**TSOM:
R&D 100
Award
Winner**

TSOM Method for Nanoelectronics Dimensional Metrology

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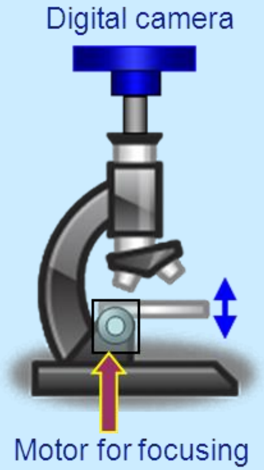
*TSOM is pronounced as "tee-som" ; A latest presentation on TSOM can be found here.

Contents

- What is TSOM ?
- Method to construct TSOM images
- Characteristics of TSOM images
- Applications

TSOM: Through-focus Scanning Optical Microscopy



TSOM transforms conventional optical microscopes into three-dimensional metrology tools with nanometer scale measurement sensitivity

Not an image resolution enhancement method

TSOM: Through-focus Scanning Optical Microscopy

- Analysis in lateral and vertical directions as large as over 50 μm.

- Requirement for defining the "Best Focus" is eliminated.

How does TSOM achieve this?

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

Requires a TSOM Image

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

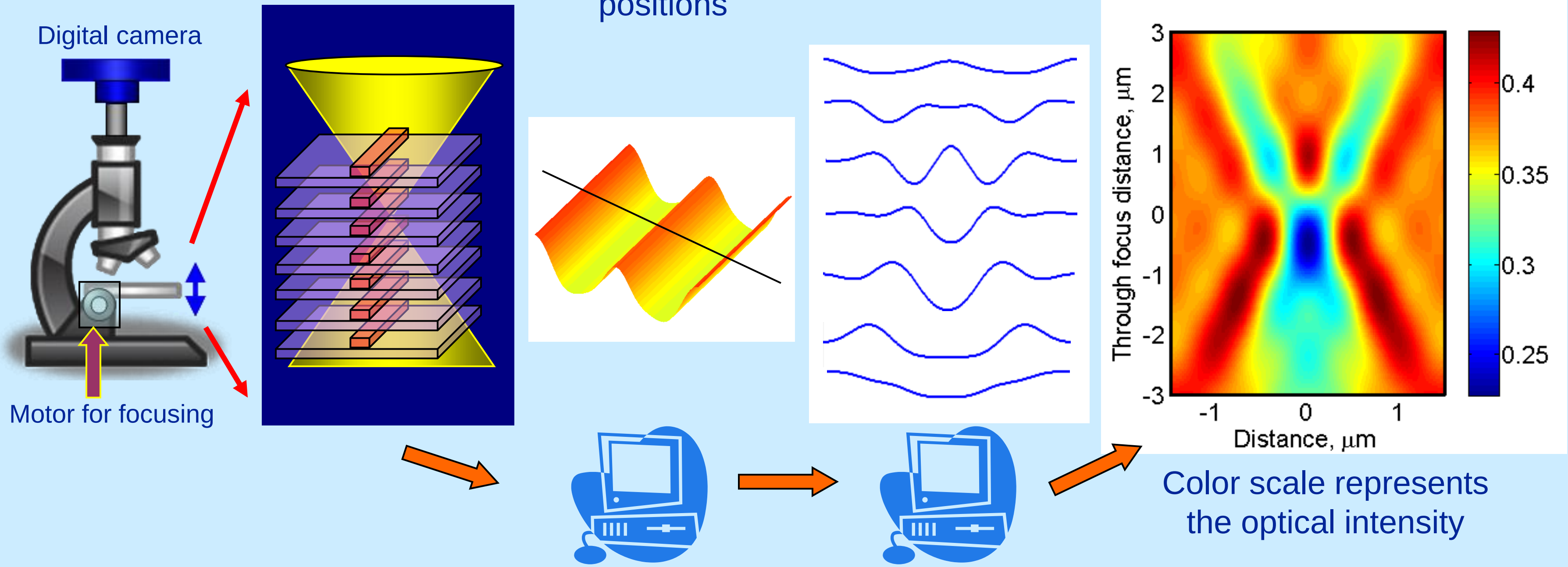
Optical Microscope

Schematic showing through-focus scanning of the target

2D optical images at different through-focus positions

Optical intensity profiles extracted from the optical images

Constructed TSOM image using the optical intensities



Color scale represents the optical intensity

Computer acquires multiple digital images of targets

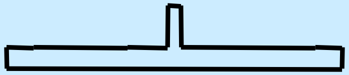
Computer algorithms process the acquired digital images and produce the TSOM images

