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Study of Critical Dimensions of Printable Phase Defects Using an Extreme Ultraviolet Microscope

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Critical issues of EUVL

１） High power EUV source　　115 W～180 W

２） Defect free Mask・Inspection
number of defects：0.003/cm2　＠25 nm

３） High speed and low LER/LW Rresist
5-10 mJ/cm2, LER　1.5 nm

Roadmap of the Mask Requirements

Year of Production	2006 70 nm	2007 65 nm	2010 45 nm	2013 32 nm	2016 22 nm
Wafer minimum half pitch (nm)	70	65	45	32	22
Mask Magnification	4	4	4	4	4
Mask minimum image size (nm)	160	140	100	72	52
Pattern Defect size (nm)	**55**	**50**	**35**	**25**	**15**
Substrate defect size (nm)	**39**	**37**	**32**	**27**	**23**
Absorber LER (3σ nm)	5	4	3	3	3

🟨 Solution are known

🟧 Solution are NOT known

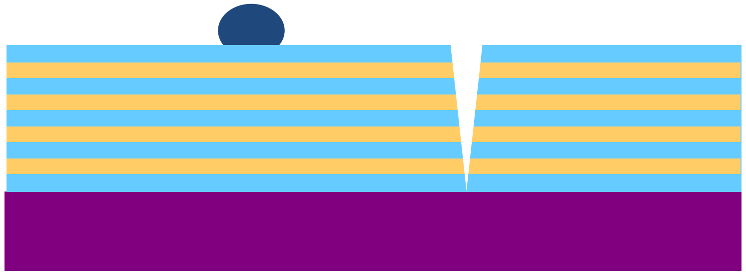
ITRS: 2001

Requirements of the Mask defect inspection

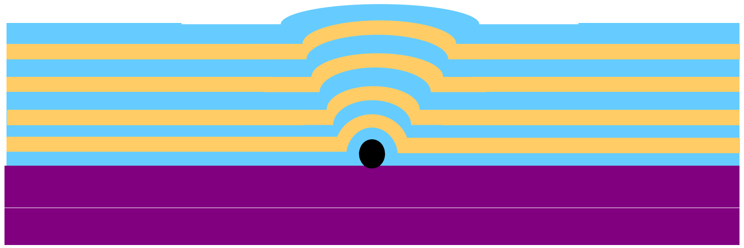
1) Detection of <25 nm size defect

2) Height resolution of <0.03 nm by Phase contrast interferometer

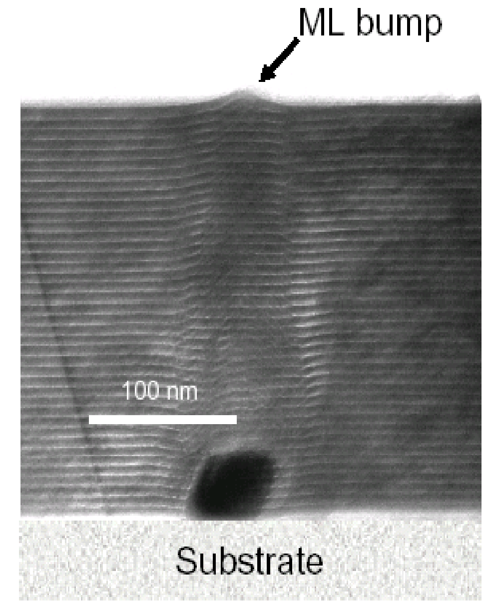
Mask Defects



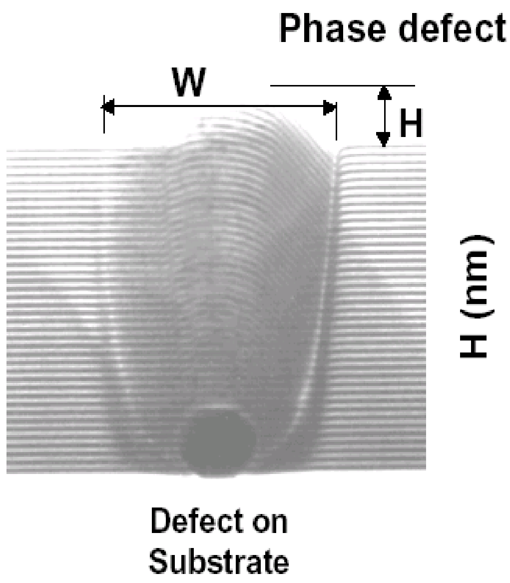
Amplitude defect



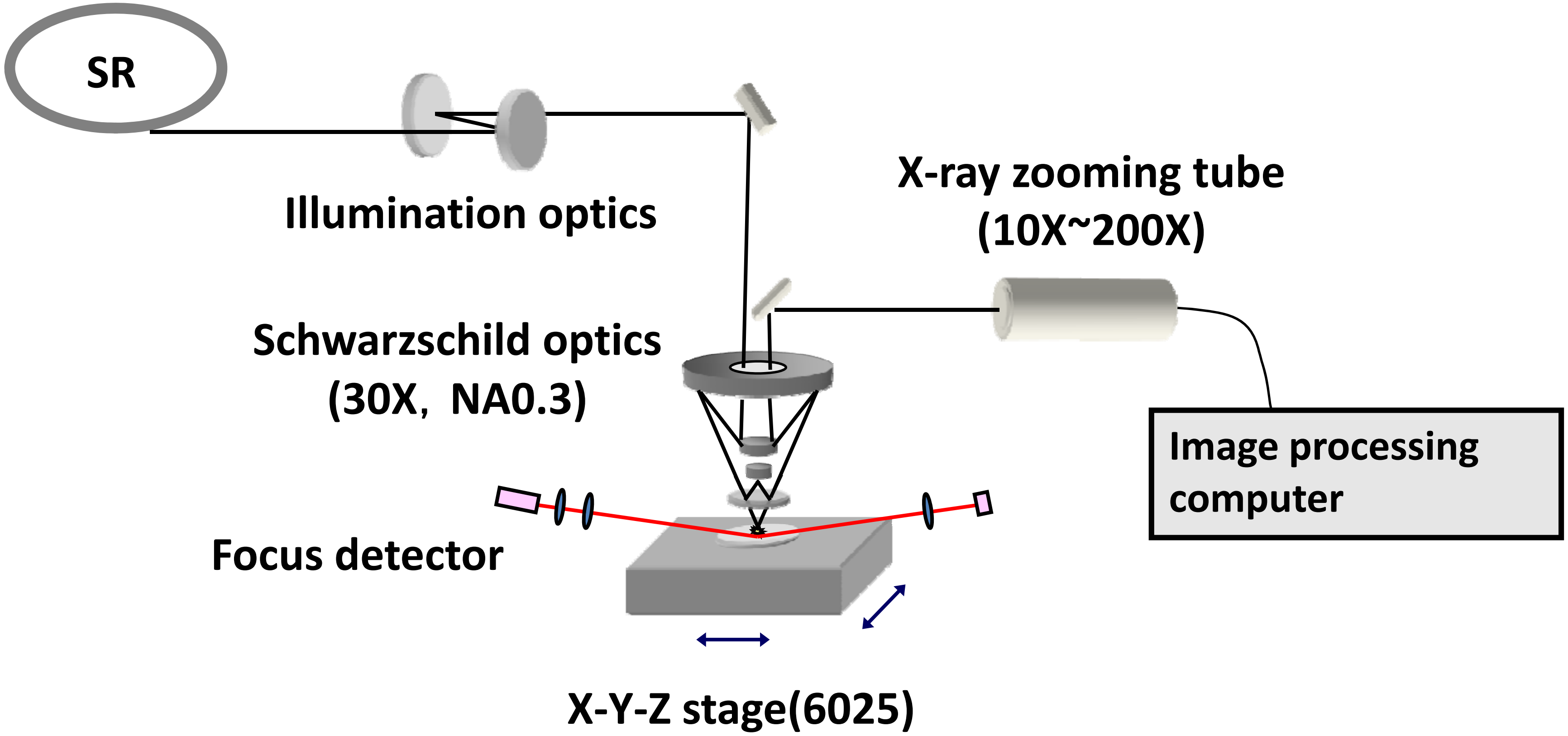
Phase defect



XTEM courtesy P. Mirkarimi, LLNL

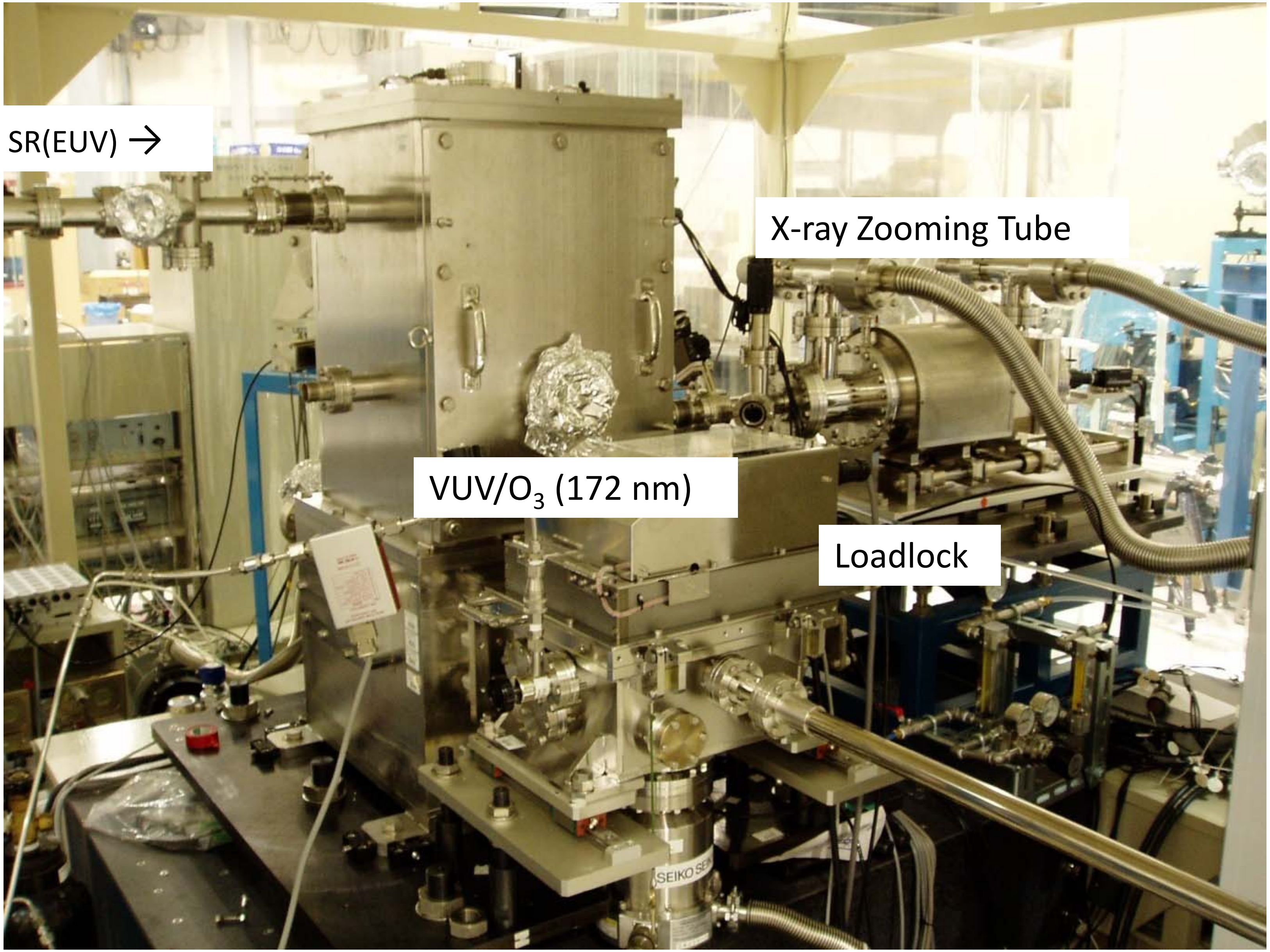


EUV microscope for mask defect inspection



Resolution: 20 nm
Magnification: 300X~6000X

EUV Microscope



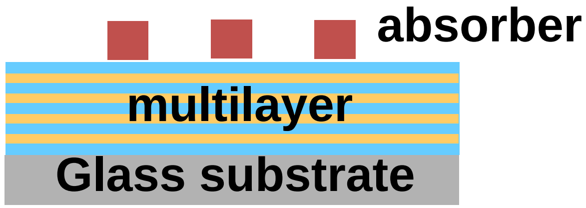
SR(EUV) →

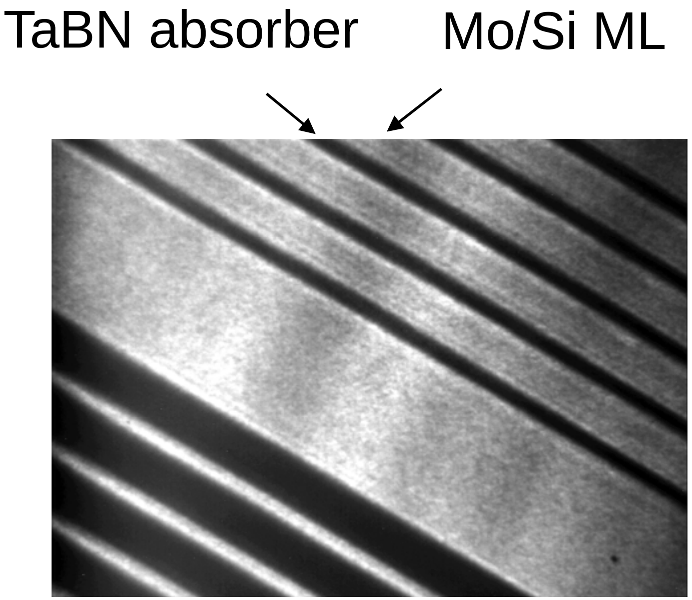
X-ray Zooming Tube

VUV/O_3 (172 nm)

