Characteristics of Mo/Ru/Si multilayer reflector structure

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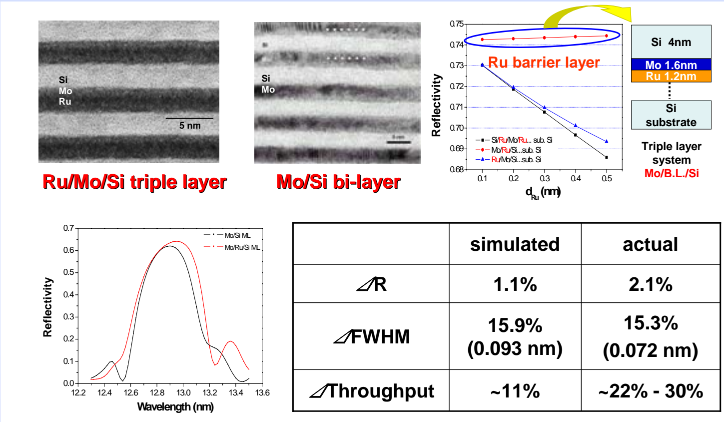
Introduction

The characteristics of *multilayer reflector* is important since it is the core optical component for EUV projection. The multilayer structure as an EUV mask application should satisfy the following properies like *high EUV reflectivity*, *low defect*, *compatibility with defect correction process* and *cleaning efficiency*. The practical reflectivity of multilayer is always lower than that of the theorical value, and its main causes are non-ideal properties at the interface (*interfacial mixing*) and inside the films (*density variation*).

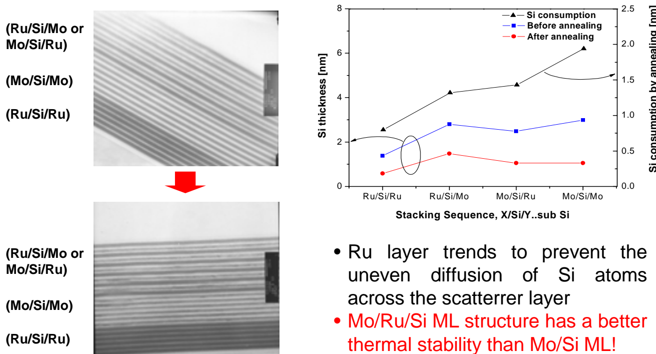
Improvement by insertion of Ru layer



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

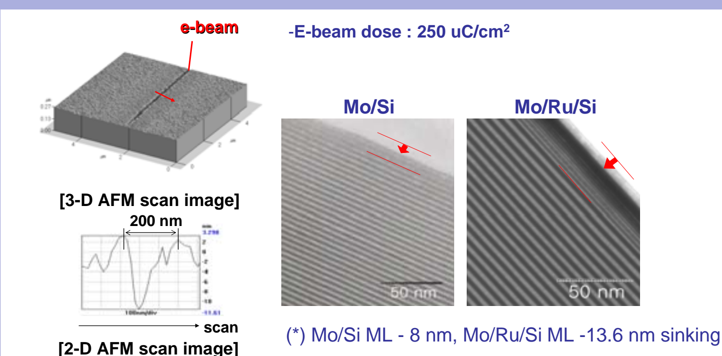
Thermal stability

Annealing (furnace : 15 min @ 400 ˚C)



- Ru layer trends to prevent the uneven diffusion of Si atoms across the scatterrer layer
- Mo/Ru/Si ML structure has a better thermal stability than Mo/Si ML!

E-beam correction feasibility



(*) Mo/Si ML - 8 nm, Mo/Ru/Si ML -13.6 nm sinking

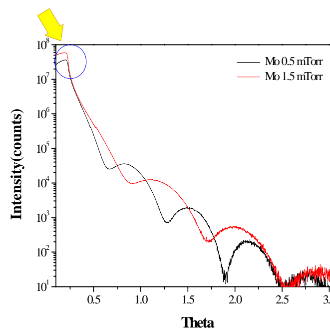
In relation to localized bump correction, flat multilayers were scanned by focused e-beam. Damaged upper layers in Mo/Ru/Si ML maintain its own stacking sequence, while the top layered structure is indistinguishable in Mo/Si ML.

Density effect

The scatterer (e.g., Mo) needs high density for the high reflectance. On the contrary, the spacer (e.g., Si) needs low density. Control of deposition pressure during sputtering can change the density of layers. By applying Snell's law and small angle approximations

$$1-\delta = \cos\theta_c \approx 1-\frac{\theta_C^2}{2} \Leftrightarrow \theta_c \approx \sqrt{2\delta} = \sqrt{\frac{r_0\lambda^2}{\pi} N_A \frac{(Z+f')}{A}\cdot\rho}$$

Deposition pressure of Mo layer : 1.5mTorr → 0.5mTorr
Density of the layer : about 10% higher
By simulation, maximum reflectance increases about 2%



[XRR measurement of Mo monolayer samples]

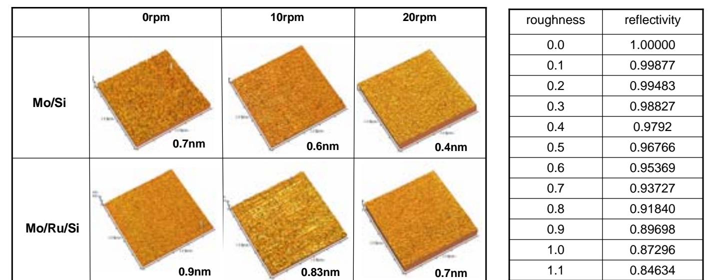
Density of Mo layer in ML	*Max. R. (Mo/Ru/Si)	Max. R. (Mo/Si)
1ρ Mo	0.7553	0.7409
0.9ρ Mo	0.7433	0.7260
0.8ρ Mo	0.7274	0.7059
0.7ρ Mo	0.7058	0.6777
∆R	0.0495	0.0632

*Density of Ru layer changed with same ratio

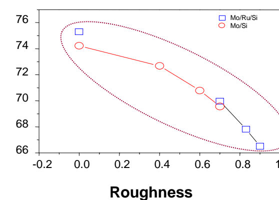
[Calculated max. reflectance with density variation of Mo layer in ML]

Roughness effect

Roughness as substrate rotation-from AFM image



roughness	reflectivity
0.0	1.00000
0.1	0.99877
0.2	0.99483
0.3	0.98827
0.4	0.9792
0.5	0.96766
0.6	0.95369
0.7	0.93727
0.8	0.91840
0.9	0.89698
1.0	0.87296
1.1	0.84634



Roughness control is very important!
In case of Mo/Ru/Si ML,
0.2 nm Roughness improvement
→ 4 % reflectivity improvement

Conclusion

Insertion of Ru layer at Mo-on-Si ML enhances EUV reflectivity by minimizing interdiffusion. This Ru barrier layer helps uniform diffusion if any diffusion process is induced. This property allows the feasibility of surface bump correction process (phase defect corection) through localized e-beam heating. Density effect on reflectivity is less sensitive in Mo/Ru/Si than in Mo/Si structure. These results confirms the superiority of Mo/Ru/Si as an application for the mask blank as well as mirrors.