Improved inspection performance of coherent scattering microscopy by applying ptychography

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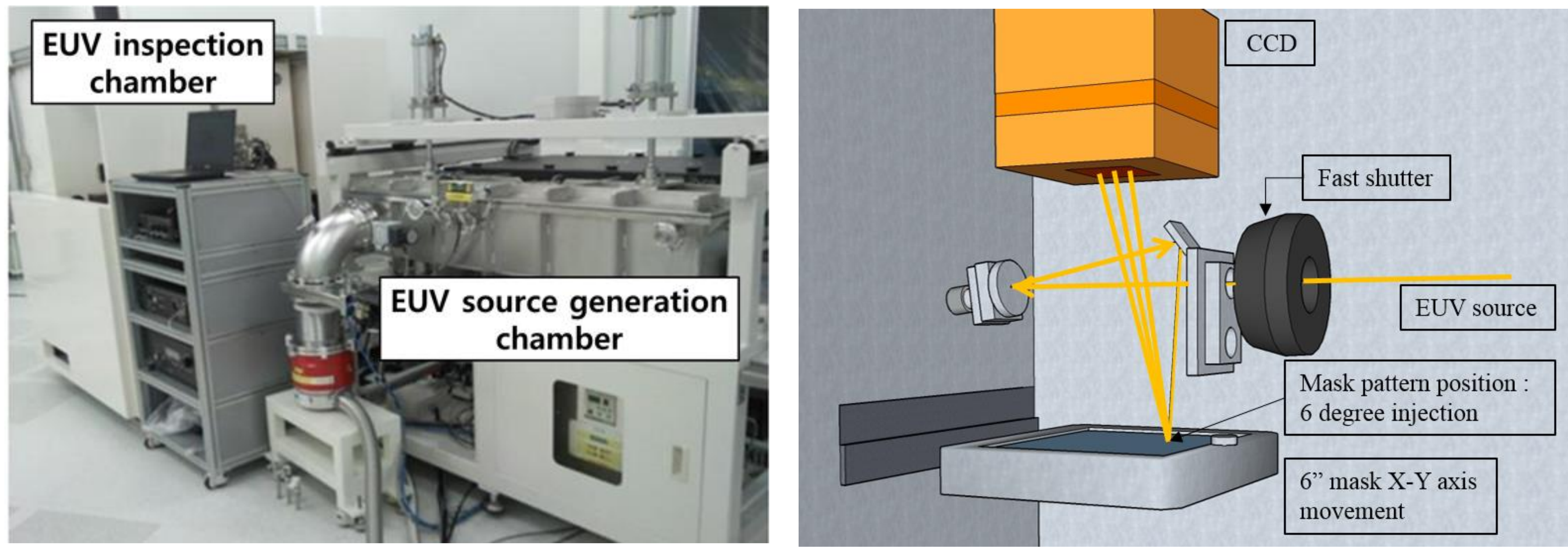
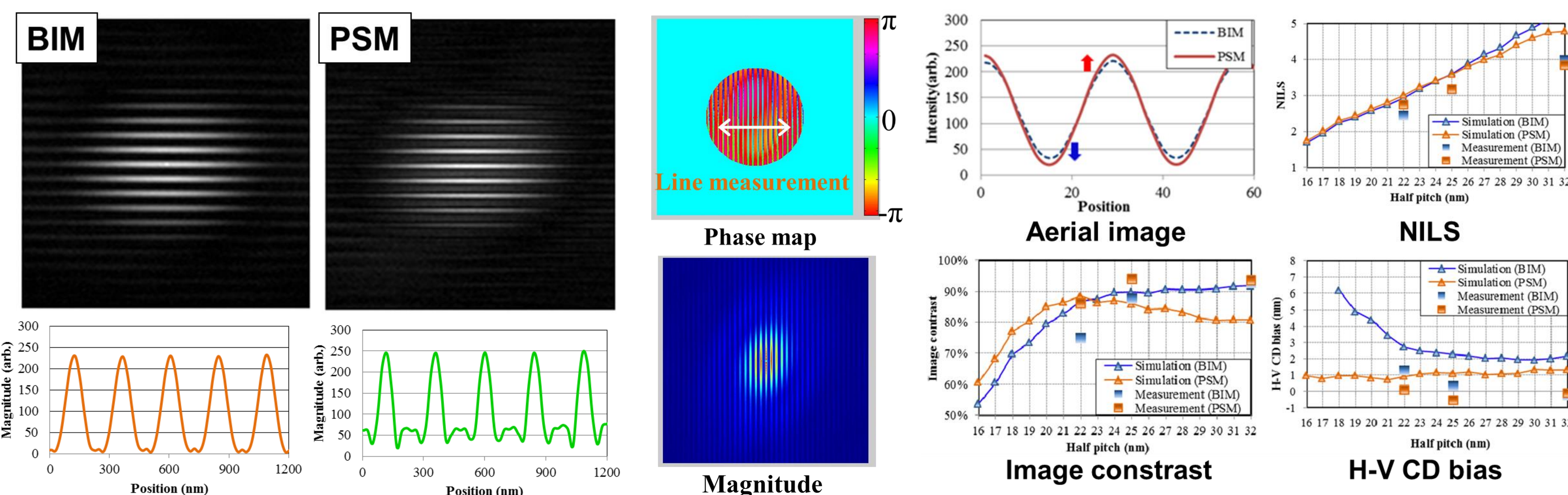
INTRODUCTION

