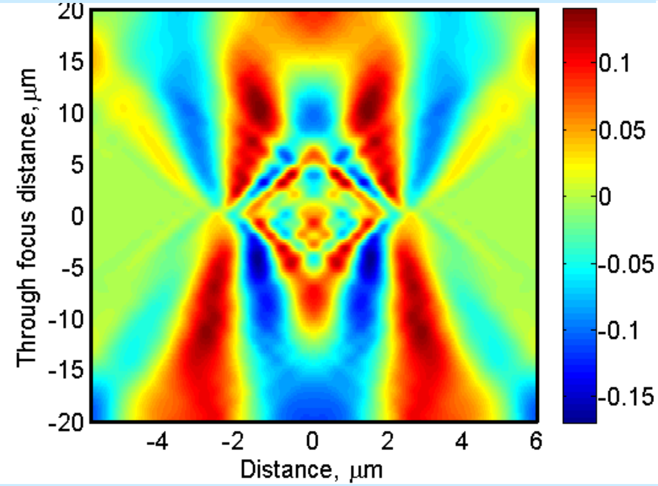
Truly 3D high aspect ratio (1:10) measurements

Dimensional analysis of 50 µm deep and 5 µm wide trenches/grooves



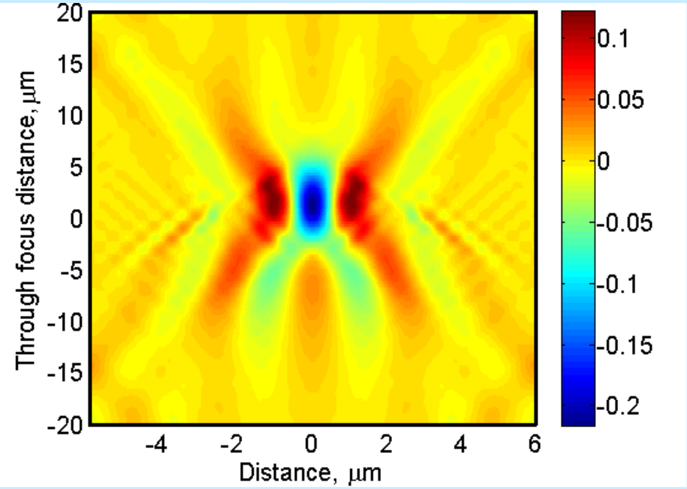
A deep trench

Differential image showing a change of 20 nm in the **depth** of 50 µm deep and 5 µm wide trench



20 nm depth change

Differential image showing a change of 20 nm in the **width** of 5 µm wide and 50 µm deep trench



