Friedrich-Schiller-Universität Jena

EOS Jena 2019

Connection of Field Solvers：Lenses and Microstructures

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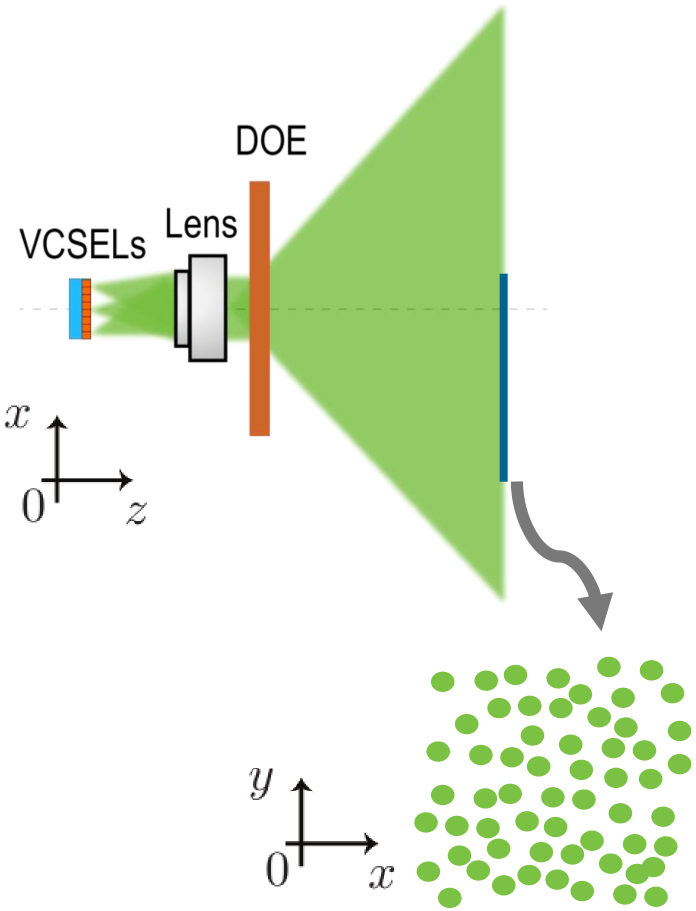
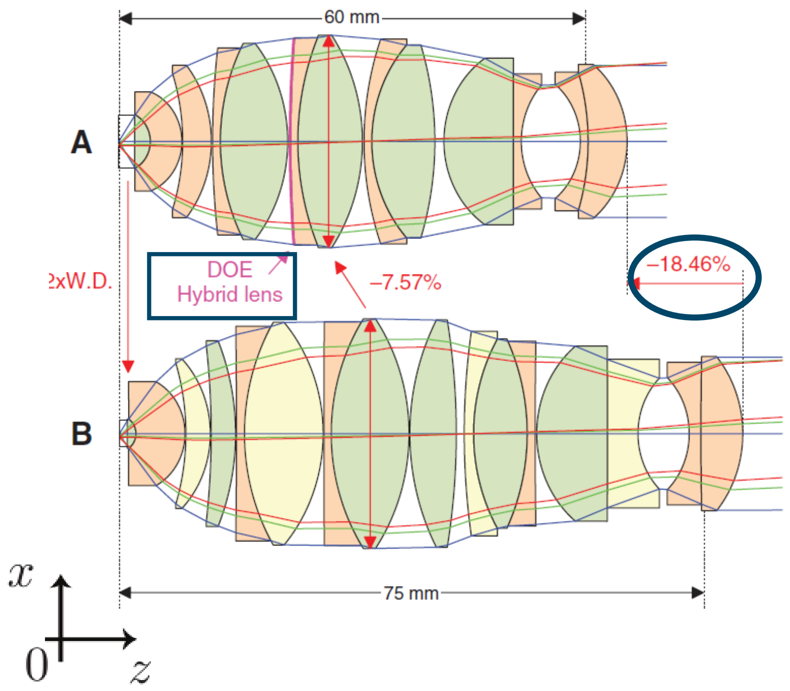
Background: Systems Containing Lenses and Microstructures

dots projection system

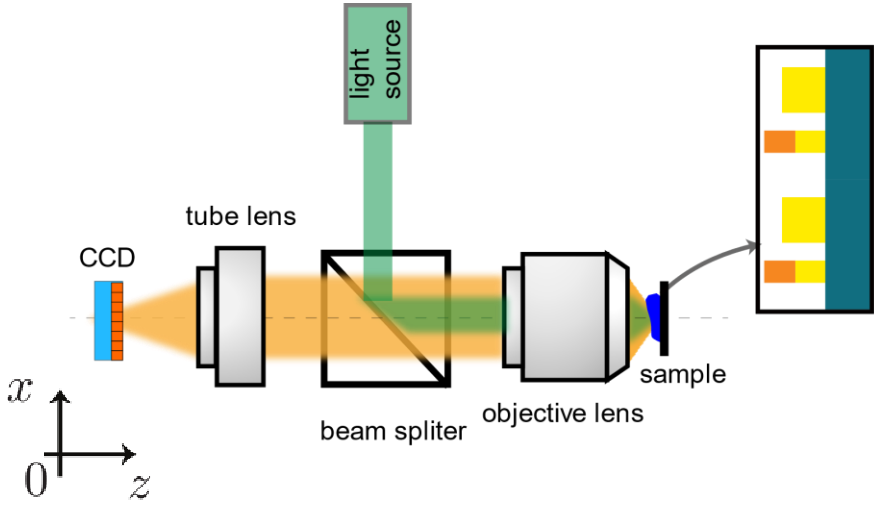


hybrid lens



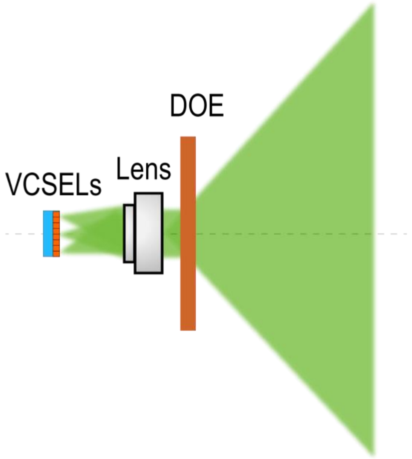
[Y. Zhang et.al Adv.Opt.Tech. 2019]