Differential TSOM images are distinct for different dimensional variations

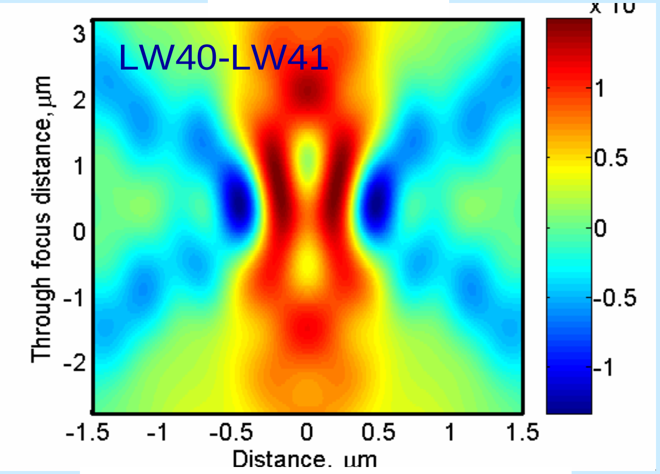
Simulation

Isolated Si line on Si substrate; λ = 546 nm; LW = 40 nm; LH = 100 nm

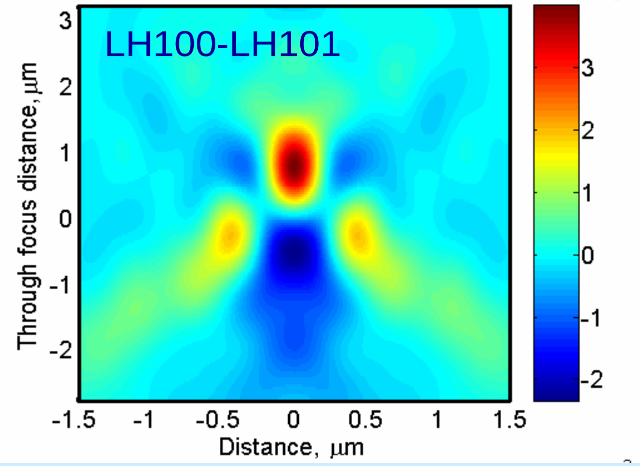
Isolated line



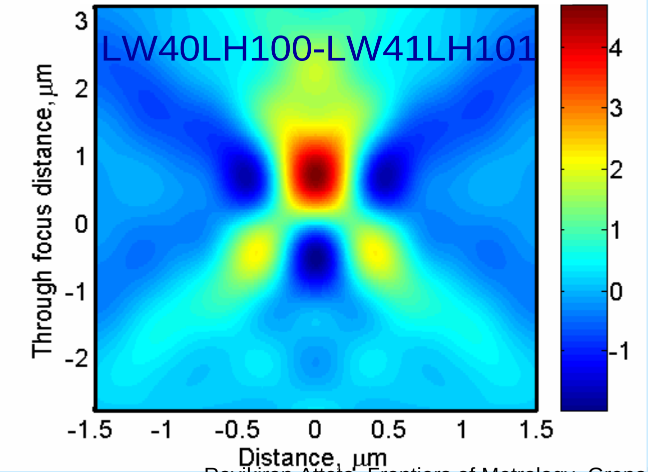
Linewidth



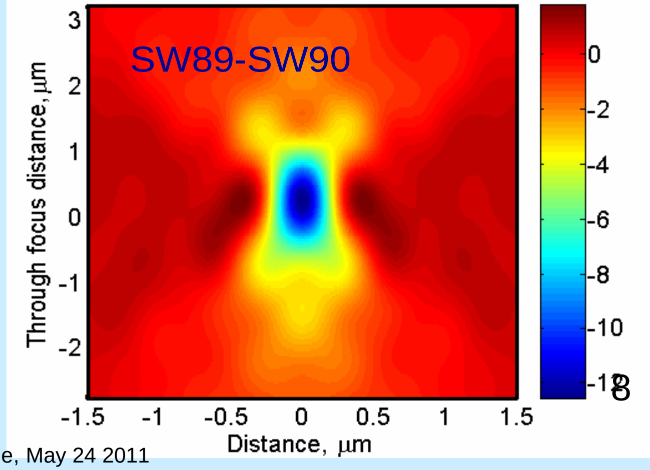
Line height



Line width and height



Sidewall angle



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

Differential images appear similar for small changes in the same dimension

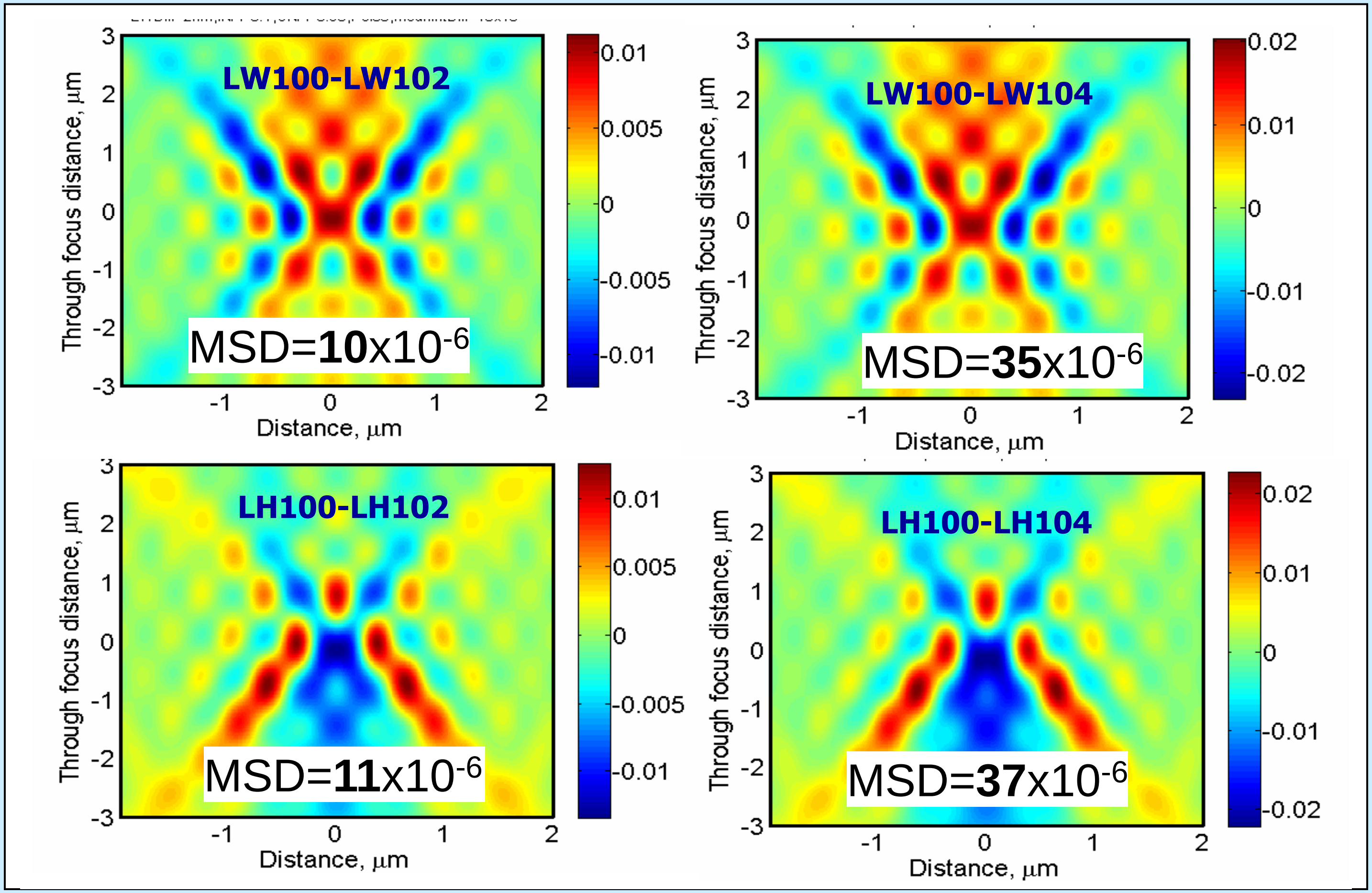
Simulation

Difference = 2 nm

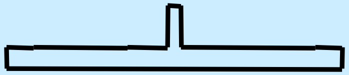
Difference = 4 nm

Linewidth difference

Line Height difference



$$\mathrm{MSD}= \sum\frac{(\text{TSOM Image1} - \text{TSOM Image2})^2}{\text{Total number of pixels}}$$



NIST

Characteristics of TSOM images: Summary

- TSOM images change with target (assumed to be unique).
- Differential TSOM images
  - Highlight nanometer scale dimensional differences using a conventional optical microscope.
  - Appear distinct for different dimensional change (breaks the correlation between parameters, e.g., height and width, in the optical signal).
  - Are additive.
  - Appear qualitatively similar for a change in the same dimension.
- Integrated optical intensity of differential TSOM image indicates the magnitude of the dimensional difference.
- TSOM images are (assumed to be) unique.
- Robust to optical aberrations and illumination variations.