20 nm width change

Wavelength = 546 nm

Differential TSOM Images for TSVs Show Consistent Pattern Across Different Dies

Experiment

Depth Varies approximately from 18 μm to 25 μm

Dies compared

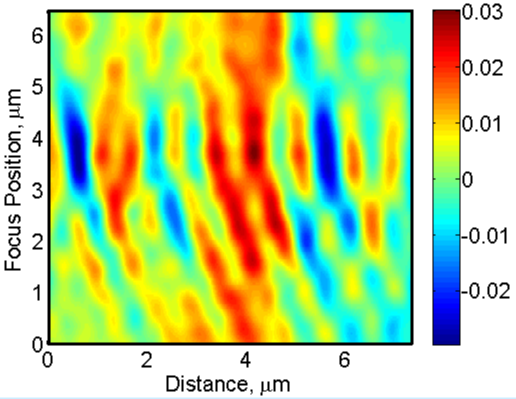
0 1

1 2

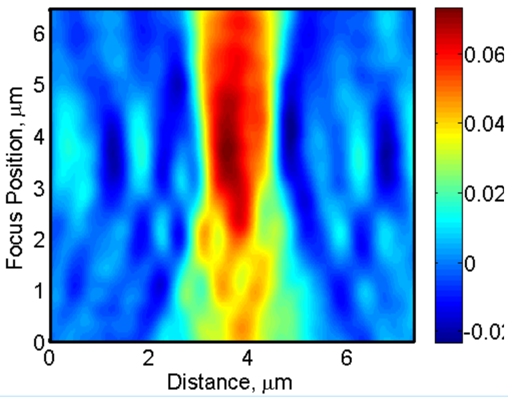
0 2

1.0 μm

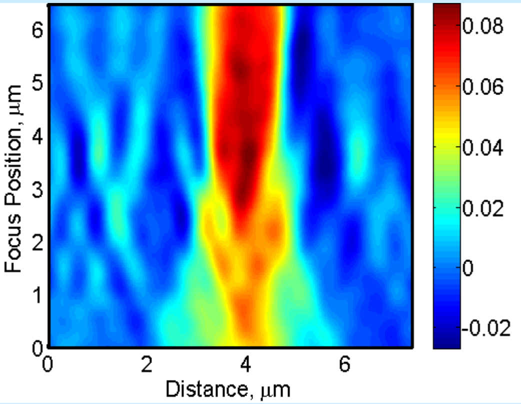
D(+0+0) & D(+1+0): **MD=7.8**



D(+1+0) & D(+2+0): **MD=14.6**

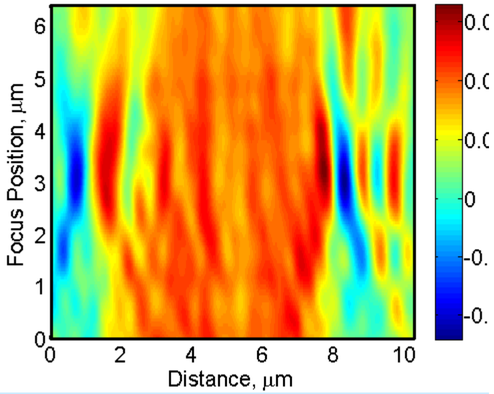


D(+0+0) & D(+2+0): **MD=18.4**

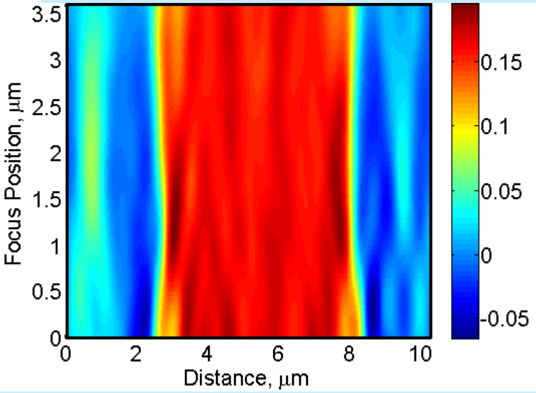


5.0 μm

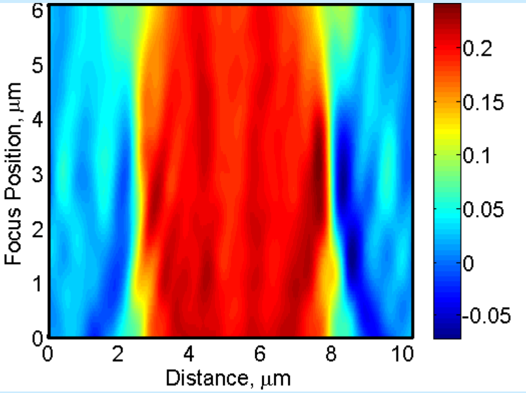
D(+0+0) & D(+1+0): **MD=27.4**



D(+1+0) & D(+2+0): **MD=92.2**



D(+0+0) & D(+2+0): **MD=114.5**



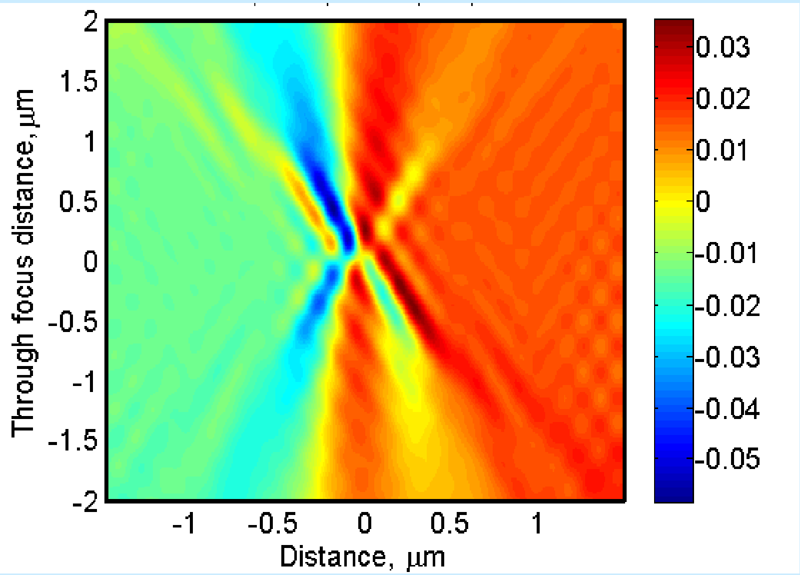
5 μm Via needs to be studied with more z-focus range

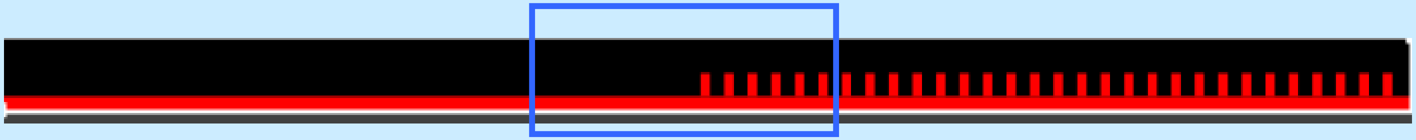
MD$\times10^{-3}$

Simulations

Critical dimension (CD) analysis of dense gratings

Differential TSOM Image at the edge of a dense grating showing a 2 nm difference in the CD





CD = 40 nm and 42 nm (2 nm difference in the line width)
Pitch = 100 nm; Wavelength = 193 nm
Si lines on Si substrate

Transmission microscope: Optimization of Illumination NA to obtain maximum sensitivity

