Evaluation of Property Change by the insertion of Ru Layer into Mo/Si Multilayer

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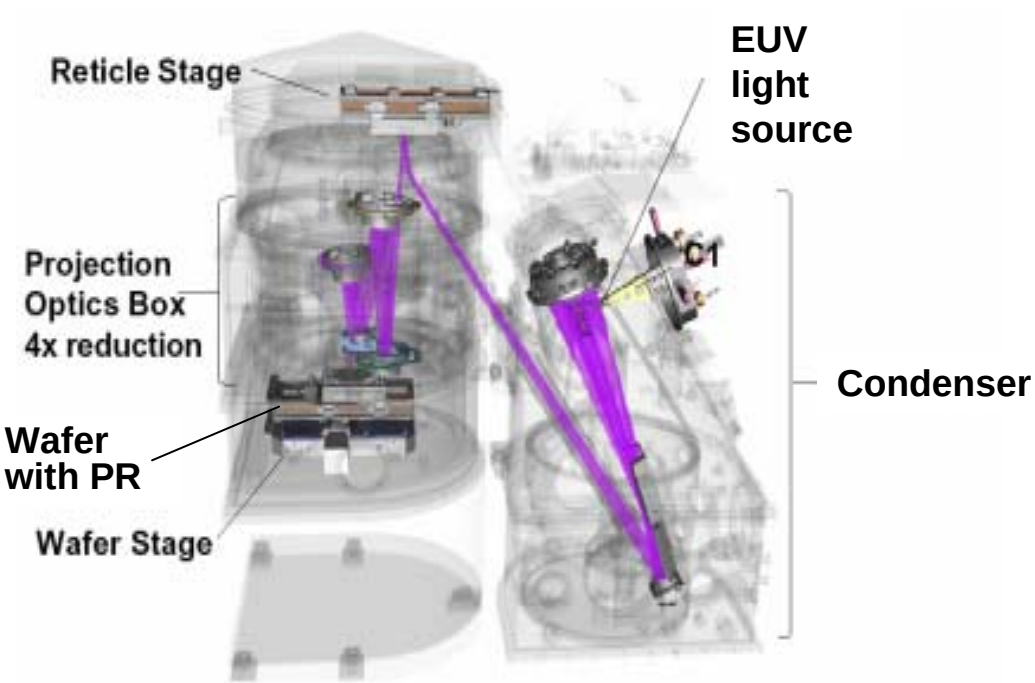
EUVL System



Advantages

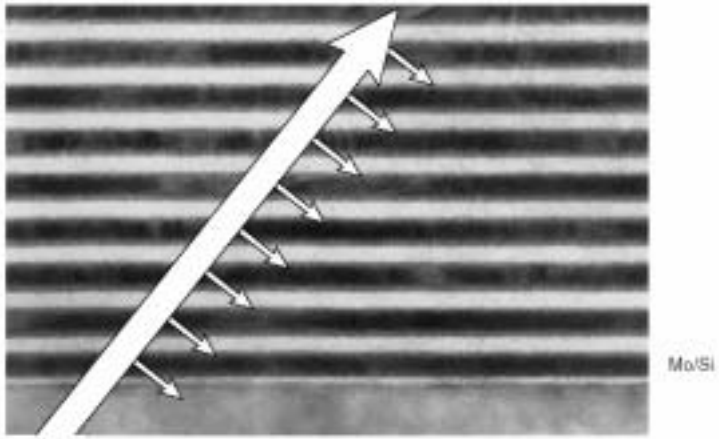
- Superior Resolution
- Similar to conventional optical lithography
- High throughput
- Robust mask structure
- DUV photoresists are extendible to EUV

- EUV light is absorbed in the atmosphere and by most materials

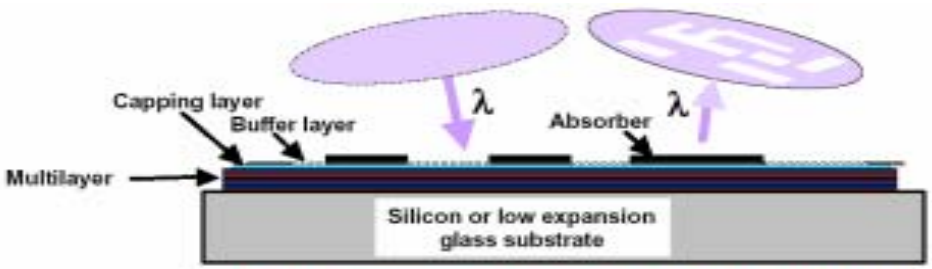
→ Reflective mirror (optics & mask) should be used.
→ Reflectivity is a critical factor for throughput

ML mirror

- Refractive index contrast at the interfaces
- Minimal absorption in the low-Z material
- Thin high-Z layer where possible
- Interfaces which are chemically stable with time
- Minimal interdiffusion at the interfaces
- Minimal interfacial roughness
- Thermal stability during EUV illumination
- Chemically stable vacuum interface
- Uniform coating thickness



