Discriminate Si-contamination from Si present in the stack of EUV reticles

AR-XPS and XPS-depth profiling

Véronique de Rooij-Lohmann, Shriparna Mukherjee, Kleopatra Papamichou

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Background

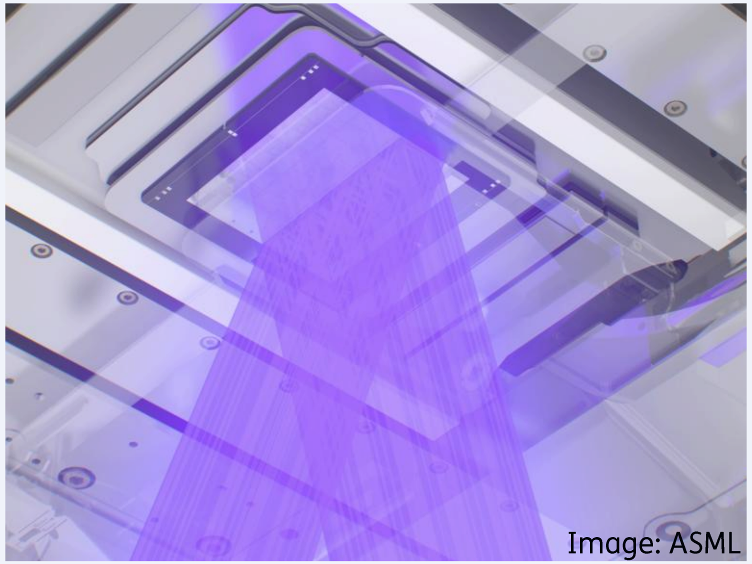
EUV reticles (a.k.a. masks) are crucial for EUV lithography.
They contain reflective and absorbing areas that define the pattern that is imaged on the photoresist on the wafer.

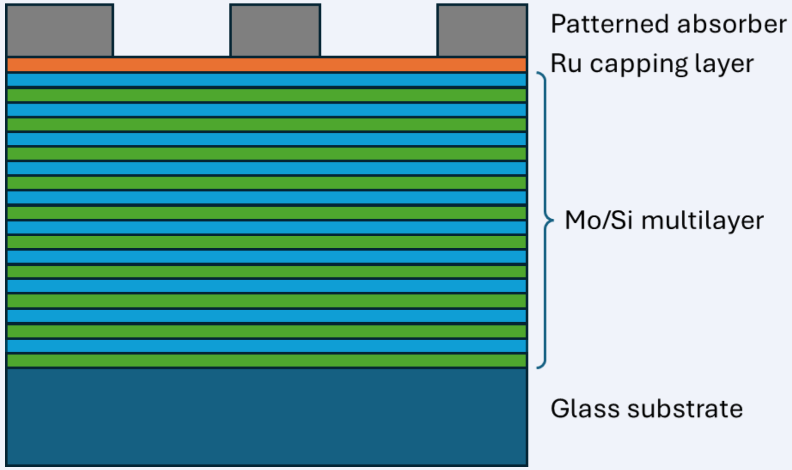
Performance of reticles reduces via several degradation mechanisms:

- Oxidation
- Intermixing/diffusion
- Delamination (blistering)
- **Contamination**

  → XPS very suitable for analysis, but

  - Si is present as contamination *and* in the stack
  - Reference samples not available