❑ Coherent Scattering Microscopy (CSM)



< Coherent Scattering Microscopy >

- Actinic inspection tool for evaluating imaging performance of EUV mask



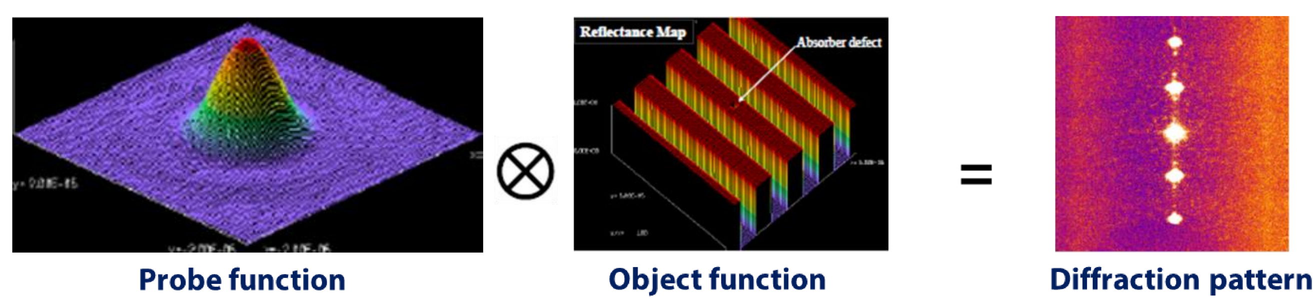
< Mask evaluation result of CSM >

- Mask performance can be analyzed by CSM (aerial image, phase information, through pellicle inspection….)
- Limited field of view (FOV) ~ inspection source size

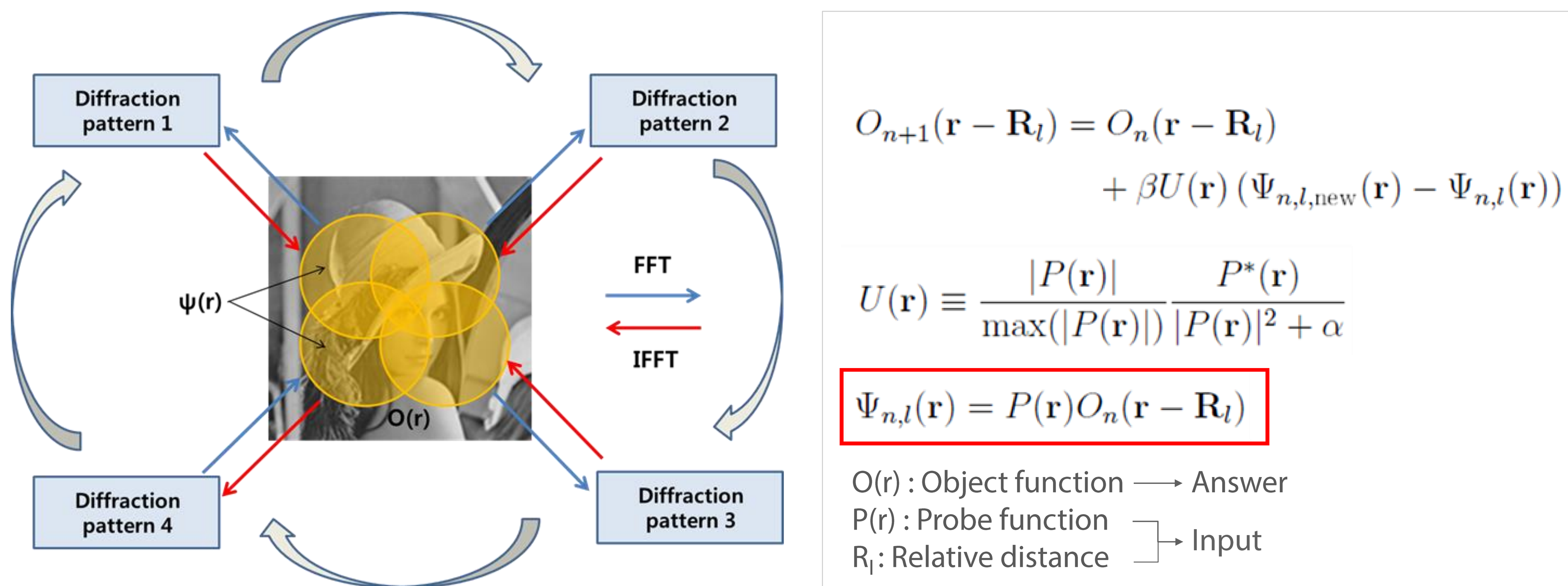
➢ Ptychographical iterative engine (PIE) is applied to expand FoV

