Phase defect mitigation strategy: Fiducial Mark requirements on EUVL mask

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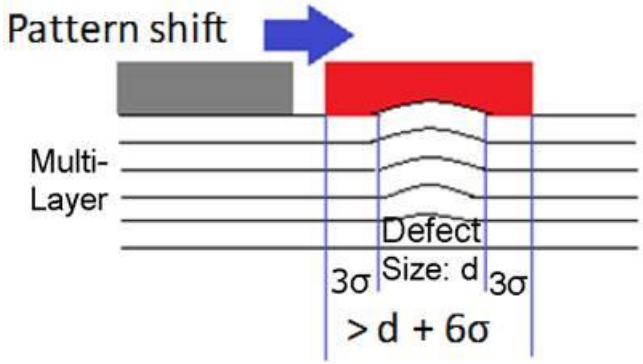
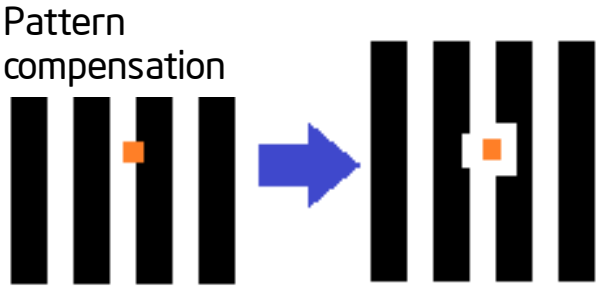
Introduction (1)

- Fabrication of Multi-Layered (ML) blank with no printable defect is one of the difficult challenges.
- However, we can cover or compensate defects by aligning the locations of patterns and defects.



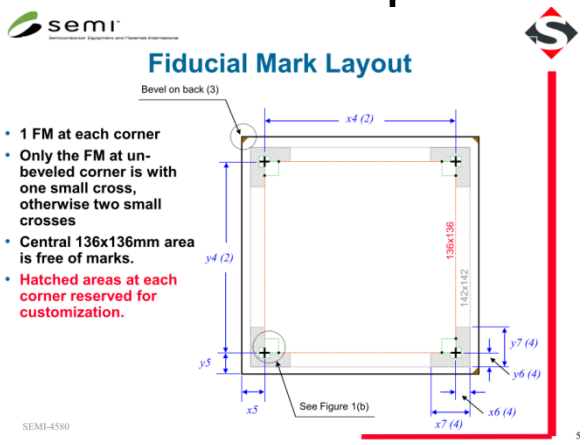


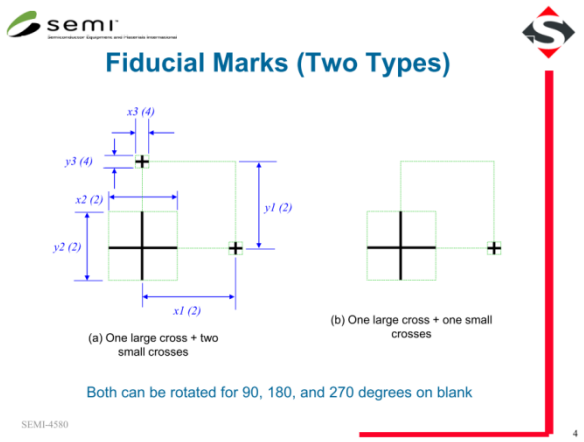
- Fiducial Mark (FM) is required to align locations.
- The proposed requirement of defect location accuracy is $\leq$ 20 nm*.

*Pei-Yang Yan, Proc. of SPIE Vol. 7488, 748819-1-8, (2009).

Introduction (2)

- SEMI defines FM specification.





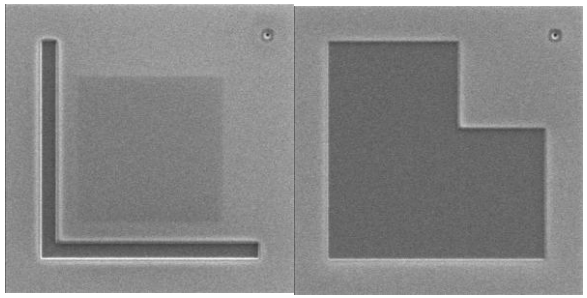
Excerpt from FM Specification

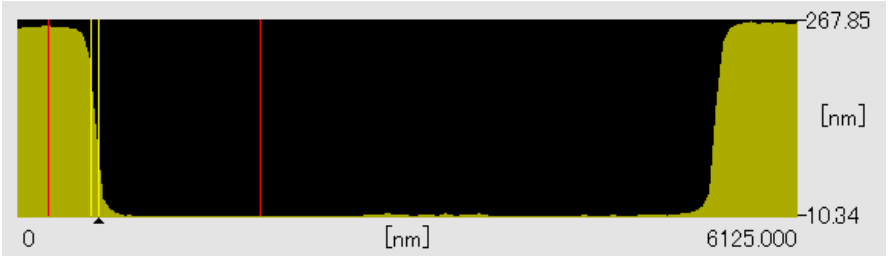
Item	Value (um)
Large cross size	550
Small cross size	100
Distance between centers of large and small cross	1500
Line CD	4 - 8

- So far FM line width, depth and fabrication method are not optimized for better location accuracy.
- We tried simulation and experiments to identify the optimum ranges of them.

Fiducial Mark fabrication

- FMs were etched to Qz & ML by FIB
  - Line width: 1, 5, 9 um
  - Line depth: 20, 120, 220 nm
  - Etching Layer: Qz and ML
- Measured profile by AFM