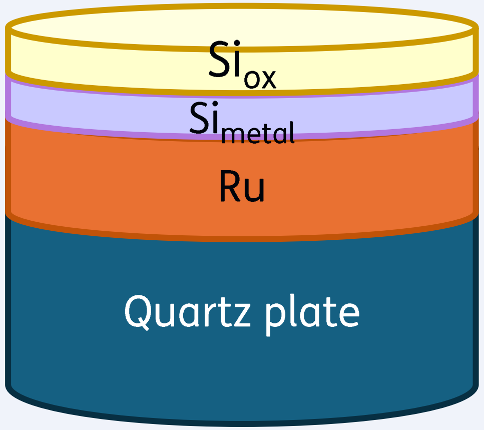


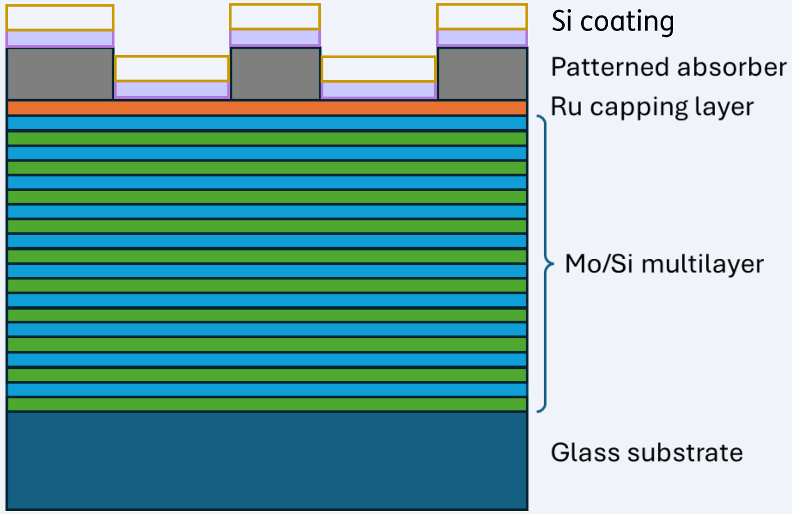


Goal and Approach

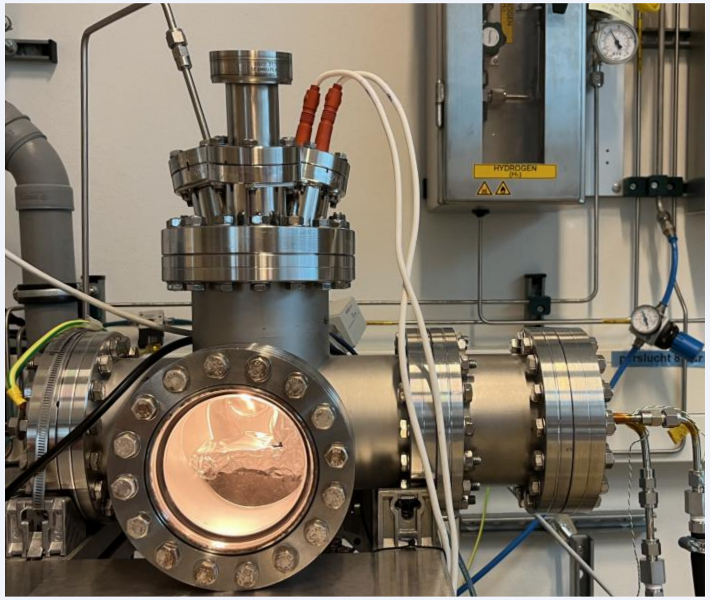
Goal:
- Improve Si quantification without reference samples

Approach:
- Contaminated model samples (Ru) and reticles with Si
- Tested Ion Scattering Spectroscopy, AR-XPS+HAXPES, mild Ar^+ sputtering