EXPERIMENT

❑ Applying ptychographical iterative engine (PIE)



< convolution of probe and object function >

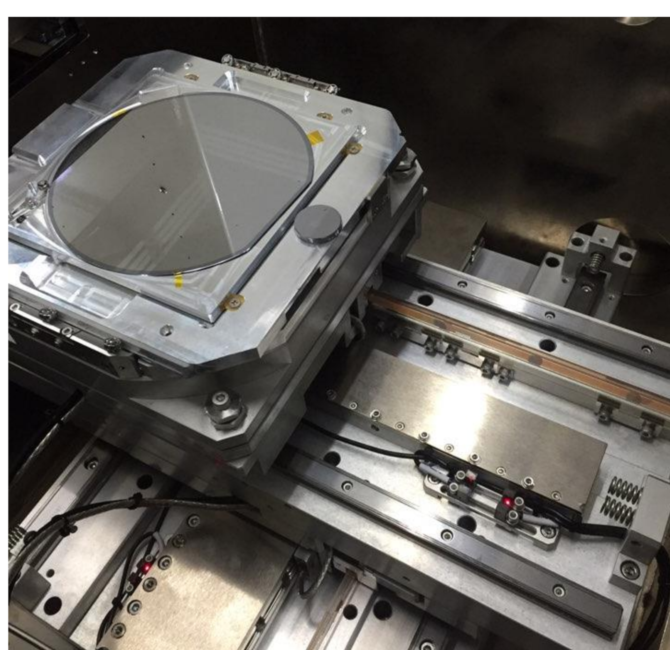


< Schematic view of ptychographical iterative engine (PIE) > < Mathematics in PIE >

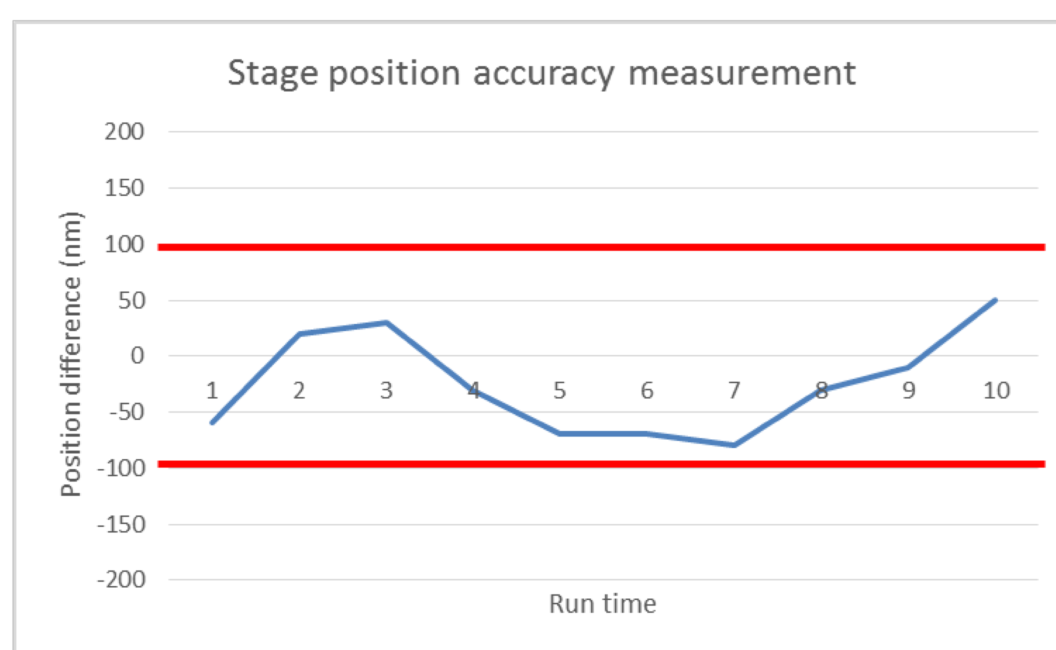
- PIE - An iterative method based on coherent diffraction imaging (CDI) for solving the object function at high resolution using overlapping of probe positions
- Separating probe function and object function ⇒ Image stitching from separated object function
- The object function is updated during iteration of the algorithm