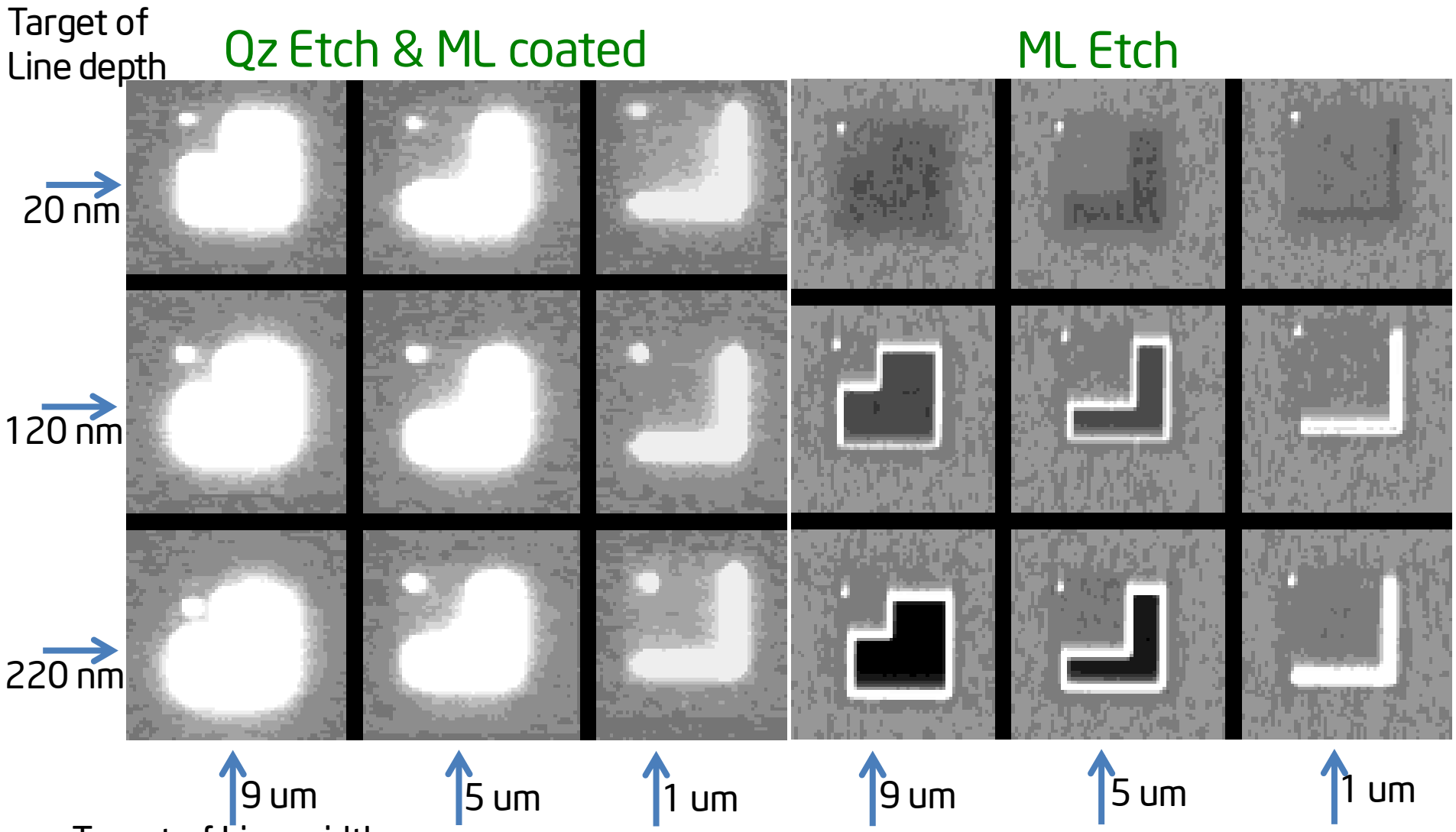




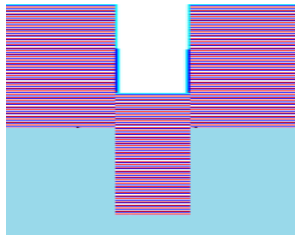
AFM result	Qz etched		ML etched	
Target of etched depth (nm)	Depth (nm)	SWA (deg)	Depth (nm)	SWA (deg)
20	9.1	-	22.0	7.5
120	-	-	134.6	41.3
220	137.8	54.1	252.9	63.2

- **Signals of FMs were measured by MIRAI EUV ABI tool**

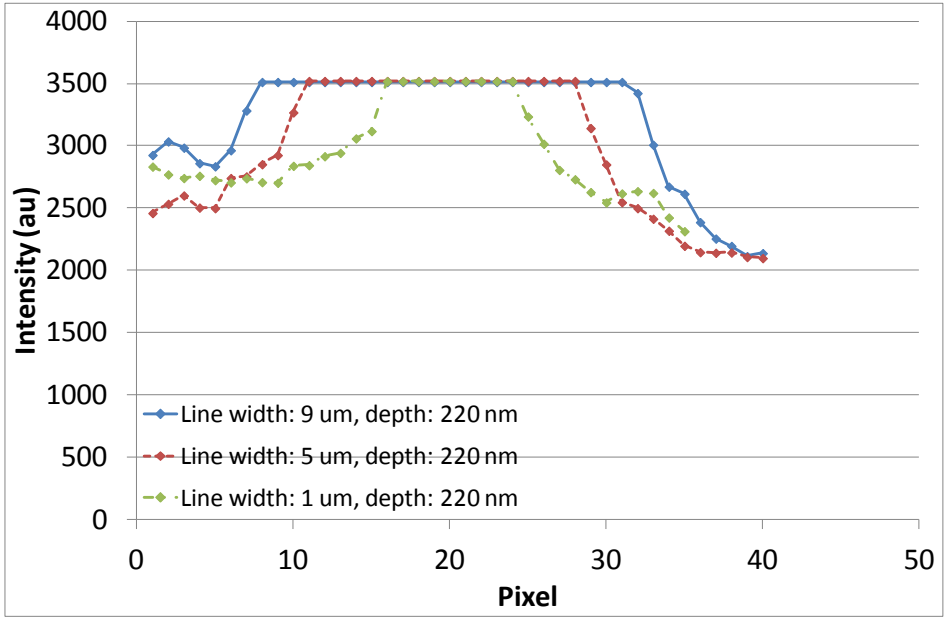
FM experiment - Image by ABI -



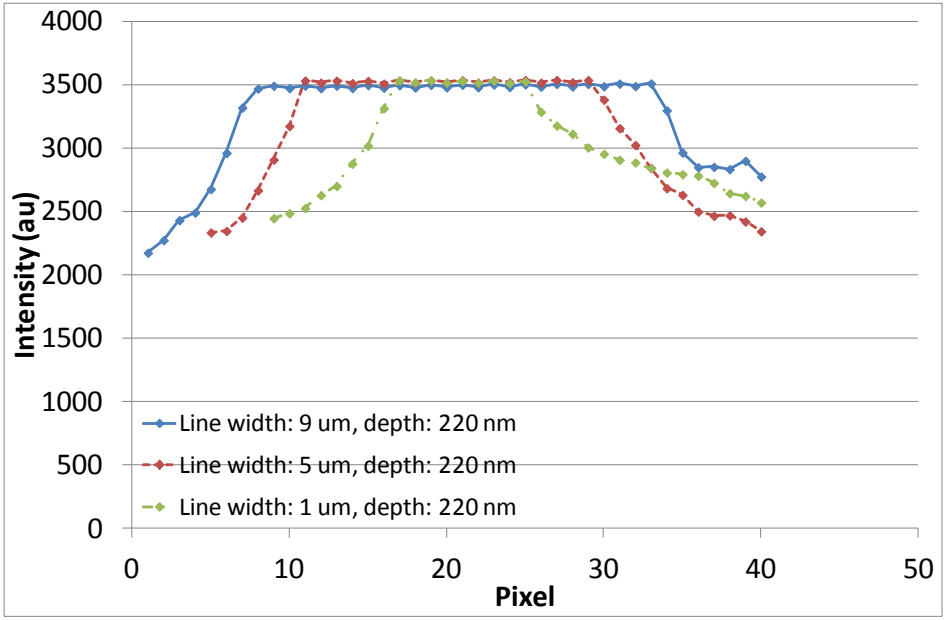
FM experiment - Signal by ABI
- Qz - 220 nm line depth -