(T. Nguyen, CXRO/LBNL)

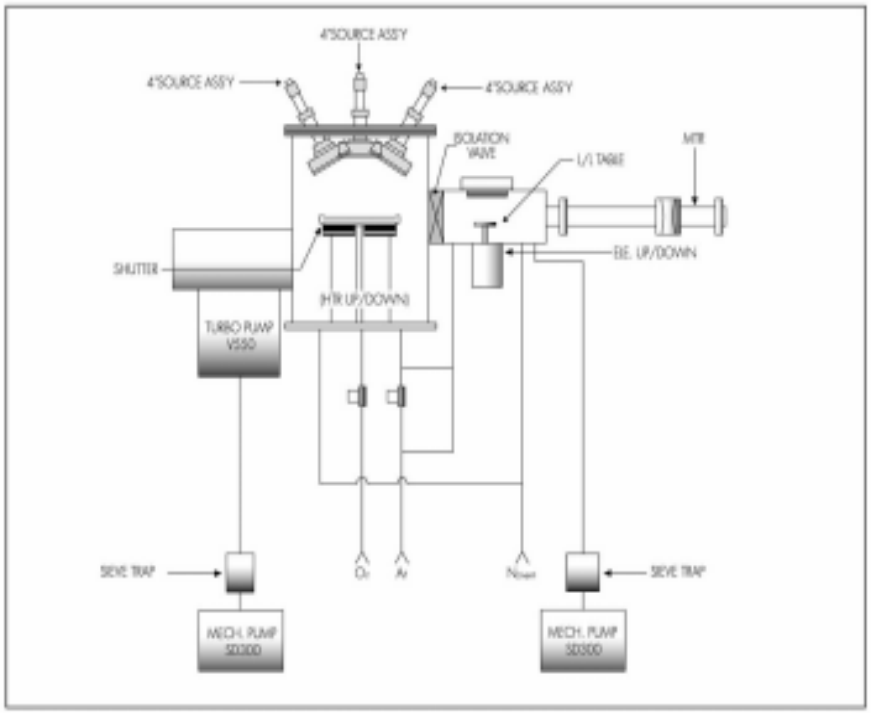


Mask Structure with incident and reflected EUV

Purposes of the experiment

- **Deposition of standard quarter wavelength multilayer**
  - **Mo/Si multilayer**
  - **Analysis method development**
- **Barrier layer selection and deposition**
  - **Simulation of various barrier layer**
- **Maximization of the empirical reflectivity**
  - **Currently, 65 - 70% at 13.5 nm (theoretically, ~ 75% in Mo/Si multilayer)**
  - **In 7 normal incident mirror system, 1% of reflectivity increase in each mirror can result in 10 - 20% of throughput increase**
- **Evaluation of new multilayer for EUV mask and optics applications**
  - **Thermal stability (Lifetime)**
  - **Correctability: e-beam, ion-beam**

