

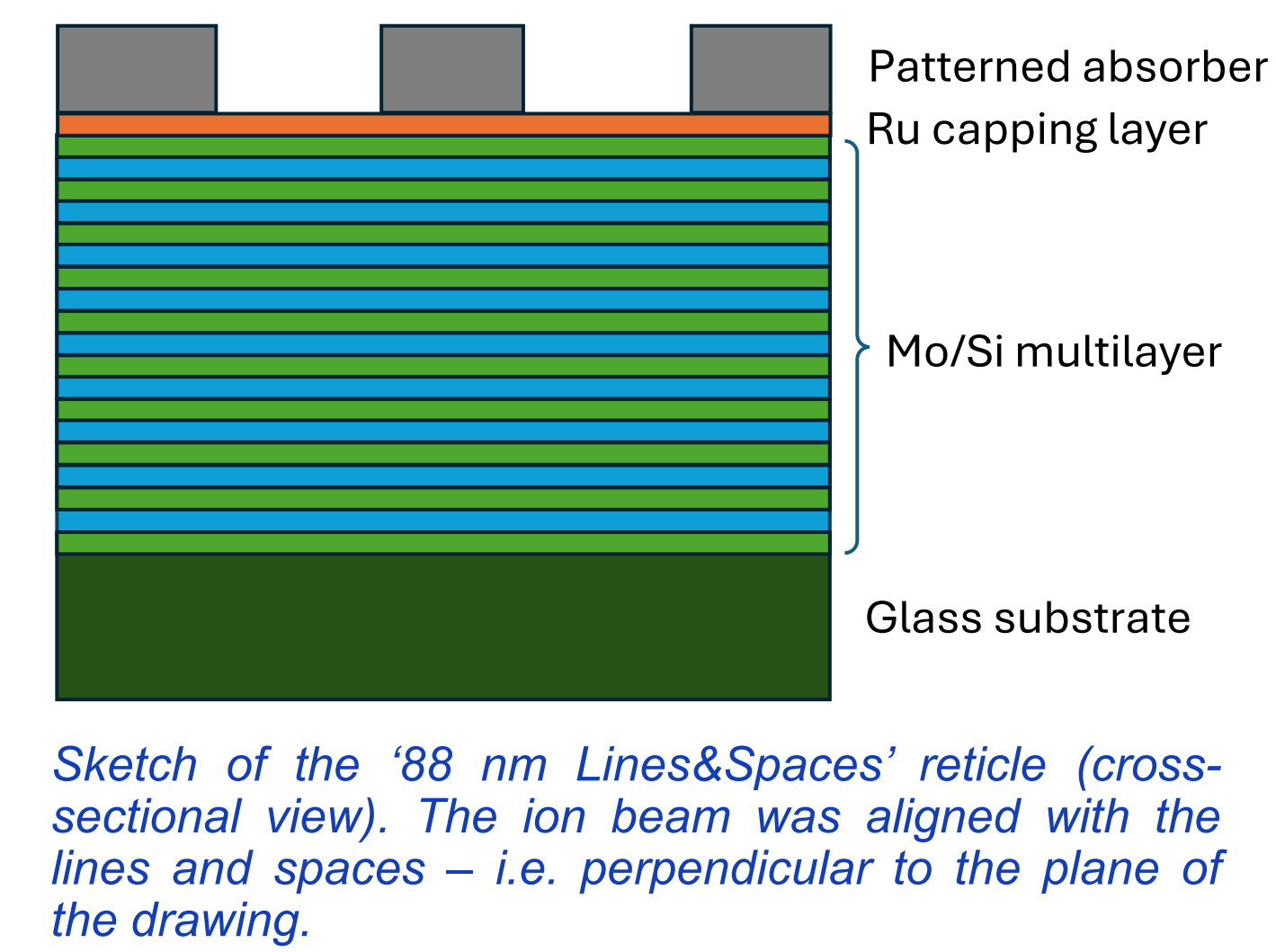
Reticle metrology for *patterned* reticles and Si-contamination with XPS

Depth Profiling and AR-XPS

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Reticle degradation compromises imaging fidelity and reduces throughput. Within the 14ACMOS project, TNO improved metrology to study reticle degradation. We demonstrate the feasibility of XPS Depth Profiling on *patterned* reticle samples. In addition, we show two ways to discriminate Si-contamination at the surface of a reticle from Si present in the multilayer stack. These methods offer more accurate quantification of Si-contamination than possible with a standard XPS measurement.

