Improvement of coherent scattering microscopy by applying ptychographic iterative engine

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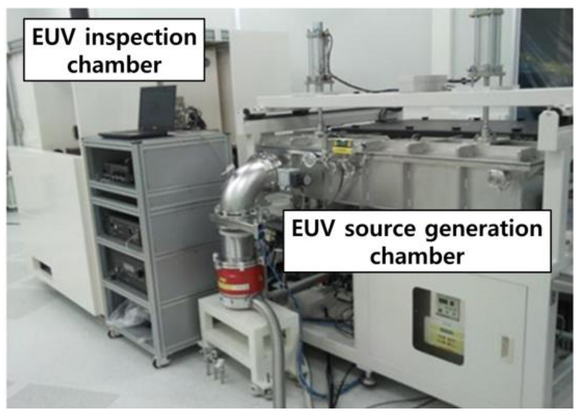
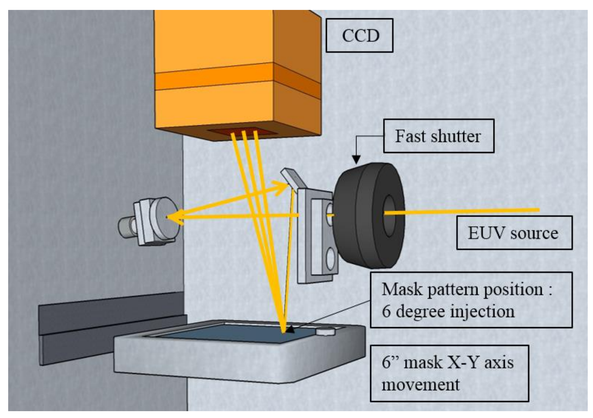
INTRODUCTION

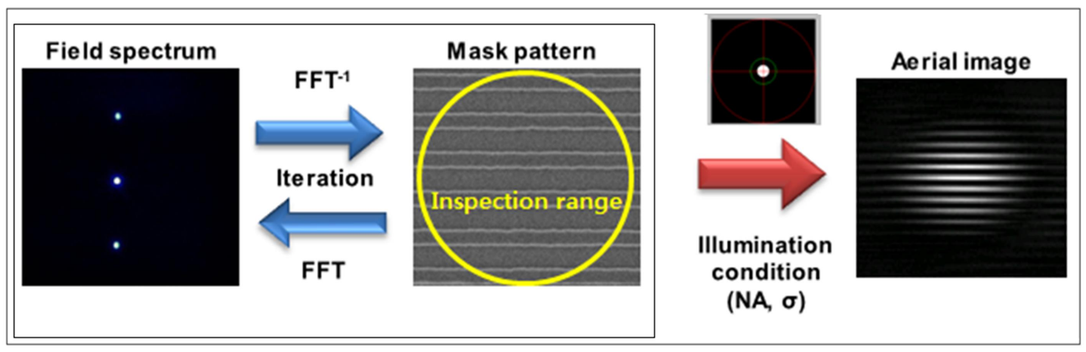
❑ Coherent Scattering Microscopy (CSM)

- Actinic inspection tool for evaluating imaging performance of EUV mask
- Lensless imaging based on coherent diffractive imaging (CDI))





< Coherent Scattering Microscopy >



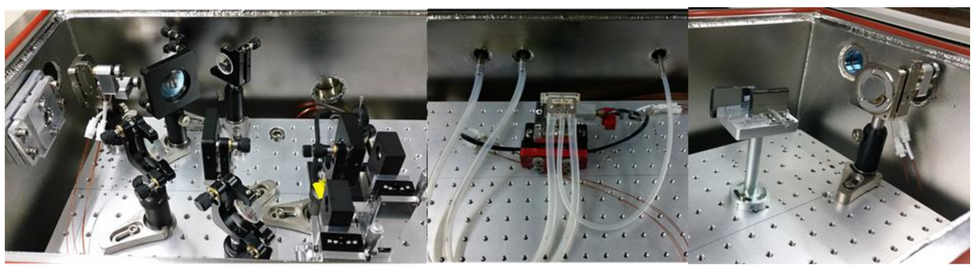
< Image reconstruction method - phase retrieval algorithm >

- Phase shift effect, pellicle transmittance can be analyzed by CSM (+ through pellicle inspection)
- Limited field of view (FOV) as inspection source size