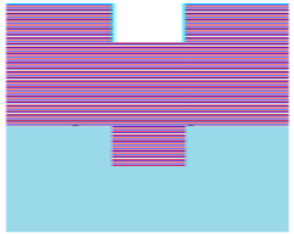
Vertical cut



Horizontal cut



FM experiment - Signal by ABI
- Qz - 120 nm line depth -



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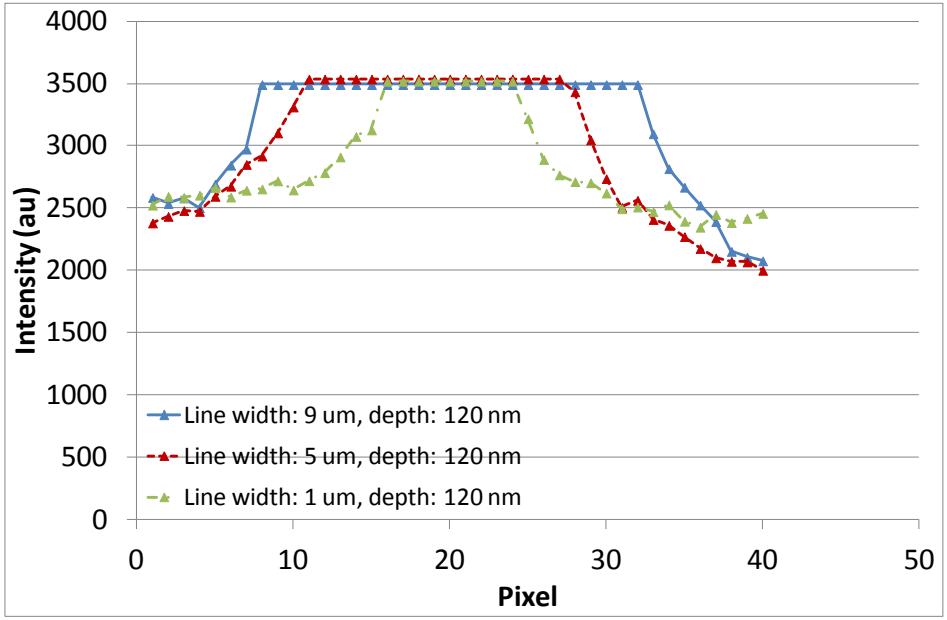

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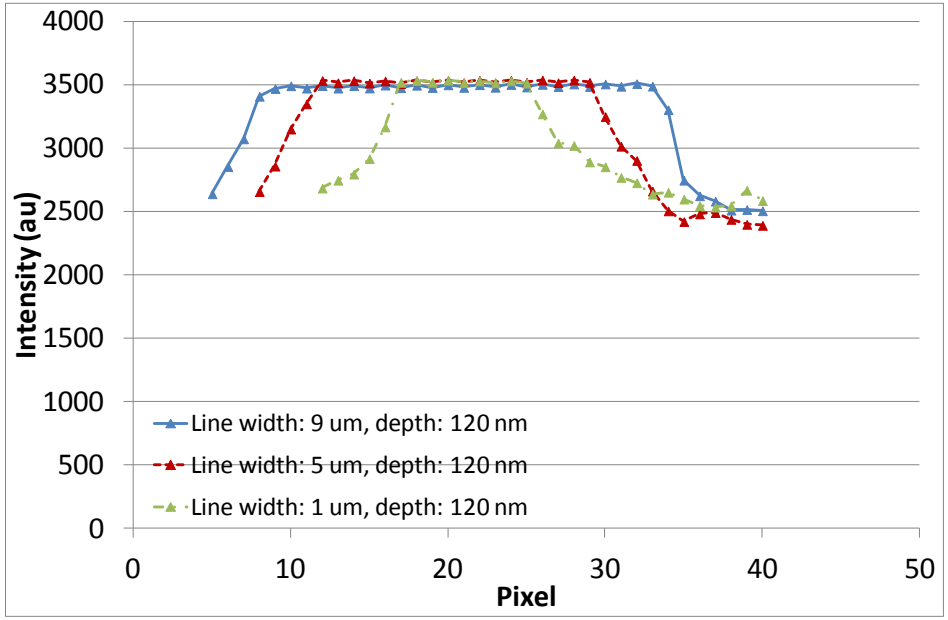
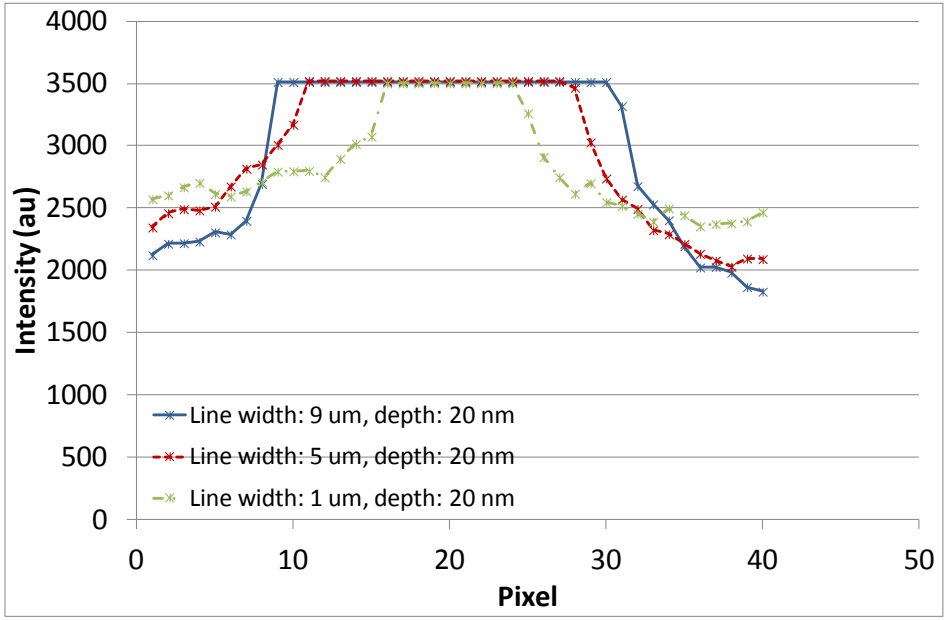