Si-deposition set-up

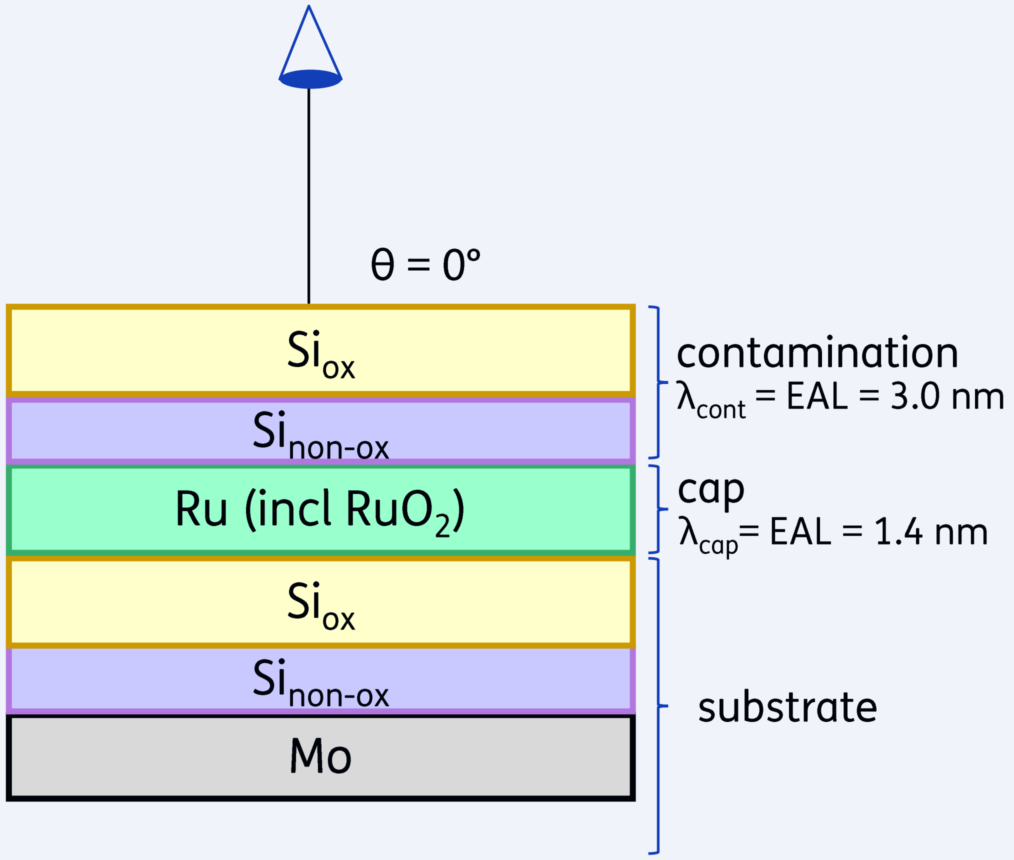


Ru-coated quartz plates

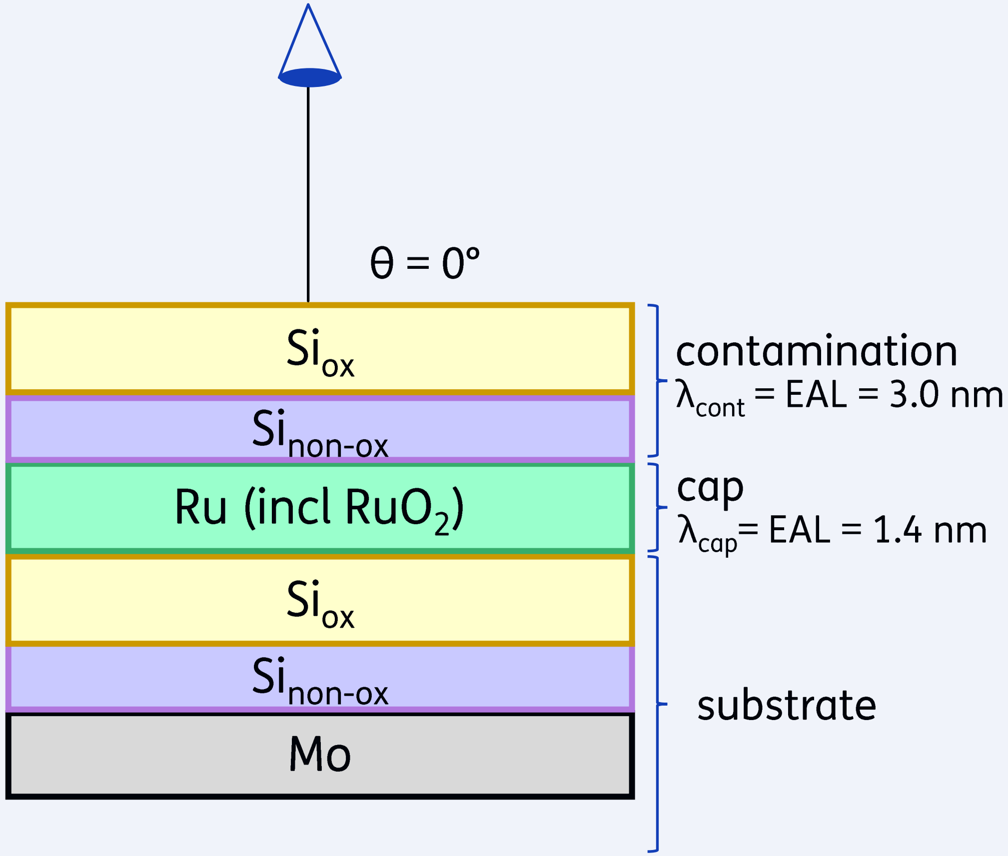
Si source

Diced reticle pieces

Approach 1: AR-XPS



Approach 1: AR-XPS



