The effect of mask background density on imaging performance in EUV lithography

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Outline

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  - Long range effect of high density area
  - Comparison of DF and BF
  - Mask Background Density effect
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Introduction

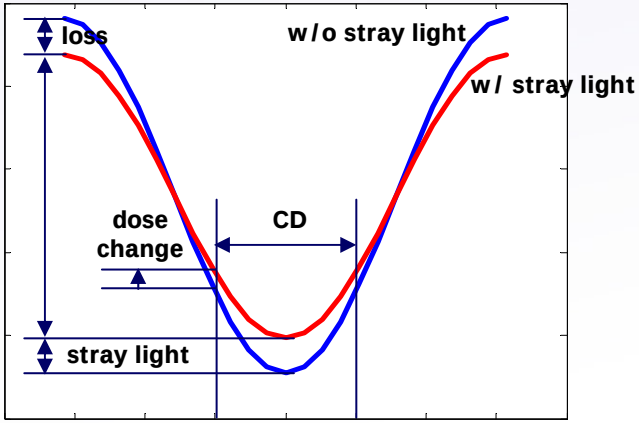
- It is well known that the effect of stray light or flare in EUV lithography is significantly higher than that of optical lithography. It is getting more important and difficult to reduce the level of stray light down to less than 10%, which is required in high volume manufacturing.
- The scattered light mainly comes from rough mirror surfaces, which are used in illumination optics and projection system.
- EUV mask as a mirror can be also one of scattering sources that cause stray light. In addition, imaging performance of feature in mask can be affected by its surrounding pattern densities.
- The effect of background density in EUV mask is studied in terms of imaging performance with experiments.

Motivation

- Various pattern densities which are included in EUV masks for device applications can be considered as one of scattering sources since they affect their neighboring patterns.
- Mask patterns can be affected as a function of distance from high density area. It shows a similar behavior comparing to effects of stray light.
- First of all, long range effect of stray light is measured with traditional method in order to determine how far it affects images.
- Then, images between completely dark and bright field are compared.
- To investigate effects of various mask background intensities, mask densities are varied from dark(0%) to bright(100%) by dummy implementation.
- As a result, an appropriate mask background density will be proposed if dummy implementation method is applied to reduce effect of stray light.

Effects of stray light on aerial image

- **Contrast (NILS) reduction**
  - Sensitivity of CD-to-dose error becomes larger.
  - Degradation of image quality
  - Poor process latitude
- **Dose change**
  - Overlap of process windows is reduced.
  - CD variations
- **Resist loss**



- **Mitigation and compensation method of stray light effects**
  - Selective bias
    - Compensation method of stray light effects
  - Dummy implementation
    - Mitigation method of stray light effects
  - Combined method

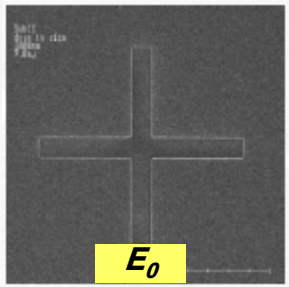
Measurement of stray light

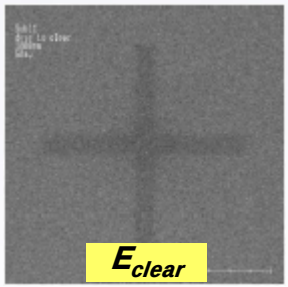
- **Disappearing pad test**
  - LBNL MET (NA 0.3, annular illumination)
  - Features are ranged from 30nm to 2um.
  - Exposure doses are varied up to 100mJ/cm^2 with 5% step.

- **In case of a large pattern, the stray light is about less than 10%. However, for smaller patterns less than 1um, it is increased rapidly up to several tens of percentages even though correction of diffraction effect are required for fine features.**
- **In EUVL applications, it is more important to consider effects of stray light on fine features.**
- **Similar effects depending on mask pattern densities are also investigated in terms of long range stray light.**