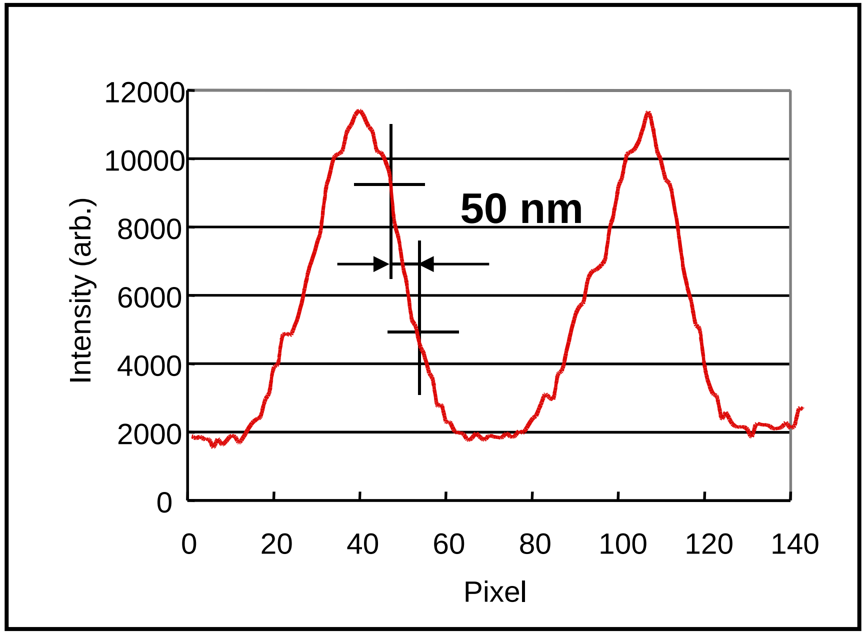
Loadlock

Finished EUVL mask observation





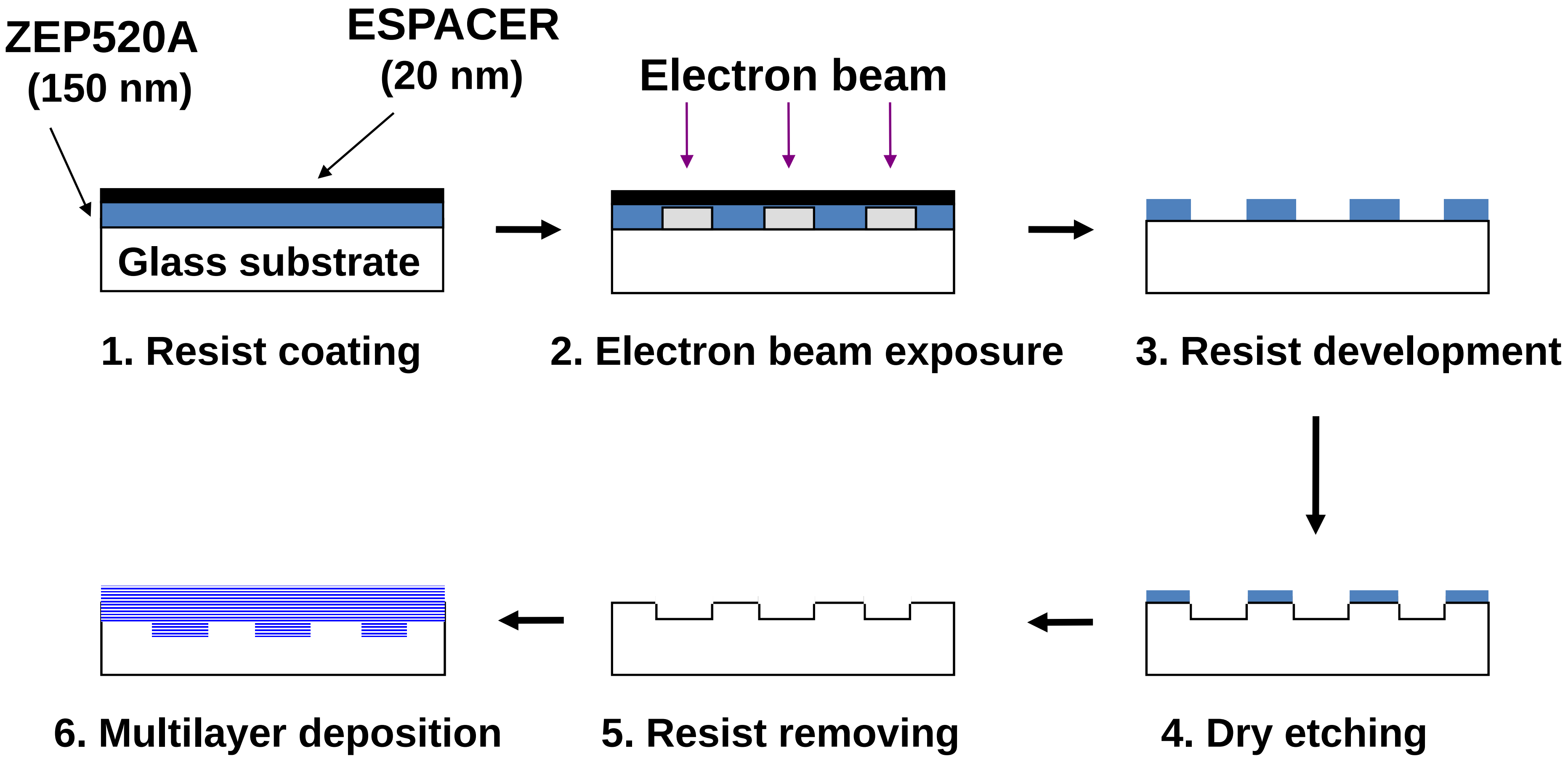
300 nm isolated line
(1200X)



Intensity distribution of the pattern edge

Resolution of 50 nm is achieved.

Formation of programmed phase defects



ZEP520A
(150 nm)

ESPACER
(20 nm)

Glass substrate

Electron beam

1. Resist coating

2. Electron beam exposure

3. Resist development

4. Dry etching

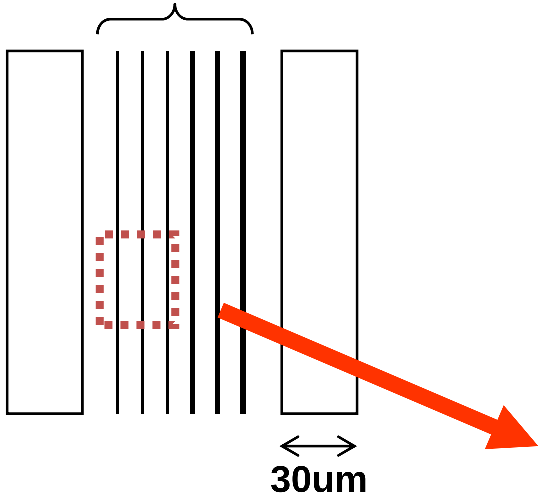
5. Resist removing

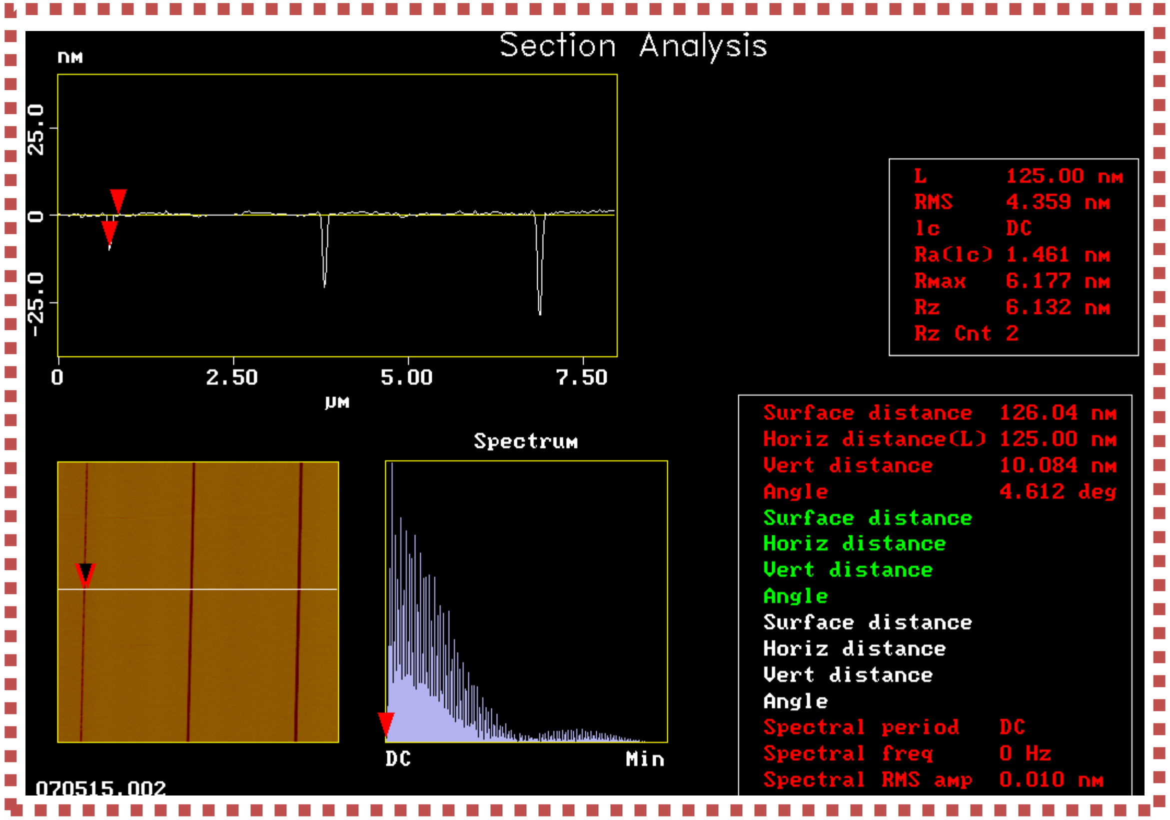
6. Multilayer deposition

AFM image of substrate surface (1)