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

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

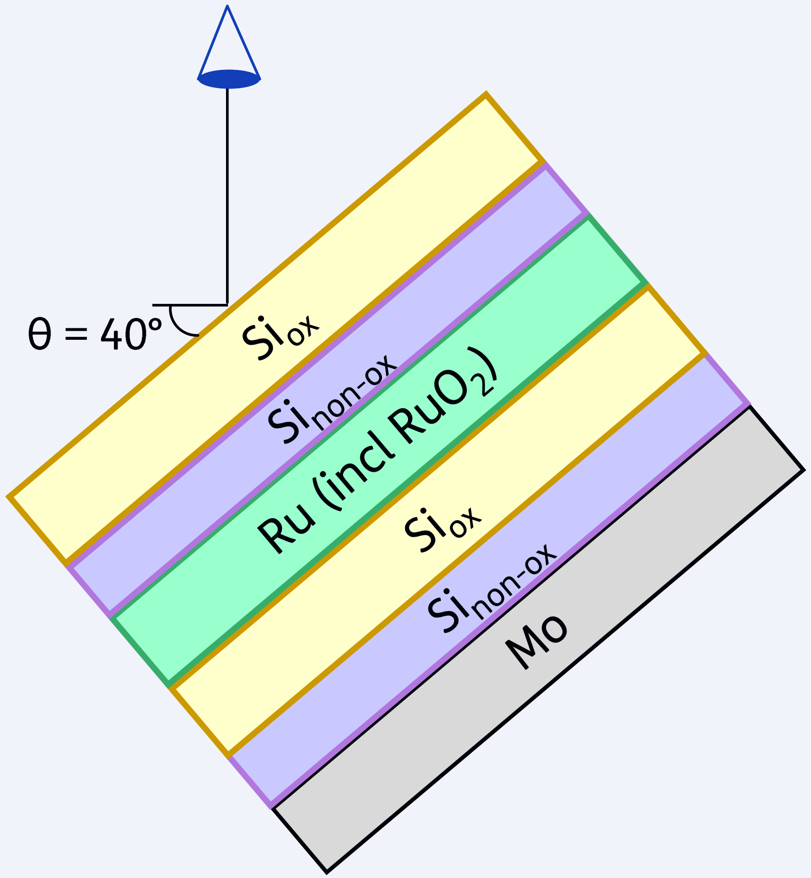
$$\Leftrightarrow F_{cap} = \exp\left(-\frac{d_{cont}}{\lambda_{cont}}\right) - F_{sub}$$