- Good quantitative agreement between measurement and simulation is not established yet.
- Trends observed in simulations generally match measurements.

Two Applications

Evaluate differences in dimensions

- Requires two targets
- Simulation is not necessary but useful

Determine dimensions of a target

- Requires a library of either

<u>Accurate simulations</u>

or

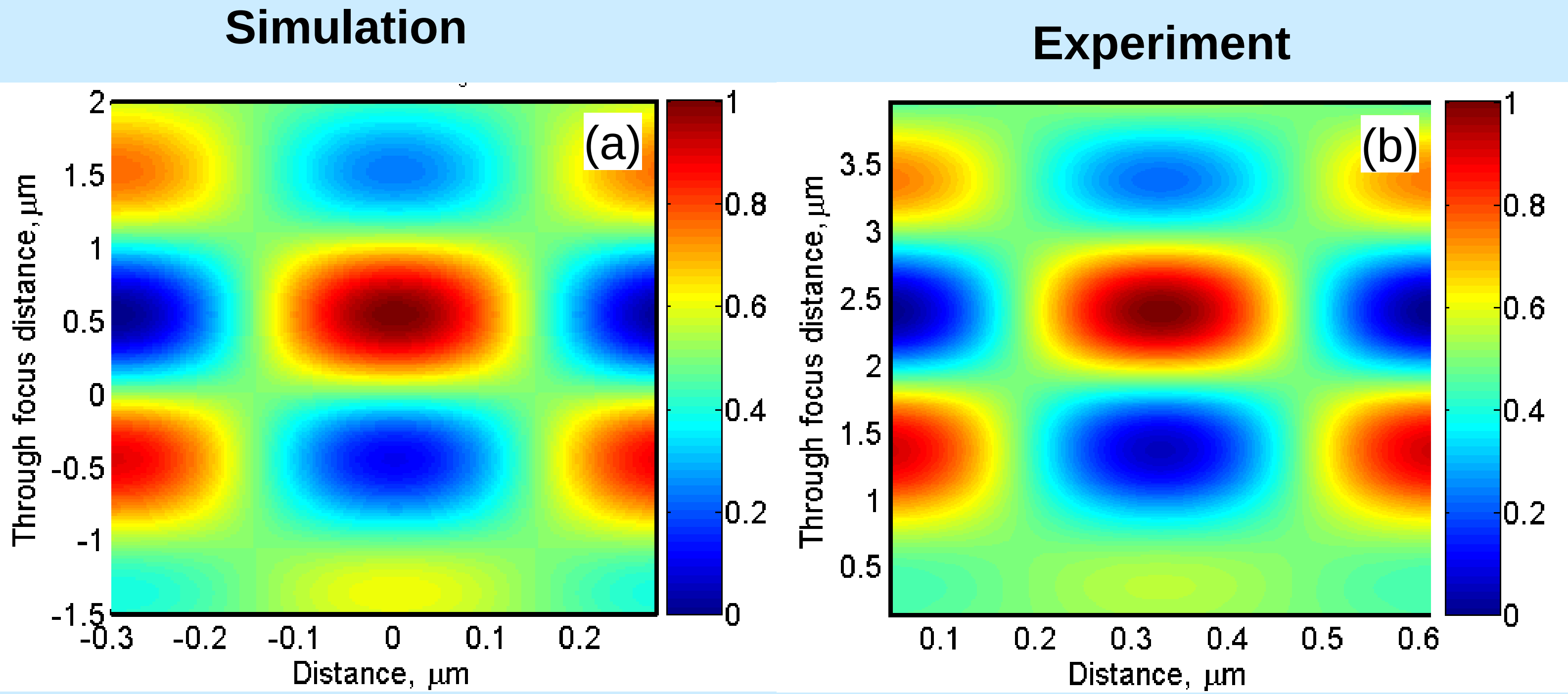
<u>Measurements</u>

- Requires good agreement between measurement and simulation
- TSOM images are assumed to be unique

Some Example applications of the TSOM method

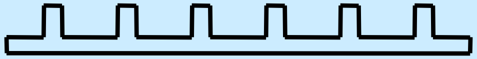
Simulation to Experiment comparison

Line gratings



Simulation

Experiment

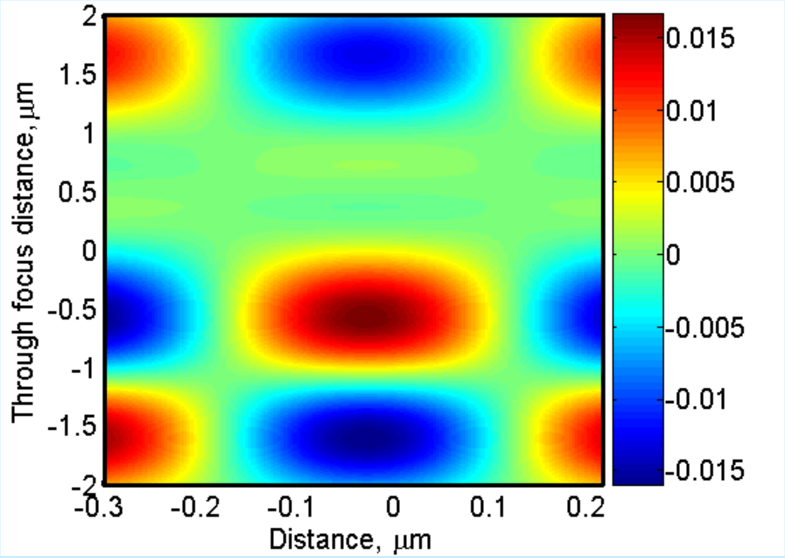


Linewidth = 152 nm, Line height = 230 nm, Pitch = 601 nm, Wavelength = 546 nm, Si line on Si substrate.