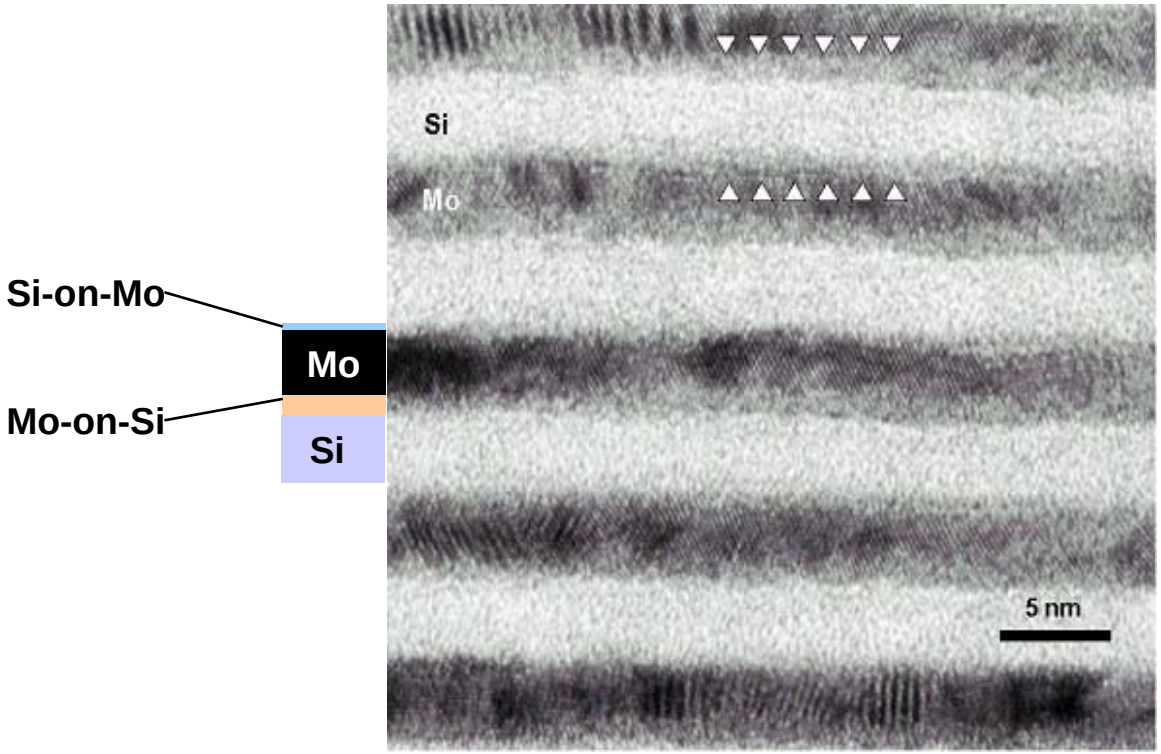
Deposition system



Sputter system is easy to

- control the thickness of thin film
- deposit other kinds of material consecutively
- deposit high purity thin film

Mo-Si multilayer stack

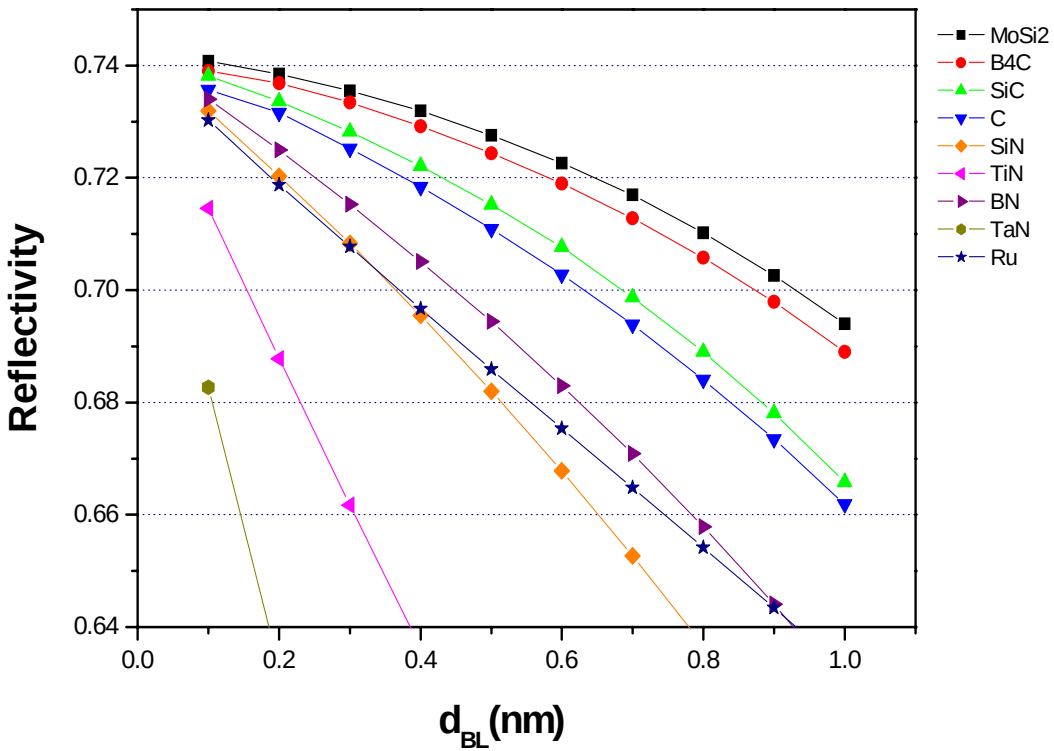


- **The thickness of interfacial layer of Mo-on-Si is thicker than the Si-on-Mo interface**

  - The crystalline Mo is more densely packed than amorphous Si.

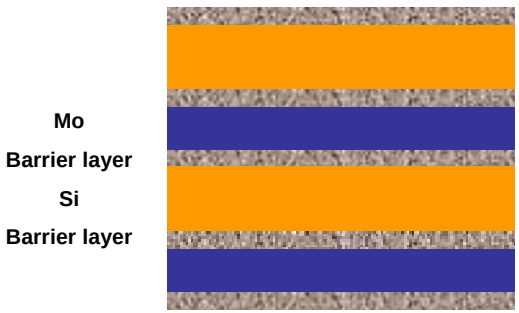
  - Atomic weight difference: Mo (95.94) vs. Si (28.09).