FM experiment - Signal by ABI
- Qz - 20 nm line depth -

Vertical cut



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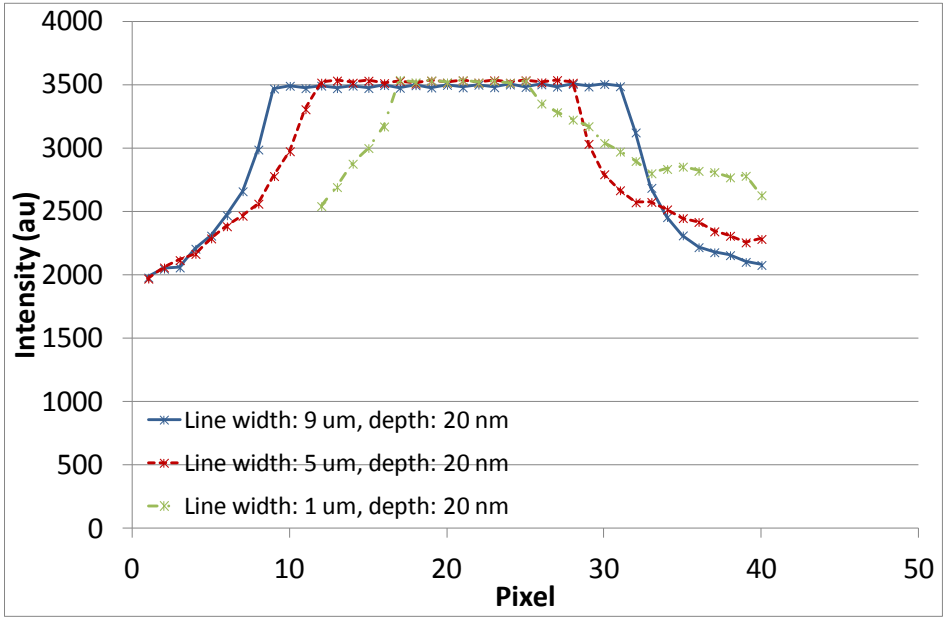
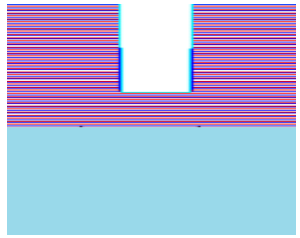


- ✓ The signals of Qz etched FMs saturated too much to detect location accurately.
  - Due to high reflectivity & scattering from rough ML surface at trench bottom etched to Qz and coated by ML

FM experiment - Signal by ABI
- ML - 220 nm line depth -



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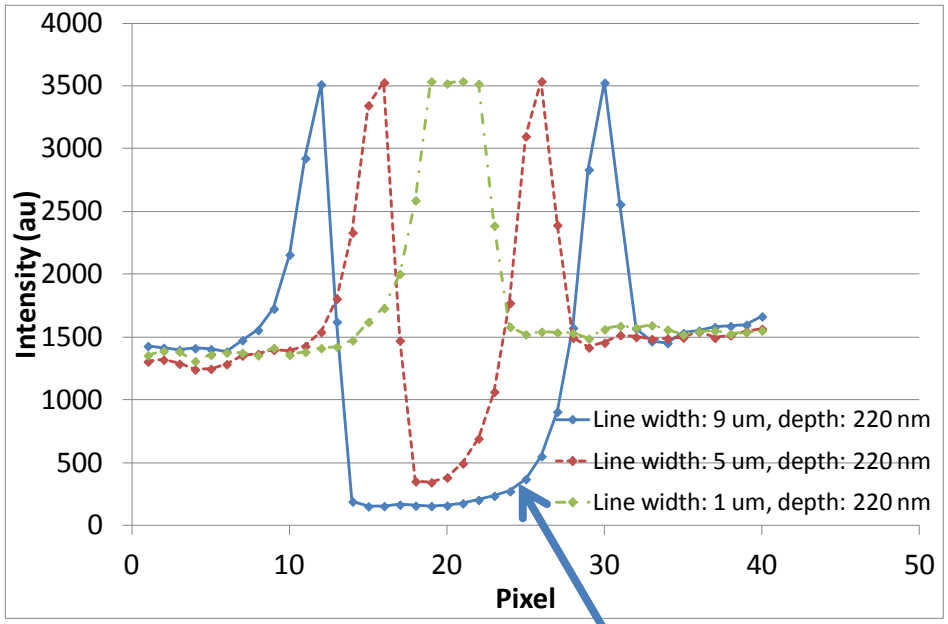

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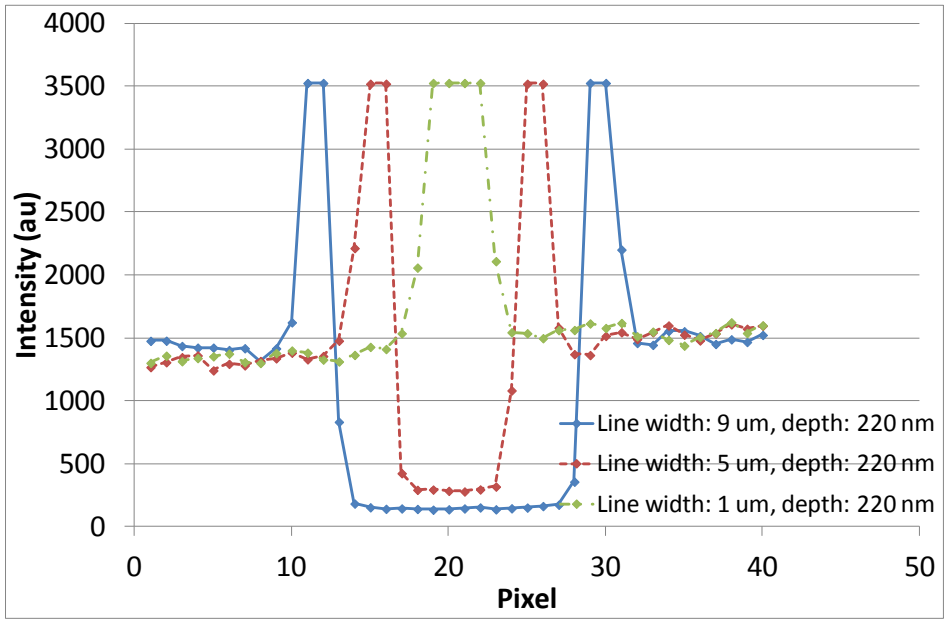
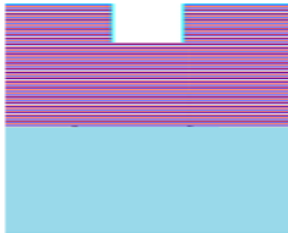