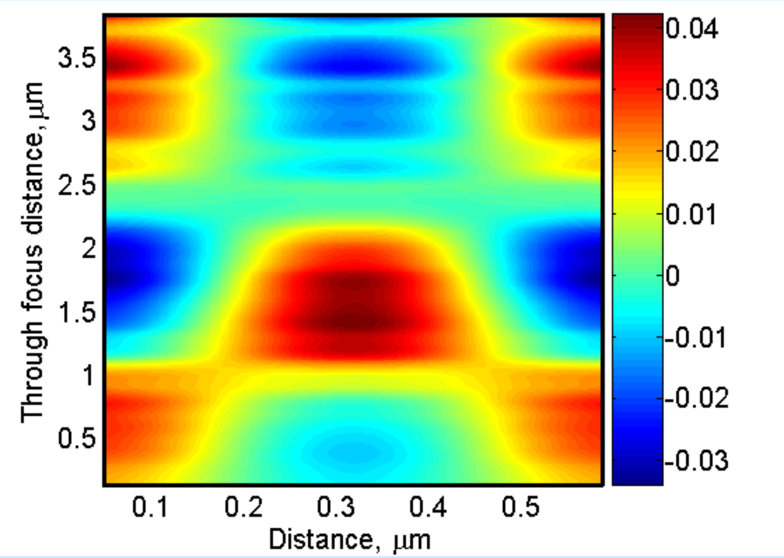
Simulation to Experiment comparison

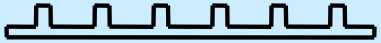
Differential TSOM images for **3 nm** difference in the line width

Simulation



Experiment

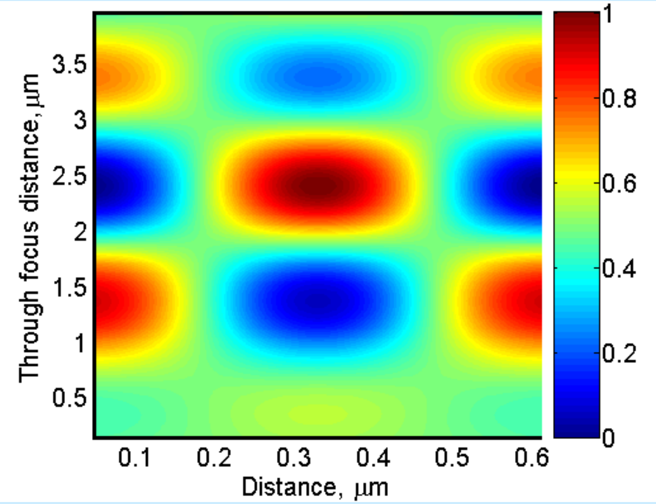




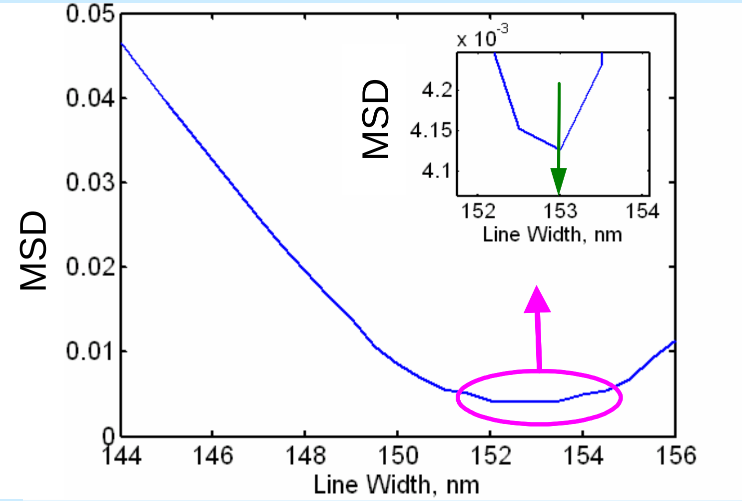
Experiment

Experimental line width determination using simulated library

Experimental TSOM image



Determining the dimension using the library matching method

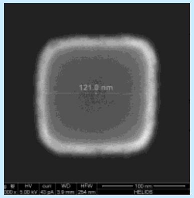


TSOM Matched target line width : 153 nm

AFM measured line width: 145 nm

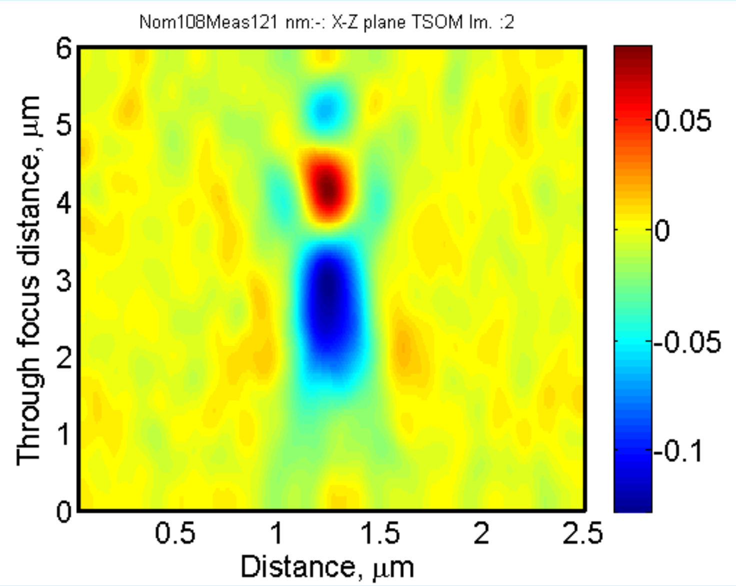
Size determination of nanodots (nanoparticles, quantum dots) using experimental library

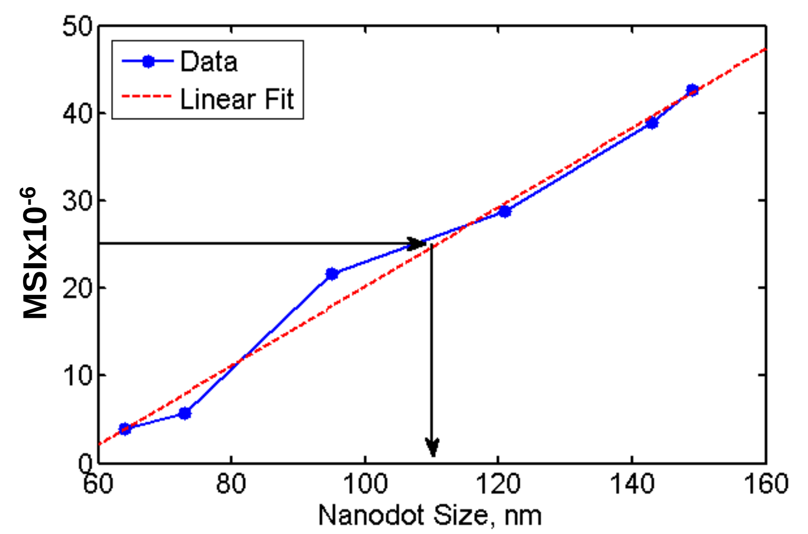
Experiment



SEM image of
121 nm nanodot

Experimentally created library.