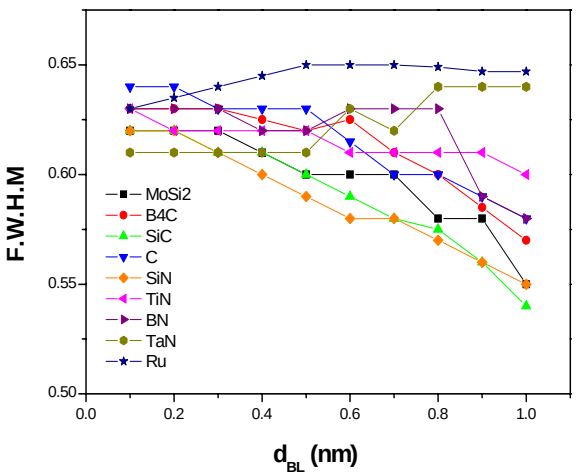
Effect of barrier material - quadruple layer (simulation)



Quadruple layer system

B.L./Mo/B.L./Si

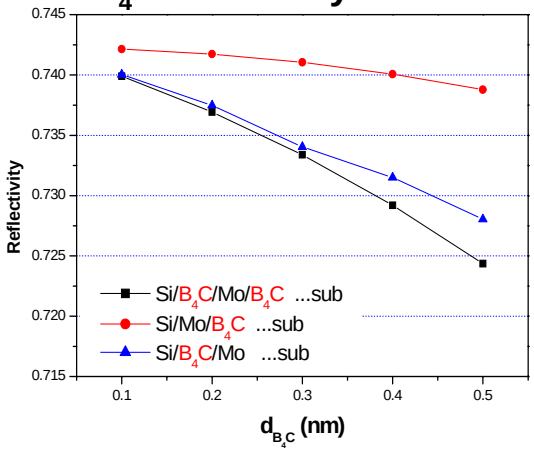




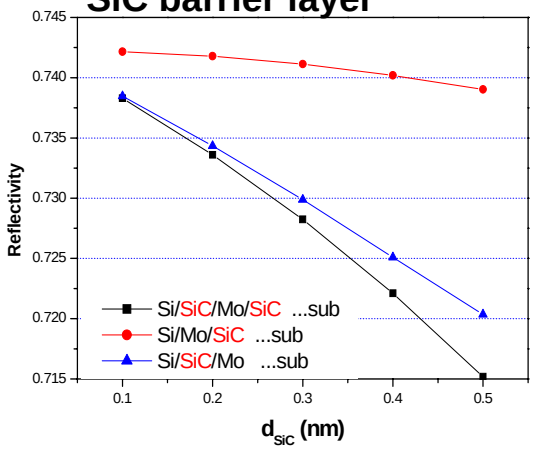
When inserted into every interface btw Mo and Si, all barrier materials tend to degrade reflectivity compared to Mo-silicide interlayer

