Connection of Field Solvers: Lenses and Microstructures

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Background: Systems Containing Lenses and Microstructures

[Image of a dots projection system, a hybrid lens, and a microscopy system with Y. Zhang et al. (2019) reference.]

[Dots projection system with DOE and VCSELs, hybrid lens diagram illustrating DOE hybrid lens, microscopy system with light source, tube lens, and sample.]
Ray tracing is limited, because diffraction, polarization, coherence is not included.

Vectorial physical-optics modeling is desired, but FEM, FMM, FDTD etc. are slow.

An efficient and accurate physical-optics modeling with fully vectorial effects is desired.

Therefore, connection of the field solvers, e.g. lenses and microstructures, is one desired option to model the system efficiently and accurately, with fully vectorial effect.
Task: Ultraviolet (UV) Microscopy for Inspection of Wafer Structure

input paraxial Gaussian wave
- wavelength: 266 nm
- linearly polarized in y direction (TE)
- linearly polarized in z direction (TM)

high-NA objective lens
- non-immersion
- NA=0.9

What is the far field images on CCD for TE and TM?

What is the near field images for TE and TM, without showing the evanescent waves?

\[ w_x \propto \|E\|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2, \]

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What is the difference between the near and far field images for TE and TM?
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How sensitive of the far image concerning the defects?
**Fully Vectorial Modeling in the Framework of Field Tracing**

Talk 22: Z. Wang et al.

Talk 25: F. Wyrowksi et.al

Talk 26: O. Baladron-Zorita et.al

**Free Space Propagation (FSP)**


**Local Plane Interface Approximation (LPIA)**


**Fourier Modal Method (FMM)**

B Operator for Lens by LPIA

Space domain
\( \rho = (x, y) \)

Fourier domain
\( \kappa = (k_x, k_y) \)

\[
\begin{align*}
\mathcal{B}^{(1)} &= \mathcal{P}^{\text{out}} \mathcal{B}^{\text{LPIA}} \mathcal{P}^{\text{in}} \\
\mathcal{B}^{\text{LPIA}} &= Y^{\text{out}} C^{\text{Fres}} Y^{\text{loc}}
\end{align*}
\]

B Operator for Lens by LPIA: Validation on Curved Surface

Results by FEM via JCMSuite

\[ B^{(1)} = P^{\text{out}} B^{\text{LPIA}} P^{\text{in}} \]

- Transmitted $y$ component
- Transmitted $x$ component

Time of LPIA: <1 s  Time of FEM: ~20 mins

B Operator for Lens by LPIA: Validation on Plane

Results by FEM via JCMSuite

\[ B^{(1)} = P_{\text{out}} B_{\text{LPIA}} P_{\text{in}} \]

Time of FEM: ~20 mins
Time of LPIA+FSP: <1 s

B Operator for Microstructure by FMM

Space domain
\[ \rho = (x, y) \]

Fourier domain
\[ \kappa = (k_x, k_y) \]

\[ \begin{bmatrix}
    \hat{E}_{\text{out}}^{(k_{-2})} \\
    \hat{E}_{\text{out}}^{(k_{-1})} \\
    \hat{E}_{\text{out}}^{(k_0)} \\
    \hat{E}_{\text{out}}^{(k_{+1})} \\
    \hat{E}_{\text{out}}^{(k_{+2})} \\
\end{bmatrix}
\]

\[ = \begin{bmatrix}
    \cdots & \cdots & \hat{B}(-2, -2) & \cdots & \hat{B}(0, -2) & \cdots & \hat{B}(+1, -2) & \cdots & \hat{B}(+2, -2) & \cdots \\
    \cdots & \cdots & \hat{B}(-1, -2) & \cdots & \hat{B}(0, 0) & \cdots & \hat{B}(+1, 0) & \cdots & \hat{B}(+2, 0) & \cdots \\
    \cdots & \cdots & \hat{B}(0, -1) & \cdots & \hat{B}(0, 1) & \cdots & \hat{B}(+1, 1) & \cdots & \hat{B}(+2, 1) & \cdots \\
    \cdots & \cdots & \hat{B}(+1, -1) & \cdots & \hat{B}(+1, 1) & \cdots & \hat{B}(+1, 2) & \cdots & \hat{B}(+2, +2) & \cdots \\
    \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\end{bmatrix}
\]

\[ \tilde{B}^{(1)} = W_{\text{out}} S (W_{\text{in}})^{-1} \]


\[ \kappa_{\text{out}} = \kappa_{\text{in}} - \frac{2\pi}{d} \]

\[ \hat{E}_{\text{out}}^{(k_{-1})} = \hat{B}_{-1}^{(k_{-1})} \]

\[ \kappa_{\text{out}} = \kappa_{\text{in}} + \frac{2\pi}{d} \]

\[ \hat{E}_{\text{out}}^{(k_{+1})} = \hat{B}_{+1}^{(k_{+1})} \]
Simulation Results via VirtualLab Fusion
Near and Far Field Images for TE and TM
Near Field for Different Polarizations, without Evanescent Waves

- The near field images for TE and TM are different.
- The contrast for TM is higher the TE in this example.

![Diagram of near field for different polarizations](image)

Several seconds
Far Field for Different Polarizations

- The far field images for TE and TM are different.
- The contrast for TM is higher than TE in this example.

Several seconds
Comparison of Near and Far Field Images
Comparison of the Near Field and Far Field Image

- TE case, the far field image is the magnified near field image.
- TM case, it is not case because of the crosstalk of vectorial components, $E_x$ and $E_z$. 

Near Field

Far Field

TE

TM
Far Field Image Sensitivity of Defects
Far Field Image Sensitivity V.S Defect of Height of PMMA

- The far field image profile has obvious change when the height of PMMA changes from ±20 nm.
The far field image profile changes but not so obviously, when the width of the gold ridge changes by $+40\,\text{nm}$. 
Summary and Conclusion

• We connect the field solvers of lenses and microstructures in the framework of field tracing;

• We apply it to the UV microscopy of inspection of wafer structure.

• We find that,
  − the near and far field images for different polarized illuminations are different.
  − the far field image is not the directly magnified near field image in the TM case.
  − the far field image is more sensitive to the height of the PMMA compared to the width of the gold ridge.
Thanks!
Appendix Near Field with Evanescent Waves
Validation of LPIA

Results by FEM via JCMSuite

Time of FEM: ~20 mins
Time of LPIA: <1 s

Validation of LPIA

Results by FEM via JCMSuite

Time of LPIA+FSP: <1 s  Time of FEM: ~20 mins

Near Field for Different Polarization with Evanescent Waves