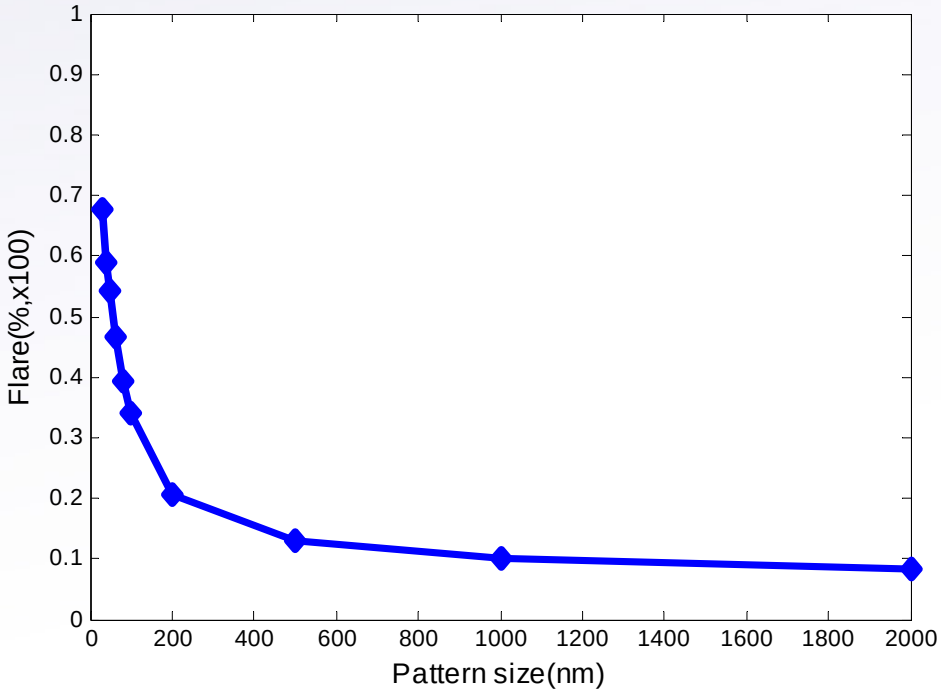
Measurement of stray light

Cross patterns for measuring stray light
- 30nm ~ 2um





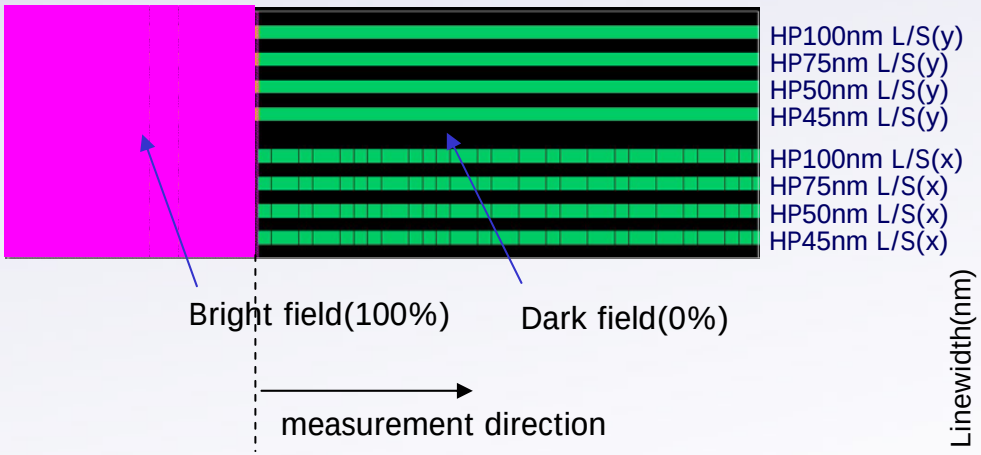
$$Flare(\%) = \frac{E_0}{E_{clear}} \times 100$$

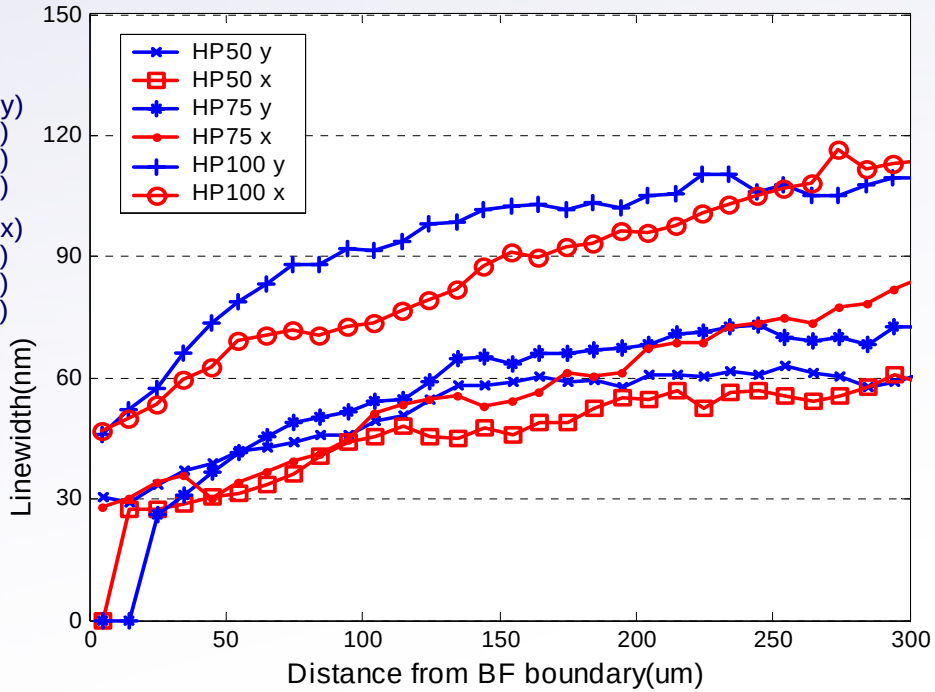


How far does high density area affect images?

- It is required to investigate long range effect of reflected and scattered light - stray light - from bright field caused by high density area on imaging performance such as resolution, LWR, depth of focus, exposure latitude, etc.
- Features which are close to bright field show a smaller linewidth. As a feature becomes more distant from bright field, it is increased continuously and saturated at around 200um far from field boundary.
- This means that the reflected and scattered light from bright field can largely affect on imaging performance of features which are located in up to about 200um range even if their sizes are different.
- As a result, the images show good pattern fidelity, profile, and LWR as it becomes more distant from bright field boundary.
- Because of limited field size and illumination uniformity, longer range effects cannot be evaluated.