Corner rounding maybe due to electron transfer registration error

- ✓ **The signals saturated on ML etched FMs with 220 nm depth.**
- ✓ Signals at the bottom of FM trench are dark due to low reflectivity & scattering from thinner ML at trench bottom

FM experiment - Signal by ABI
- ML - 120 nm line depth -



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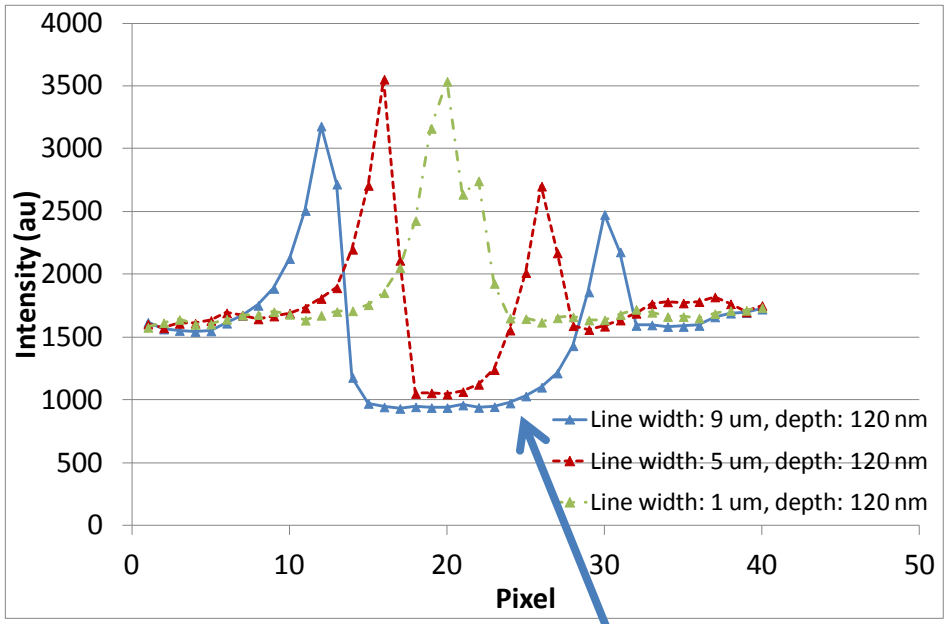

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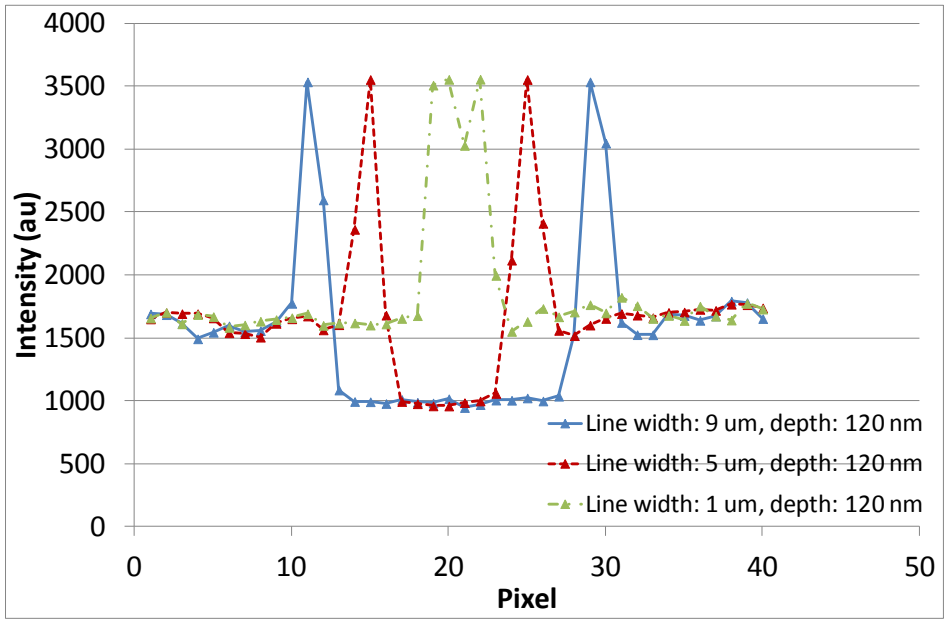
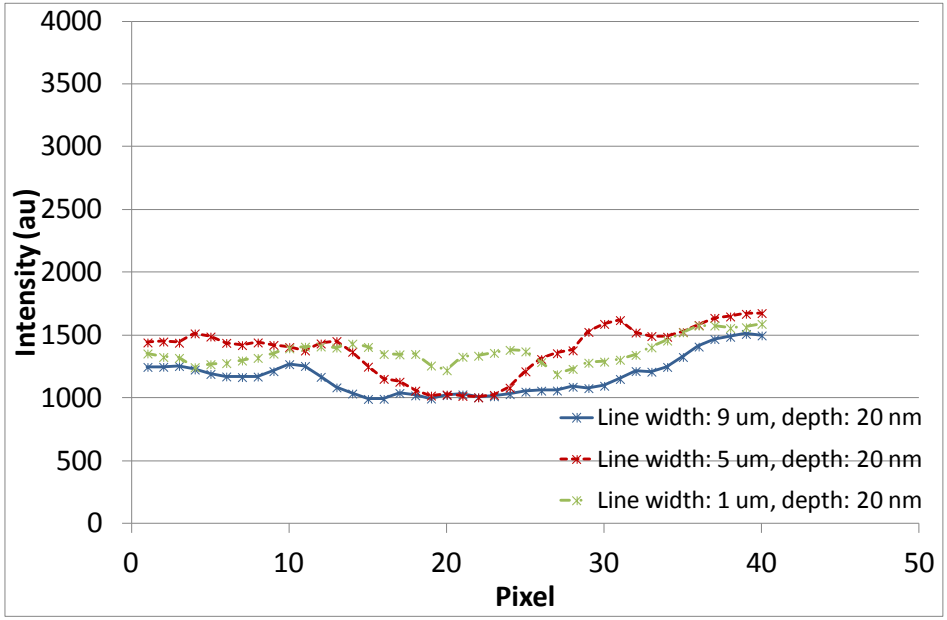


Corner rounding maybe due to electron transfer registration error

- ✓ The signals of ML etched FMs with 120 nm depth were appropriate for current system's dynamic range.
  -> Calculated FM location center (Page 16)

