Assessing Quantitative Optical Imaging for Realizing In-die Critical Dimension Metrology

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Optics-based linewidth and contour metrology

Optical methods yield high throughput, low cost, and are non-destructive, but without adequate resolution these advantages have little meaning. A new model-based optical approach allows for measurements of deep sub-wavelength features with sub-nanometer parametric uncertainties.

Optical in-die targets would sacrifice a small area for improved critical dimension (CD) metrology in the active area.

Our project is evaluating how attain key CD and shape parameters from engineered in-die capable metrology targets.

Sidestepping the Rayleigh resolution limit

This approach utilizes the scattered electromagnetic field which contains a wealth of accessible information, even as images may be unresolved. Scattered phase and spatial frequency information are captured using focus-resolved images, leading to quantitative 3-D reconstruction of fine structures.

Fourier domain normalization ties several of these key steps together to fundamentally improve the theory-to-experiment fits.

The simulated scattered field can be discretized into Fourier components of index $i, j$ such that each individual component is

$$U_{ij} = C_{ij} \cdot S_{ij} \cdot I \cdot U_0,$$

where $U_i$ and $U_j$ are Jones amplitude vectors for the source plane wave and the $i$th Fourier component of the scattered plane wave, respectively. $S_{ij}$ is the Jones matrix for the scattering for the $ij$th component.

An inverse Fourier transform combines tool-corrected electric fields to compute the image.

Parametric fitting of a finite set of features

Focus-resolved fitting of an array of 30 lines with nominally 14 nm CD imaged at $\lambda = 450$ nm [2]

PATTERNED TARGETS
1 line targets imaged at 193 nm
Length of lines

Patterned target dimensions are about 2 $\mu$m x 6 $\mu$m for these 30 line arrays w/ 60 nm pitch & 6 $\mu$m line lengths. Simulations suggest leaving an unpatterned buffer of 10 $\lambda$ at the array edges, yielding a 10 $\mu$m x 6 $\mu$m target.

Tailoring a metrology target for $\lambda = 193$ nm

Subsequent work has concentrated on establishing the capabilities and challenges of designing and measuring in-die capable targets using shorter wavelengths.

Key parameters include:
- Length of lines
- Number of lines
- Number of focus positions
- Wavelength effects
- Polarization dependence

Experimental sensitivity

10 line targets imaged at 193 nm

Simulation data indicate for $\lambda = 193$ nm [4]
- Total # lines can be reduced to 12
- # of focus position needed as few as 4
- One polarization may be sufficient

These latter two results lead to faster data acquisition.

Maintaining accuracy while optimizing the target

Addressing systematic bias due to 2-D modeling

Length limitations arise as finite features inherently scatter differently from infinite lines, though this may be negligible for long finite lines. However, even a 21 $\lambda$ long line can yield systematic bias when fitted using a 2-D code [5]. Alternatives are to model the library in 3-D or to address the source of the systematic bias. By evaluating fits at each focal position for bias using simulation, consistent solutions can be found.

Conclusions

- With this approach, nanometer scale details are determined by fitting, such as three-dimensional contours of features as small as 15 nm in size using 400 nm wavelength light, or 30 nm.
- Initial targets designed were not rigorously optimized. A new set of targets for $\lambda = 193$ nm microscopy have been designed to minimize patterned area while maintaining desired uncertainties.
- In order to utilize the through focus data, the systematic error needs to be considered, or a full 3-D model needs to be used.
- Such checks should enable consistent solutions with reliable parametric uncertainties for patterned targets potentially as small as 1 $\mu$m x 2 $\mu$m, or 5 $\mu$m x 2 $\mu$m in total area.

References