XPS Depth Profiling on a *patterned* reticle



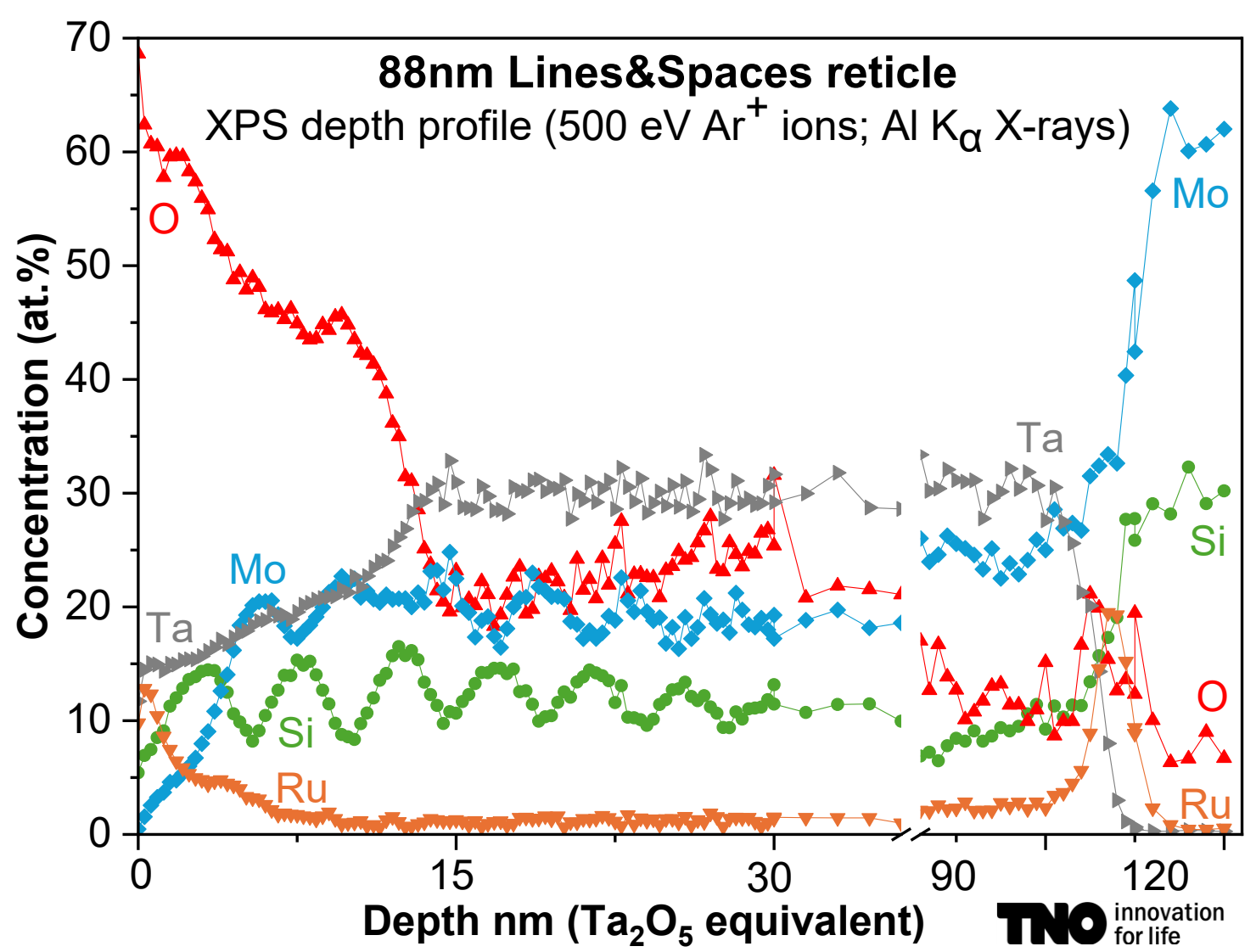
Results

All features are well-visible:
Initially, ~50% Ta-based absorber + ~50% multilayer:

- the Ru-cap with Ru-Si intermixing
- Mo/Si oscillations

Then, the transition from absorber to multilayer:

- Ta-signal disappears
- Ru (cap) appears, followed by increase of Mo and Si.

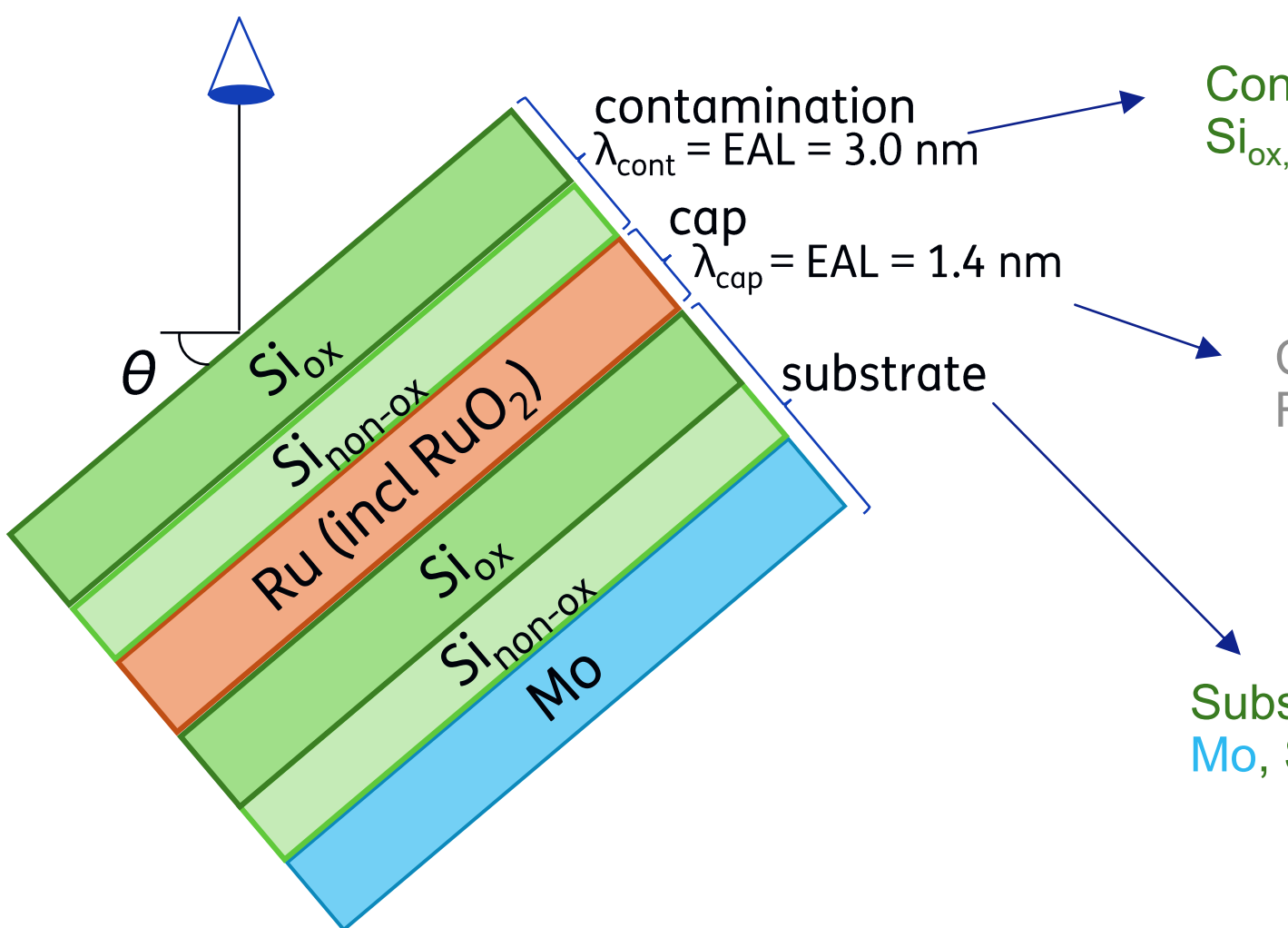


Conclusion

Despite the patterning, XPS depth profiling yields valuable information about the absorber, the cap and the multilayer.

Angle-resolved XPS to quantify Si-contamination

1. Si-contaminated ML-pad



The layered system is divided into three parts:

- Contamination layer (Si; SiO_x – deposited)
- Ru cap layer (Ru; RuO_x)
- 'Substrate' = Mo/Si ML (Mo; Si; SiO_x)

2. AR-XPS equations

Contamination:
Si_{ox, cont} + O, Si_{non-ox, cont}

$$F_{cont}(\theta) = 1 - F_{cap}(\theta) - F_{sub}(\theta)$$
$$F_{cap}(\theta) + F_{sub}(\theta) = \exp\left(-\frac{d_{cont}}{\lambda_{cont} \cos \theta}\right)$$
$$\Leftrightarrow F_{cap}(\theta) = \exp\left(-\frac{d_{cont}}{\lambda_{cont} \cos \theta}\right) - F_{sub}(\theta)$$
$$\Leftrightarrow F_{cap}(\theta) = \exp\left(-\frac{d_{cont}}{\lambda_{cont} \cos \theta}\right) \cdot \left(1 - \exp\left(-\frac{d_{cap}}{\lambda_{cap} \cos \theta}\right)\right)$$