The effects of insertion manner - simulation

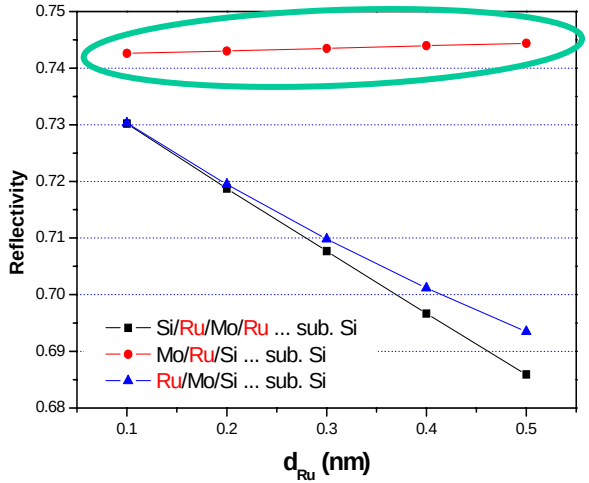
B_4C barrier layer

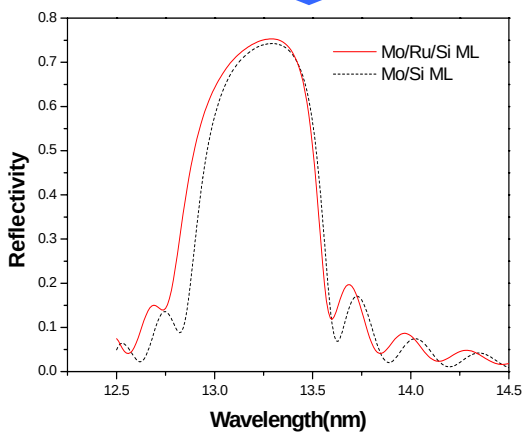


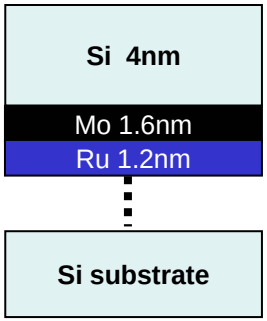
SiC barrier layer



Ru barrier layer

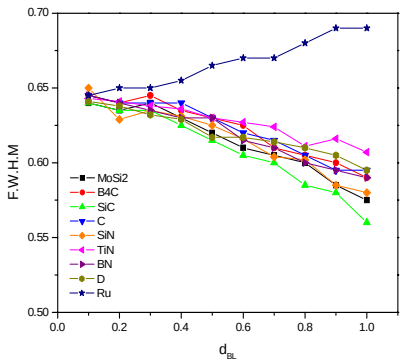






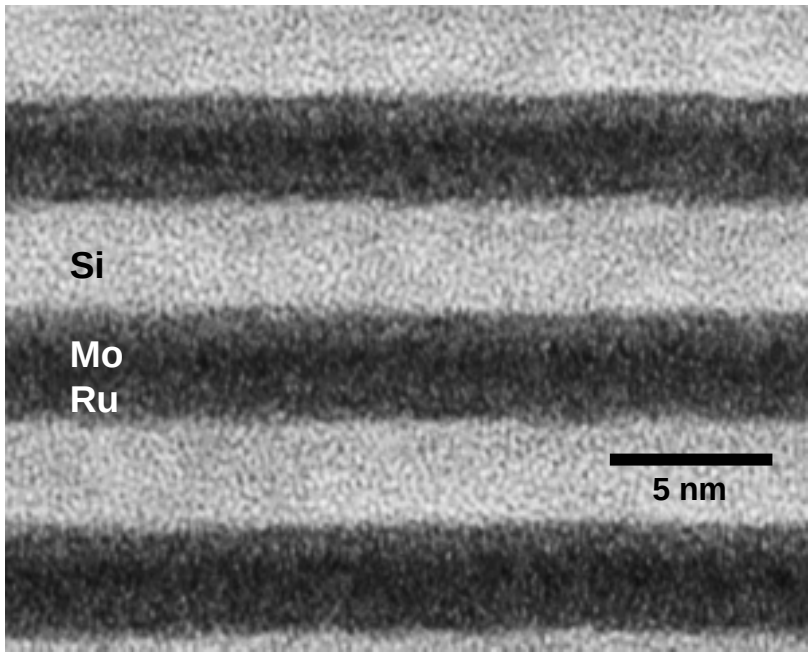
Triple layer system

Mo/B.L./Si

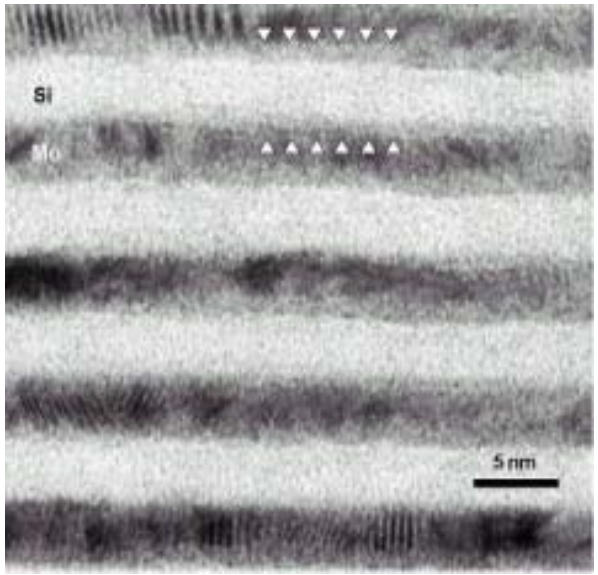


Theoretical peak reflectivity
- Mo/Si ML : 74.25% @ 13.29nm
- Ru/Mo/Si ML : 75.32% @ 13.29nm
Ru inserted into Mo-on-Si interface
1.2% max. reflectivity increase

Ru triple layer – interface

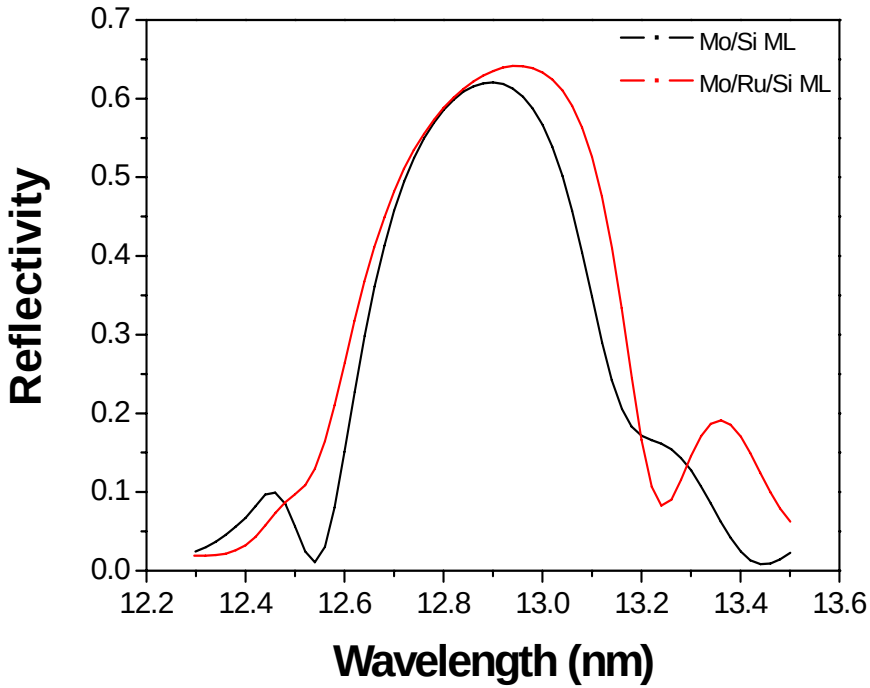


Ru/Mo/Si triple layer



- **More distinctive and smother interface in Mo/Ru/Si triple layer compared to Mo/Si bi-layer.**