microscopy system

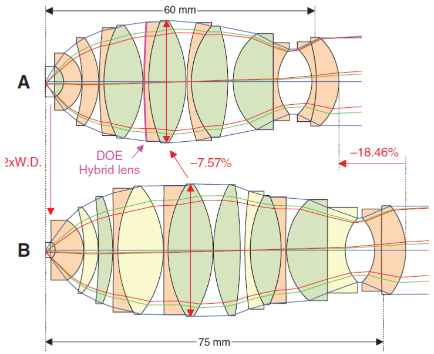


Motivation: Connection of Field Solvers

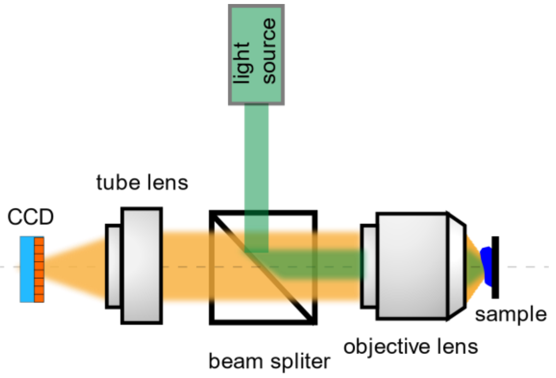
dots projection system



hybrid lens



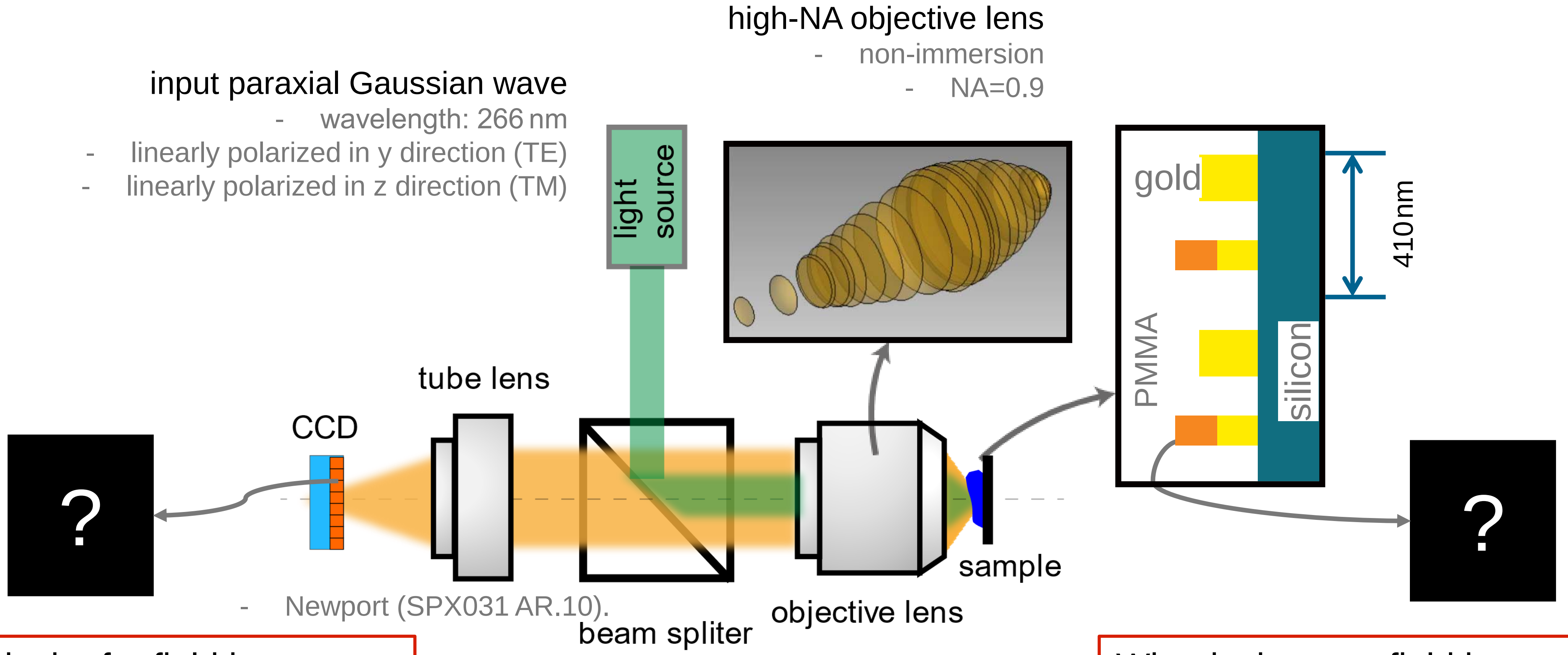
microscopy system



- ➢ Ray tracing is limited, because diffraction, polarization, coherence is not included.
- ➢ Vectorial physical-optics modeling is desired, but FEM, FMM, FDTD etc. are slow.

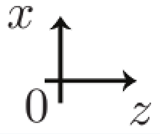
- An efficient and accurate physical-optics modeling with fully vectorial effects is desired.
- Therefore, connection of the field solvers, e.g. lenses and microstructures, is one desired option to model the system efficiently and accurately, with fully vectorial effect.

Task: Ultraviolet (UV) Microscopy for Inspection of Wafer Structure



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

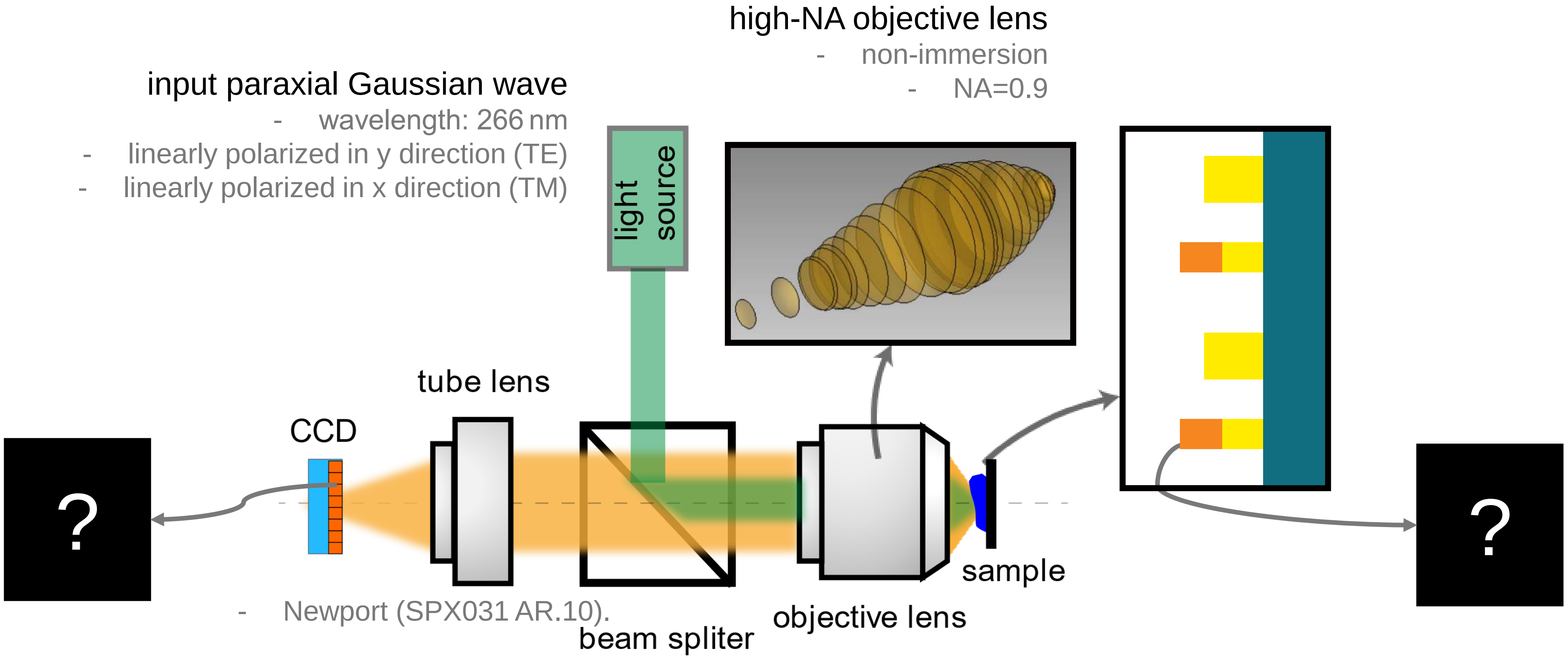
$$w_e \propto \|\boldsymbol{E}\|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2,$$



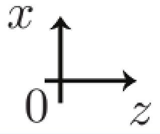
What is the near field images for TE and TM, without showing the evanescent waves?

$$w_e \propto \|\boldsymbol{E}\|^2 = |E_x|^2 + |E_y|^2 + |E_z|^2,$$

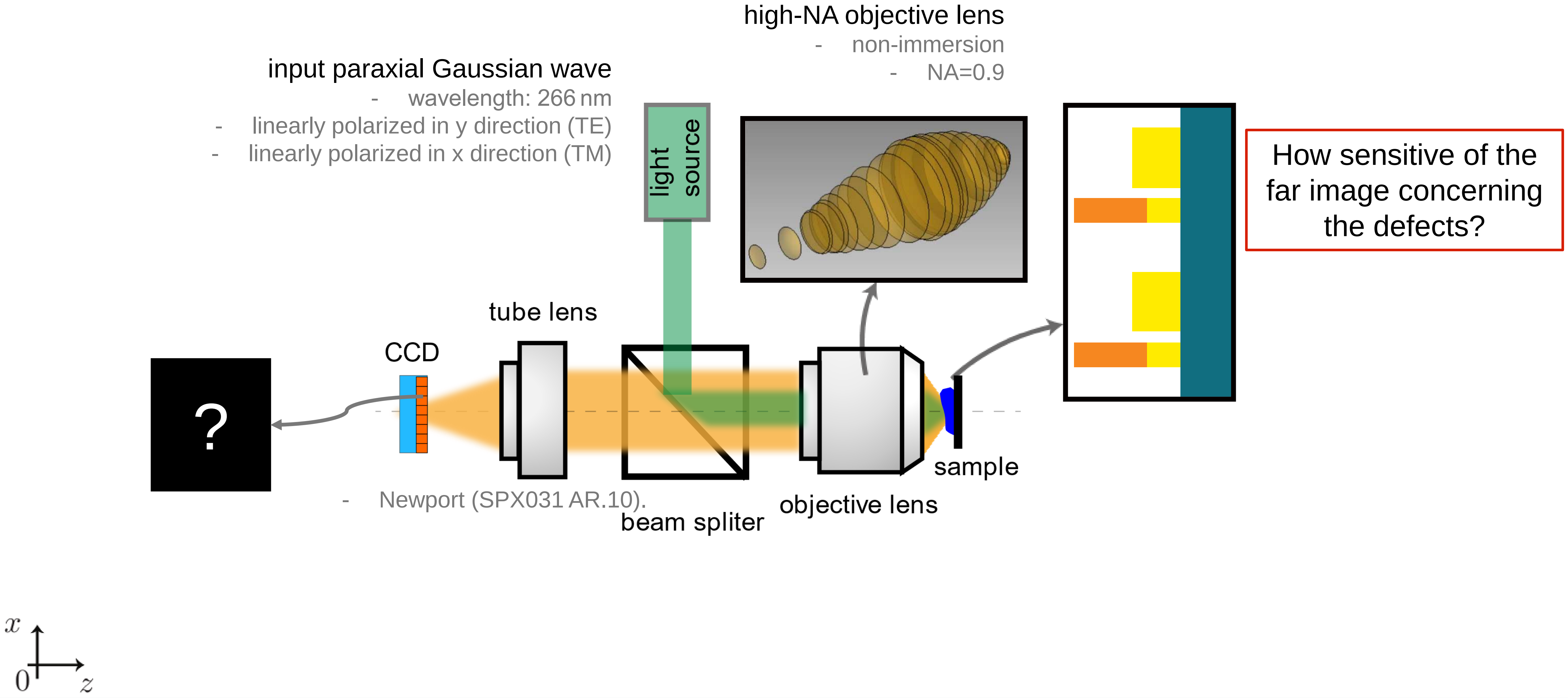
Task: Ultraviolet (UV) Microscopy for Inspection of Wafer Structure