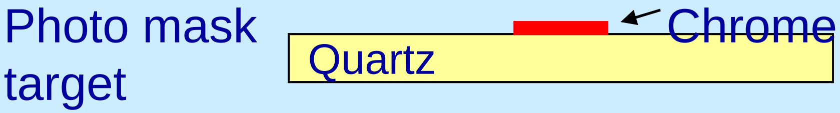


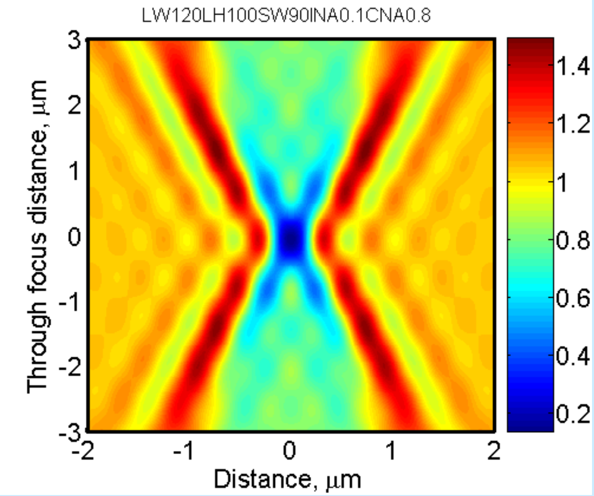
Photo mask target

Quartz

Chrome

Dimension	Diff.	INA	**MSD**		$x10^{-6}$
	(nm)		UP	TE	TM
Line width	2	0.1	9.5	**15.7**	6.6
Line width	2	0.6	2.0	2.9	1.5
Line height	2	0.1	4.3	4.0	**5.8**
Line height	2	0.6	0.6	1.0	0.5

Simulated TSOM image of a chrome line on a quartz substrate using transmission microscope



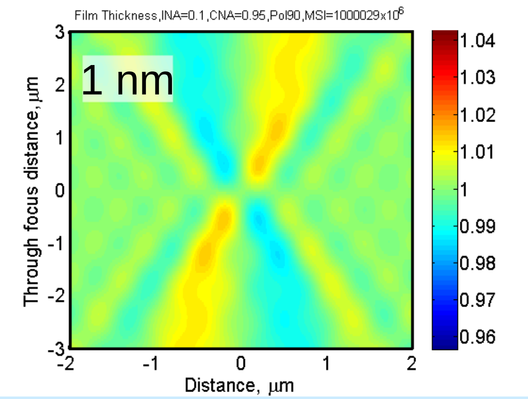
For line width measurements select low INA and TE polarization
For line height measurements select low INA and TM polarization

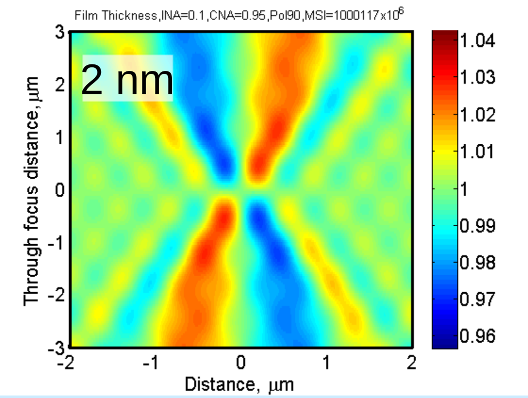
Line width = 120 nm, Line height = 100 nm, Wavelength = 365 nm,
UP=Unpolarized, TE=TE polarized, TM=TM polarized,
MSD=Mean Square Difference

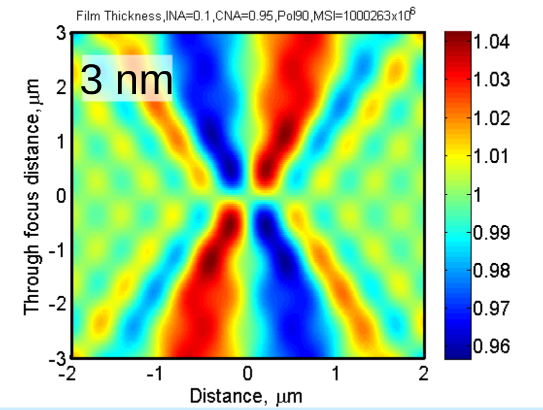
Thin film metrology

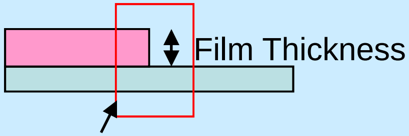
Simulations

Intensity normalized TSOM images at the edge of thin films for different film thickness