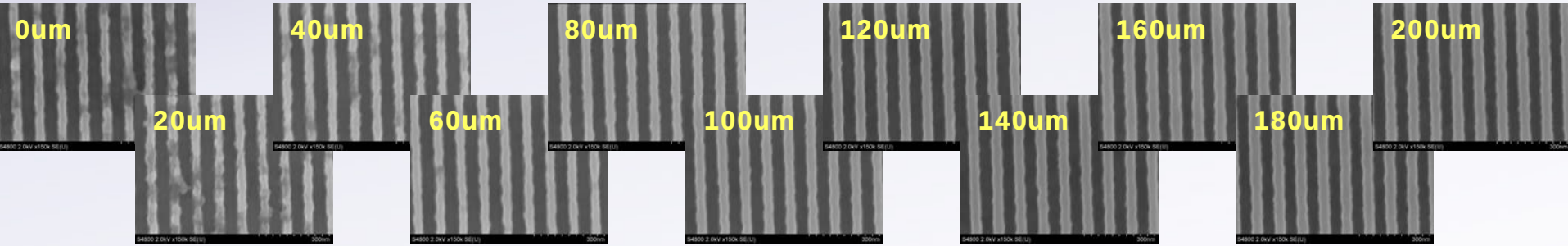
Experiment for long range effects

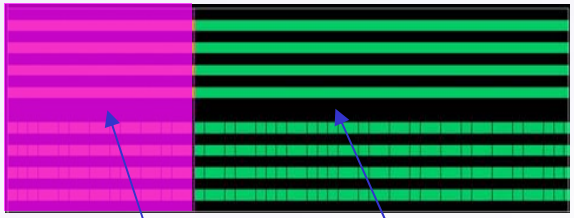




- **Although a linewidth can be measurable, severe resist top loss and collapse of features adjacent to high density area is observed due to high level of stray light.**
- **Pattern collapse of horizontal features is more critical because shadowing effect affects vertical patterns only even if they are designed identically.**

Long range effects of high density area



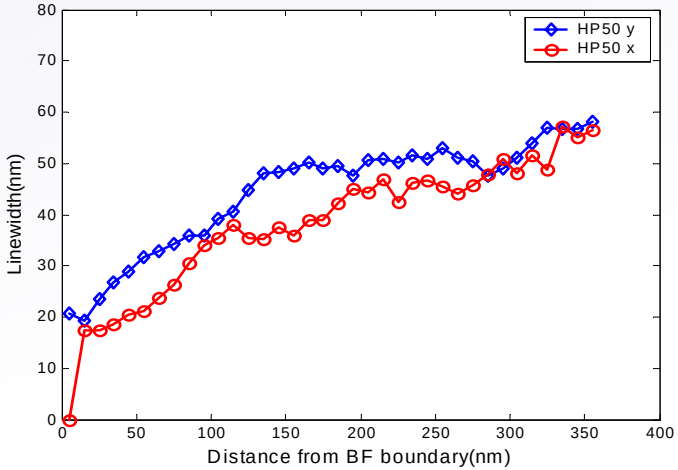


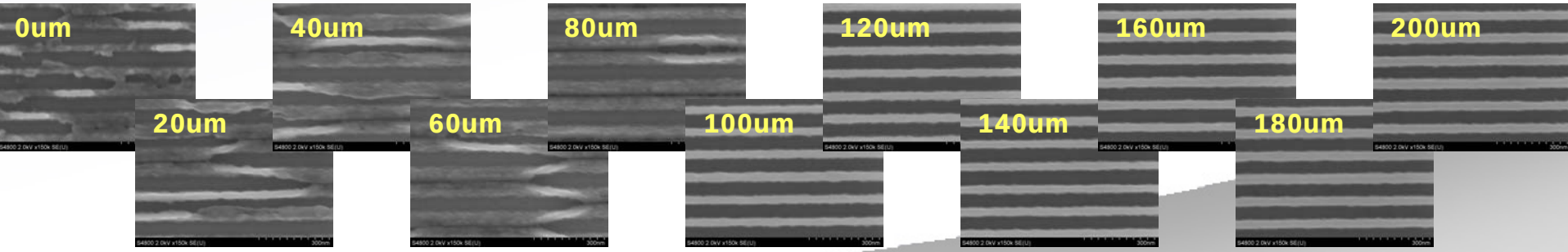
HP100nm L/S(y)
HP75nm L/S(y)
HP50nm L/S(y)
HP45nm L/S(y)

HP100nm L/S(x)
HP75nm L/S(x)
HP50nm L/S(x)
HP45nm L/S(x)

Bright field(100%)

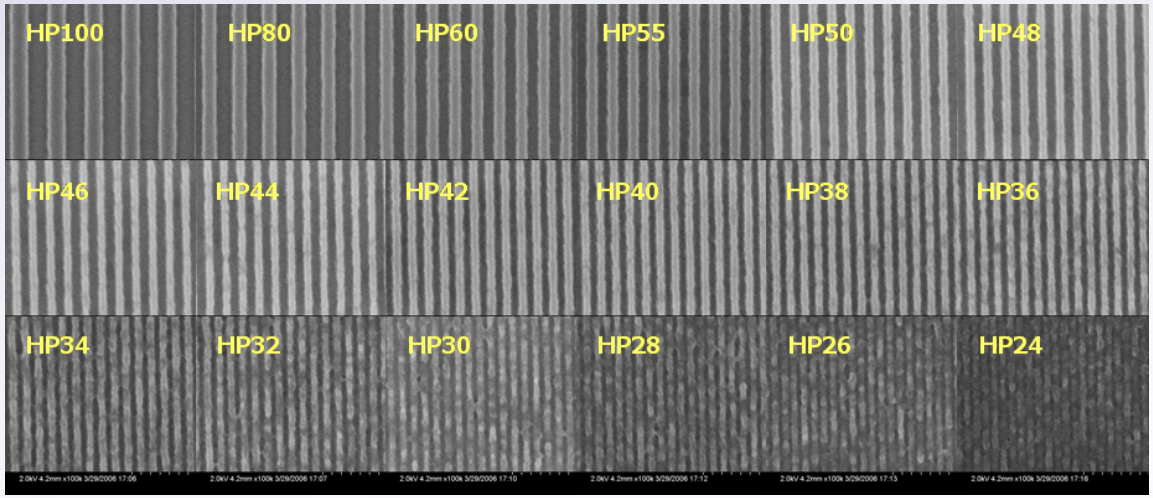
Dark field(0%)