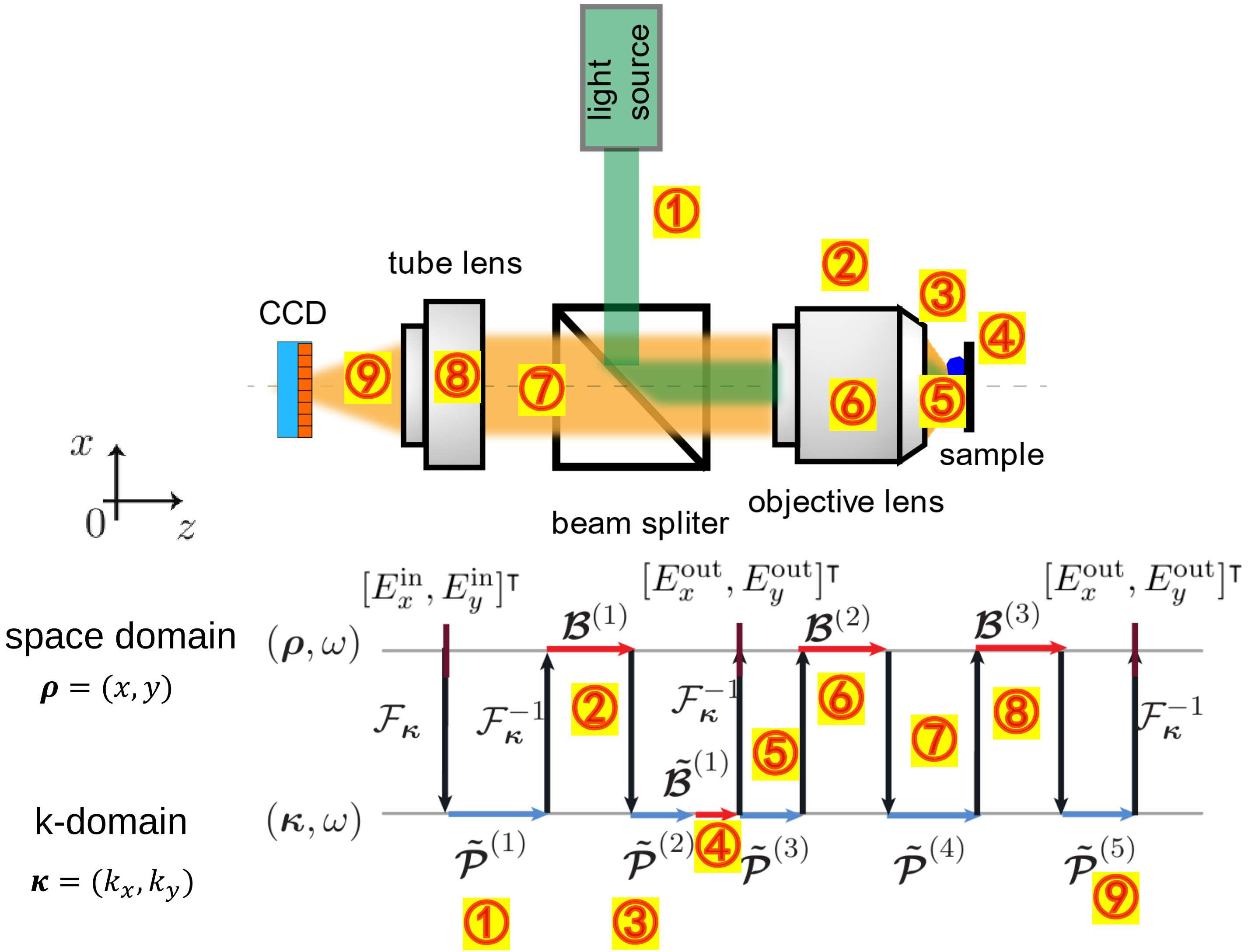
What is the difference between the near and far field images for TE and TM?



Task: Ultraviolet (UV) Microscopy for Inspection of Wafer Structure



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)

① ③ ⑤ ⑦ ⑨

[S. Zhang et al. Appl. Opt. (2016)]

Local Plane Interface Approximation (LPIA)

② ⑥ ⑧

[A. Pfeil et al., Appl. Opt. (2000)]

Fourier Modal Method (FMM)

④

[L.Li, Opt. Soc. Am. A (1993)]

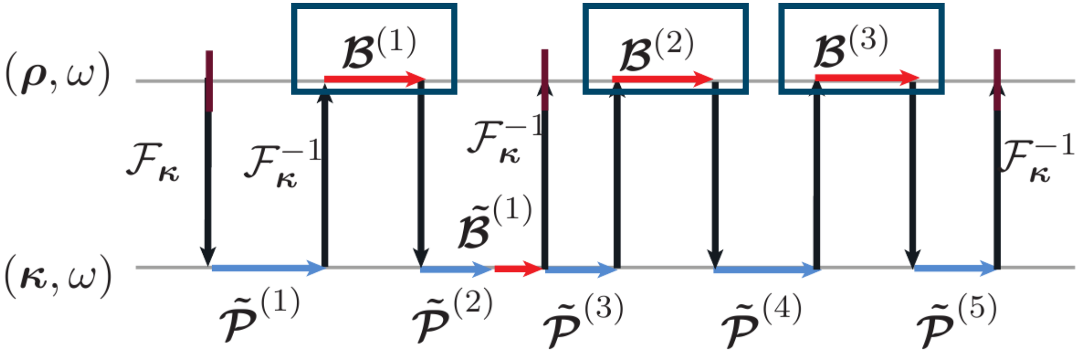
B Operator for Lens by LPIA

Space domain

$\boldsymbol{\rho} = (x, y)$

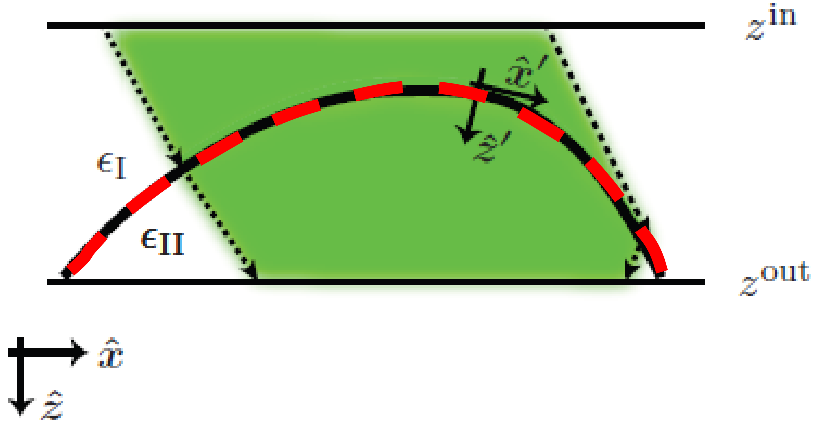
Fourier domain

$\boldsymbol{\kappa} = (k_x, k_y)$



$$\mathcal{B}^{(1)} = \mathcal{P}^{\mathrm{out}} \mathcal{B}^{\mathrm{LPIA}} \mathcal{P}^{\mathrm{in}}$$

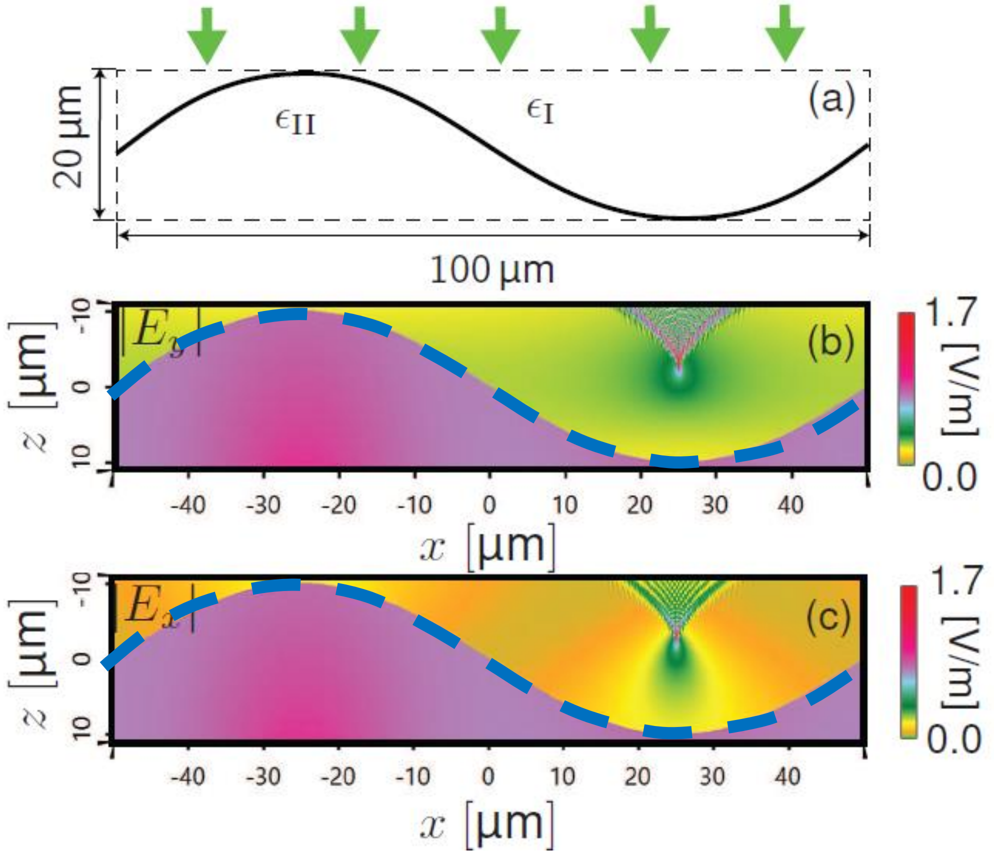
$$\mathcal{B}^{\mathrm{LPIA}} = \boldsymbol{Y}^{\mathrm{out}} \mathcal{C}_{t/r}^{\mathrm{Fres}} \boldsymbol{Y}^{\mathrm{loc}}$$