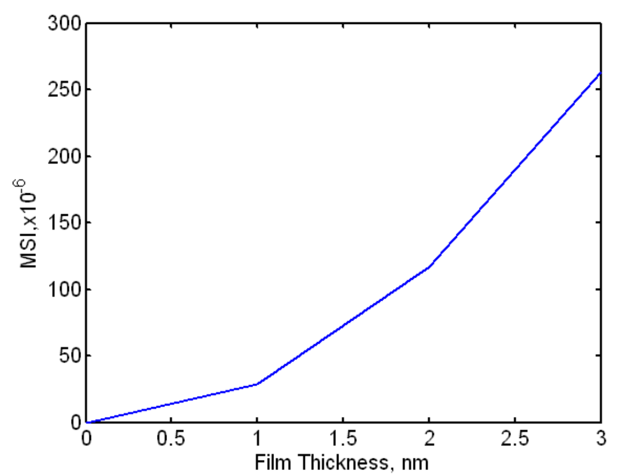






Film Thickness

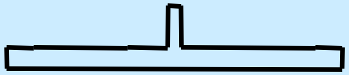
Area of analysis

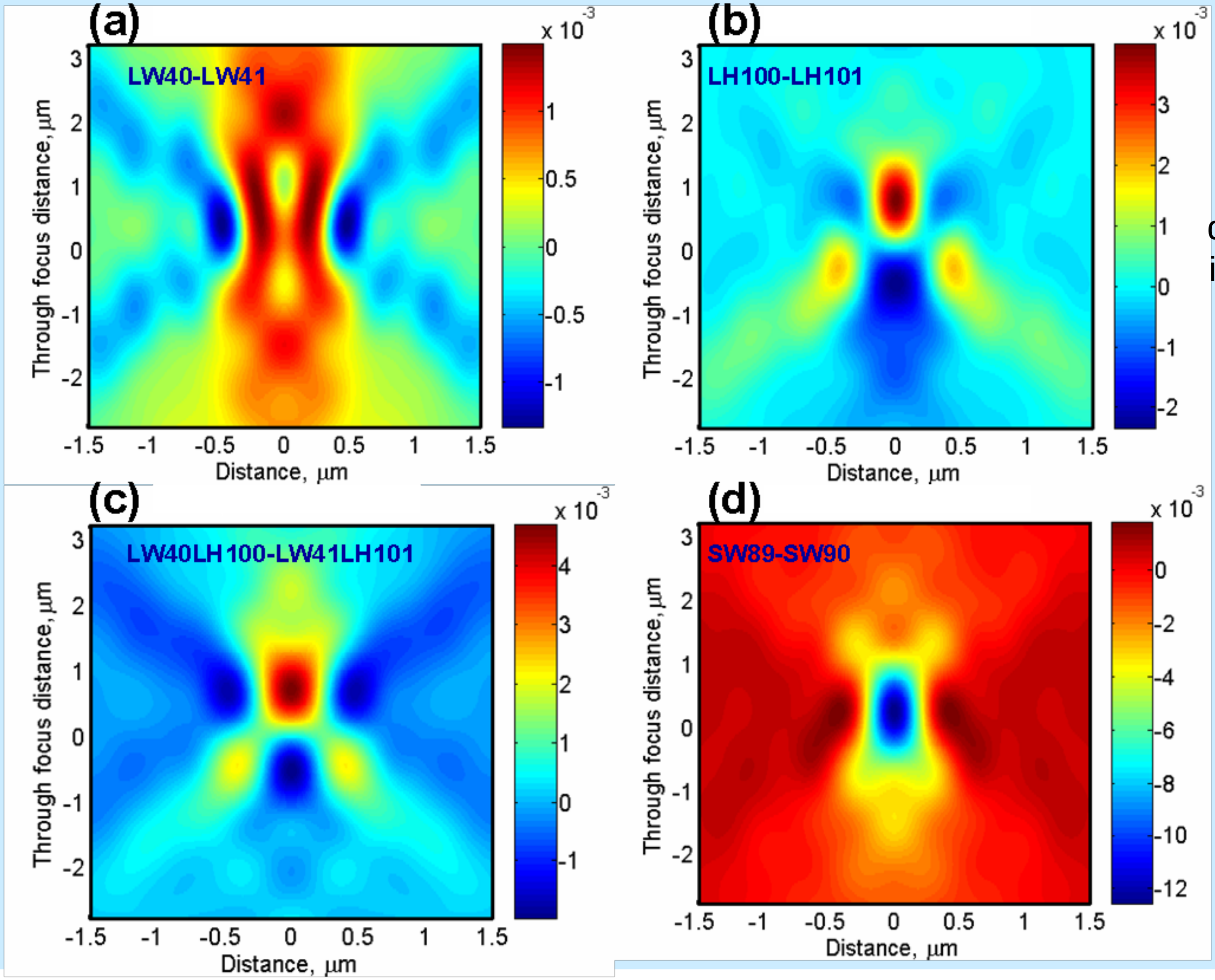


A plot of mean square intensities (MSI) of the TSOM images as a function of the film thickness. This serves as a calibration curve to measure films of unknown thickness

Analysis showing uniquely the presence of different dimensional variations for <u>isolated lines</u>

Simulations





1 nm difference in the line width

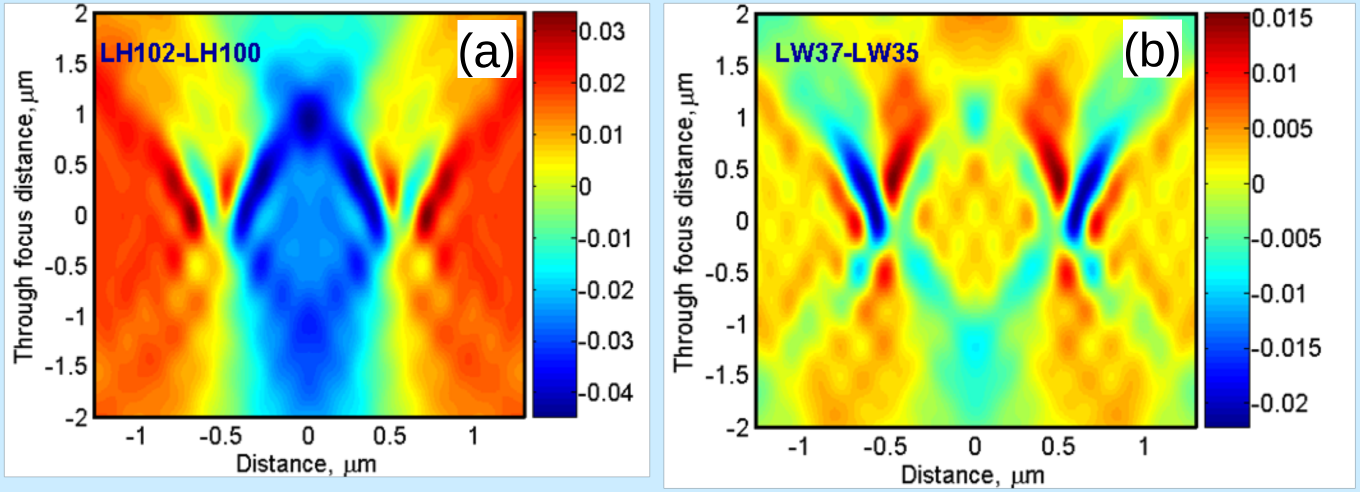
1 nm difference in the line height

1 nm difference in the line height and width

1° sidewall angle difference

The simulated differential TSOM images obtained for the isolated lines. (a) 1.0 nm change in the line width (b) 1.0 nm change in the line height (c) 1.0 nm change in the line height and the line width, and (d) one degree change in the sidewall angle (Wavelength = 546 nm, LW = Line width in nm, LH = Line height in nm).