Experimental TSOM image of 121 nm nanodot. λ = 546 nm. Si nanodot on Si substrate.

SEM measured size = 103 nm
TSOM measured size = 106 nm

Experiment

Experimental defect analysis of four types of 10 nm defects in dense gratings

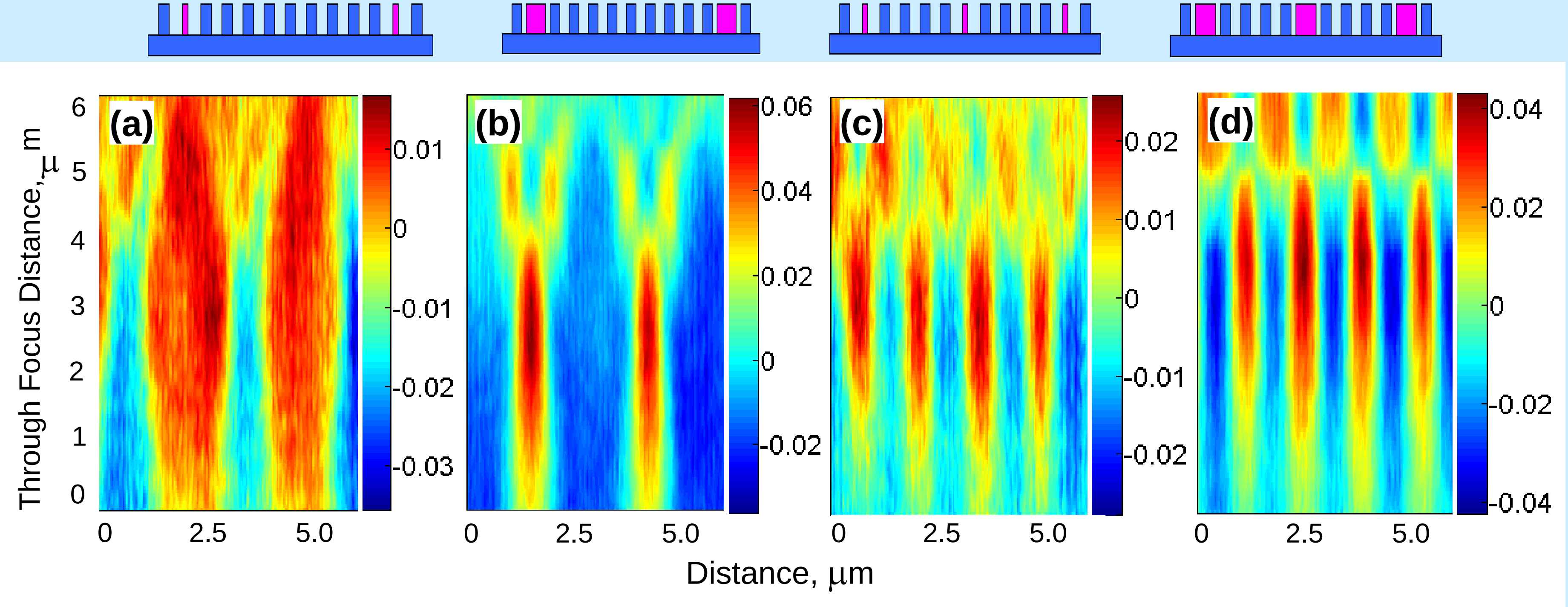
Pitch = 270 nm, Linewidth = 100 nm, λ = 546 nm

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

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

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

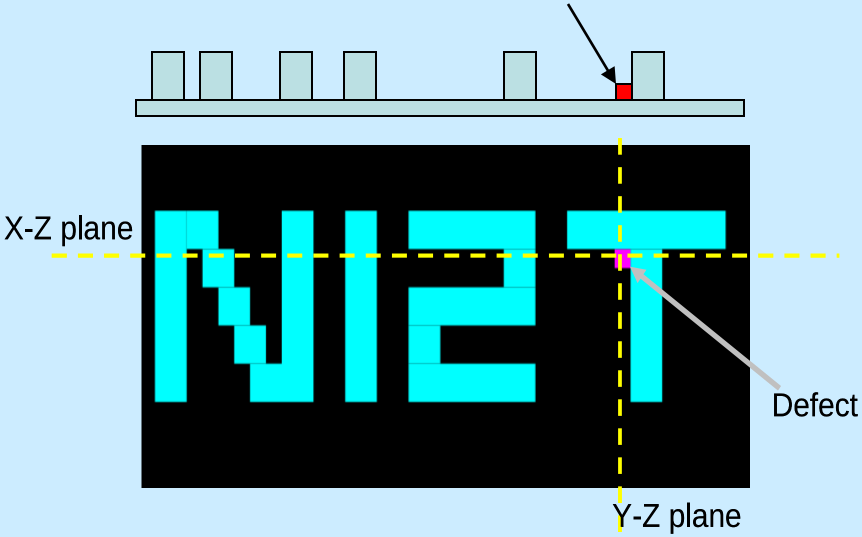
Every 5th line **larger** by 10 nm



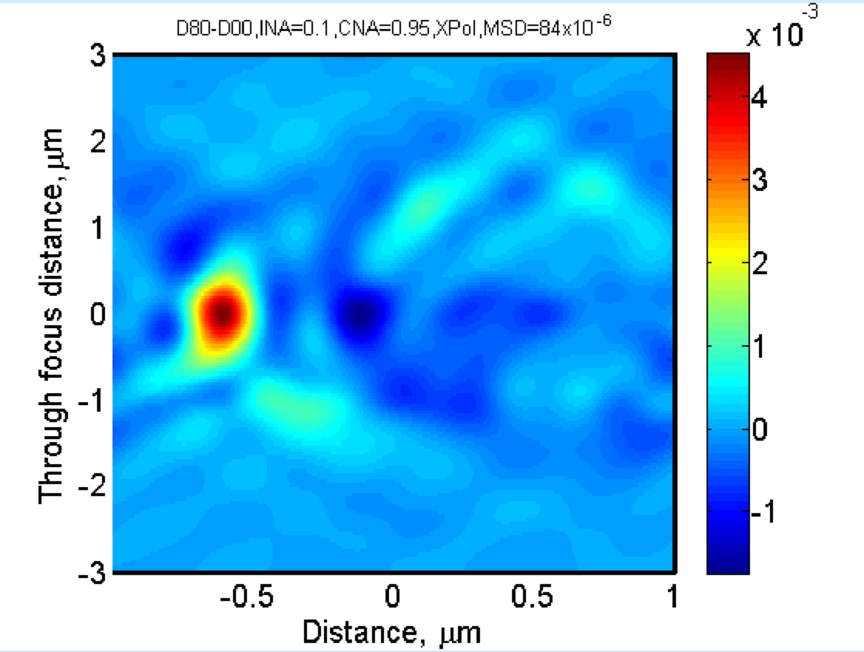
Simulation

Defect analysis: Random structure

Cross section **25 nm Defect**



Detected 25 nm defect that is 25 nm tall, (one fourth the height of the features)