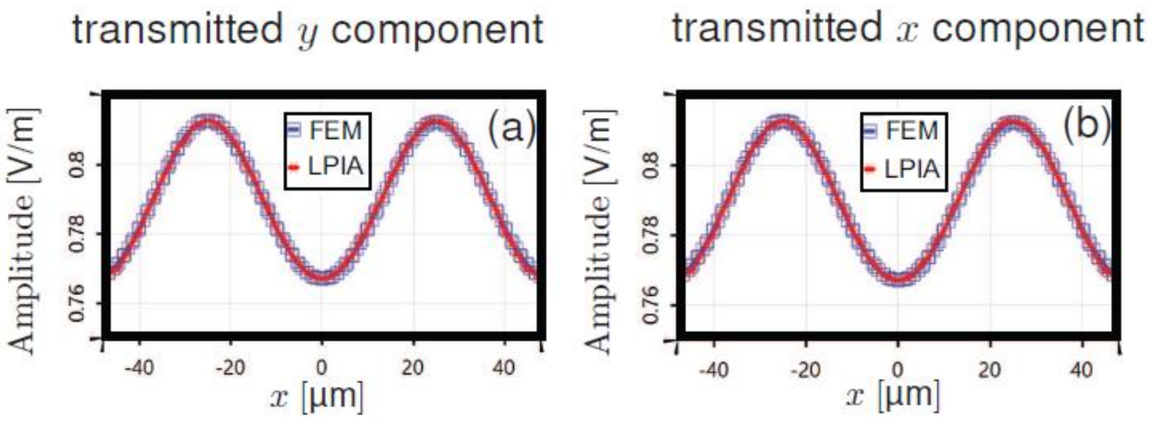
R. Shi, C. Hellmann, and F. Wyrowski, J. Opt. Soc. Am. A **36**, (2019).

B Operator for Lens by LPIA: Validation on Curved Surface

Results by FEM via JCMSuite



$$\mathcal{B}^{(1)} = \mathcal{P}^{\text{out}} \boxed{\mathcal{B}^{\text{LPIA}}} \mathcal{P}^{\text{in}}$$



Time of LPIA: <1 s

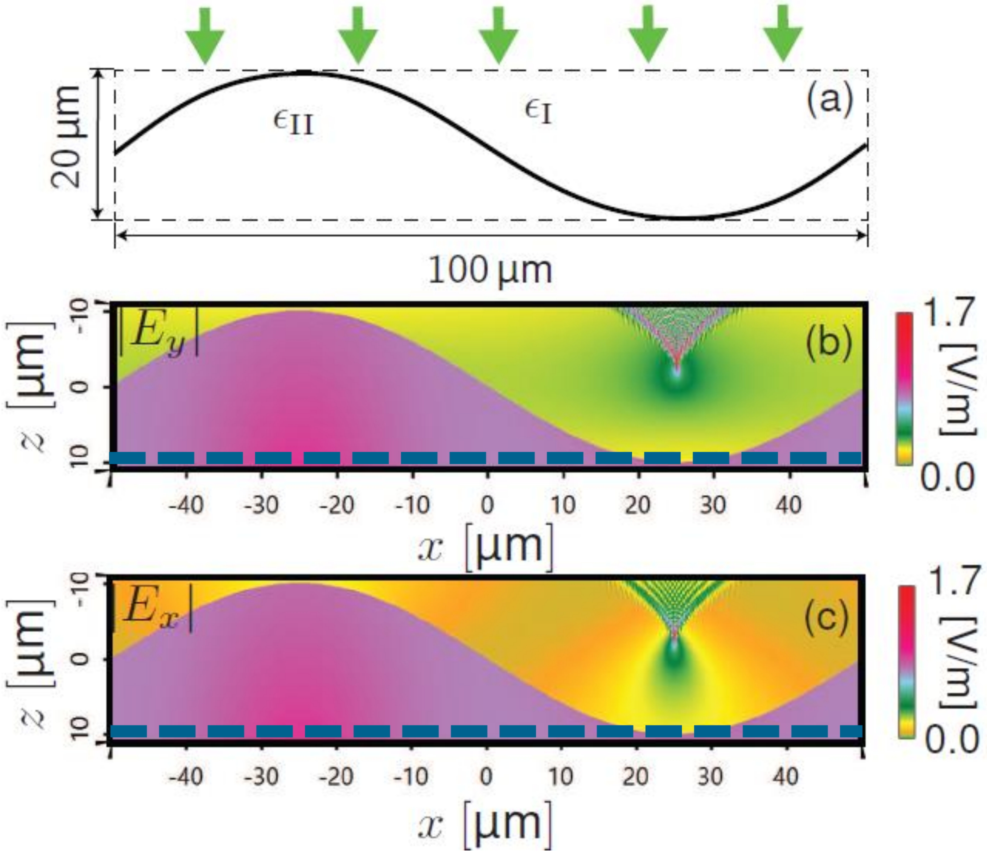
Time of FEM: ~20 mins

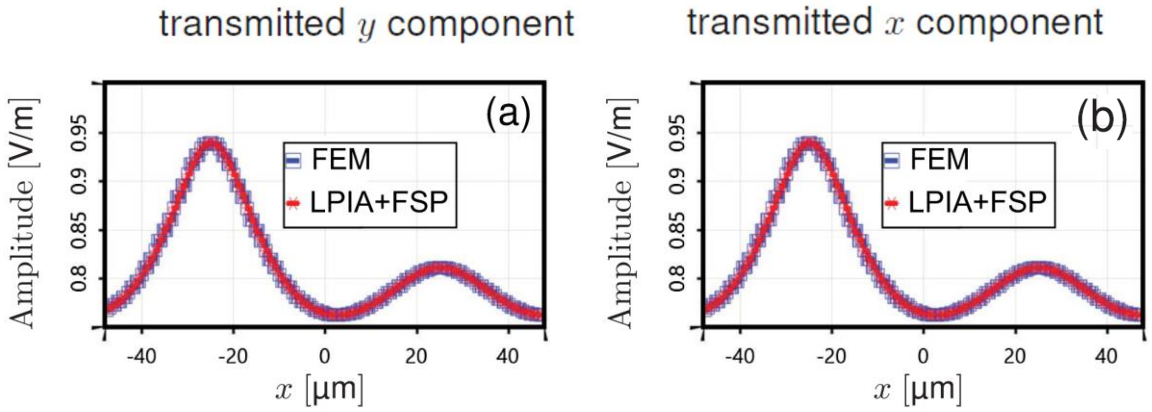
R. Shi, C. Hellmann, and F. Wyrowski, J. Opt. Soc. Am. A **36**, (2019).