➢ **Ptychographical iterative engine (PIE) is applied to achieve the large FOV**

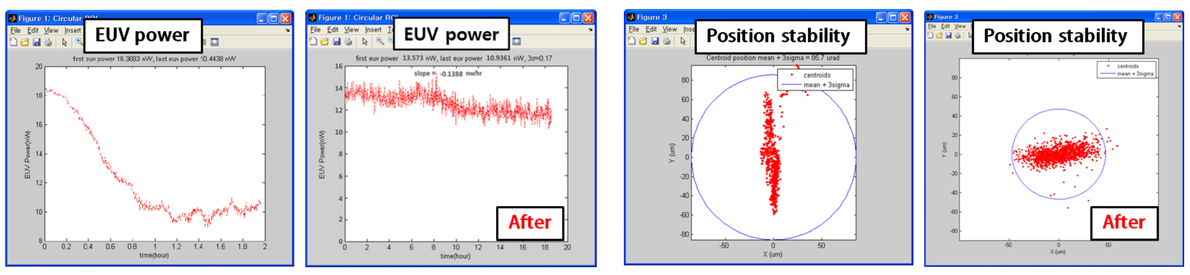
Hardware improvement

❑ EUV source stablizer



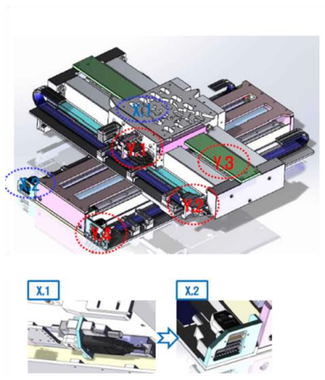
< EUV stabilizer system >

- Two quadrant sensor and piezo components are applied to maintain the laser propagation
- EUV power and position stability are improved by continuous modification of seed laser propagation

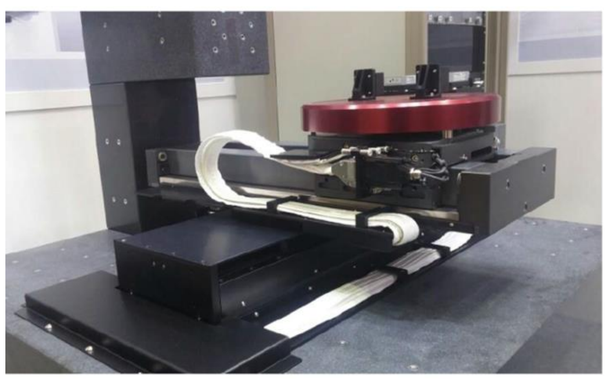


< Comparison of power and position stability after applying stabilizer >

- Long-term stability of EUV power and position stability are improved after applying stablizer



< Schematic of designed stage >



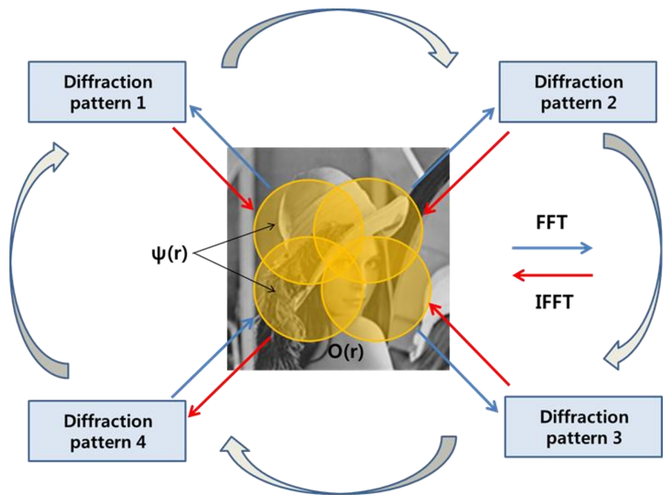
< Proto-type of high precision stage >

- Designing precision stage to minimize the physical position error
- Position accuracy : 100nm
- Resolution : sub-micrometer

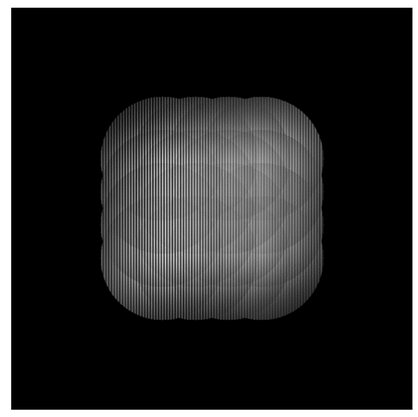
➢ **Ptychography requires finite probe function and accurate relative position between diffraction patterns**
➢ **Stable EUV source and high precision stage can be a physical solution**

Software improvement (Ptychographical iterative engine, PIE)