Reflectivity comparison



	simulated	actual
⊿R	1.1%	2.1%
⊿FWHM	15.9% (0.093 nm)	15.3% (0.072 nm)
⊿Throughput	~11%	~22% - 30%

- Reflectivity curves are in good accordance with simulated value.
- The FWHM value is also enhanced by the Ru addition as simulated.
- The high FWHM value not only enlarges the process latitude in the fabrication of mask and optics but also enhanced the throughput by increasing the total energy under a reflectivity curve.
- 1.1% R increase → 10.9 % throughput increase with 7 normal incident mirror system

Annealing of ML (1) – w & w/o Ru barrier layer

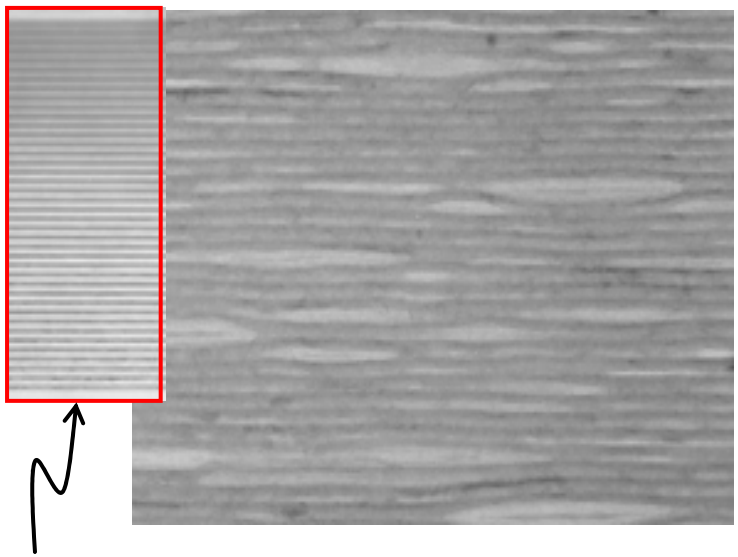
Annealing condition: 350˚C, 1hr

Mo/Si ML

Ru/Mo/Si…sub Si ML

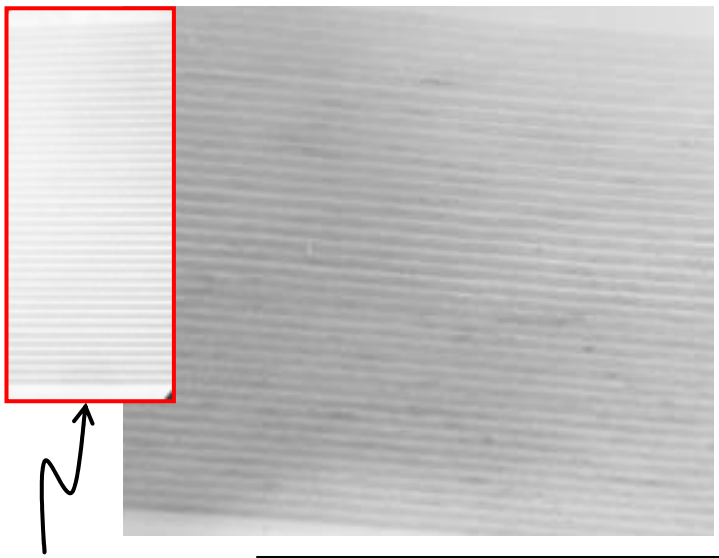
Annealing of ML (2) – w & w/o Ru barrier layer