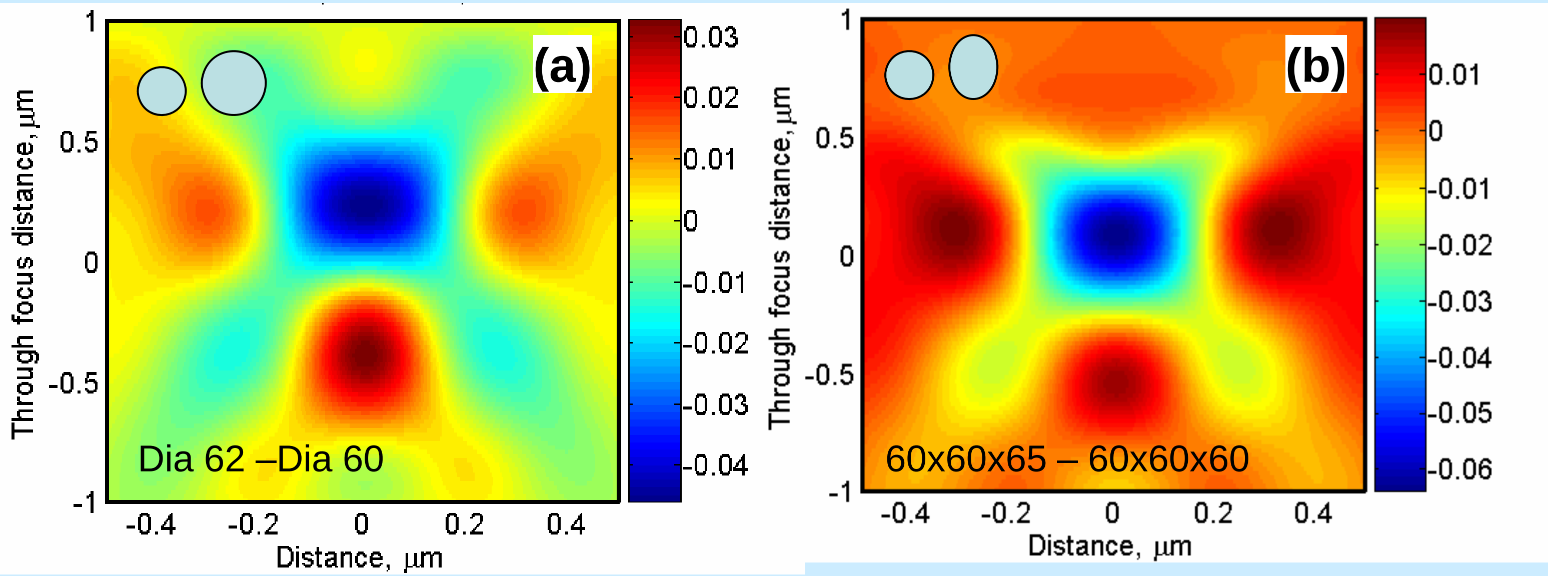
Differential TSOM images showing uniquely the presence of different dimensional variations for <u>dense finite gratings</u>


2 nm difference in the line height

2 nm difference in the line width

The simulated differential TSOM images obtained for finite dense arrays for (a) 2.0 nm change in the line height, and (b) 2.0 nm change in the line width. Line width = 35 nm, Line height = 100 nm, Wavelength = 193 nm, Si line on Si substrate.

Differential TSOM images for nanoparticles identifying size and shape differences

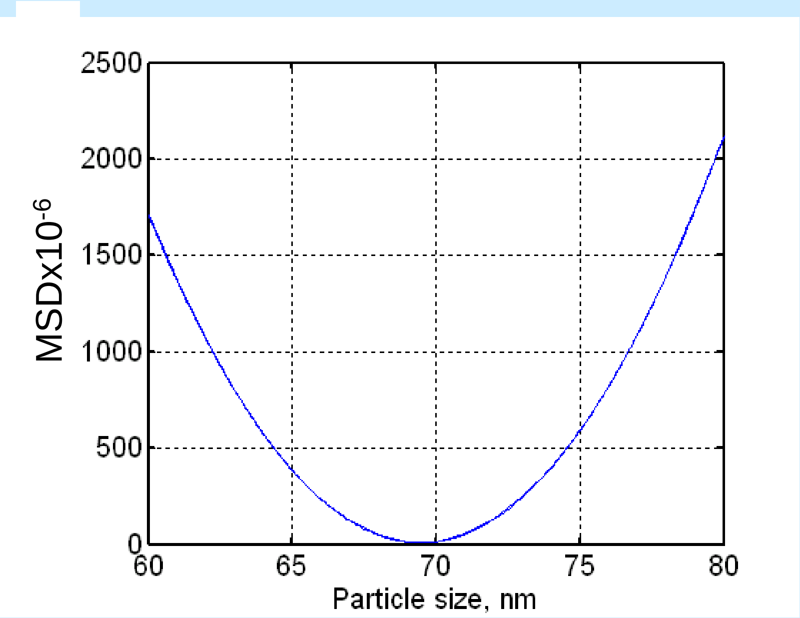


2 nm Size difference

5 nm shape difference

Figure showing distinct differential TSOM images highlighting (a) 2 nm difference in size (diameters of 60 nm and 62 nm) and (b) 5 nm difference in shape (60 nm diameter spherical particle vs. an ellipsoid with 5 nm larger dimension in the vertical direction). Illumination wavelength = 365 nm, Gold particle on quartz substrate.