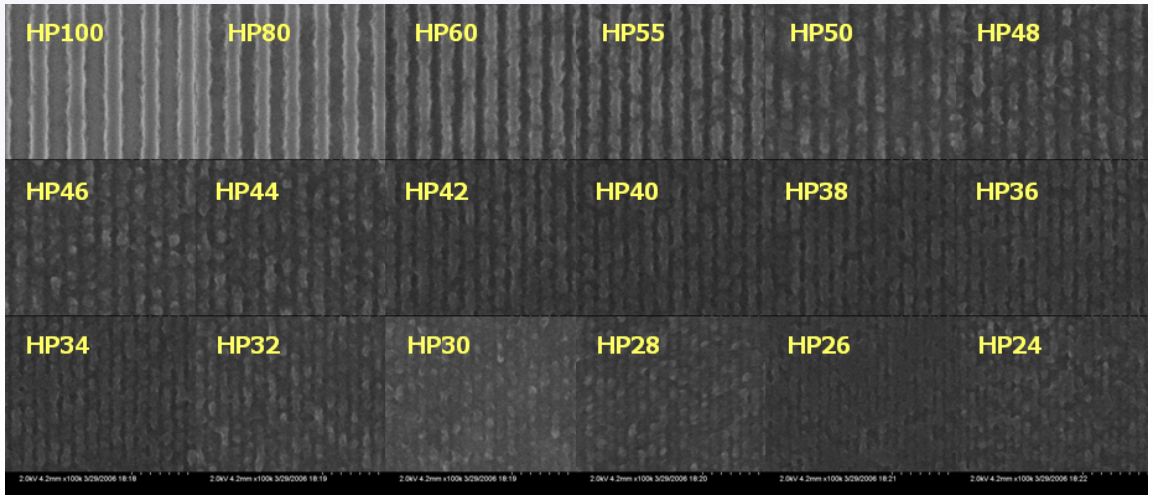


Comparison of DF and BF @ same dose

DF(0%)



BF(100%)

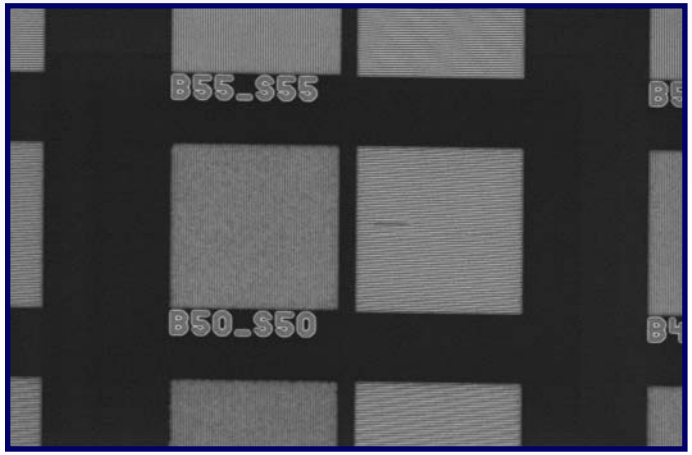


- **Severe resist loss and collapse is existed.**
- **Exposure dose for patterns in bright field should be changed to obtain better patterning results.**

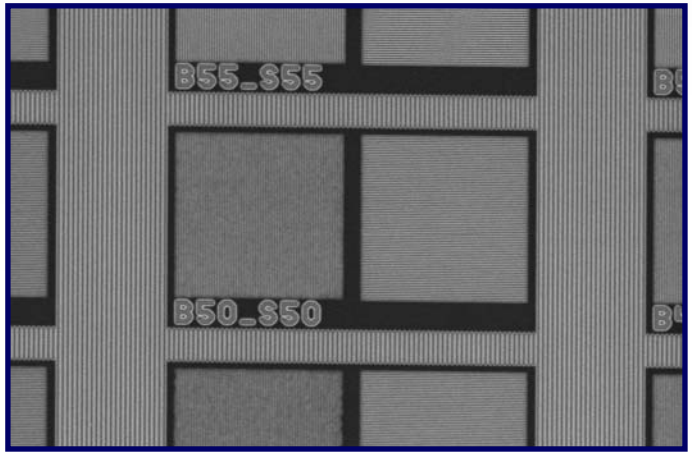
Open density variation (0, 25, 50, 100%)

- Mask background density is varied discretely from dark field(0%) to bright field(100%) by controlling duty ration of dummy pattern.
- The density effect may be not high as expected because open area is relatively smaller than interesting pattern.