～Before the coating of Mo/Si multilayer～

Width:40nm,60nm,80nm,100nm,120nm,200nm





L 125.00 nм
RMS 4.359 nм
lc DC
Ra(lc) 1.461 nм
Rmax 6.177 nм
Rz 6.132 nм
Rz Cnt 2

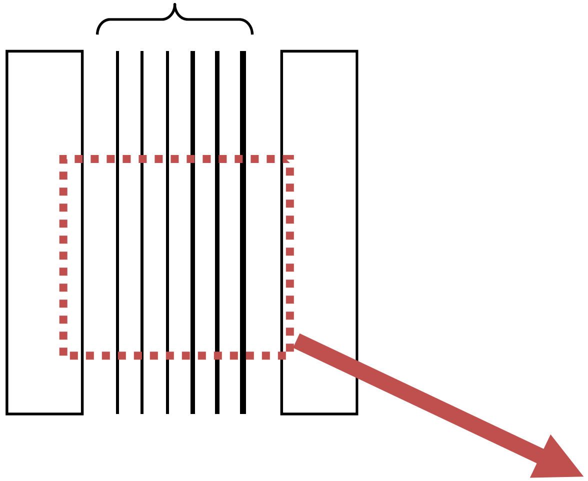
Surface distance 126.04 nм
Horiz distance(L) 125.00 nм
Vert distance 10.084 nм
Angle 4.612 deg
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period DC
Spectral freq 0 Hz
Spectral RMS amp 0.010 nм

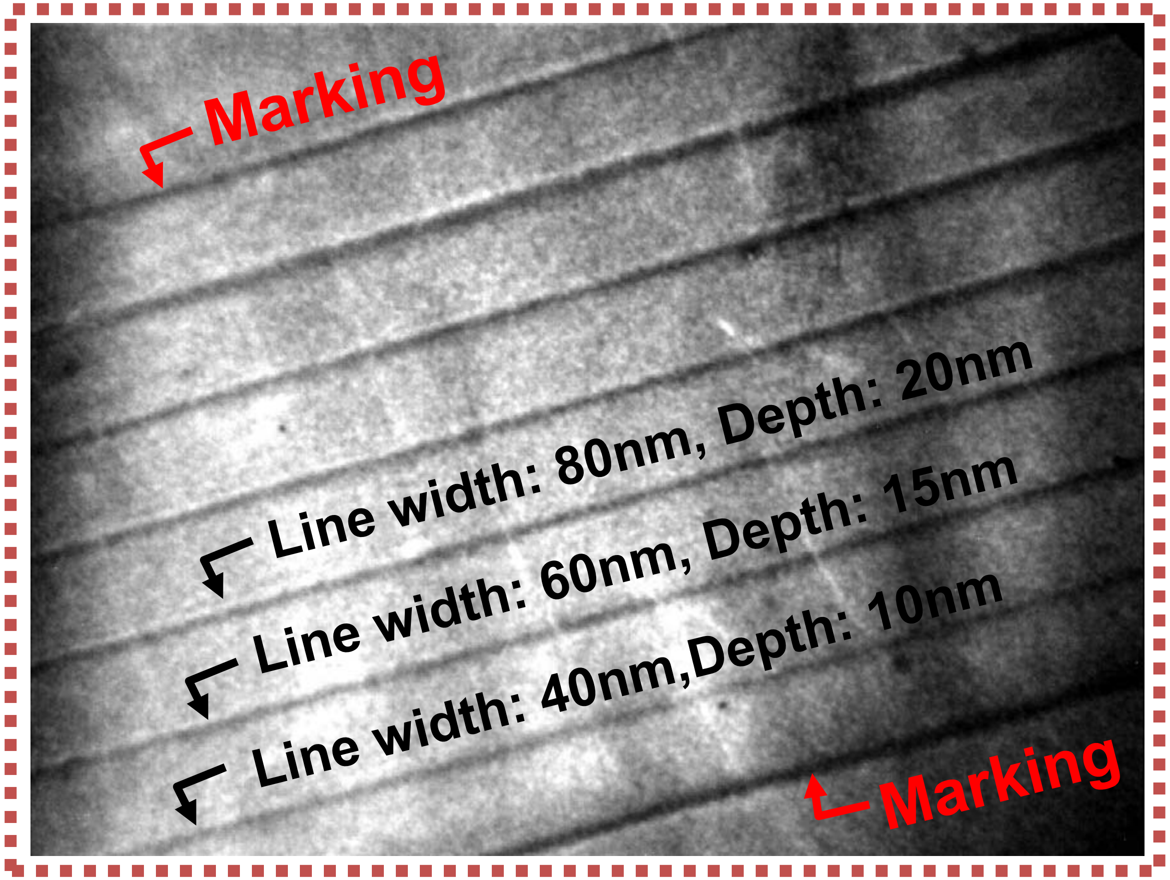
Width：40nm,Depth：10nm

Observation results by EUV Microscope (1)

～After the coating of Mo/Si multilayer～

40nm,60nm,80nm,100nm,120nm,200nm

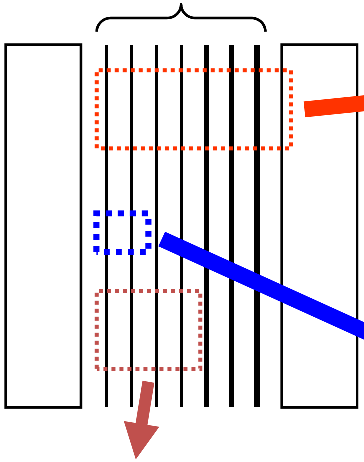


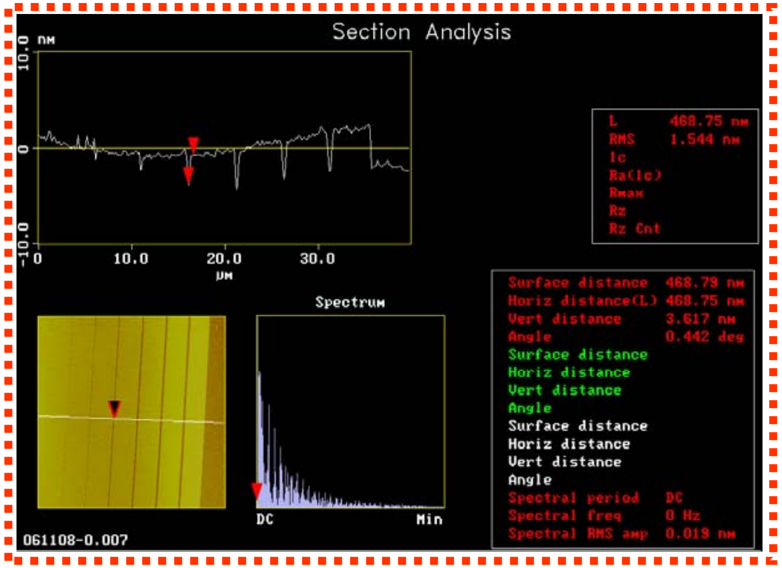


AFM image of substrate surface (2)

～Before the coating of Mo/Si multilayer～

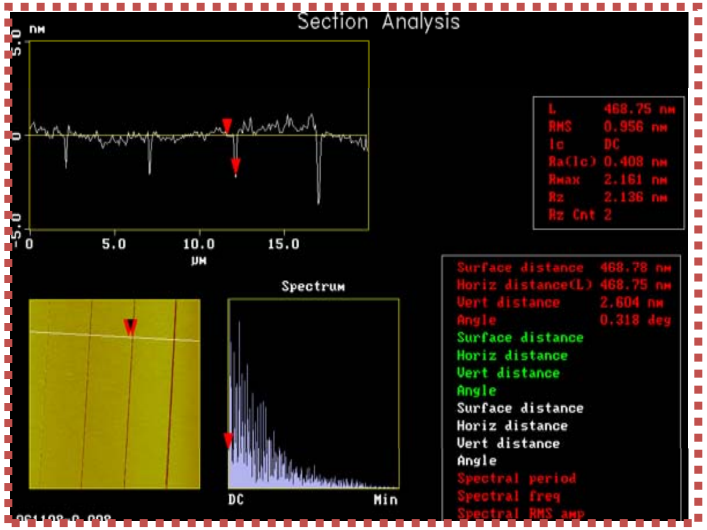
Width:75nm,100nm,150nm,250nm,350nm,450nm,550nm