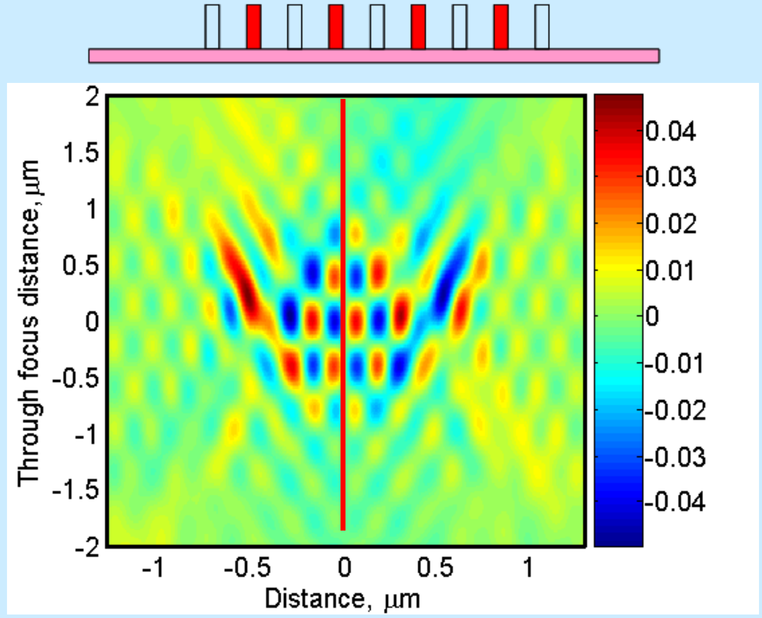
Method showing absolute size determination of nanoparticles using a library of simulations



Estimation of nanoparticle size using the library-matching method. Minima identifies the size of the particle. Gold particle on quartz substrate. Wavelength = 365 nm

Simulations

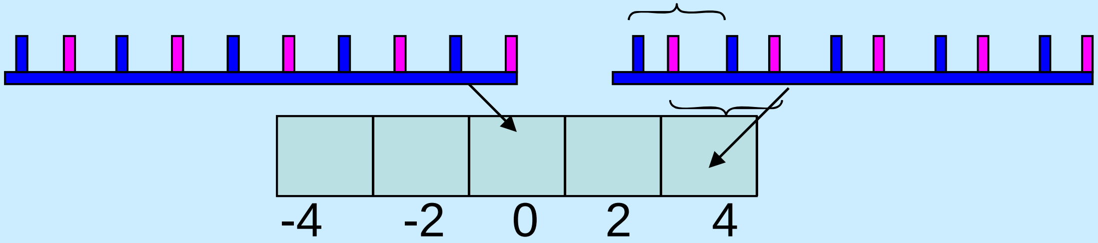
Differential TSOM image showing the presence of 2 nm overlay for finite dense grating (applicable to double patterning)

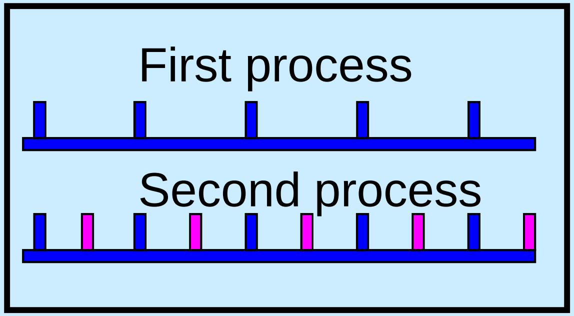


The differential TSOM image application for double patterning overlay analysis showing an overlay offset of 2 nm for finite dense array. LW=35 nm, LH=100 nm, Pitch=105 nm, Total number of lines simulated=9, Illumination wavelength = 193 nm, Si line on Si substrate.

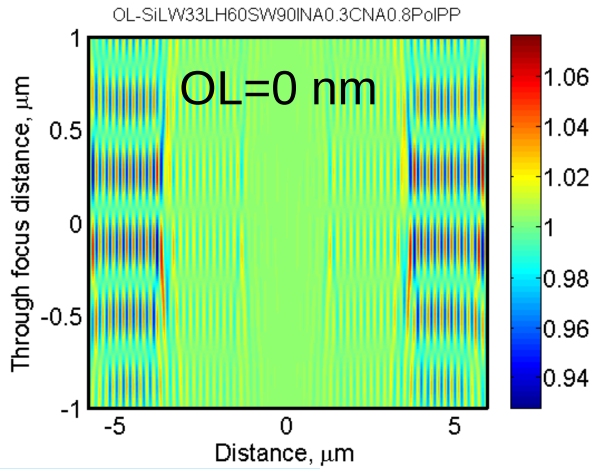
TSOM Based Overlay (OL) Targets for Double Patterning