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

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

$$F_{cont} = 1 - F_{cap} - F_{sub}$$

Approach 1: AR-XPS



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

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

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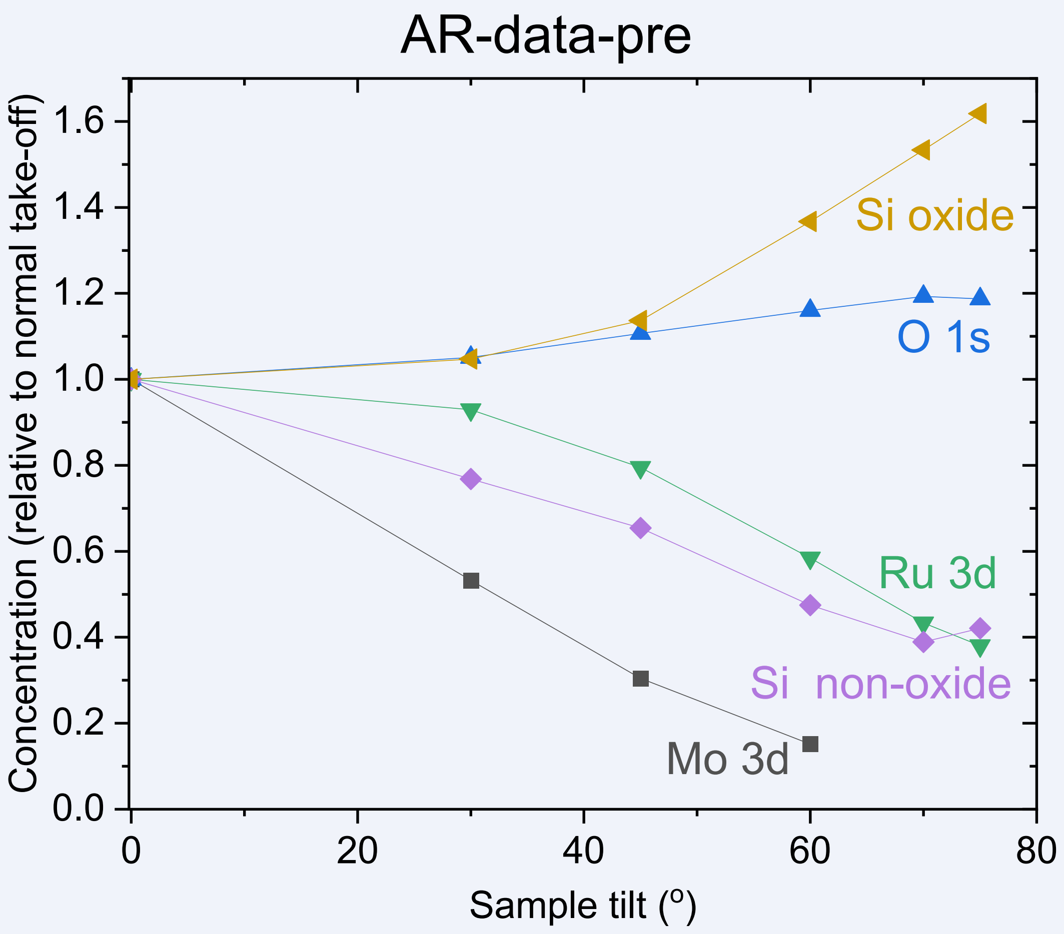