Mo/Si multilayer



Before annealing

Ru/Mo/Si…sub Si multilayer

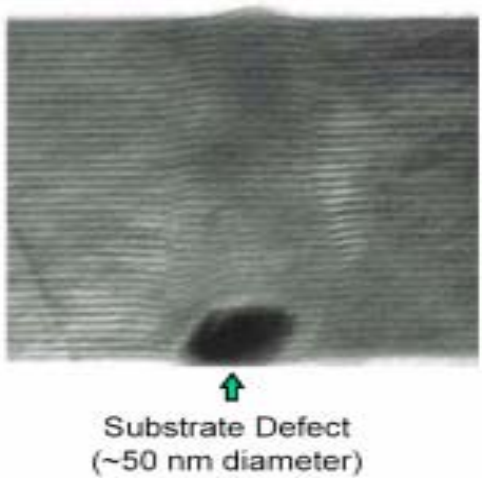


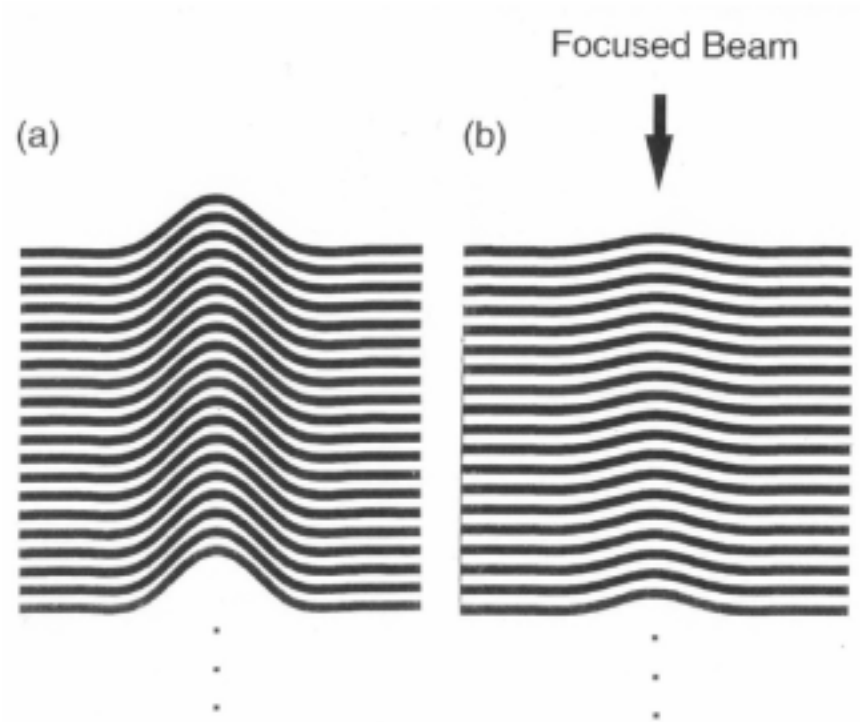
Before annealing

- **Annealing condition: 470°C, for 15 min.**
- **Ru layer trends to prevent the uneven diffusion of Si atoms across the scatterer layer.**

Sample	Ru power (DC) / Ar pressure	Mo power (DC) / Ar pressure	Si power (RF) / Ar pressure	Decrease in d-spacing
Ru/Mo/Si	50W / 1.5 mTorr	50W / 3 mTorr	100W / 1.5 mTorr	4.6 %
Mo/Si ML	- / 1.5 mTorr	50W / 1.5 mTorr	100W / 1.5 mTorr	8.2 %

Phase defect – generation & correction





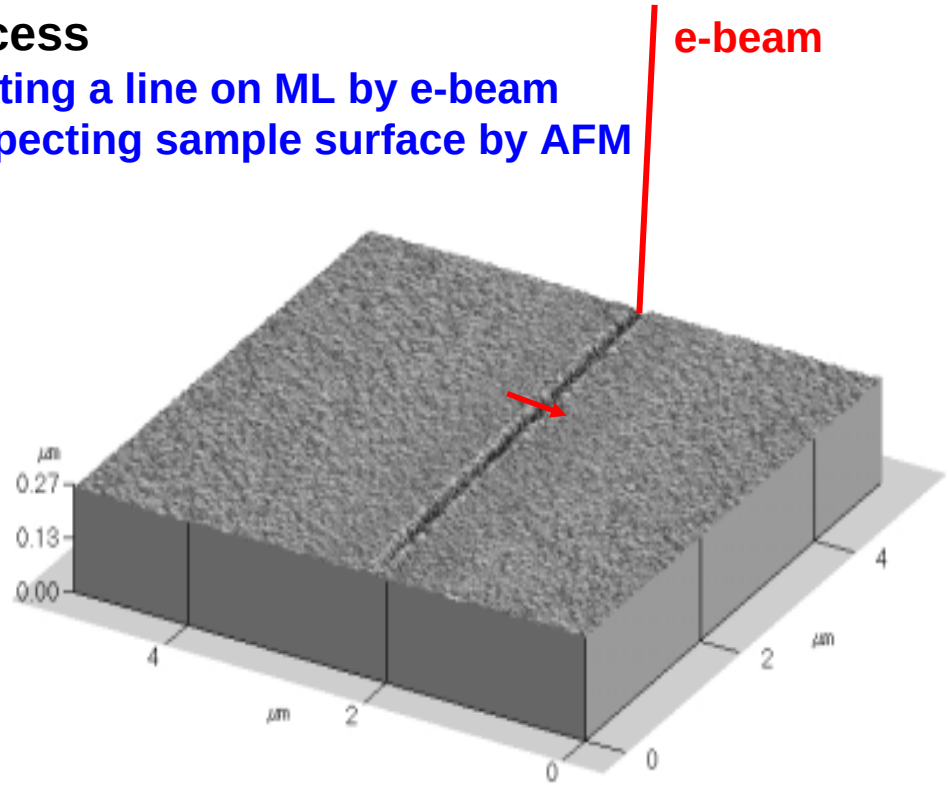
Focused e-beam : localized heating promotes interdiffusion btw Si & Mo