Open density 0%

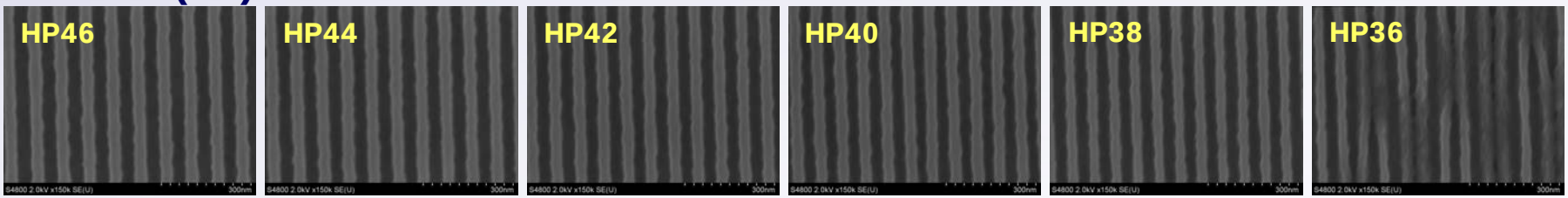


Open density 25~100%

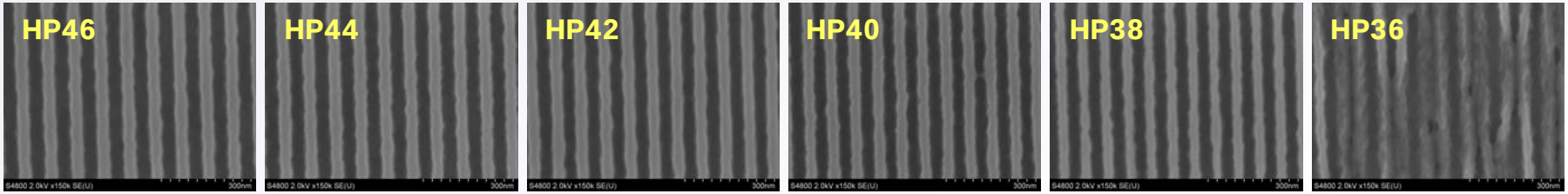


Mask Background Density effect – Resolution

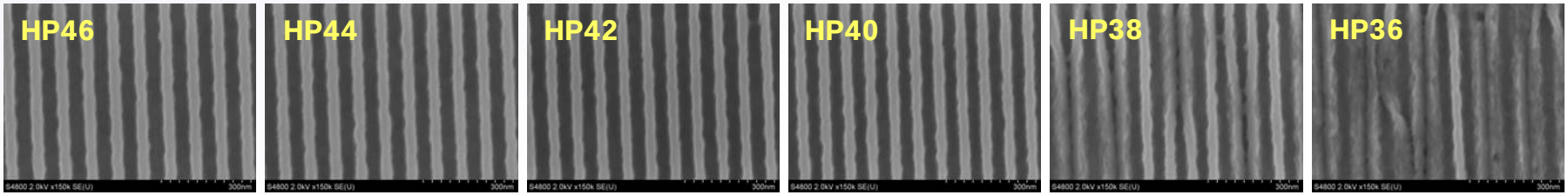
BGD 0% (DF)



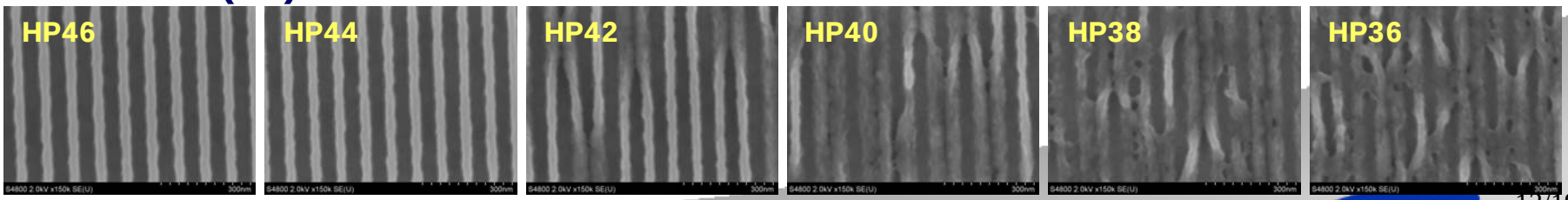
BGD 25%



BGD 50%



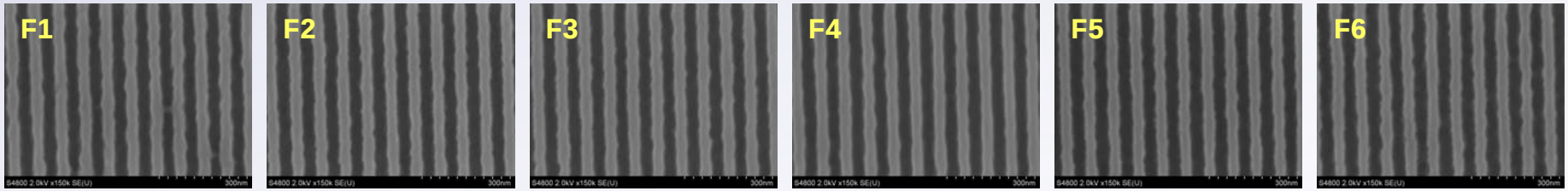
BGD 100% (BF)



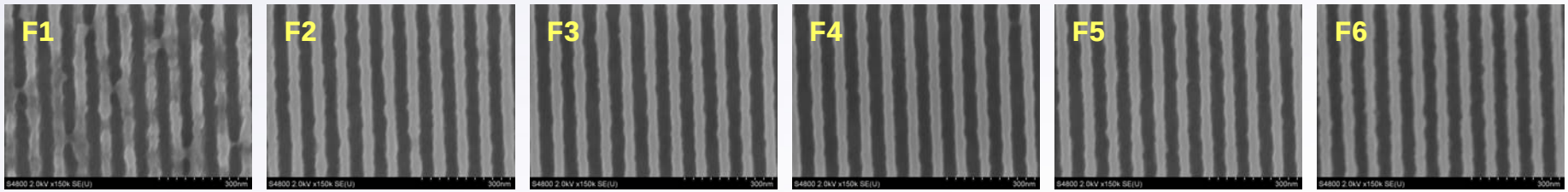
Mask Background Density effect – DoF@HP42