(XZ-plane reversed)

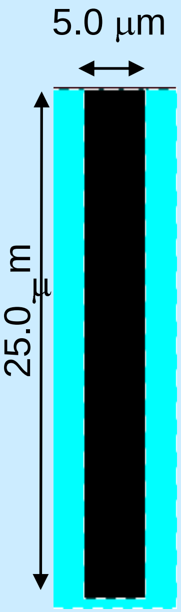
Defect size: 25 nm, Defect height = 25 nm;
Linewidth of the features= 100 nm, Line height =100 nm
Wavelength = 365 nm, Si features on Si substrate

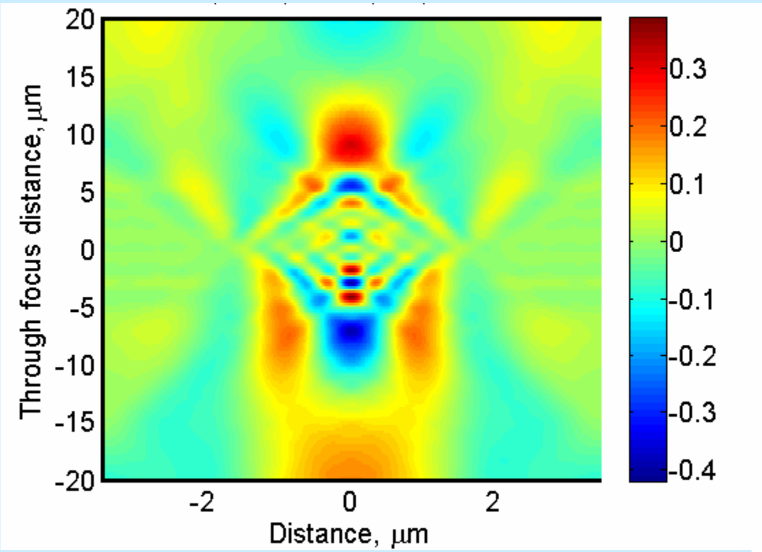
3D Metrology

Simulation

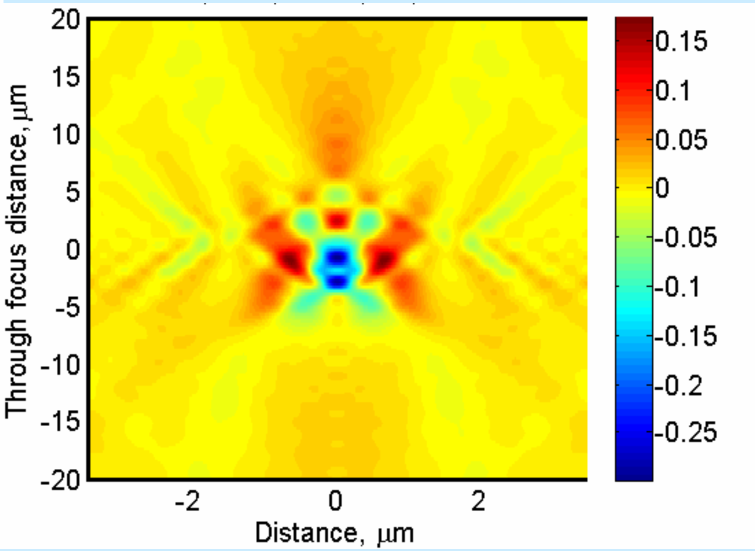
High aspect ratio through silicon via (TSV) dimensional analysis

TSV Diameter = 5 µm, Depth = 25 µm, λ = 546 nm





20 nm change in the depth



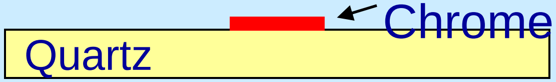
20 nm change in the diameter

Photo mask application: Transmission microscope

Simulation

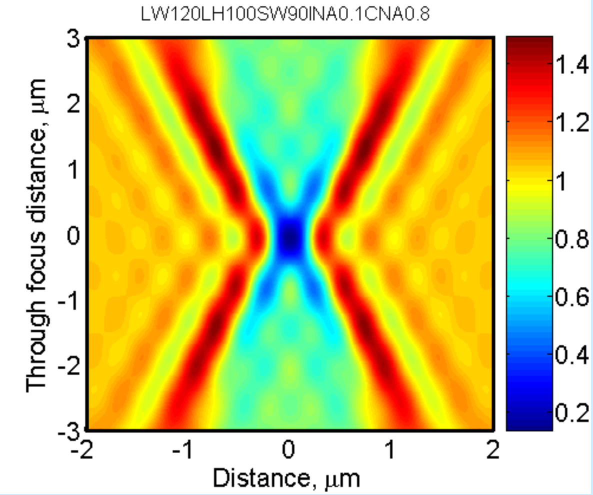
Optimization of Illumination NA to obtain maximum sensitivity

Photo mask target



Dimension	Diff. (nm)	INA	MSD		x10^{-6}
			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