B Operator for Lens by LPIA: Validation on Plane

Results by FEM via JCMSuite

$$\boxed{\boldsymbol{\mathcal{B}}^{(1)}} = \boldsymbol{\mathcal{P}}^{\mathrm{out}}\boldsymbol{\mathcal{B}}^{\mathrm{LPIA}}\boldsymbol{\mathcal{P}}^{\mathrm{in}}$$





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

R. Shi, C. Hellmann, and F. Wyrowski, J. Opt. Soc. Am. A **36**, (2019).

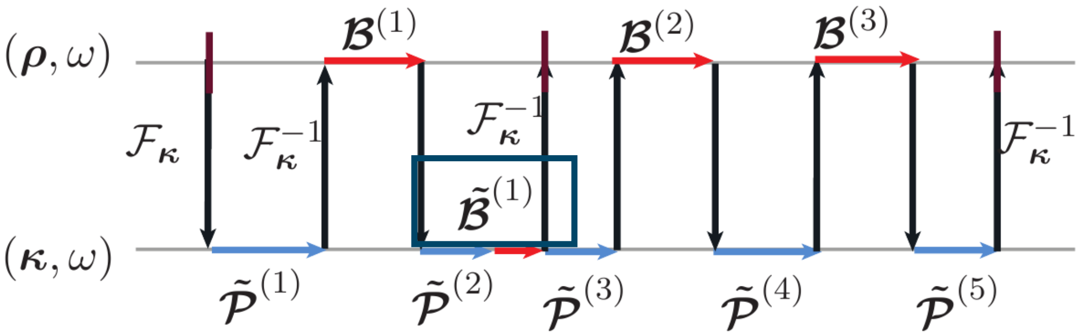
B Operator for Microstructure by FMM

Space domain

$\boldsymbol{\rho} = (x, y)$

Fourier domain

$\boldsymbol{\kappa} = (k_x, k_y)$



[L. Li, J. Opt. Soc. Am. A (2003)]

$$\tilde{\mathcal{B}}^{(1)} = \boldsymbol{W}^{\text{out}} \boldsymbol{\mathcal{S}} \left(\boldsymbol{W}^{\text{in}}\right)^{-1}$$

$$\begin{bmatrix} \cdots \\ \cdots \\ \tilde{\boldsymbol{E}}_\perp^{\text{out}}\left(\boldsymbol{\kappa}_{-2}^{\text{out}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{out}}\left(\boldsymbol{\kappa}_{-1}^{\text{out}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{out}}\left(\boldsymbol{\kappa}_{0}^{\text{out}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{out}}\left(\boldsymbol{\kappa}_{+1}^{\text{out}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{out}}\left(\boldsymbol{\kappa}_{+2}^{\text{out}}\right) \\ \cdots \\ \cdots \end{bmatrix} = \begin{bmatrix} \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \tilde{\mathcal{B}}(-2,-2) & \tilde{\mathcal{B}}(-2,-1) & \tilde{\mathcal{B}}(-2,0) & \tilde{\mathcal{B}}(-2,1) & \tilde{\mathcal{B}}(-2,2) & \cdots \\ \cdots & \tilde{\mathcal{B}}(-1,-2) & \tilde{\mathcal{B}}(-1,-1) & \tilde{\mathcal{B}}(-1,0) & \tilde{\mathcal{B}}(-1,1) & \tilde{\mathcal{B}}(-1,2) & \cdots \\ \cdots & \tilde{\mathcal{B}}(0,-2) & \tilde{\mathcal{B}}(0,-1) & \tilde{\mathcal{B}}(0,0) & \tilde{\mathcal{B}}(0,1) & \tilde{\mathcal{B}}(0,2) & \cdots \\ \cdots & \tilde{\mathcal{B}}(+1,-2) & \tilde{\mathcal{B}}(+1,-1) & \tilde{\mathcal{B}}(+1,0) & \tilde{\mathcal{B}}(+1,1) & \tilde{\mathcal{B}}(+1,2) & \cdots \\ \cdots & \tilde{\mathcal{B}}(+2,-2) & \tilde{\mathcal{B}}(+2,-1) & \tilde{\mathcal{B}}(+2,0) & \tilde{\mathcal{B}}(+2,+1) & \tilde{\mathcal{B}}(+2,+2) & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \end{bmatrix} \begin{bmatrix} \cdots \\ \cdots \\ \tilde{\boldsymbol{E}}_\perp^{\text{in}}\left(\boldsymbol{\kappa}_{-2}^{\text{in}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{in}}\left(\boldsymbol{\kappa}_{-1}^{\text{in}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{in}}\left(\boldsymbol{\kappa}_{0}^{\text{in}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{in}}\left(\boldsymbol{\kappa}_{+1}^{\text{in}}\right) \\ \tilde{\boldsymbol{E}}_\perp^{\text{in}}\left(\boldsymbol{\kappa}_{+2}^{\text{in}}\right) \\ \cdots \\ \cdots \end{bmatrix}$$

$$\boldsymbol{\kappa}^{\text{out}} = \boldsymbol{\kappa}^{\text{in}} - 2\pi/d$$

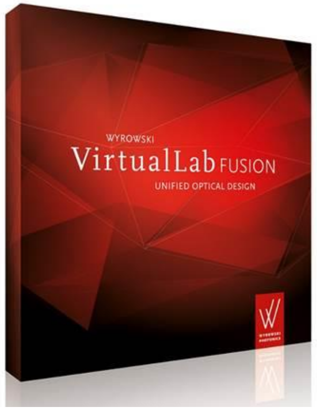
$$\tilde{\boldsymbol{E}}_{\perp,-1}^{\text{out}} = \tilde{\mathcal{B}}_{-1}\tilde{\boldsymbol{E}}_\perp^{\text{in}}$$

$$\boldsymbol{\kappa}^{\text{out}} = \boldsymbol{\kappa}^{\text{in}}$$

$$\tilde{\boldsymbol{E}}_{\perp,0}^{\text{out}} = \tilde{\mathcal{B}}_{0}\tilde{\boldsymbol{E}}_\perp^{\text{in}}$$

$$\boldsymbol{\kappa}^{\text{out}} = \boldsymbol{\kappa}^{\text{in}} + 2\pi/d$$

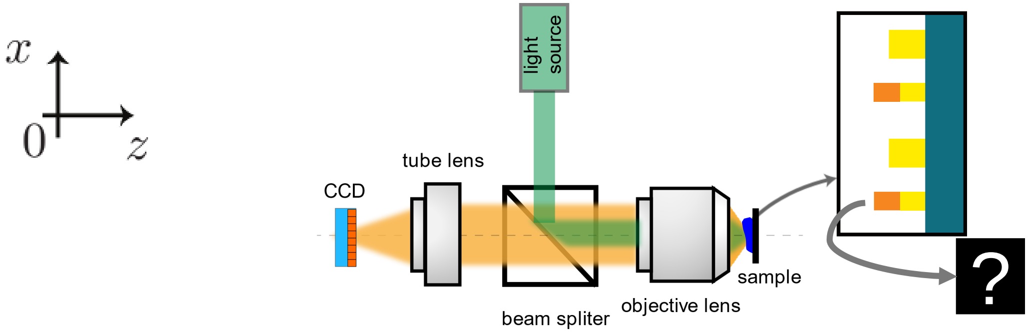
$$\tilde{\boldsymbol{E}}_{\perp,+1}^{\text{out}} = \tilde{\mathcal{B}}_{+1}\tilde{\boldsymbol{E}}_\perp^{\text{in}}$$



Simulation Results via VirtualLab Fusion

Near and Far Field Images for TE and TM

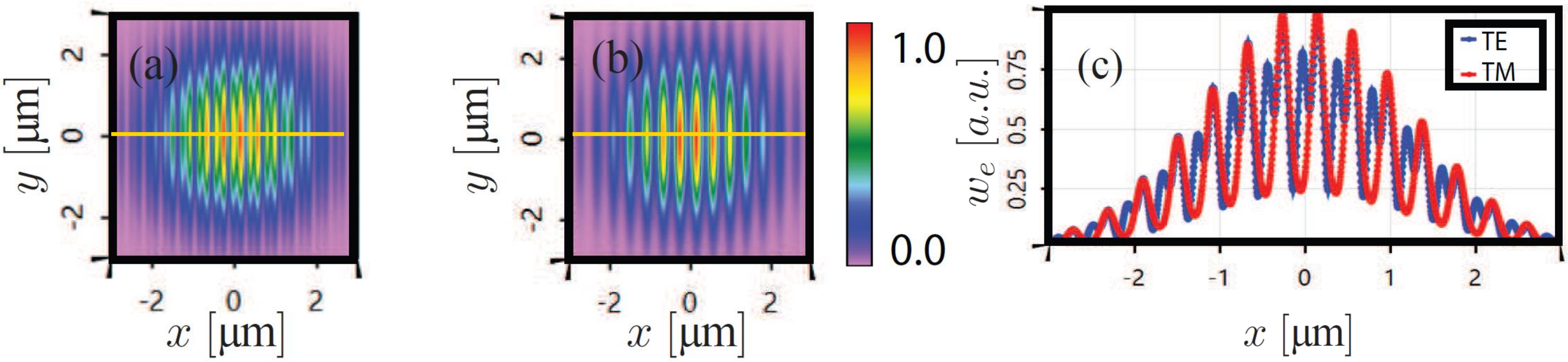
Near Field for Different Polarizations, without Evanescent Waves