Focus step = 50nm

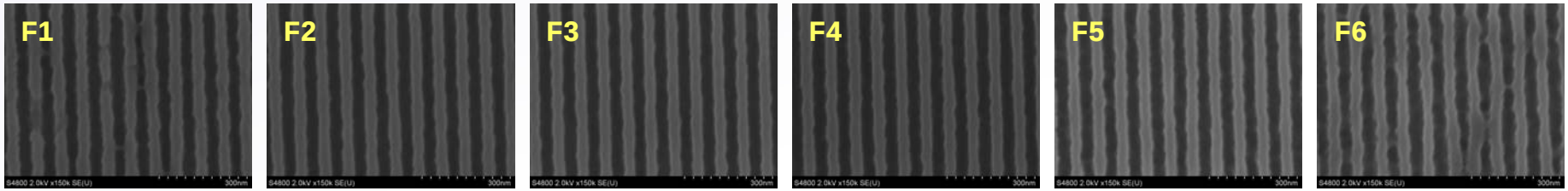
BGD 0% (DF)



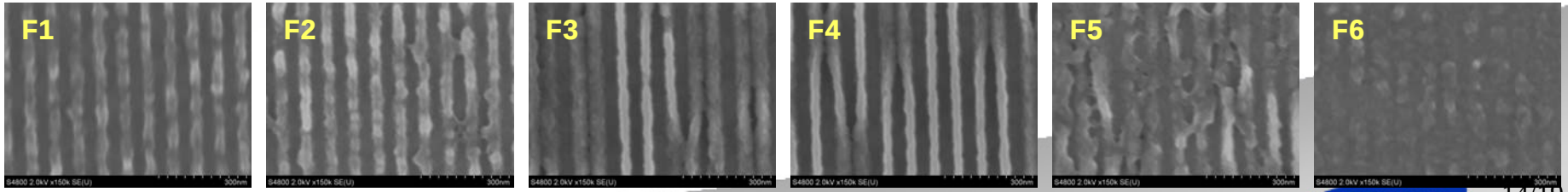
BGD 25%



BGD 50%

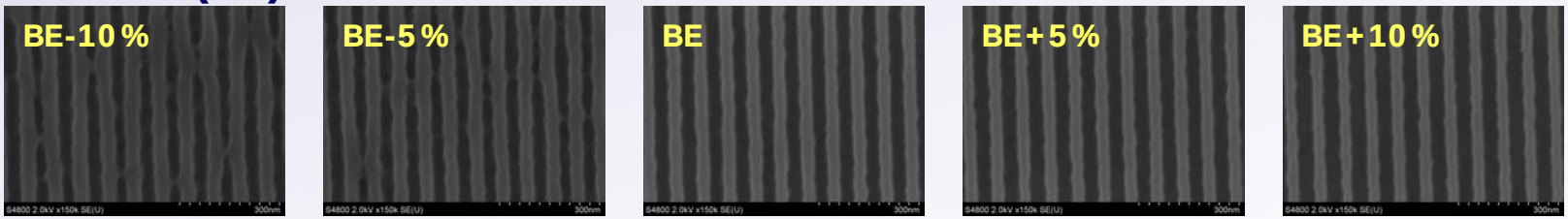


BGD 100%

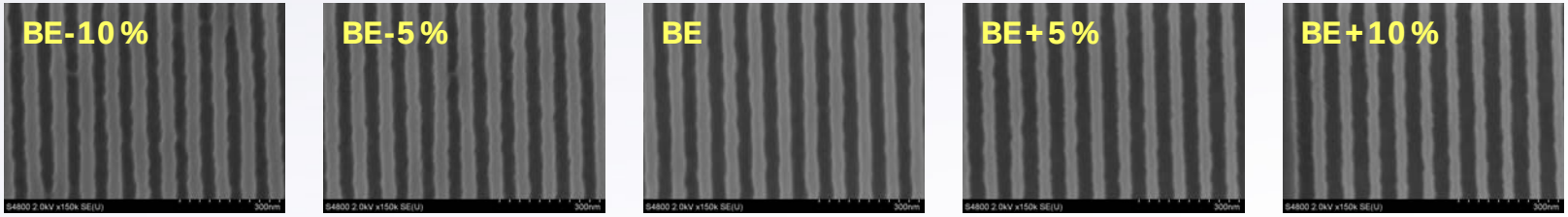


Mask Background Density effect – EL@HP42

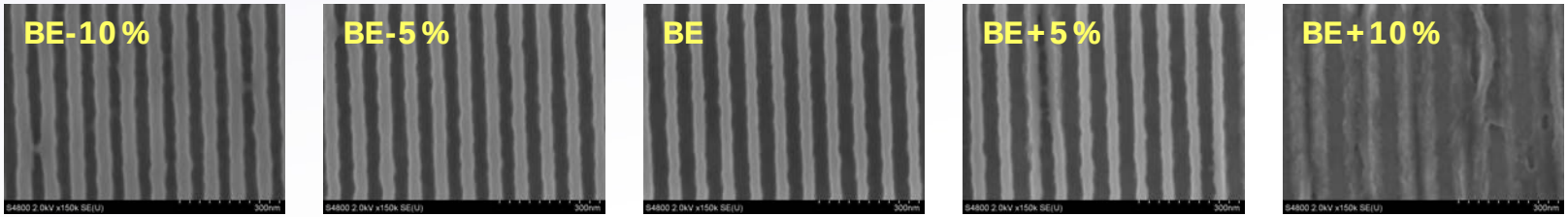
BGD 0% (DF)