→ volume contraction

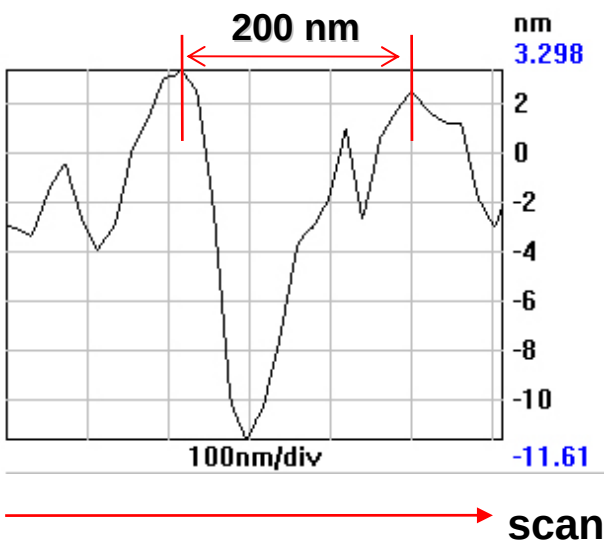
Phase defect correction (1) – AFM scan

Process

- **Writing a line on ML by e-beam**
- **Inspecting sample surface by AFM**



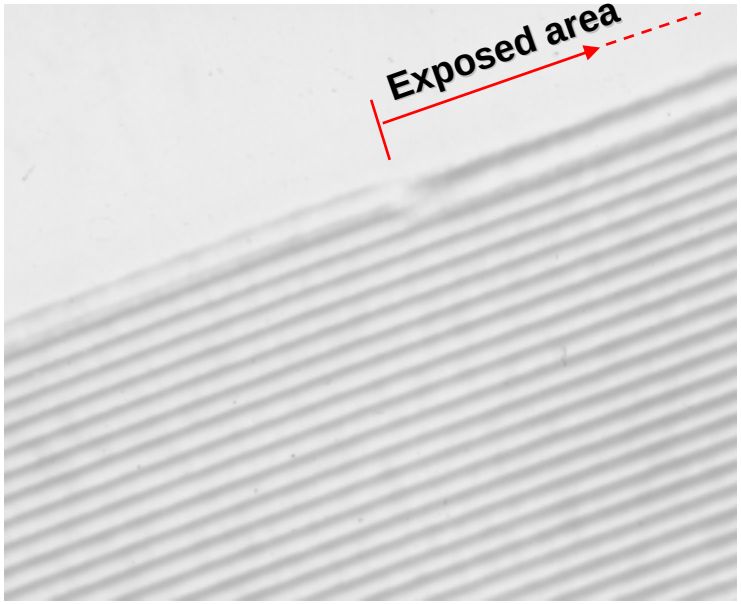
Accl. Voltage	30keV
Beam Current	5pA
Beam dose	1.0nC/cm^2



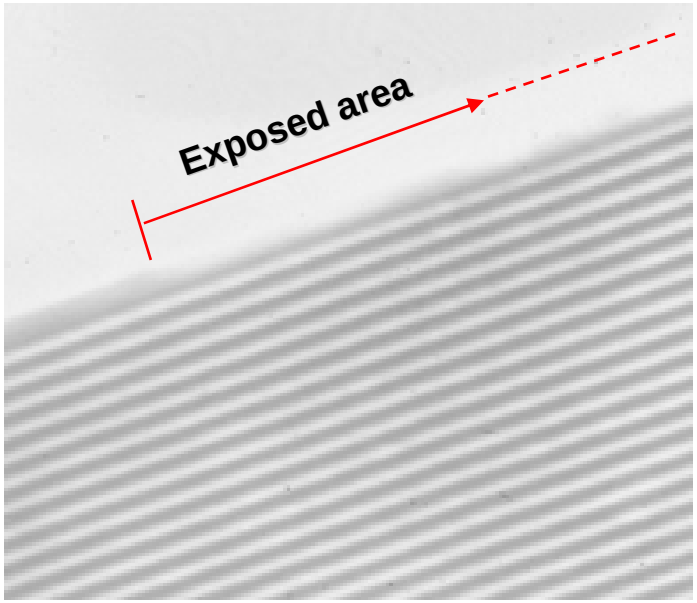
- **Line width : 200 nm, Line length : 10 um**

Phase Defect correction (2) - FIB TEM

Accl. Voltage	35keV
Beam Current	5pA
Beam dose	1.0nC/cm^2



Mo/Si ML



Mo/Ru/Si…sub ML

- Si diffused out in the e-beam exposed area thorough Mo grain boundary

Summary

- The peak reflectivity obtained from Mo/Si ML was 62.6%.
- According to optical simulation, Ru has potential to be a barrier material in Mo/Si ML, which can result in the improved EUV reflectance.
- The peak reflectivity of the Mo/Ru/Si ML was 64.2%
- Through the incorporation of Ru barrier layer, ML had more desirable interfacial structure.
- Thermal stability and phase defect correctability of multilayer was improved by the insertion of Ru barrier layer.