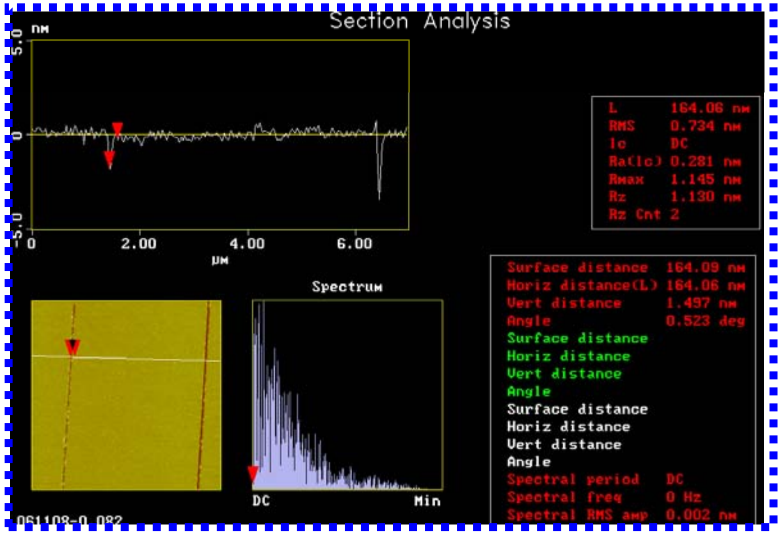
```
L          468.75 nm
RMS        1.544 nm
Ic
Ra(Ic)
Rmax
Rz
Rz Cnt

Surface distance     468.79 nm
Horiz distance(L)    468.75 nm
Vert distance        3.617 nm
Angle                0.442 deg
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period      DC
Spectral freq        0 Hz
Spectral RMS amp     0.019 nm

061108-0.007
```

Width：250nm,Depth：3.6nm



```
L          468.75 nm
RMS        0.956 nm
Ic         DC
Ra(Ic)     0.408 nm
Rmax       2.161 nm
Rz         2.136 nm
Rz Cnt     2

Surface distance     468.78 nm
Horiz distance(L)    468.75 nm
Vert distance        2.604 nm
Angle                0.318 deg
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period
Spectral freq
Spectral RMS amp
```

Width：150nm,Depth：2.6nm



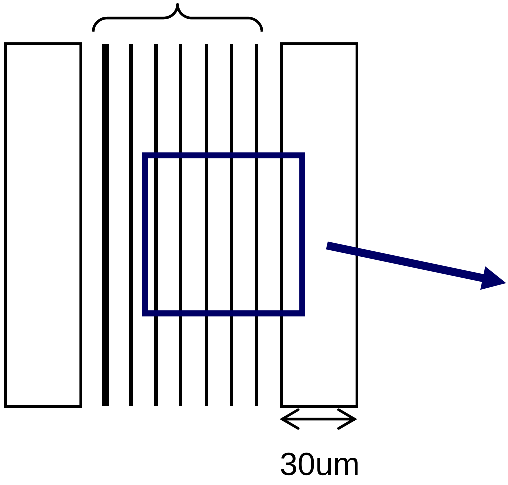
```
L          164.06 nm
RMS        0.734 nm
Ic         DC
Ra(Ic)     0.281 nm
Rmax       1.145 nm
Rz         1.130 nm
Rz Cnt     2

Surface distance     164.09 nm
Horiz distance(L)    164.06 nm
Vert distance        1.497 nm
Angle                0.523 deg
Surface distance
Horiz distance
Vert distance
Angle
Surface distance
Horiz distance
Vert distance
Angle
Spectral period      DC
Spectral freq        0 Hz
Spectral RMS amp     0.002 nm

061108-0.082
```

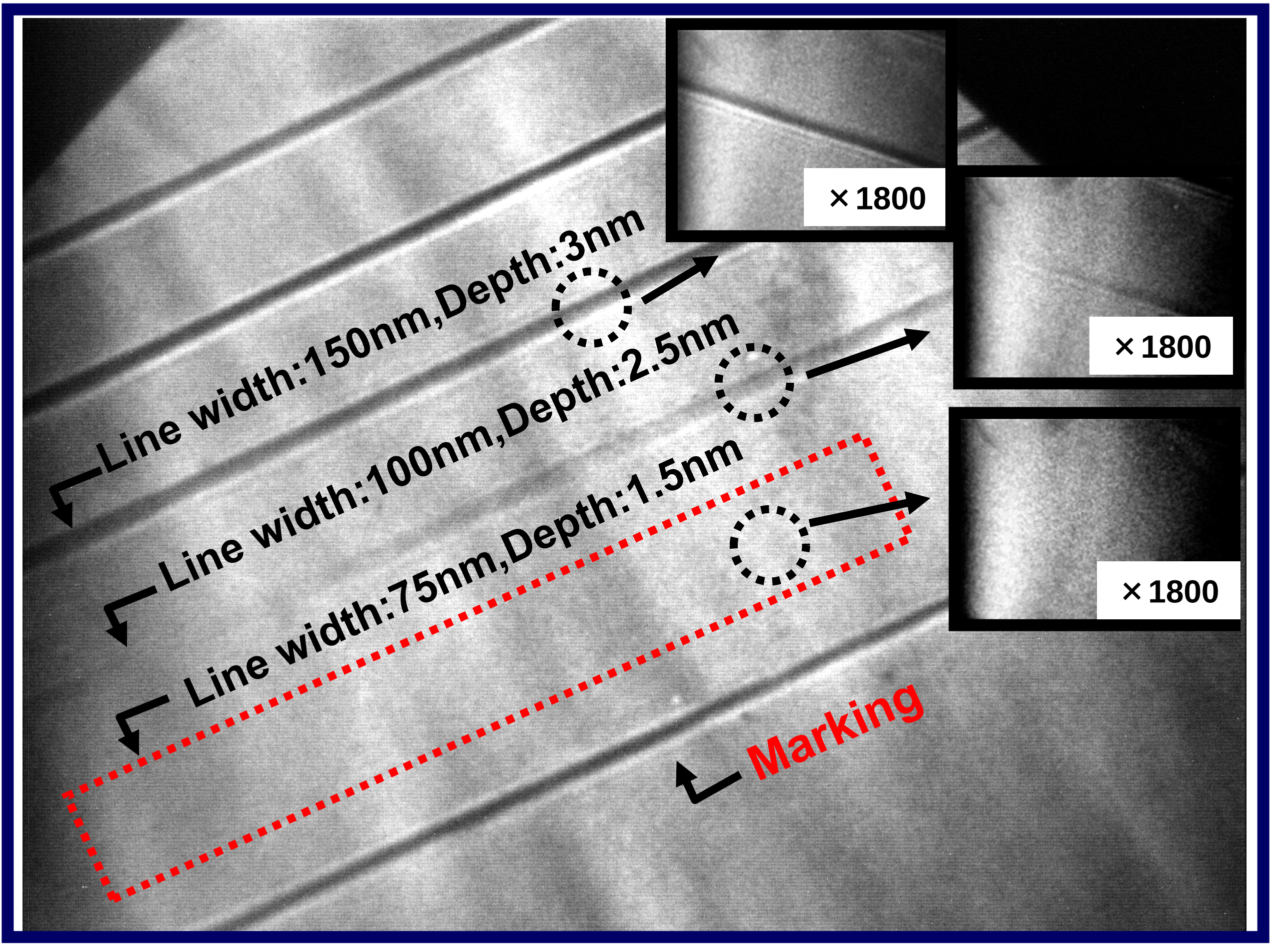
Width：75nm,Depth：1.5nm

Observation results by EUV Microscope (2)