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

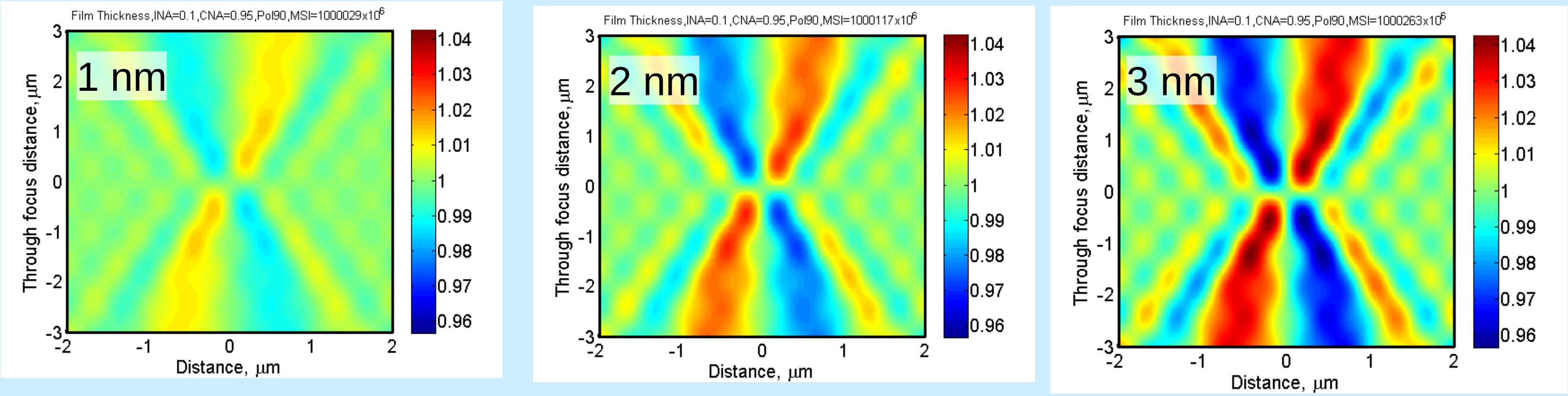
Line width = 120 nm, Line height = 100 nm, Wavelength = 365 nm,
UP=Unpolarized, TE=TE polarized, TM=TM polarized,
MSD=Mean Square Difference

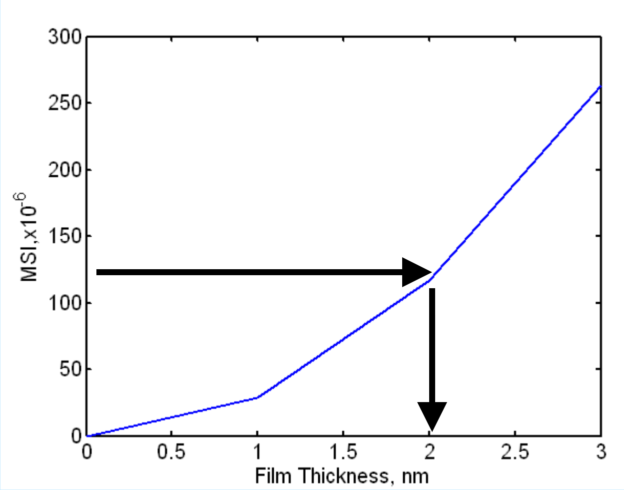
Experiment

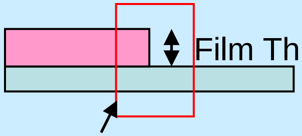
Simulation

Thin film metrology

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







Film Thickness

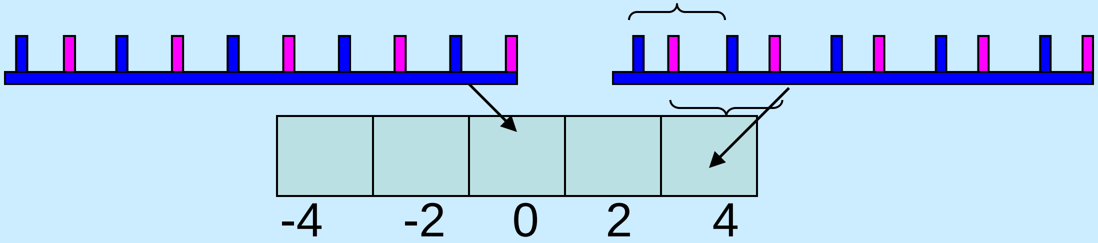
Area of analysis

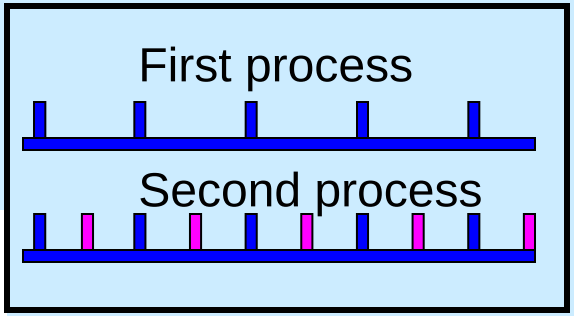
Calibration curve to measure films of unknown thickness