❑ Principle of PIE



< Schematic view of ptychographic iterative engine (PIE) >



< Reconstructed image of CSM using PIE, 128 nm L/S EUV mask, 3㎛ x 3㎛ >

$$O_{n+1}(\mathbf{r}-\mathbf{R}_l) = O_n(\mathbf{r}-\mathbf{R}_l) + \beta U(\mathbf{r})\,(\Psi_{n,l,\mathrm{new}}(\mathbf{r}) - \Psi_{n,l}(\mathbf{r}))$$

$$U(\mathbf{r}) \equiv \frac{|P(\mathbf{r})|}{\max(|P(\mathbf{r})|)} \frac{P^*(\mathbf{r})}{|P(\mathbf{r})|^2 + \alpha}$$

$$\Psi_{n,l}(\mathbf{r}) = P(\mathbf{r}) O_n(\mathbf{r}-\mathbf{R}_l)$$

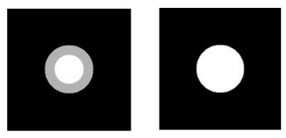
< Mathematics in PIE >

- Separating probe function and object function
- Image stitching from separated object function

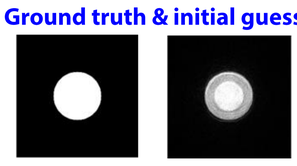
➢ **Accuracy of probe function is the key of resolution of reconstructed image**

Software improvement (extended PIE, ePIE)

❑ extended PIE, reconstruction of probe function



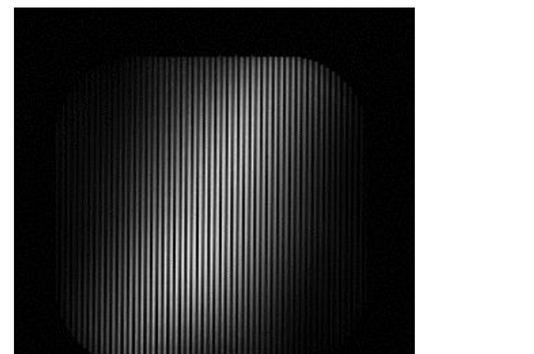
< Ground truth & initial guess >



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

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

< Added update function of ePIE >

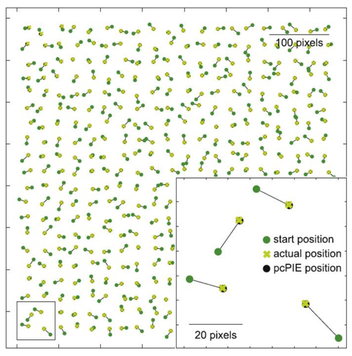


< Reconstructed image of CSM using ePIE, 128 nm L/S EUV mask, 3㎛ x 3㎛ >

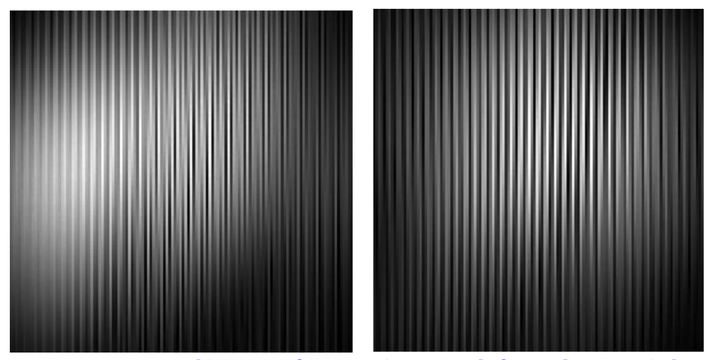
- Boundary occurrence between reconstructed image has been solved
- However, still insufficient resolution
  - ➢ Relative distance between diffraction patterns are inaccurate
  - ➢ **Position correcting PIE (pcPIE) can compensate the position error**

Software improvement (position correcting PIE, pcPIE)

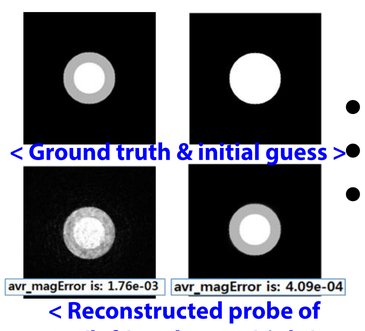
❑ position correcting PIE, compensating position error



< Position correcting results of pcPIE >



< Reconstructed image of CSM using ePIE(left) and pcPIE(right), 128 nm L/S EUV mask, 3㎛ x 3㎛ >



< Ground truth & initial guess >

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

- Improvement of reconstructed image resolution by compensating position error
- Noise of reconstructed probe also decreases by modification of position error
- Tolerance of position accuracy could be relieved from 1% to 15% of step size
  - ➢ Stabilizing EUV source and position accuracy should be achieved
  - ➢ Super-resolution PIE should be studied to achieve improved resolution

CONCLUSION

- FOV of CSM has been enlarged by applying ptychographic iterative engine
- Possibility of compensating inevitable error of hardware has been verified
- Improvement of hardware (EUV source, precision stage) has been established
- Super-resolution PIE is expected to enhance the performance of PIE