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

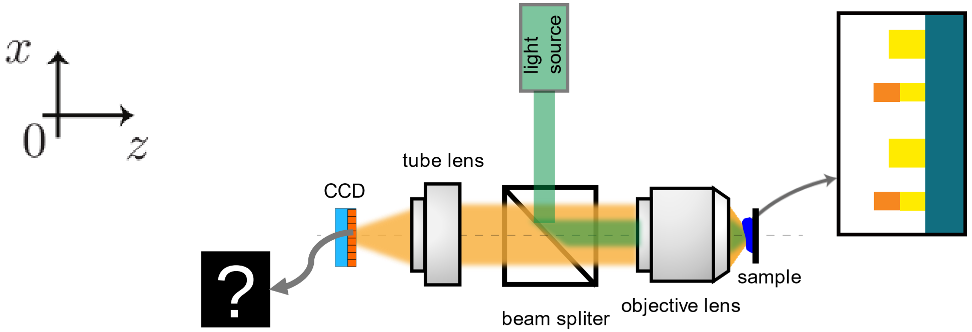
TE

TM

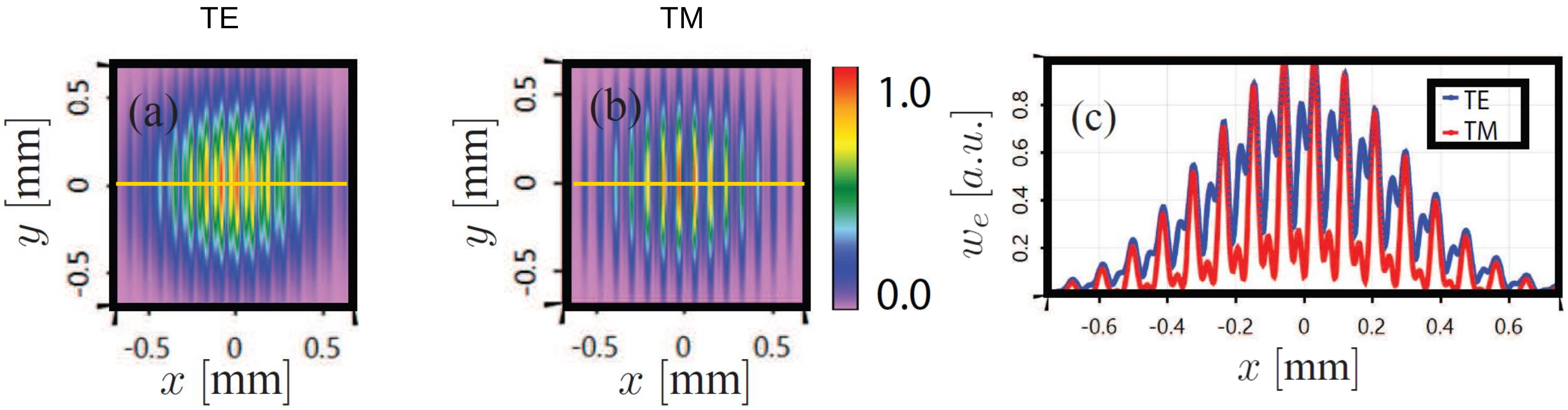


several seconds

Far Field for Different Polarizations



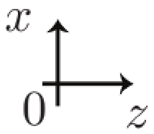
- The far field images for TE and TM are different.
- The contrast for TM is higher the TE in this example.

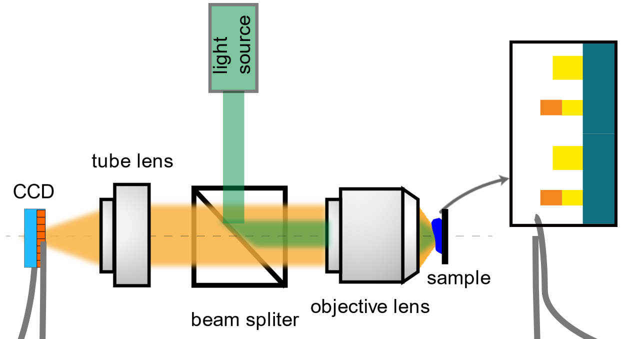


several seconds

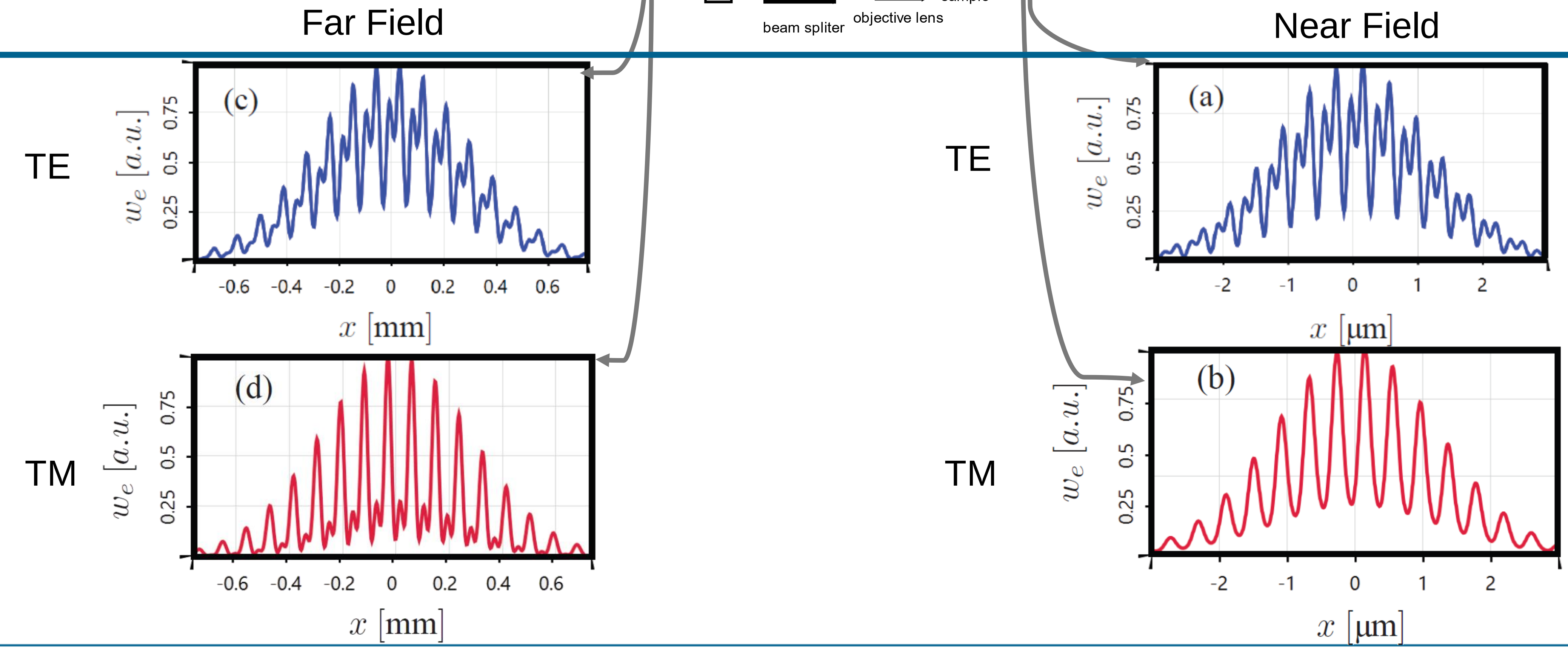
Comparison of Near and Far Field Images

Comparison of the Near Field and Far Field Image



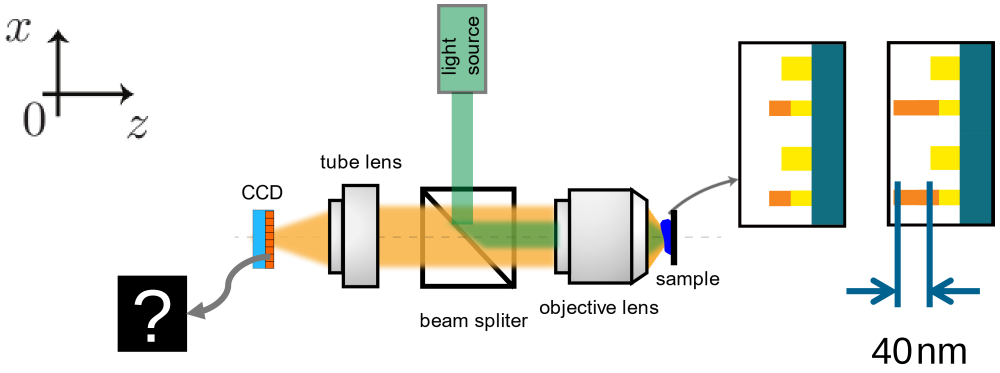


- TE case, the far field image is the magnified near field image.
- TM case, it is not case because of the crosstalk of vectorial components, E_x and E_z .