FM experiment - Signal by ABI
- ML - 20 nm line depth -

Vertical cut



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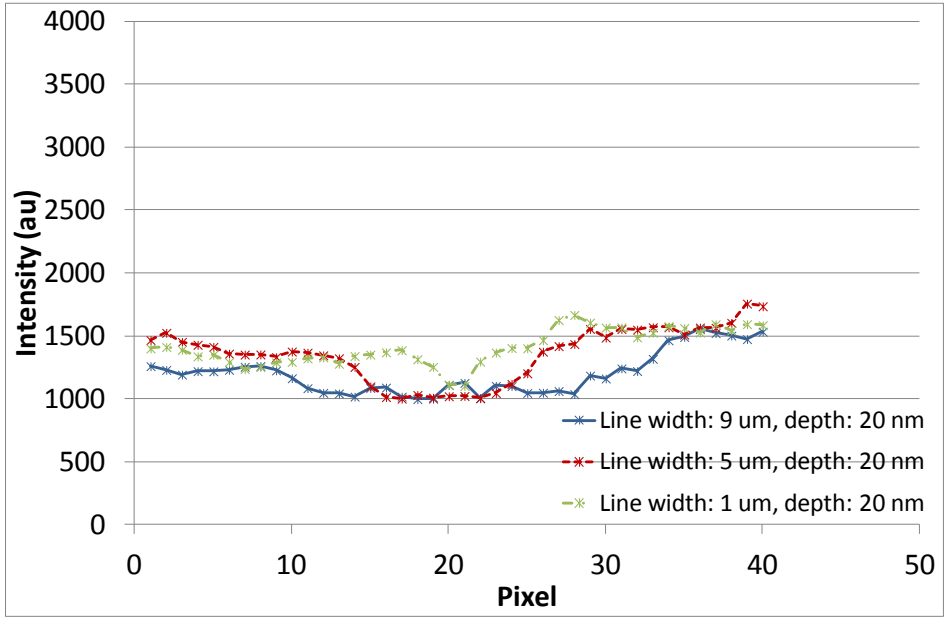

- ✓ Signals on ML etched FMs with 20 nm depth was slightly lower than background level.

Estimation of FM location from ABI signals

- Calculated center locations of 120 nm depth ML FMs from 6 data sets along line direction

Calculated center location (nm)		5 um line width		9 um line width	
		V line	H line	V line	H line
Including peak	2nd order polynomial (3 pixels)	-18.1	-24.0	80.1	111.4
	Gaussian (5 pixels)	13.8	-40.2	119.2	161.0
	Gaussian (7 pixels)	-33.9	-42.5	66.4	158.5
Excluding peak	2nd order polynomial (4 pixels)	-109.7	-64.3	-10.6	82.4
	Gaussian (4 pixels)	4.5	-15.6	30.9	63.0
	Gaussian (6 pixels)	-59.4	-58.1	57.2	115.5
Maximum difference in column		**123.5**	**48.7**	**129.8**	**98.0**

- ✓ **The worst difference of center location between fitting methods is 130 nm, much larger than 20 nm requirement.**
- ✓ **We had better prepare additional FMs for finer alignment for magnified optics** as this may be due to MIRAI EUV ABI CCD pixel size.

Summary and conclusion

- For current MIRAI EUV ABI tool, the optimum of FM line width, depth, and fabrication method are:
  - ≥ 5 um line width is preferred
  - Around 120 nm line depth
  - ML etching is required
  - Additional finer FMs for magnified optics
- Additional functions to ABI tool will expand its capacity of FM signal detection.
  - ND filter
  - Adjustable shutter speed
  - CCD electron transfer timing
  - Light source power adjustment
- Experiment and Simulation are agreed well.

Future study

- Further measurement of FM Signal
  - With Absorber
  - By EB writer
- Cross section observation of fabricated FMs
- Trial of other FM fabrication method and signal measurement

Acknowledgement

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- Engineers of HOYA and Dai Nippon Printing

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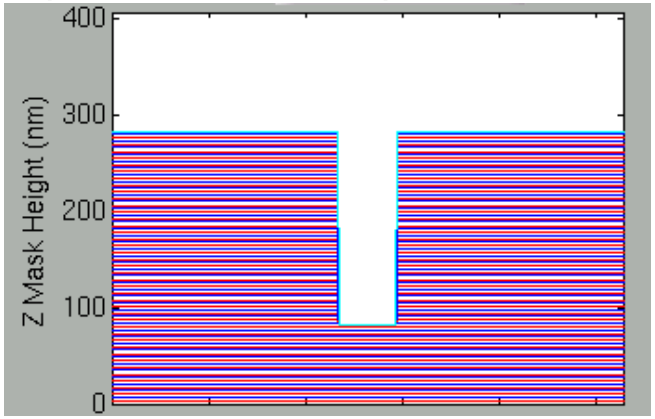
Thank you for your attention!

Backup

Simulation conditions

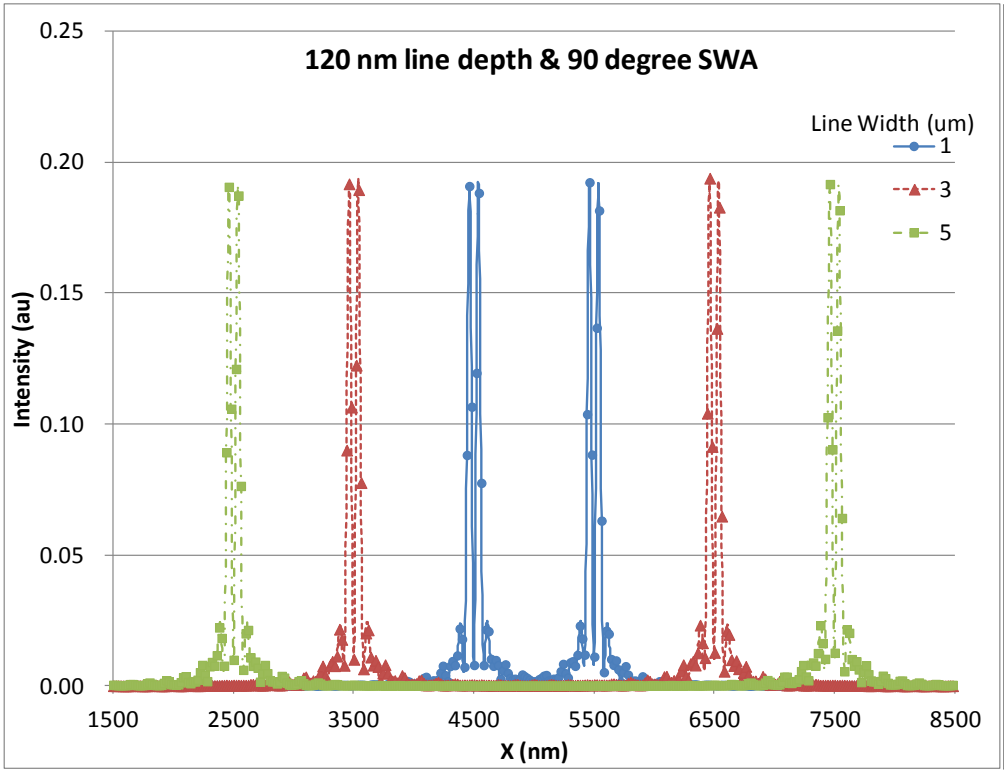
- Simulator: Luminescent EUV Defect Printability Simulator (DPS)
- Optics conditions
  - Imaging Optics: Schwarzschild Optics
    26 x magnification
    0.1 NA_{in} (5.7 degree), 0.27 NA_{out} (15.7 degree)
  - Illumination: $0.054NA_{ill}$ (3.0 degree)
  - Wavelength: 13.5 nm
- ML stack conditions
  - ML: 40 pair of Mo/Si (2.8 / 4.2 nm)
  - Capping: 2.5 nm Ru
  - Etching: ML
  - SideWall Angle (SWA): 50 - 90 degree
  - Etching depth: 70 – 220 nm