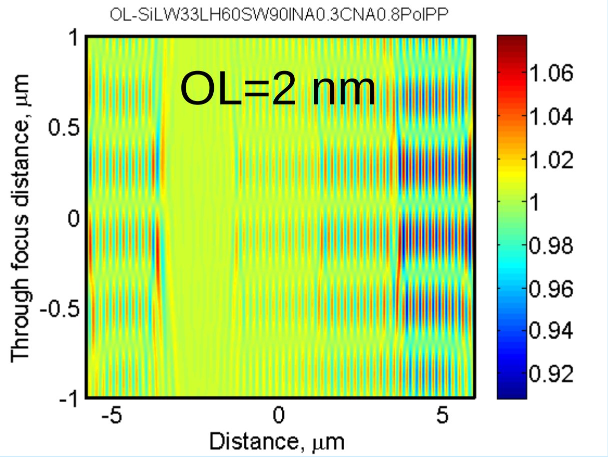
Simulations

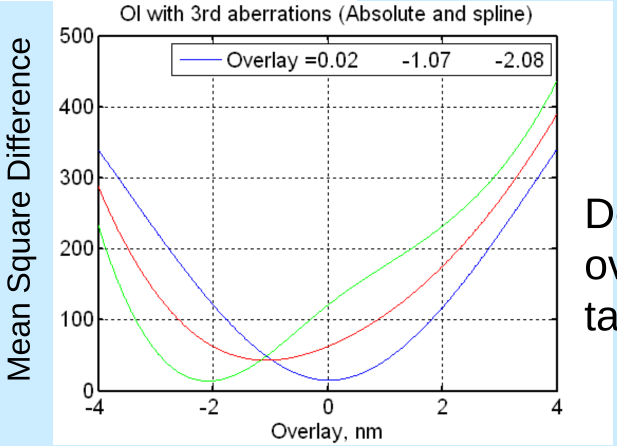



First process

Second process







Determination of the overlay value using the target

Advantages of the TSOM Method

- Transforms conventional optical microscopes to truly 3D metrology tools that provide excellent lateral and vertical measurement sensitivity comparable to typical Scatterometry, SEM and AFM
- Has the ability to decouple vertical, lateral or any other dimensional changes, i.e. distinguishes different dimensional variations and magnitudes at nanoscale with less or no ambiguity
- Has the ability to analyze large dimensions both in lateral and vertical direction

Advantages of the TSOM Method…

- Inexpensive, fast and simple, requiring merely ubiquitous conventional optical microscopes and is perfectly suitable for industrial, high-throughput mass metrology
- Can be used with a variety of targets ranging from opaque (reflection mode) to transparent (transmission mode) materials and geometries ranging from simple nanoparticles to complex semiconductor memory structures
- Applicability to a wide variety of measurement tasks
- Requirement for defining the "Best Focus" is eliminated

Limitations of the TSOM Method

- Optical system errors (for the second method)

- Experiment to simulation agreement (for the second method)

Potential Applications (not exhaustive)

Areas

- Defect analysis
- Inspection and process control
- Quantum dots/nanoparticles/nanotubes
- Critical dimension (CD) metrology
- Overlay registration metrology
- 3D interconnect metrology (TSV)
- Photo mask metrology
- Film thickness metrology
- Line-edge roughness measurement
- Nanometrology
- Relative movements of parts in MEMS/NEMS

Industries

- MEMS
- NEMS
- Semiconductor industry
- Biotechnology
- Nanomanufacturing
- Nanotechnology
- Data storage industry
- Photonics
- Nanotechnology

Companies openly working or interested in the technology

SEMATECH, A large US Semiconductor Company, Bruker (Veeco), Nanometrology Intl., aBeam

Any suggestions? Please contact: ravikiran.attota@nist.gov

Conclusions

- Through-focus Scanning Optical Microscopy (TSOM) images are constructed using optical images obtained from conventional optical microscopes
- The TSOM method provides dimensional analysis of nano/micrometer scale targets with potential lateral and vertical dimensional measurement resolutions comparable to typical SEM and AFM (of less than a nanometer)
- Differential TSOM images highlight the dimensional differences with nanometer sensitivity
- Distinguishes different dimensional variations with less or no ambiguity
- Potentially evaluates absolute dimensions

Publications on the TSOM method

Latest initial review paper:

- Ravikiran Attota, and Richard M. Silver, "Nanoscale measurements with through-focus scanning optical microscopy method," Measurement Science and Technology, **22,** 024002, (2011) (http://iopscience.iop.org/0957-0233/22/2/024002/) .

- Ravikiran Attota, Richard Kasica, Lei Chen, Purushotham Kavuri, Richard Silver and Andras Vladar, “Nanoparticle size and shape evaluation using the TSOM optical microscopy method,” NSTI-Nanotech 2010, Vol. 3, pp 172-175, (2010).

  Ravikiran Attota, Thomas A. Germer, and Richard M. Silver, "Nanoscale measurements with a through-focus scanning optical microscope," Future Fab, 30, pp 83-88, (2009).