Overlay Targets for Double Patterning

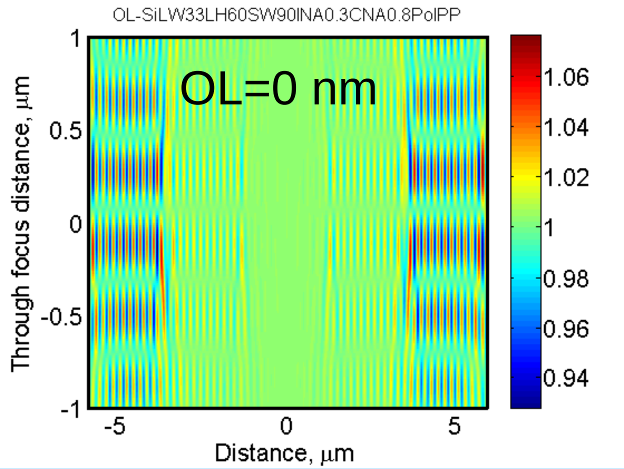
Simulations

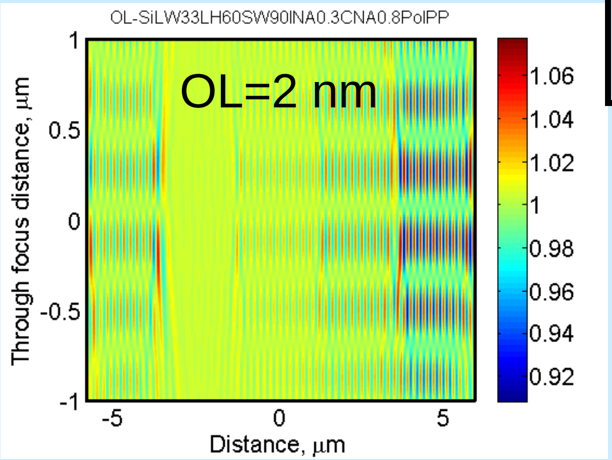
Experiment



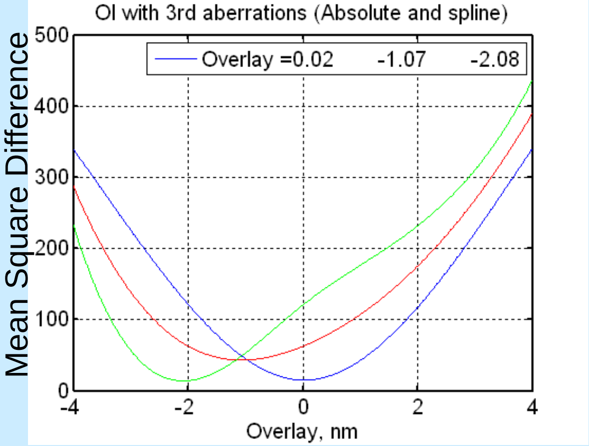

First process

Second process

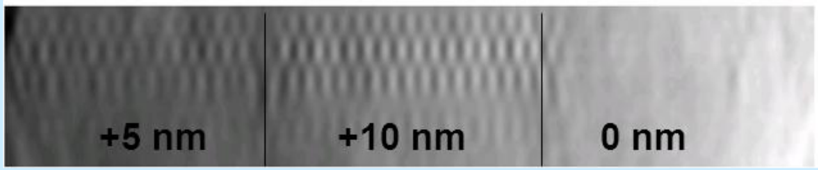




Determination of the overlay value using the target

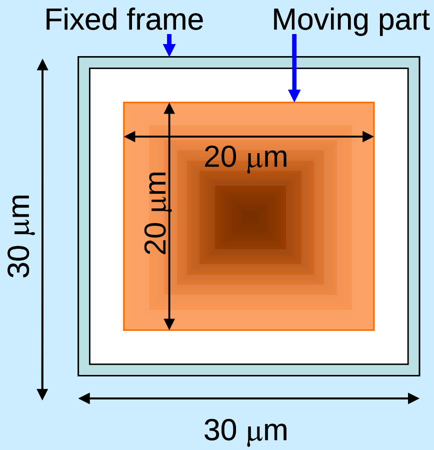


Measured TSOM Image



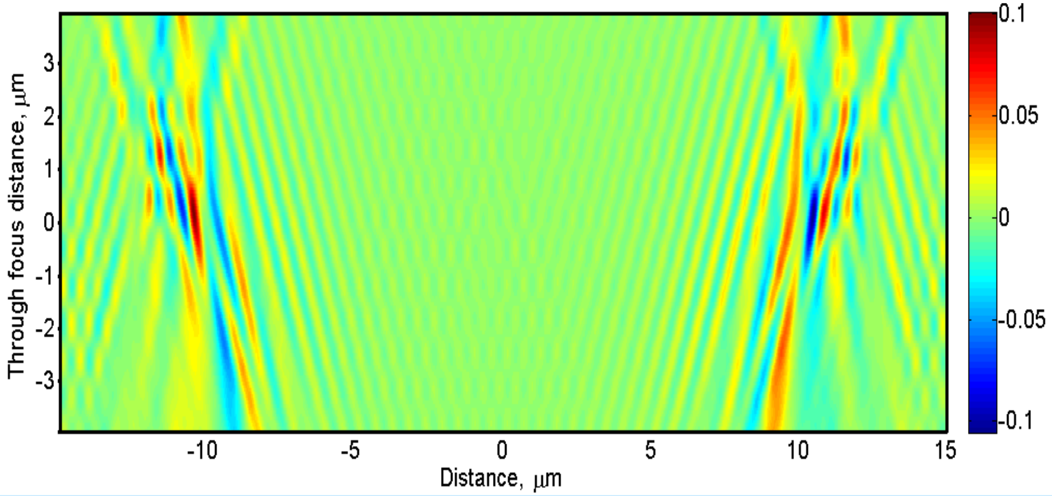
Monitoring/Measuring Nanoscale Movements for MEMS/NEMS Devices

Simulation



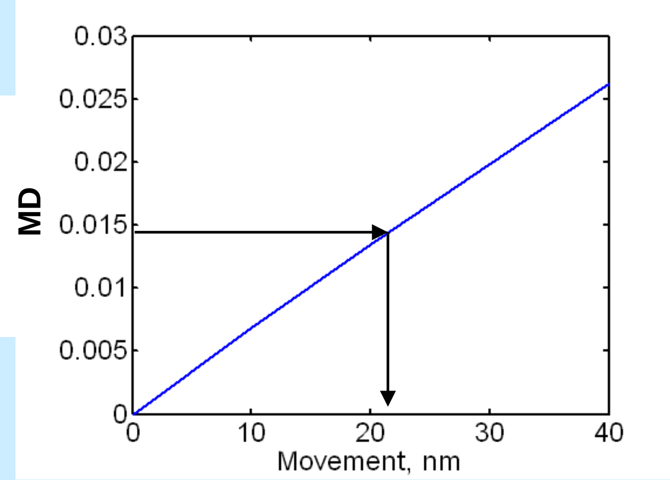
A simplified schematic of a MEMS device (fabricated at NIST) containing inner 20 µmx20 µm movable part and the outer fixed frame. Every time the device is powered the inner part moves 10 nm to the right side relative to the outer frame.

Differential TSOM image showing 10 nm movement of the inner part



Calibration Curve

Mean Intensity difference as a function of movement



Wavelength = 546 nm

Advantages of the TSOM Method

- Transforms conventional optical microscopes to truly 3D metrology tools that provide excellent lateral and vertical measurement resolutions 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 (over 50 μm) both in lateral and vertical direction.
- Robust to optical and illumination aberrations.

Advantages of the TSOM Method

- Inexpensive, nondestructive, fast and simple, requiring merely ubiquitous conventional optical microscopes and is perfectly suitable for industrial, high-throughput 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)
- FinFET metrology
- 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 collaborating or assessing the technology

SEMATECH, A large US Semiconductor Company, Veeco (Bruker), Toshiba, and several emerging companies

Any suggestions are welcome

Conclusion

Through-focus scanning optical microscopy (TSOM) method provides 3D metrology with nanometer scale measurement sensitivity using a conventional optical microscope

Acknowledgements

Michael Postek: Chief - Mechanical Metrology Division
John Kramar: Leader - Nanoscale Metrology Group, discussions
James Potzick: Discussions
Richard Silver: Leader - For providing NIST optical microscope
Rich Kasica and Lei Chen: NIST NanoFab – Fabrication
Andras Vladar, Prem Kavuri and Bin Ming: SEM measurements
Ronald Dixson: AFM measurements
Andrew Rudack, Ben Bunday, Erik Novak , Victor Vartanian: For providing targets

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

Thank you

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Google search: Ravikiran, Attota, TSOM