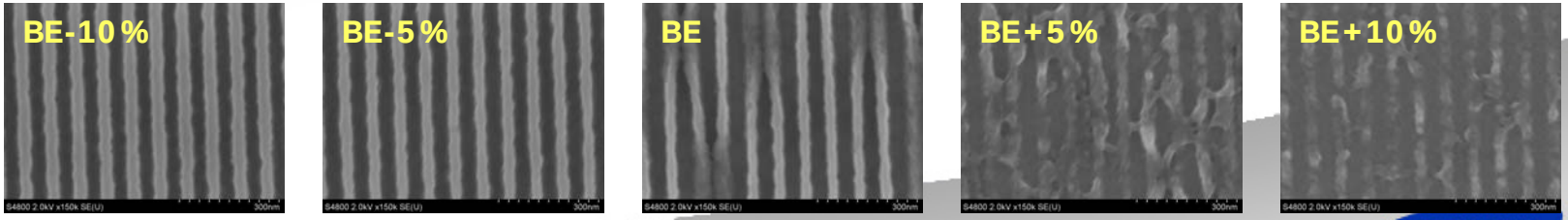
BGD 25% (DF)



BGD 50% (DF)



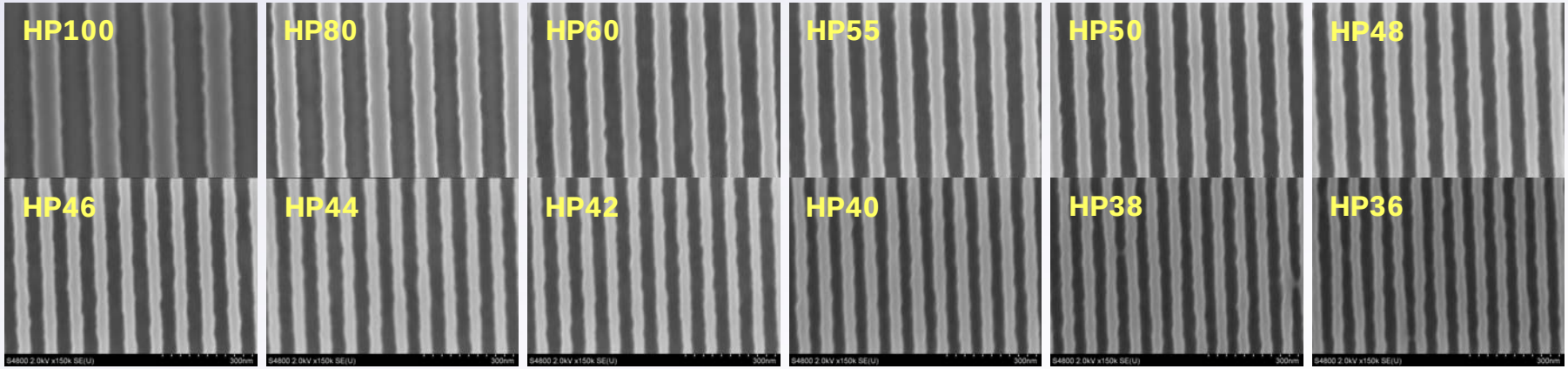
BGD 100% (DF)