- Ravikiran Attota, *et al.*, "Through-focus Scanning and Scatterfield Optical Methods for Advanced Overlay Target Analysis ," Proc. SPIE 7272, In Press, (2009).
- Ravikiran Attota, Thomas A. Germer, and Richard M. Silver, "Through-focus scanning-optical-microscope imaging method for nanoscale dimensional analysis," Optics Letters, Vol. 33, Issue 17, pp. 1990-1992, (2008).
- Ravikiran Attota, Richard M. Silver, and Bryan M. Barnes, “Optical through-focus technique that differentiates small changes in line width, line height, and sidewall angle for CD, overlay, and defect metrology applications,” Proc. SPIE 6922, 6922OE-1-13, (2008).
- Ravikiran Attota, Richard M. Silver, and James Potzick, “Optical illumination and critical dimension analysis using the through-focus focus metric,” Proc. SPIE, 6289, p. 62890Q-1-10 (2006).

Recognitions/Highlights

The TSOM method has been selected for "R&D 100 Award" for 2010 year.
(http://www.rdmag.com/Awards/RD-100-Awards/2010/07/R-D-100-2010-Winners-Overview/
http://www.nist.gov/public_affairs/tech-beat/tb20100721.cfm#nanoscale)

NIST Tech Beat Highlight
Nanoscale Dimensioning Is Fast, Cheap with New NIST Optical Technique (October 28, 2008).
(http://www.nist.gov/public_affairs/techbeat/tb2008_1028.htm#tsom)

The National Nanotechnology Initiative (NNI) (supplement to the President's FY 2010 budget)
One of the six nanotechnologies selected from NIST

Invited Presentation
Gave over half a dozen invited presentations at various venues.

Invited Article
An invited article was published in FutureFab magazine catering to semiconductor industry.

Recognitions/Highlights…

Article on the TSOM method highlighted
The journal article published in Optics Letters has been selected to be included in the
"Virtual Journal of **Nanoscale Science & Technology**" and
"Virtual Journal of **Biological Physics Research**" published by American Institute of Physics and the American Physical Society in cooperation with numerous other societies and publishers

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John Kramar: *Leader - Nanoscale Metrology Group*
Richard Silver: *Leader - Surface and Microform Metrology Group*
Ronald Dixson: AFM
James Potzick: Discussions
Rich Kasica and Lei Chen: NIST NanoFab – Fabrication
Prem Kavuri and Bin Ming: SEM

Mike Stocker, Yeung-Joon Sohn, Bryan Barnes, Richard Quintanilha, Thom Germer, Andras Vladar, Jayson Gorman, and Egon Marx

Author's bio and contact information

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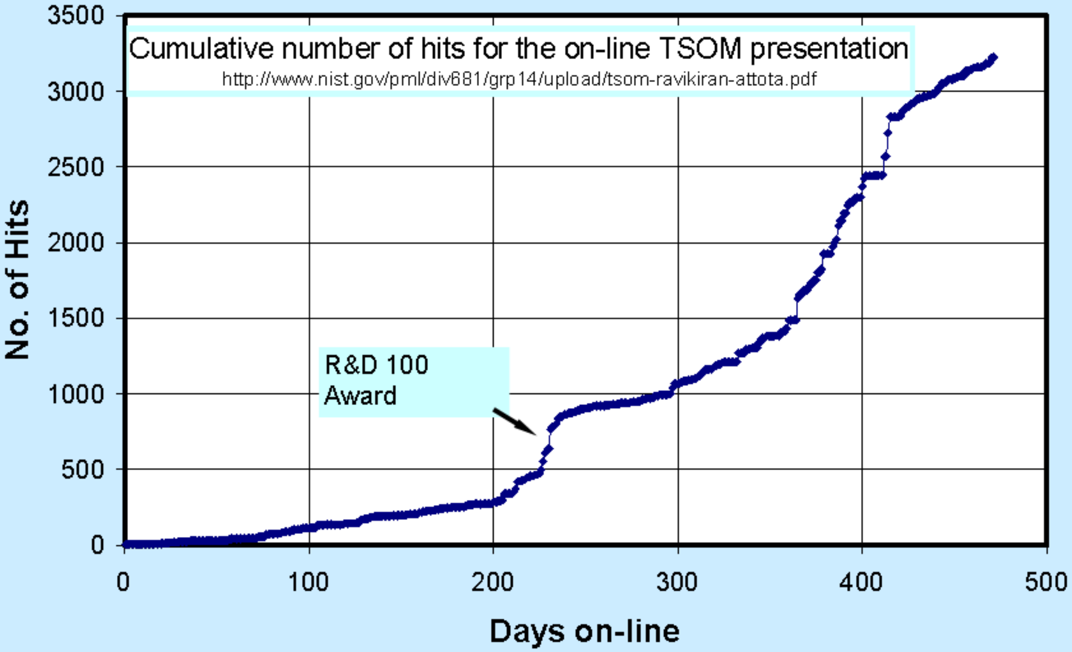
http://www.nist.gov/pml/div681/grp14/rattota.cfm

Dr. Ravikiran Attota is a research engineer at NIST. His current research interest is in nanometrology using primarily optical methods. He is the developer of TSOM optical method for dimensional analysis with potential applications in areas such as MEMS, NEMS, nanotechnology, the semiconductor industry, biotechnology, nanomanufacturing, nanometrology, the data storage industry, and photonics. Dr. Attota is a recipient of an Alexander von Humboldt Fellowship from Germany (1996), a Silver Medal Award from Department of Commerce (2008) and an R&D 100 Award from R&D Magazine (2010). He has been at NIST since 1999. Prior to joining NIST he worked in Singapore with Data Storage Institute and in Germany with Forschungszentrum Karlsruhe. He received his Ph.D. from the Indian Institute of Science, Bangalore, India.

Thank you!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