➢ Ptychography requires finite probe function and accurate relative position between diffraction patterns

❑ Hardware requirement



< High precision stage of CSM >

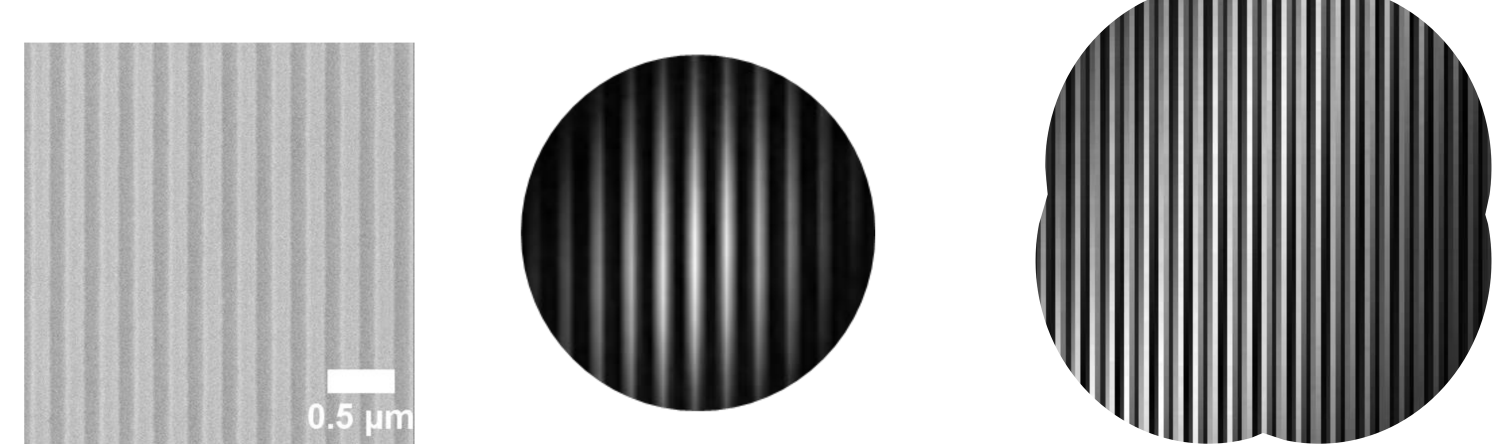


< Stage position accuracy measurement >

- High precision stage for minimizing the physical error ⇒ Essential for applying ptychography
- Position accuracy : within in 100nm (@1㎛ step size)
- Resolution : sub-micron

RESULTS & DISCUSSION (PIE)

❑ Comparison of conventional CDI and ptychography



➢ Probe information & position error

< Comparison of reconstructed image of 128 nm L/S EUV mask, CD-SEM (left, 3㎛ x3 ㎛), CSM, conventional CDI (middle, 2.5㎛ x 2.5㎛), PIE (right, 3㎛ x 3㎛) >

- FoV can be enlarged by image stitching
- Difficulty in pattern identification due to inaccuracy of the probe function between reconstructed images

➢ Need to modify PIE for compensating the probe function error

RESULTS & DISCUSSION (Modified PIE)

❑ extended PIE (ePIE)

$$O_{j+1}(\mathbf{r}) = O_j(\mathbf{r}) + \alpha \frac{P_j^*(\mathbf{r}-\mathbf{R}_{s(j)})}{|P_j(\mathbf{r}-\mathbf{R}_{s(j)})|^2_{\max}} (\psi_j'(\mathbf{r}) - \psi_j(\mathbf{r})).$$