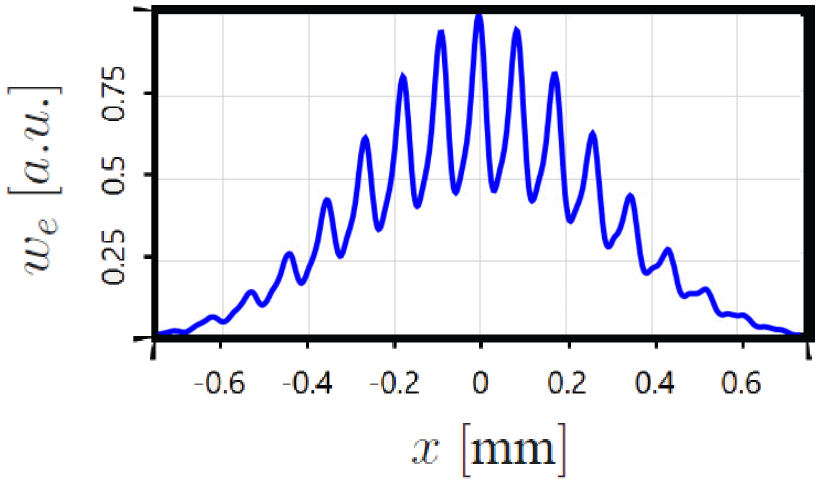
Far Field Image Sensitivity of Defects

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

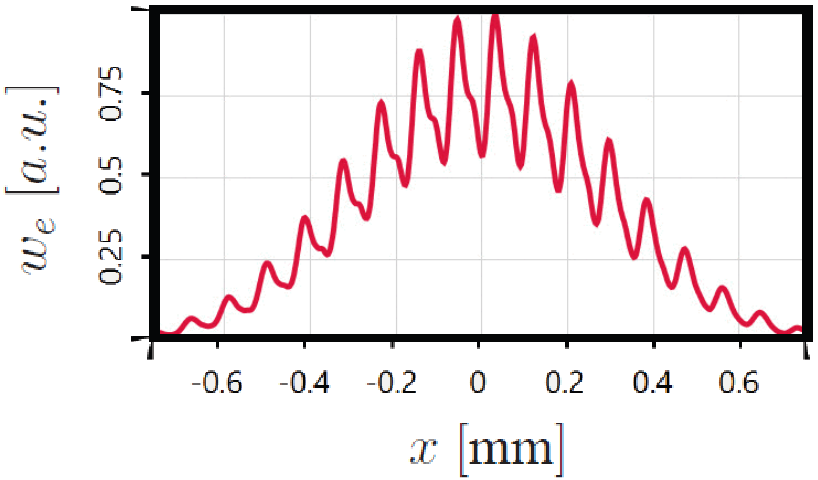


- The far field image profile has obvious change when the height of PMMA changes from ± 20 nm.

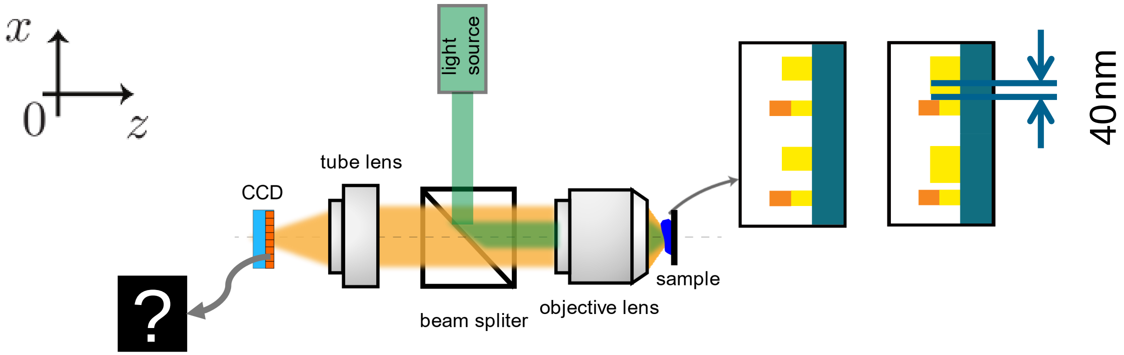
TE



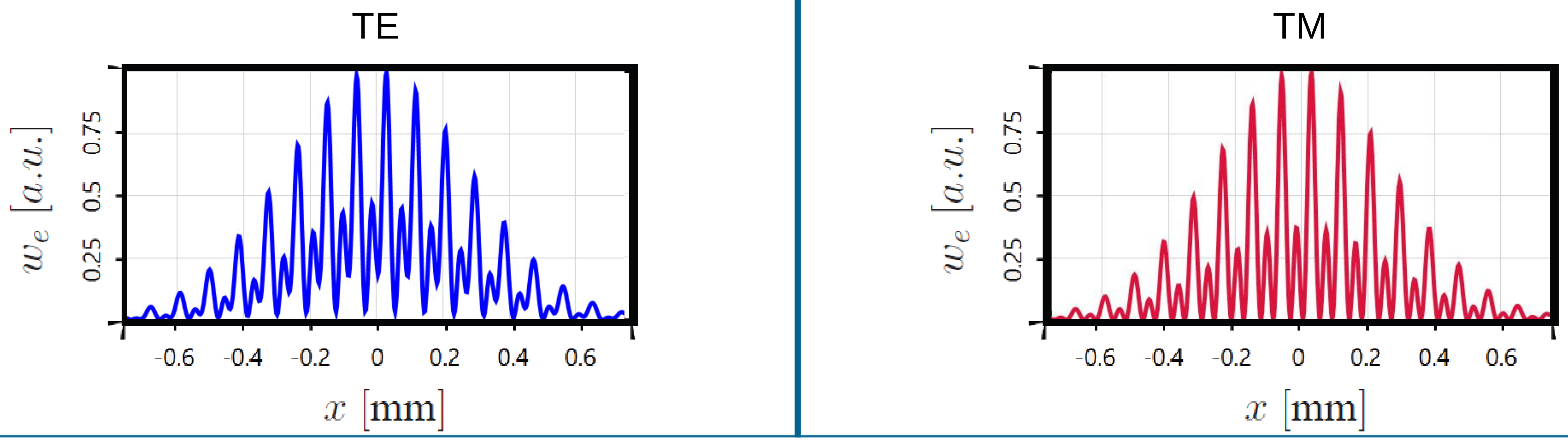
TM



Far Field Image Sensitivity V.S Defect of Width of Gold Ridge



- The far field image profile changes but not so obviously, when the width of the gold ridge changes by $+40\,$nm.



Summary and Conclusion

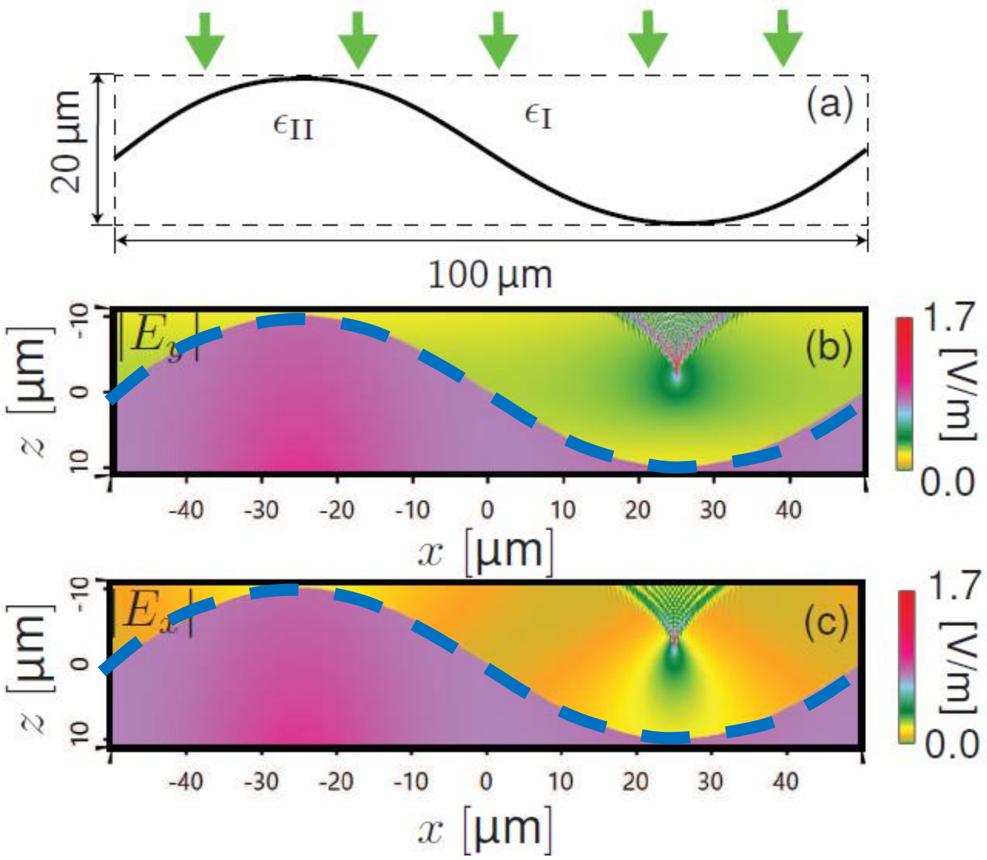
- We connect the field solvers of lenses and microstructures in the framework of field tracing;
- We apply it to the UV microscopy of inspection of wafer structure.
- We find that,
  - the near and far field images for different polarized illuminations are different.
  - the far field image is not the 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.