Cap:
Ru + O

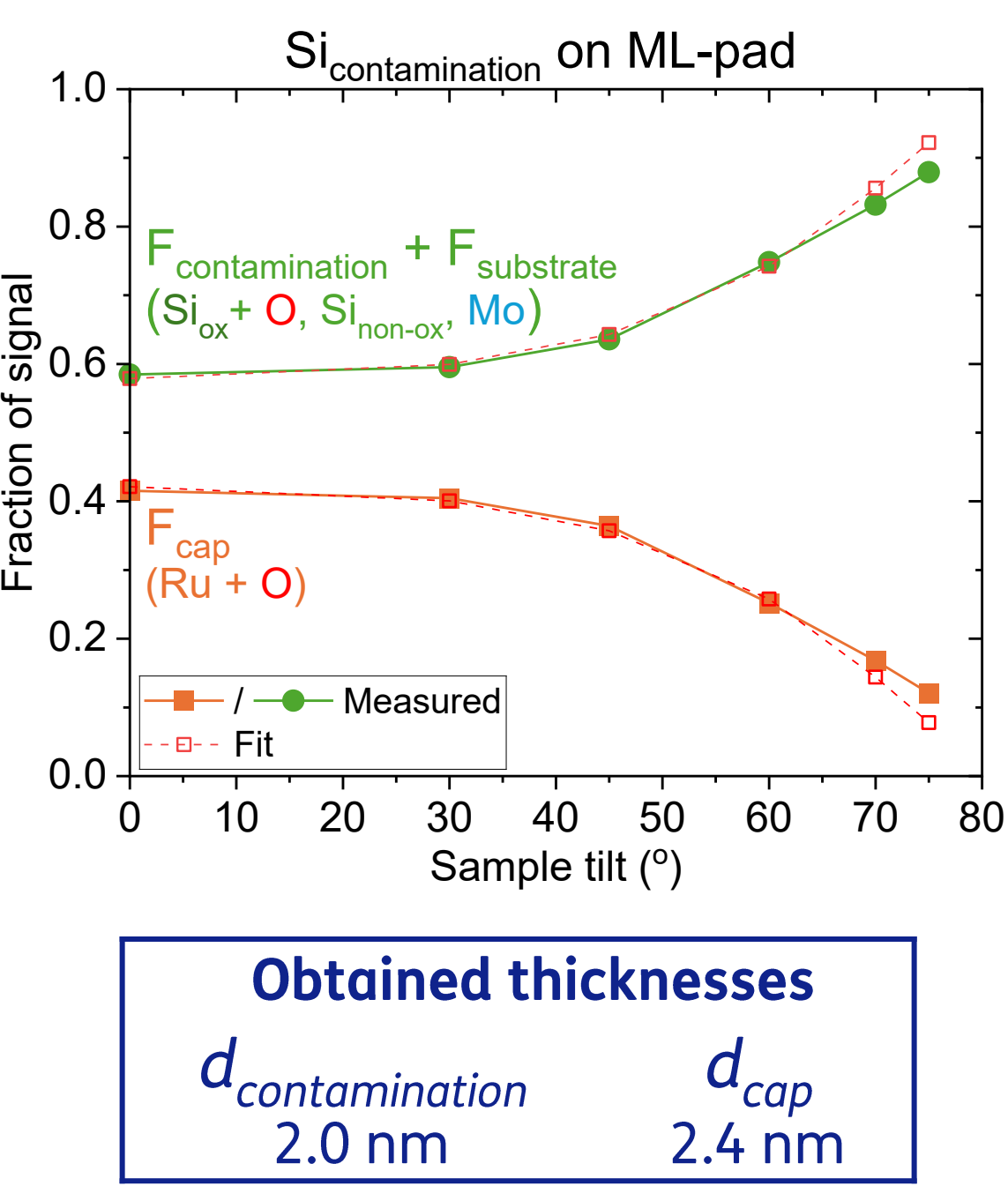
Substrate:
Mo, Si_{ox, sub} + O, Si_{non-ox, sub}

$$F_{sub}(\theta) = \exp\left(-\frac{d_{cont}}{\lambda_{cont} \cos \theta}\right) \cdot \exp\left(-\frac{d_{cap}}{\lambda_{cap} \cos \theta}\right)$$

These equations describe how the signal intensities of the substrate and the Ru-cap are attenuated by the layers above them.