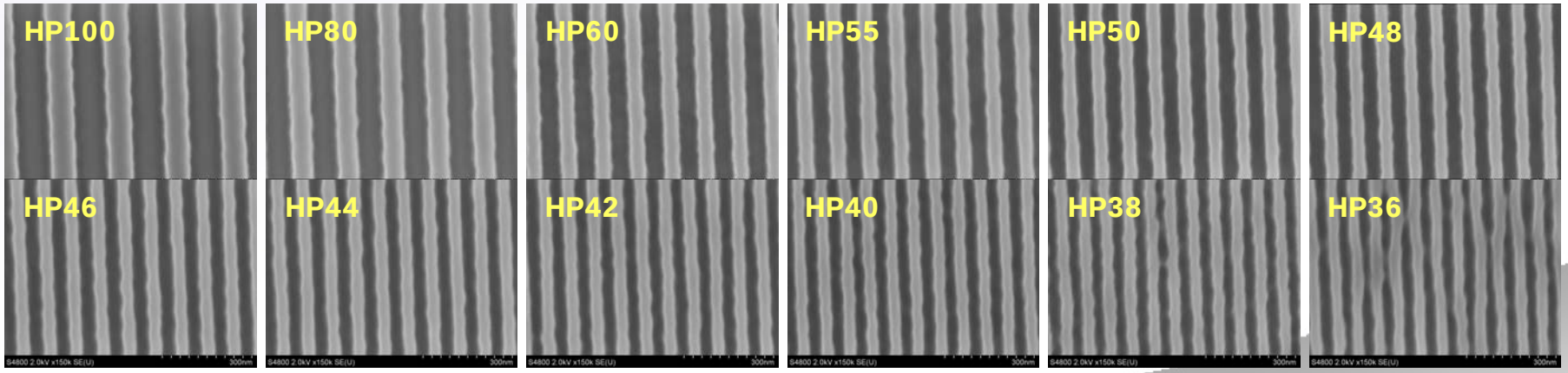
Comparison of DF and BF - Resolution

- **After dose optimization for each field**

DF



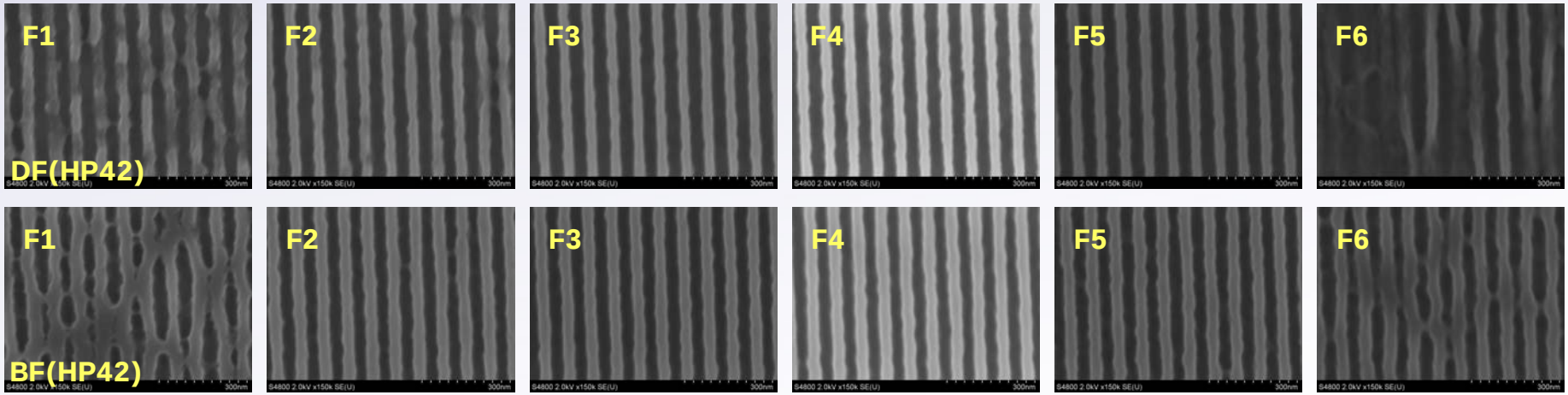
BF



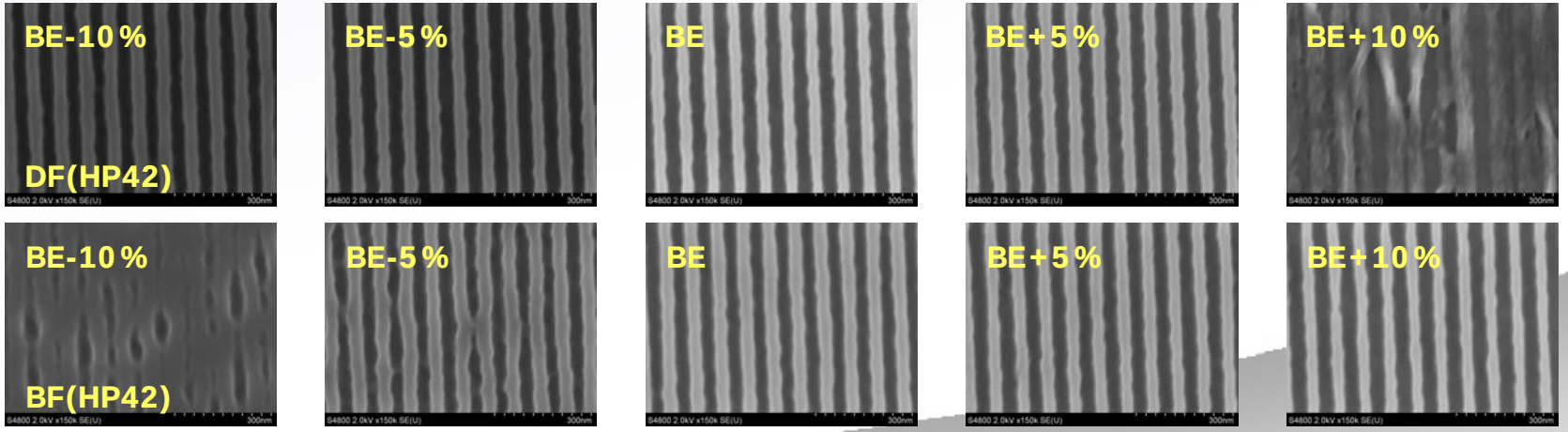
Comparison of DF and BF – DoF and EL

- **After dose optimization for each field**

Focus step = 50nm



- **After dose optimization for each field**



Summary and Conclusion

- In EUV lithography, effects of stray light should be considered as one of key factors for OPC optimization.
- Mask can be considered as one of stray light sources because it has various pattern densities in device applications.
- The patterns adjacent to high density area are affected up to around 200um ranges from bright field.
- The effect of mask background density is investigated by implementing dummy in bright field to control background density in order to reduce these effects.
- As a result, mask background density should be controlled less than 25% in order to minimize pattern density effect in view point of resolution, DoF and exposure latitude.
- After dose optimization, image performance in bright field can be improved as similar as effect of dummy implementation.
- For high level of stray light, singe correction method such as selective bias or dummy implementation is not enough to reduce stray light effect but the hybrid method which is combined with above two methods is strongly required.

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