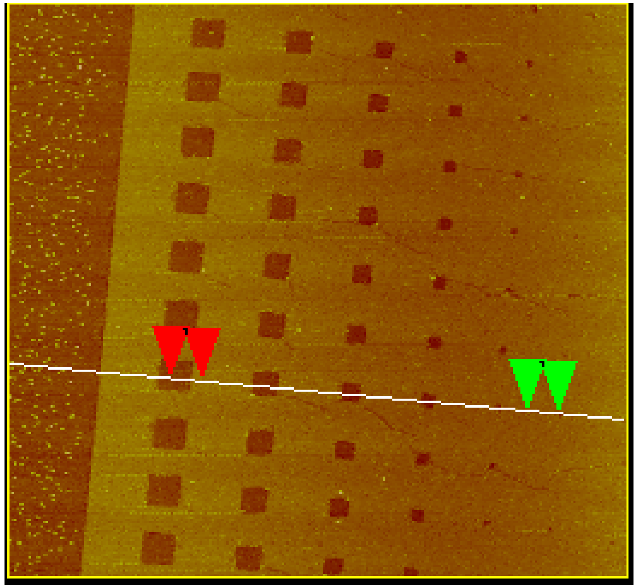
～After the coating of Mo/Si multilayer～

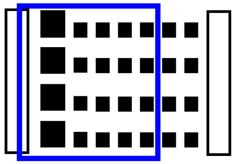
550nm,450nm,350nm,250nm,150nm,100nm,75nm



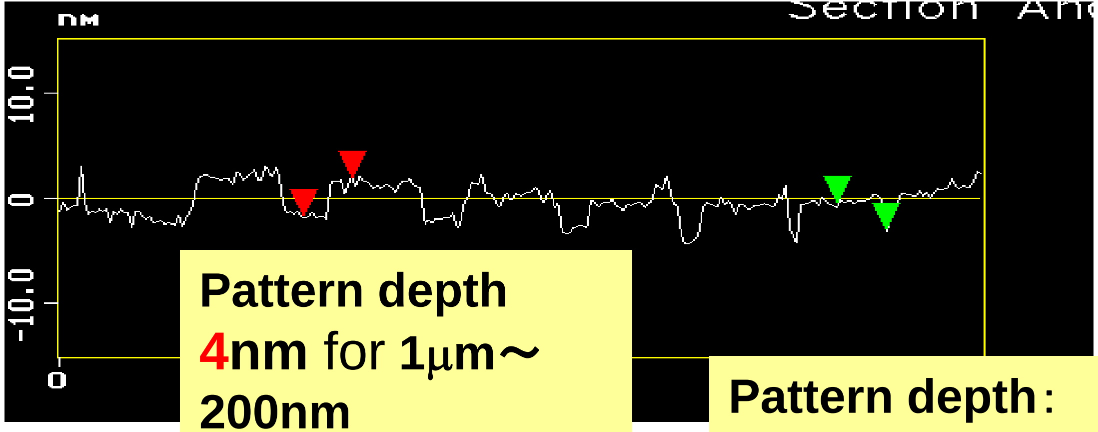


AFM image of dot pattern on substrate surface (2)