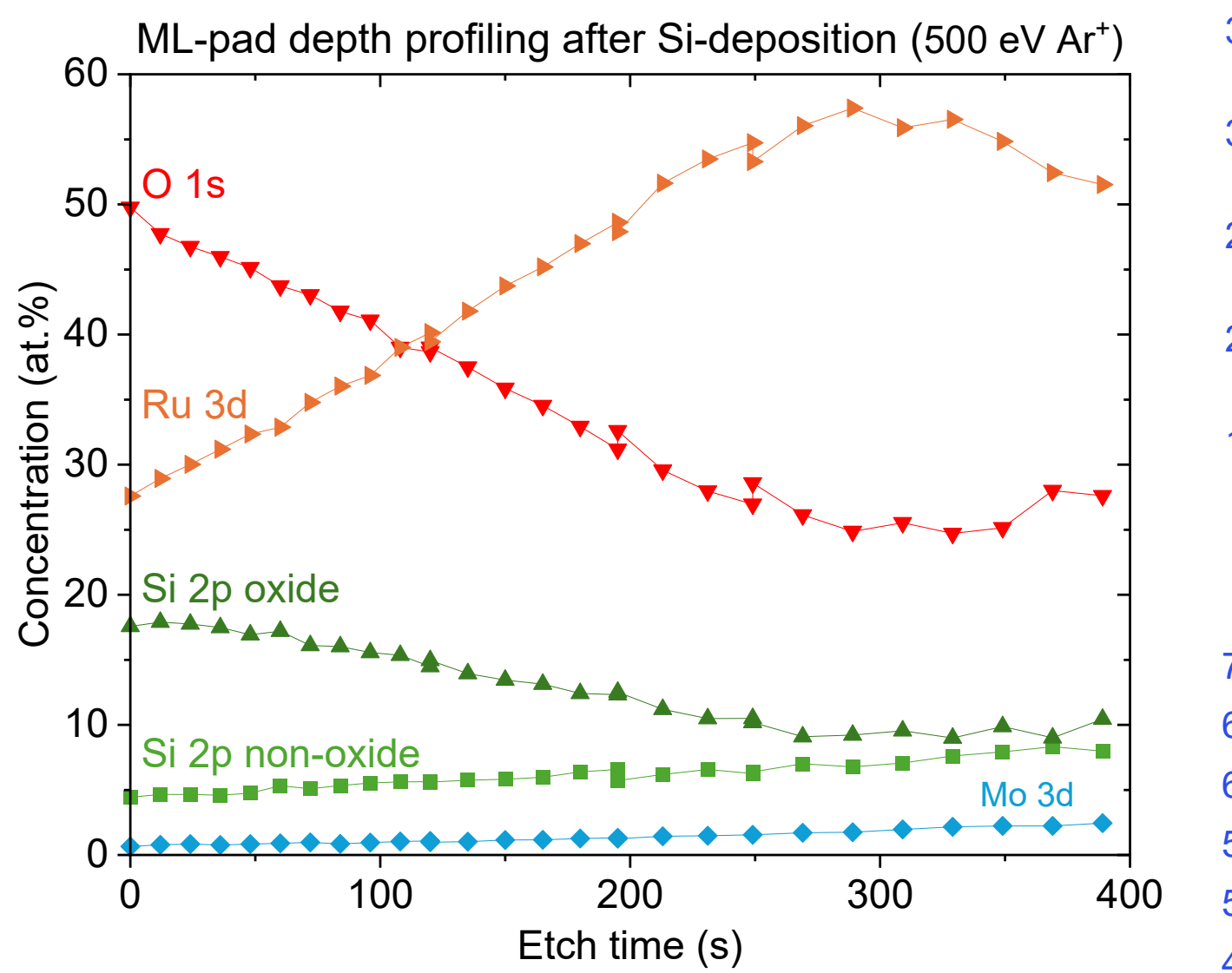
$F_{cap}(\theta)$ can be obtained (= Ru + corresponding O);
 $F_{cont}(\theta)$ and $F_{sub}(\theta)$ both contain Si and thus only the joint fraction (= $F_{cont}(\theta) + F_{sub}(\theta)$ = Mo + Si + corresponding O) can be obtained.