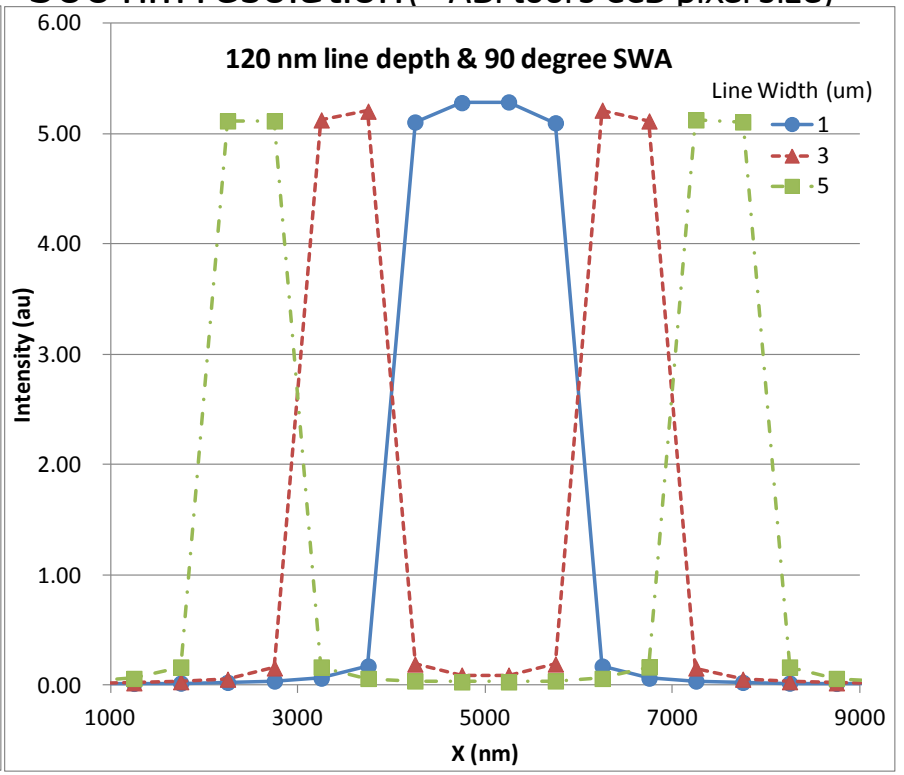
Simulation result (1)

- Intensity trends of FM line width changes between 1, 3, and 5 um for 120 nm line depth & 90 degree SWA.

2 nm resolution for X direction



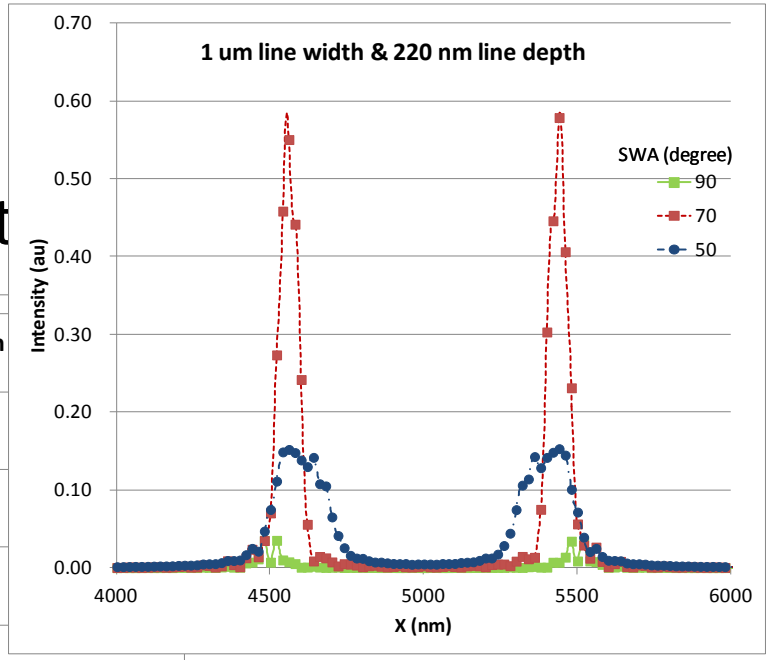
500 nm resolution (= ABI tool's CCD pixel size)