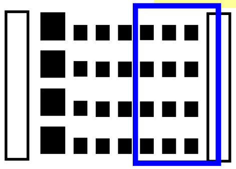


1μm～100nm

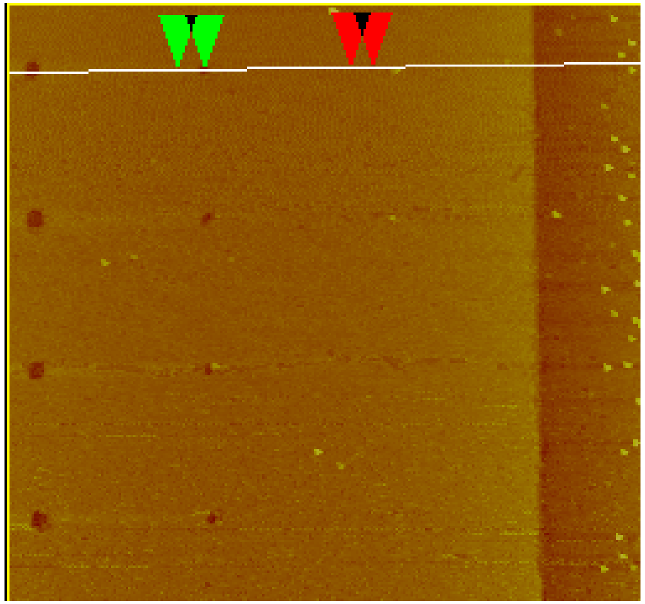


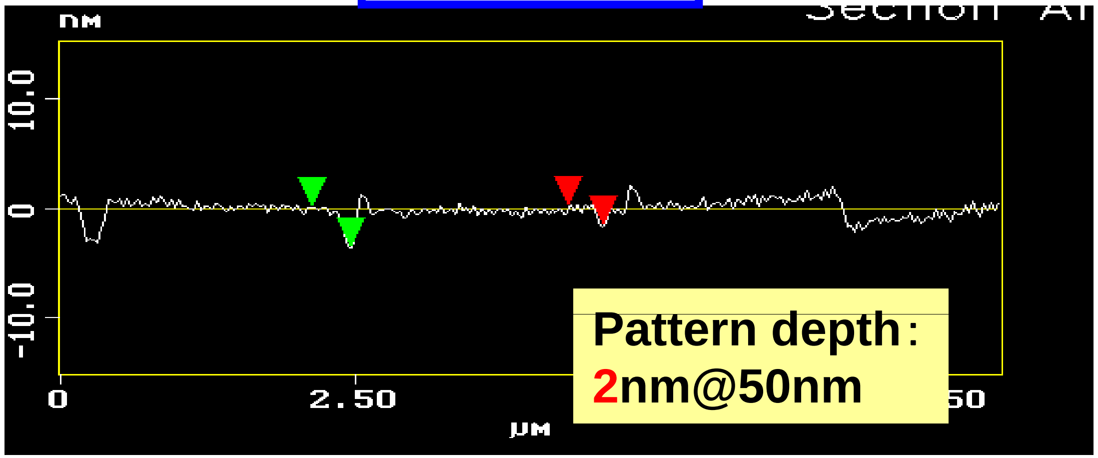
Pattern depth
4nm for **1μm～200nm**

Pattern depth:
3nm for **100nm**



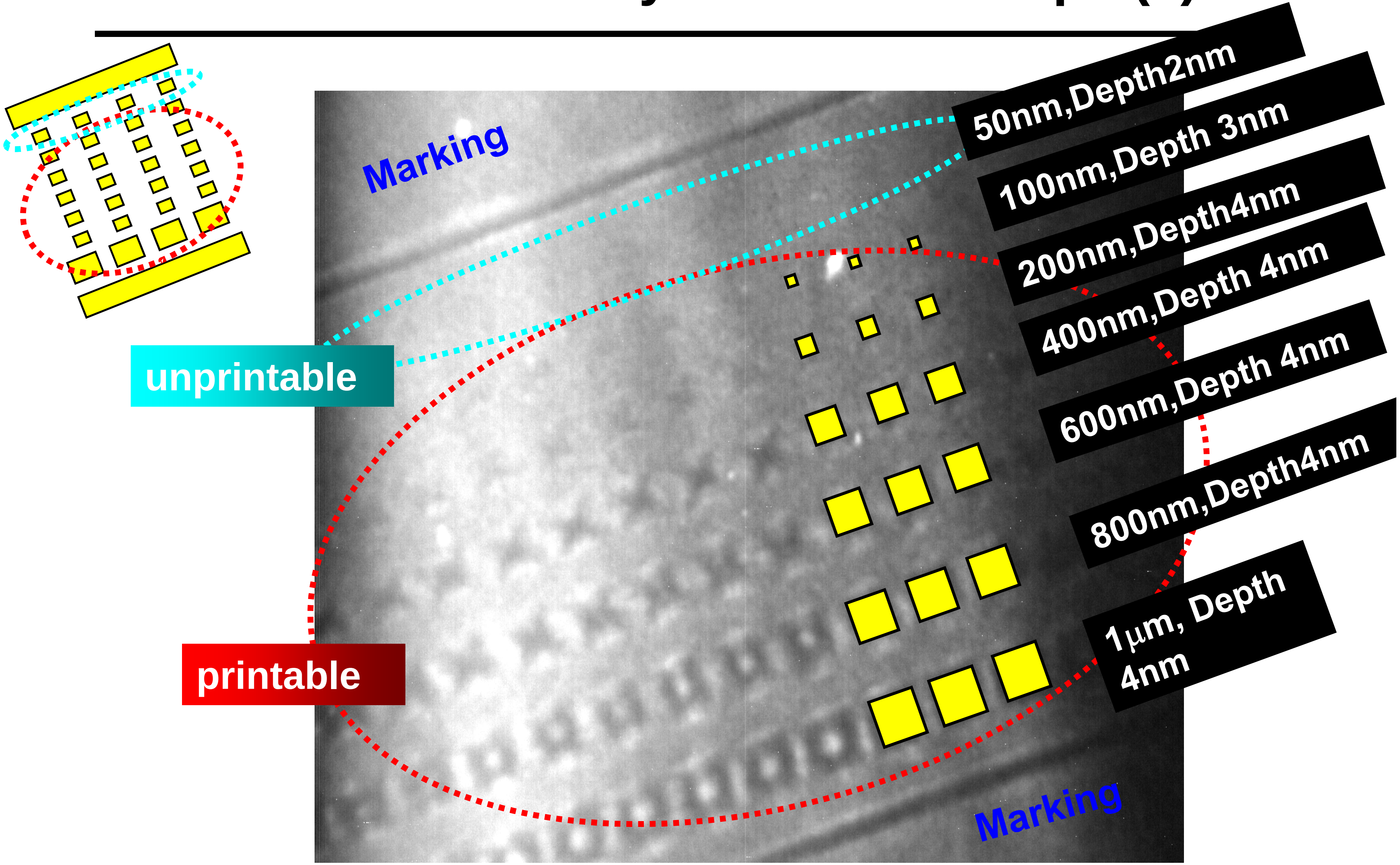
200nm～50nm





Pattern depth:
2nm@50nm

Observation results by EUV Microscope (3)



unprintable

printable

Marking

Marking

50nm,Depth2nm

100nm,Depth 3nm

200nm,Depth4nm

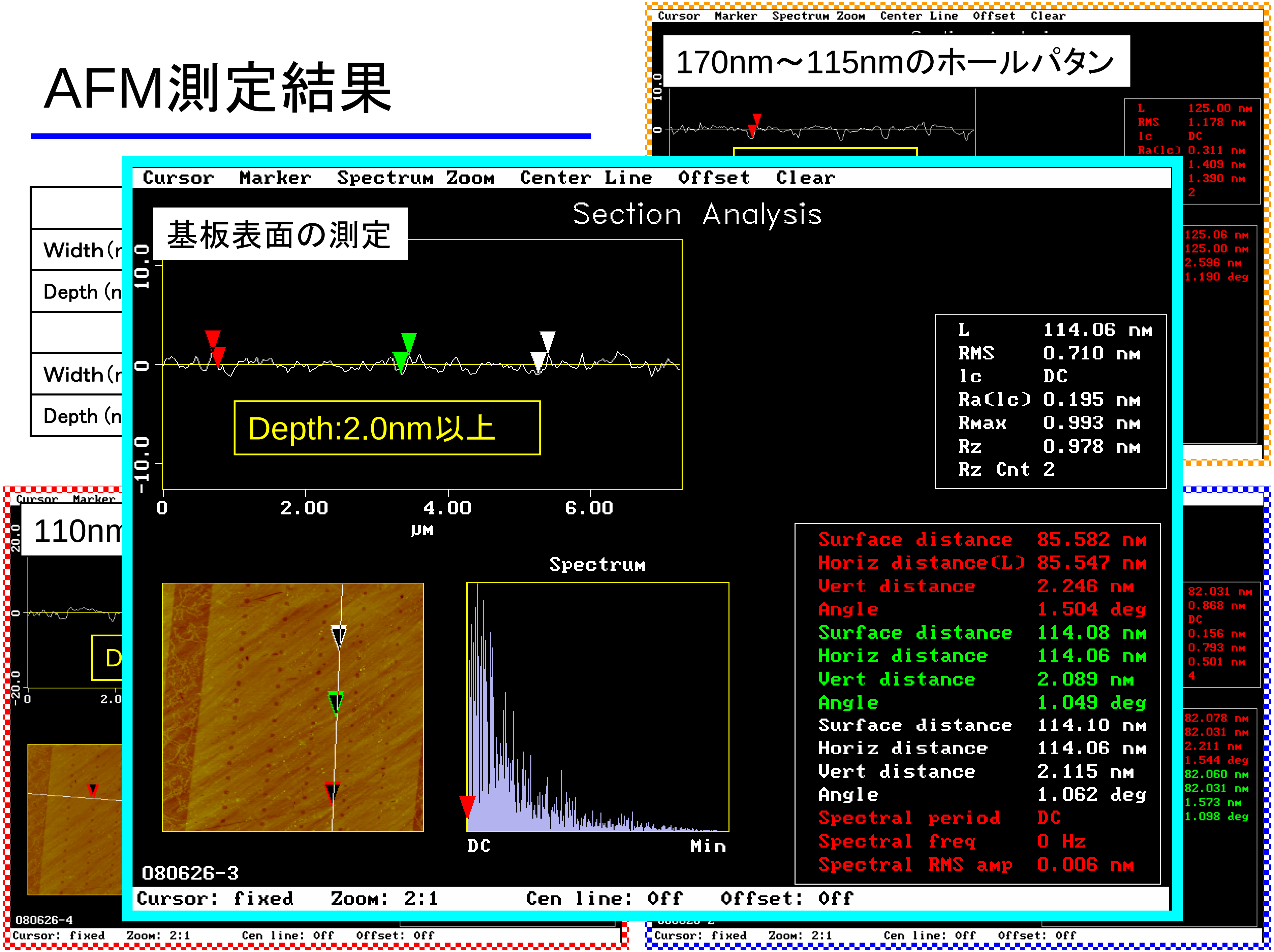
400nm,Depth 4nm

600nm,Depth 4nm

800nm,Depth4nm

1μm, Depth 4nm

AFM測定結果



Width (n
Depth (n
Width (n
Depth (n

170nm～115nmのホールパタン

```
L         125.00 nm
RMS       1.178 nm
lc        DC
Ra(lc)    0.311 nm
          1.409 nm
          1.390 nm
          2
```

```
125.06 nm
125.00 nm
2.596 nm
1.190 deg
```

110nm

080626-4

Cursor: fixed   Zoom: 2:1   Cen line: Off   Offset: Off

基板表面の測定

Depth:2.0nm以上

```
L          114.06 nm
RMS        0.710 nm
lc         DC
Ra(lc)     0.195 nm
Rmax       0.993 nm
Rz         0.978 nm
Rz Cnt     2
```

```
Surface distance      85.582 nm
Horiz distance(L)     85.547 nm
Vert distance         2.246 nm
Angle                 1.504 deg
Surface distance      114.08 nm
Horiz distance        114.06 nm
Vert distance         2.089 nm
Angle                 1.049 deg
Surface distance      114.10 nm
Horiz distance        114.06 nm
Vert distance         2.115 nm
Angle                 1.062 deg
Spectral period       DC
Spectral freq         0 Hz
Spectral RMS amp      0.006 nm
```

080626-3

Cursor: fixed   Zoom: 2:1   Cen line: Off   Offset: Off

```
82.031 nm
0.868 nm
DC
0.156 nm
0.793 nm
0.501 nm
4
```