Conventional PIE

+

$$P_{j+1}(\mathbf{r}) = P_j(\mathbf{r}) + \beta \frac{O_j^*(\mathbf{r}+\mathbf{R}_{s(j)})}{|O_j(\mathbf{r}+\mathbf{R}_{s(j)})|^2_{\max}} (\psi_j'(\mathbf{r}) - \psi_j(\mathbf{r})).$$

The probe update function

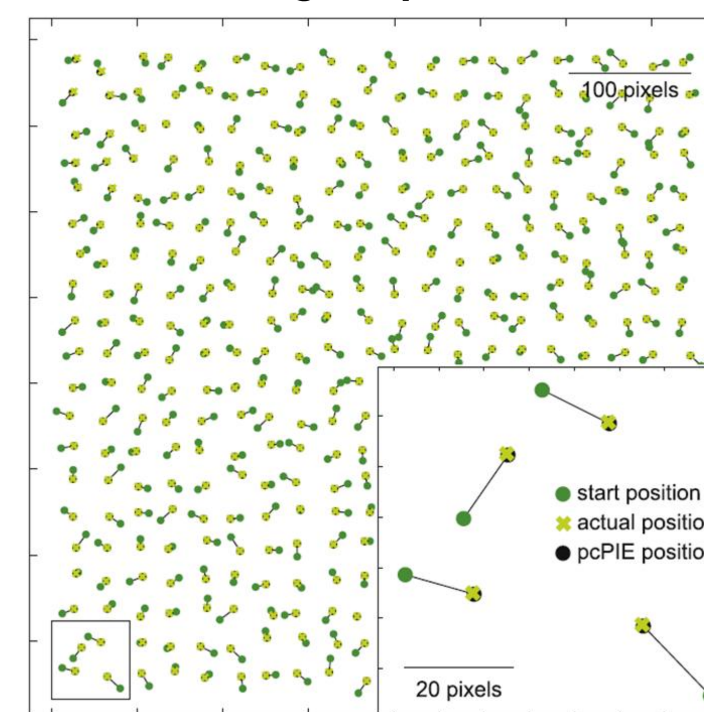
ePIE

< Update function of PIE and ePIE >

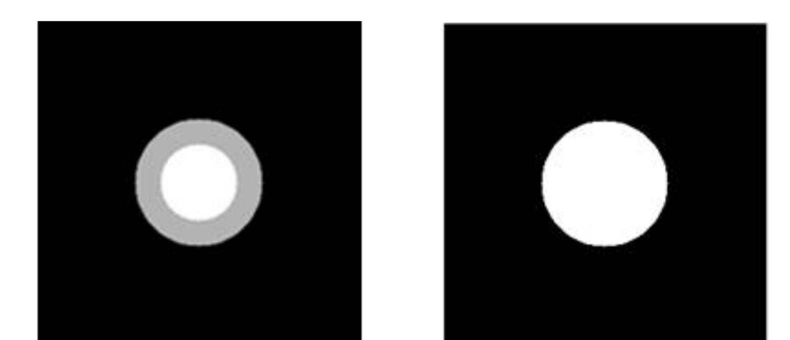
< Simulated reconstructed image of PIE (left) and ePIE (right) >

- ePIE – Extended algorithm which updates both the object and the probe functions during image reconstruction to compensate the probe function error
- Boundaries between reconstructed images are removed due to the probe function update
- However, still insufficient resolution ⇒ Relative distance between diffraction patterns are inaccurate

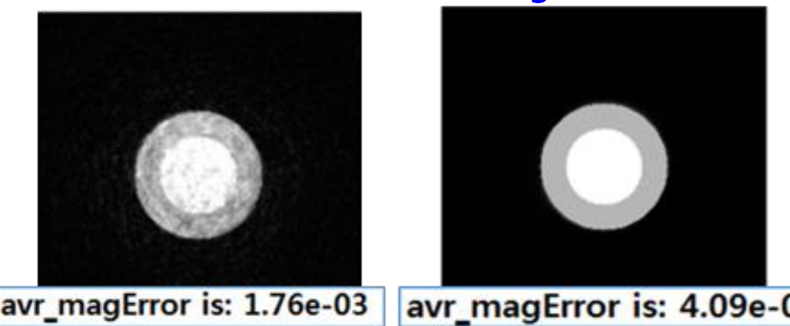
❑ position correcting PIE (pcPIE)