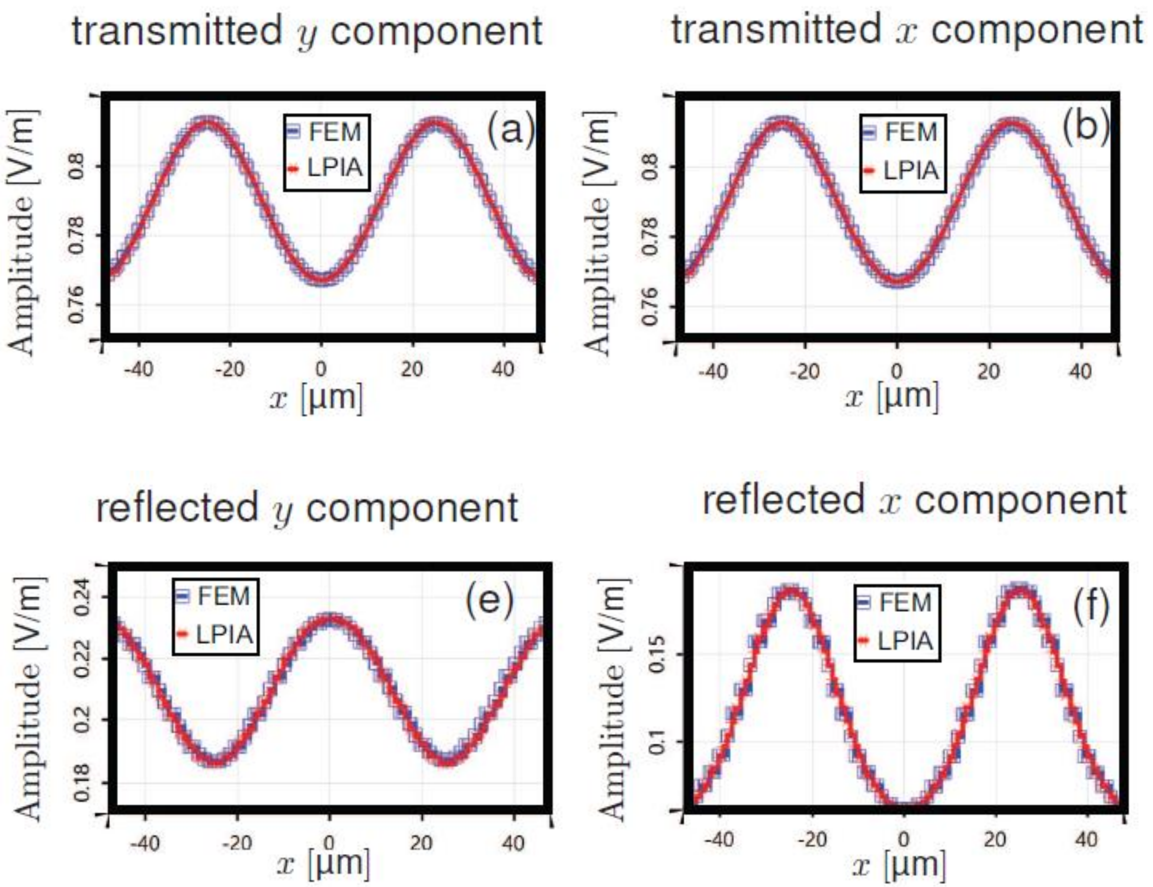
Thanks!

Appendix Near Field with Evanescent Waves

Validation of LPIA

Results by FEM via JCMSuite





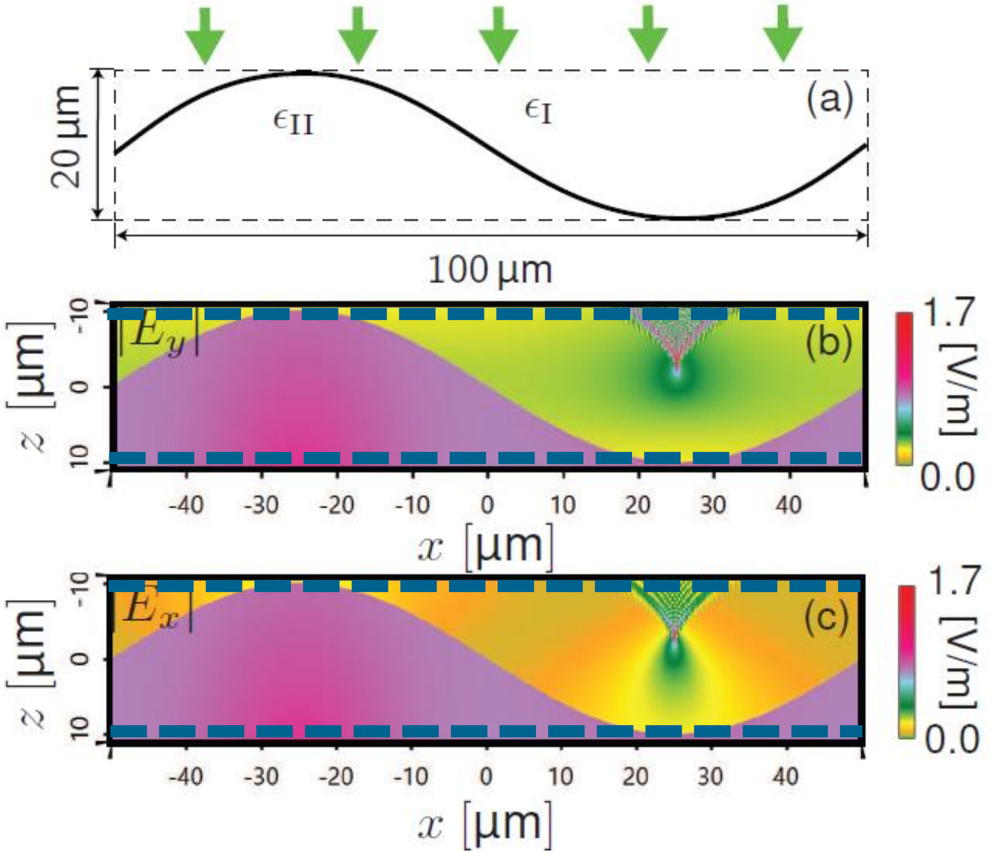
Time of LPIA: <1 s

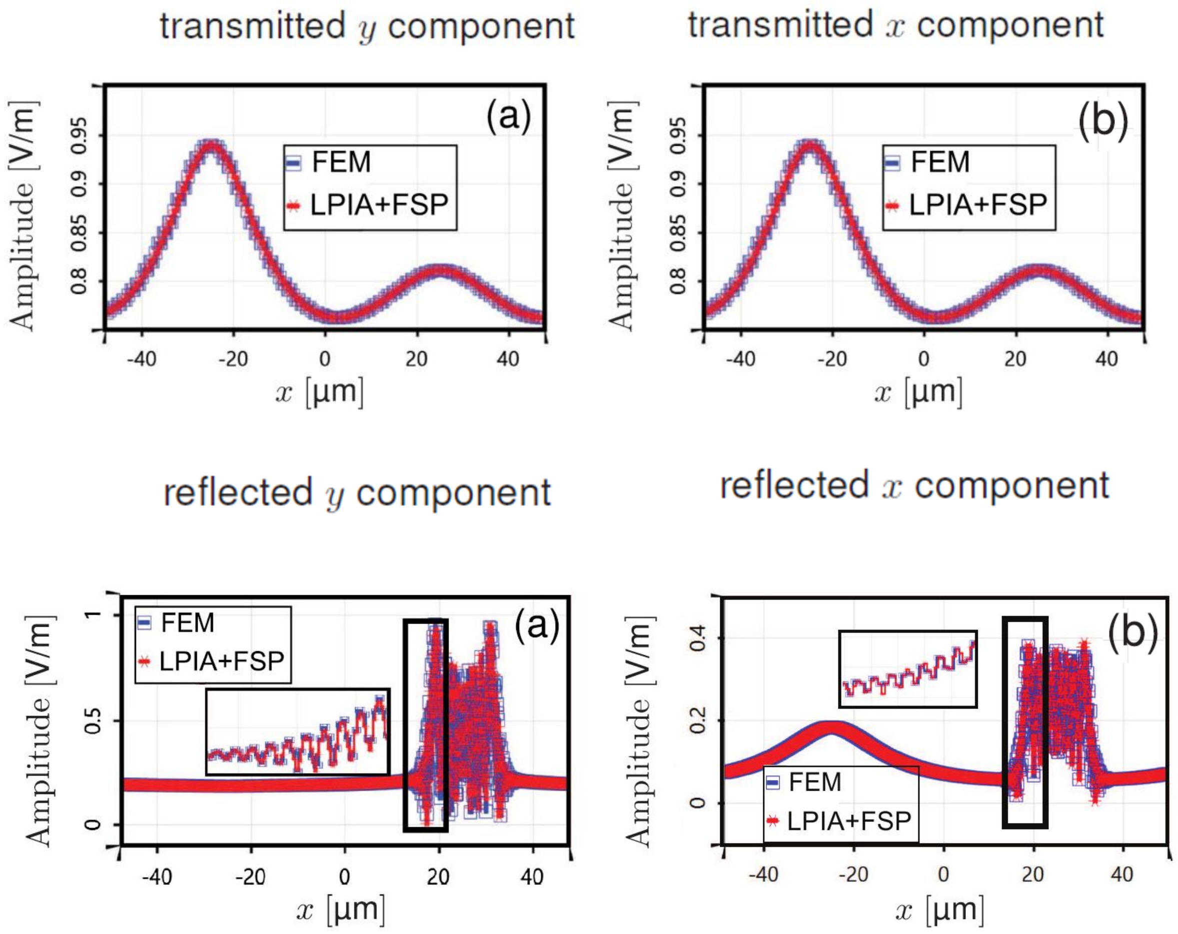
Time of FEM: ~20 mins

R. Shi, C. Hellmann, and F. Wyrowski, J. Opt. Soc. Am. A **36**, (2019).

Validation of LPIA

Results by FEM via JCMSuite





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

R. Shi, C. Hellmann, and F. Wyrowski, J. Opt. Soc. Am. A **36**, (2019).

Near Field for Different Polarization with Evanescent Waves