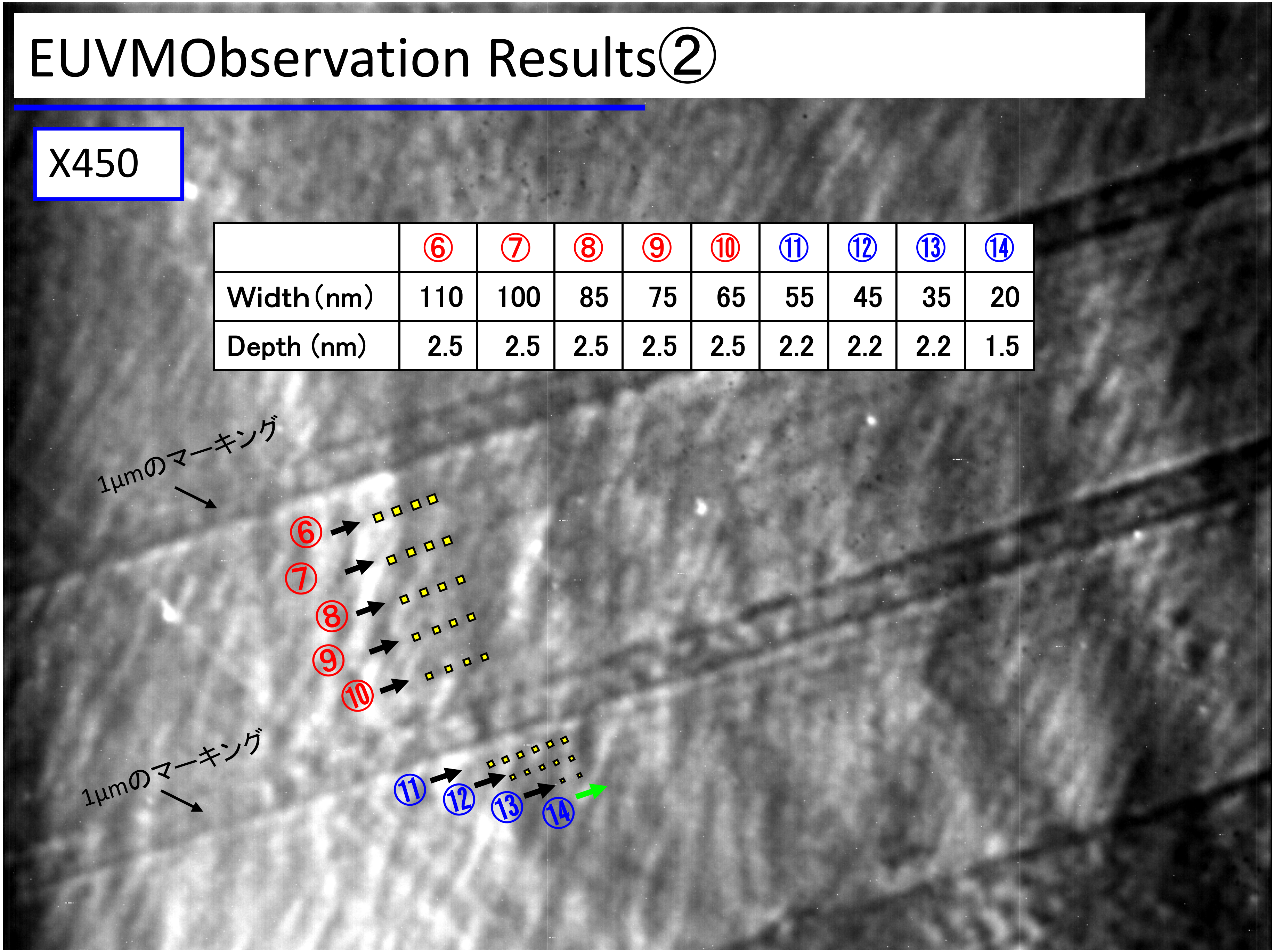
```
82.078 nm
82.031 nm
2.211 nm
1.544 deg
82.060 nm
82.031 nm
1.573 nm
1.098 deg
```

Cursor: fixed   Zoom: 2:1   Cen line: Off   Offset: Off

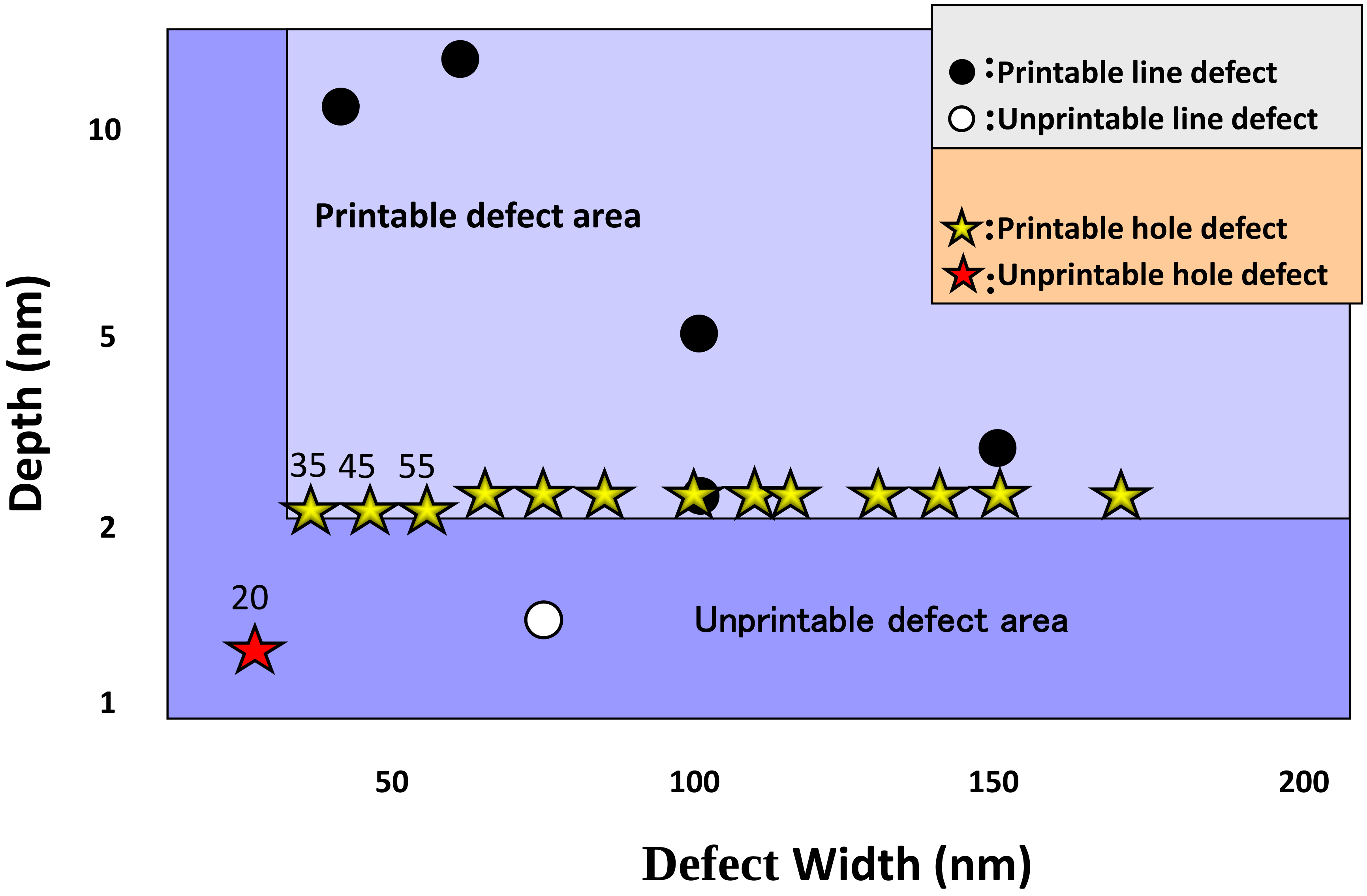
EUVMObservation Results②

X450

	⑥	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
Width（nm）	110	100	85	75	65	55	45	35	20
Depth（nm）	2.5	2.5	2.5	2.5	2.5	2.2	2.2	2.2	1.5



Summary of pit typed phase defect



Summary

1. We have constructed an EUV microscope for observing an aerial image of an EUV mask.

2. Using the EUV microscope, images of a finished mask and blank were observed clearly.

3. Pattern resolution of finished mask was estimated to be 50 nm

4. For a programmed pit defect of 75-nm width and 1.5-nm depth could not be observed. Also, dot defect of 20 nm wide and 1.5 nm depth could not observed.
   We conclude the critical dimension of pit on glass substrate is 2 nm in depth.

5. Resolution has been improved by cooling CCD, scanning mirror mechanism.