< Position correcting results of pcPIE >



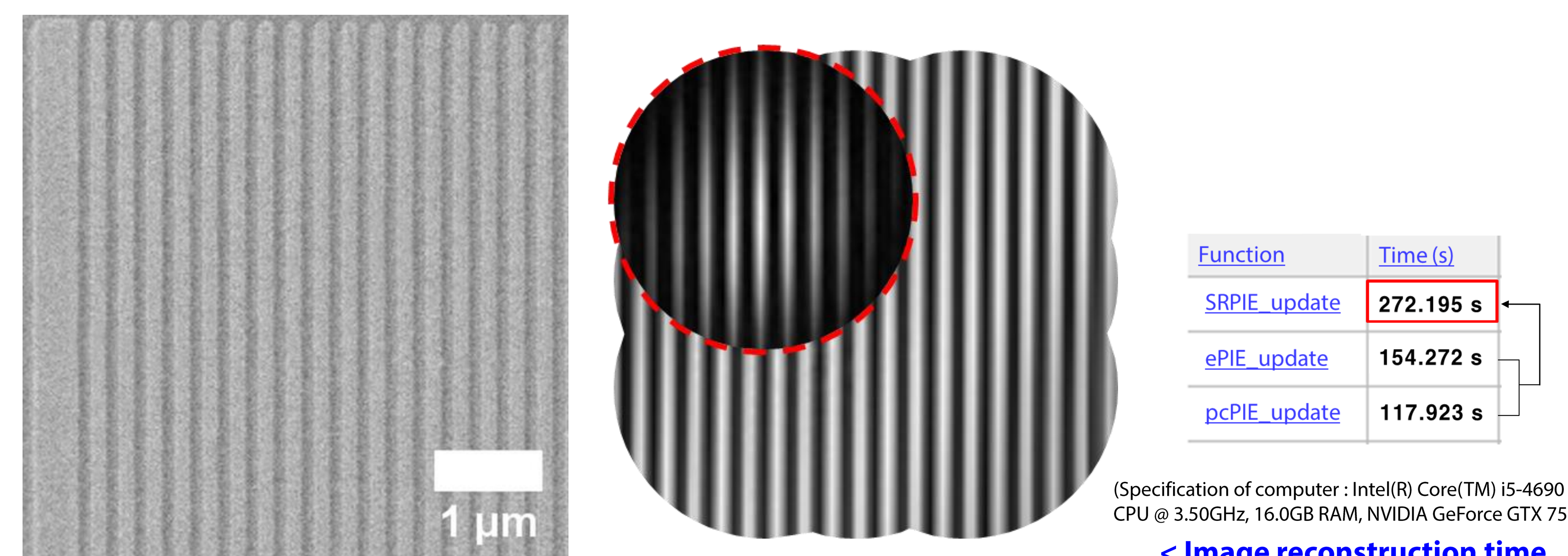
< Ground truth & initial guess >



< Reconstructed probe of ePIE (left) and pcPIE (right) >

- pcPIE – Algorithm for correcting experimental position deviation caused by inaccuracy of stage and thermal drift
- The initial object and probe function are updated by ePIE + the position correction vectors are updated simultaneously
- Noise of reconstructed probe also decreases by modification of position error

❑ Reconstructed image via modified PIE



Function	Time (s)
SRPIE_update	272.195 s
ePIE_update	154.272 s
pcPIE_update	117.923 s

(Specification of computer : Intel(R) Core(TM) i5-4690 CPU @ 3.50GHz, 16.0GB RAM, NVIDIA GeForce GTX 750)

< Mask image using CD-SEM (left, 5㎛ x 5㎛) and reconstructed image using modified PIE(right, 4.3㎛ x 4.3㎛) : Circular image is before applying ptychography >

< Image reconstruction time of modified PIE>

- 128 nm (32nm at wafer scale) L/S EUV mask patterns, 4.3㎛ x 4.3㎛
  - 9 point measurements (500nm shifting per point) ,100 iterations of each algorithm
- Resolution improvement of reconstructed image resolution by compensating position error
- When replaced with an i7 CPU, image reconstruction time is 5~10 times faster.
- Applying laser interferometer can reduce algorithm operation time by 43% (except for pcPIE)

SUMMARY & CONCLUSION

- FOV of CSM has been enlarged by applying ptychographical iterative engine (4.3㎛ x 4.3㎛)
- The reconstructed image resolution is improved by modified PIE that update the probe function and compensate for experimental position errors
- Image reconstruction time is about 272 seconds, it can be more shorted by hardware improvement
- Super-resolution PIE is expected to enhance the performance of PIE