3. Fit results to equations

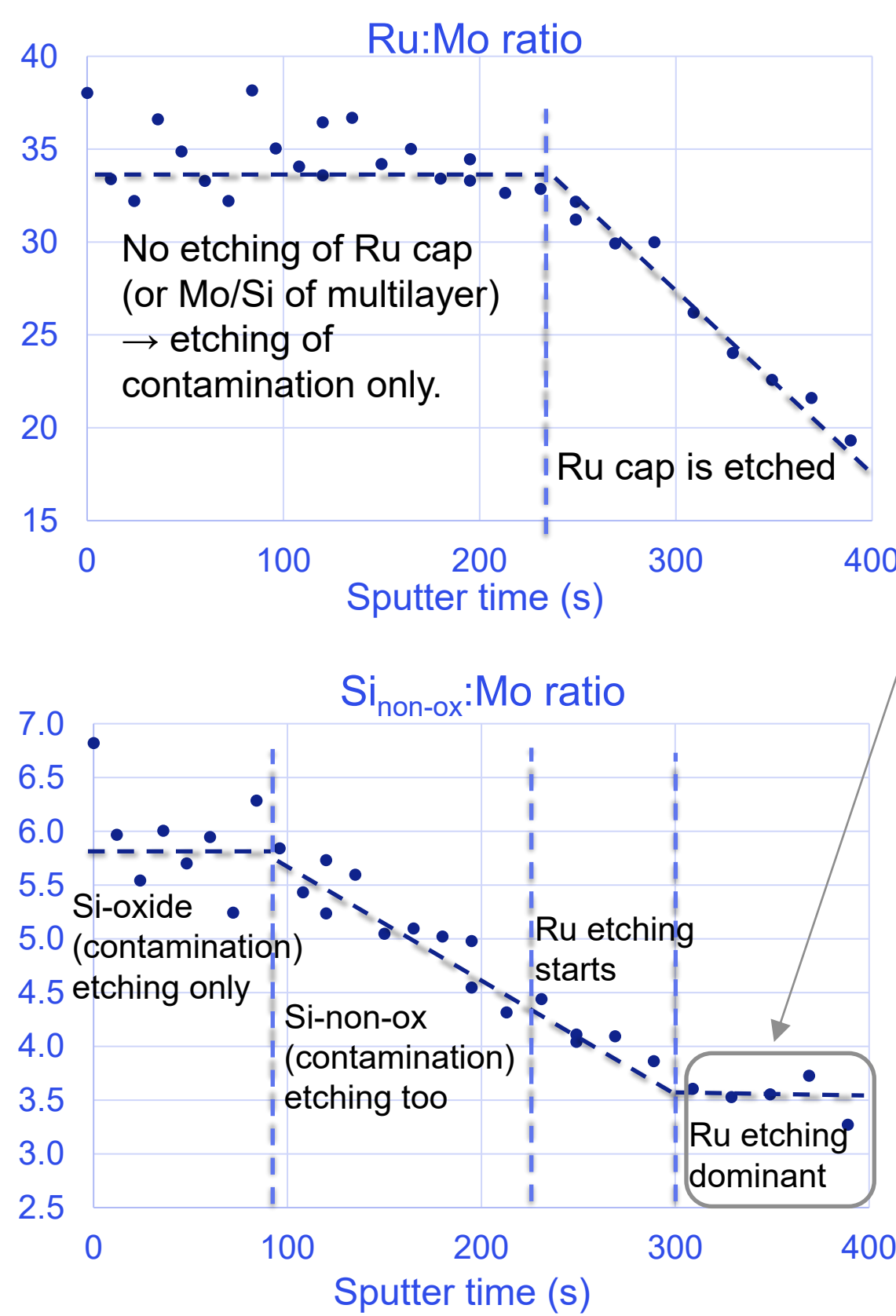


XPS Depth profiling to quantify Si-contamination

1. XPS depth-profiling with small steps on Si-contaminated ML-pad



2. Determine elemental ratios and etch regimes



3. Calculating contamination-Si

All contamination-Si has been removed
→ Mo:Si_{non-ox} and Mo:Si_{oxide} ratios are representative for the ML:

Si_{non-ox} : Mo (ML) = 3.6
Si_{oxide} : Mo (ML) = 4.4

Apply these ratios to the *pre-etch* XPS-results to calculate ML-Si and thus the contamination-Si.

Etch time (s)	Ru 3d	O 1s	Mo 3d	Si non-ox	Si oxide
0	27.6	49.8	0.65	4.4	17.6
	at. %				
				x3.6 x4.4	
				Multilayer-Si	
				Si non-ox	Si oxide
				2.3	2.8
				Contamination Si	
				Si non-ox	Si oxide
				2.1	14.7
				at. %	

Contamination layer
Si+corresponding O
46.2 at. % $d_{contamination}$ 1.9 nm

Summary and Conclusions

- XPS depth profiling was successfully demonstrated on *patterned* reticles. Typical features and degradation can be observed. Additional insightful results were obtained with AR-XPS on such patterned reticles (results not shown due to space restrictions).
- Quantification of Si-contamination on reticles is difficult because with regular XPS-analysis it is not possible to discriminate between Si-contamination and Si in the Mo/Si multilayer. We showed two independent XPS-based methods (AR-XPS and XPS depth profiling) to overcome this issue and accurately quantify Si-contamination.

Acknowledgements



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