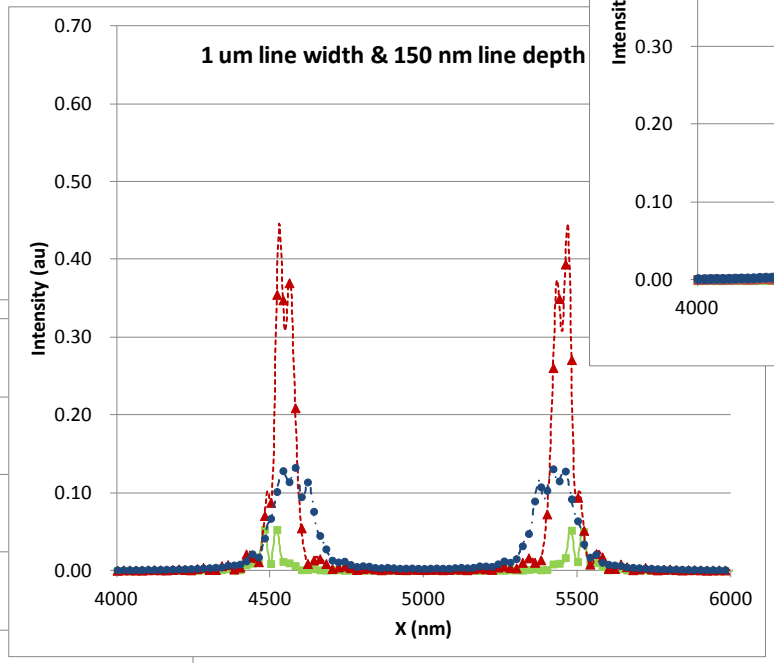


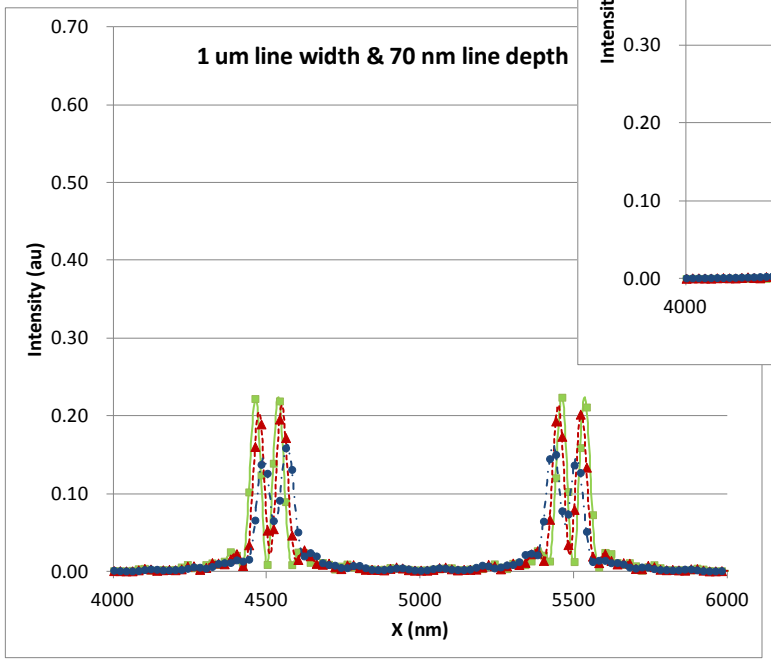
- ✓Intensity is expected to be independent to line width.
- ✓Multiple peaks are preferred to single peak for higher accuracy.

Simulation result (2)

- Intensity trends of FM SWA changes btw 50 to 90 degree for 1 um line width & 70, 150, and 220 nm line dept

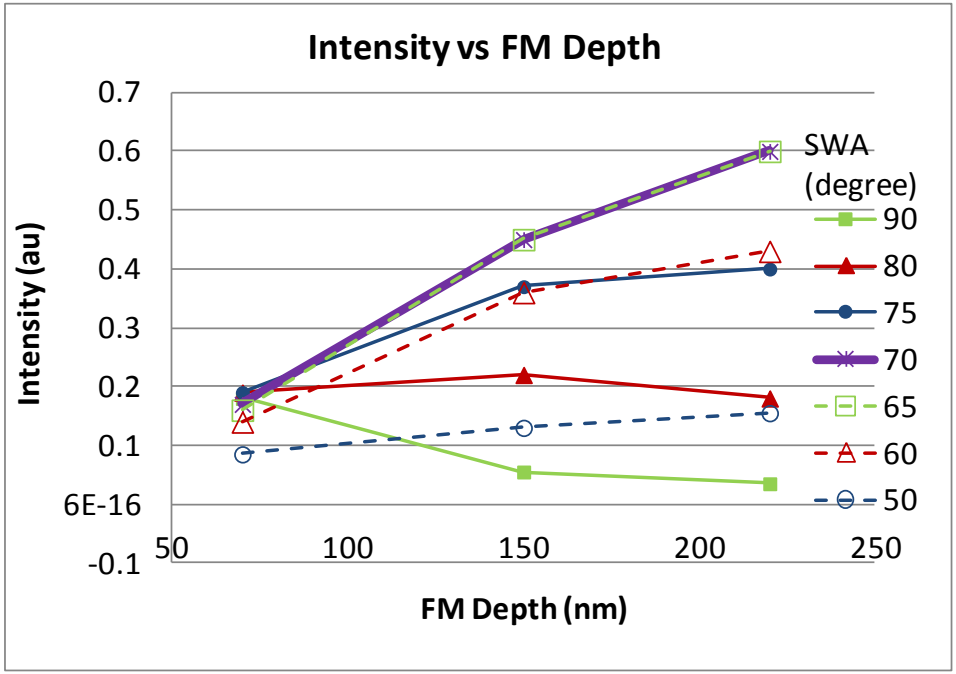


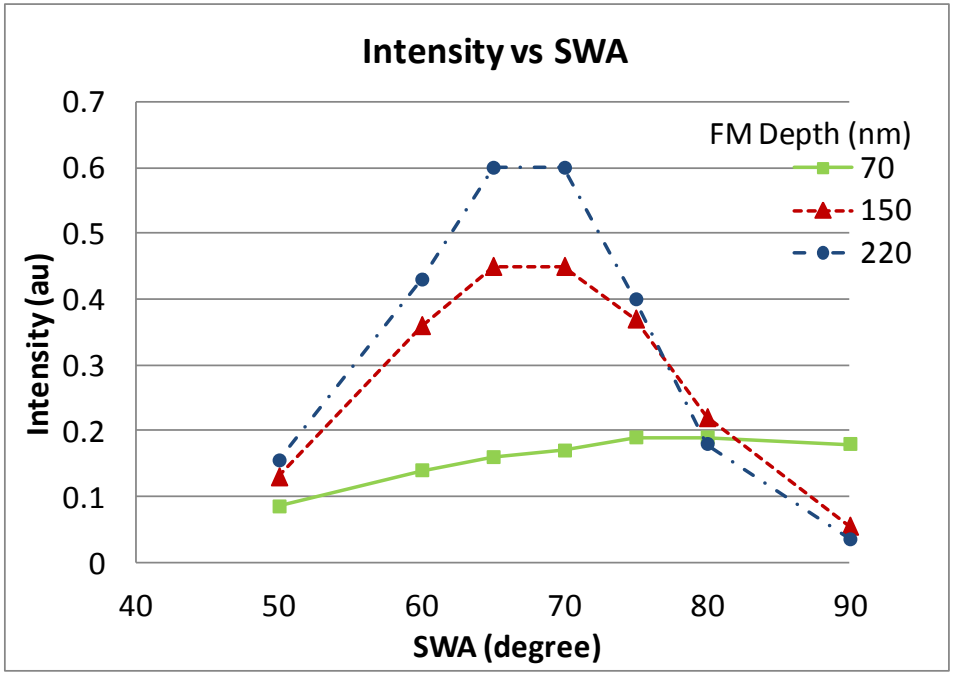




Simulation result (3)

- Intensity trends of FM line depth changes for several SWA, and SWA changes for several FM depth.





✓Maximum intensity is expected at 65 – 70 degree SWA and deeper FM line depth.