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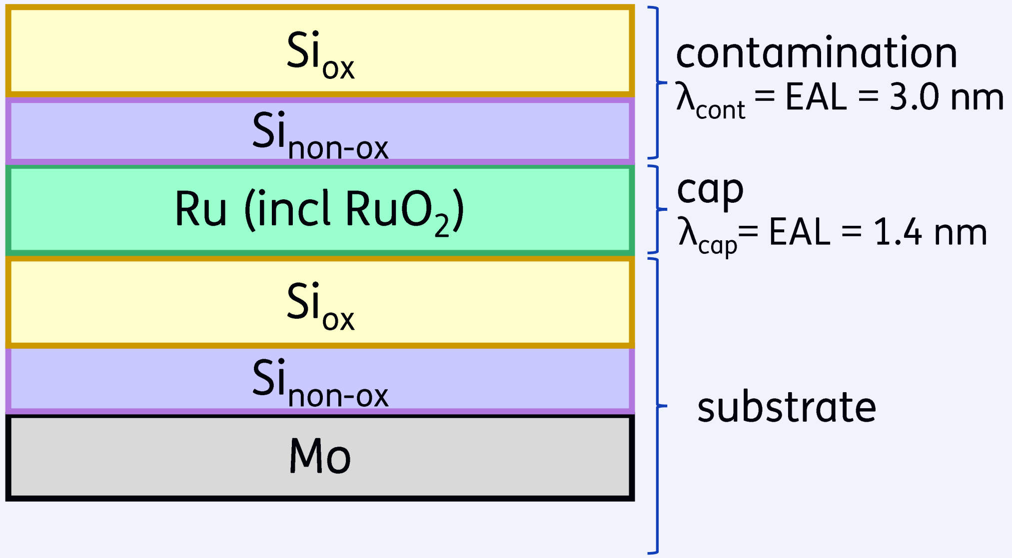
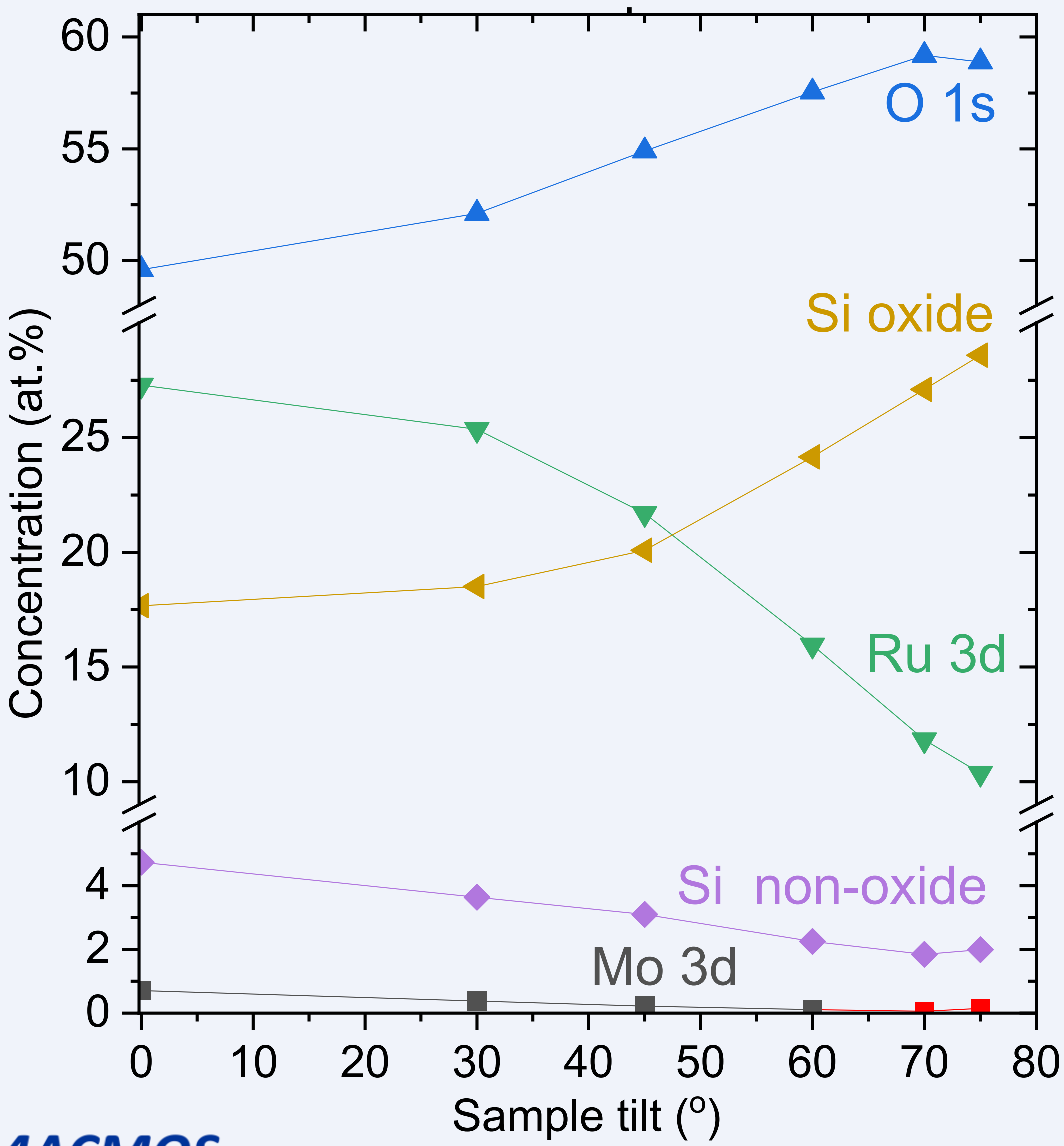


Approach 1: AR-XPS



Mo, $Si_{ox,\,sub}$ + O, $Si_{non\text{-}ox,\,sub}$

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

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

Ru + O

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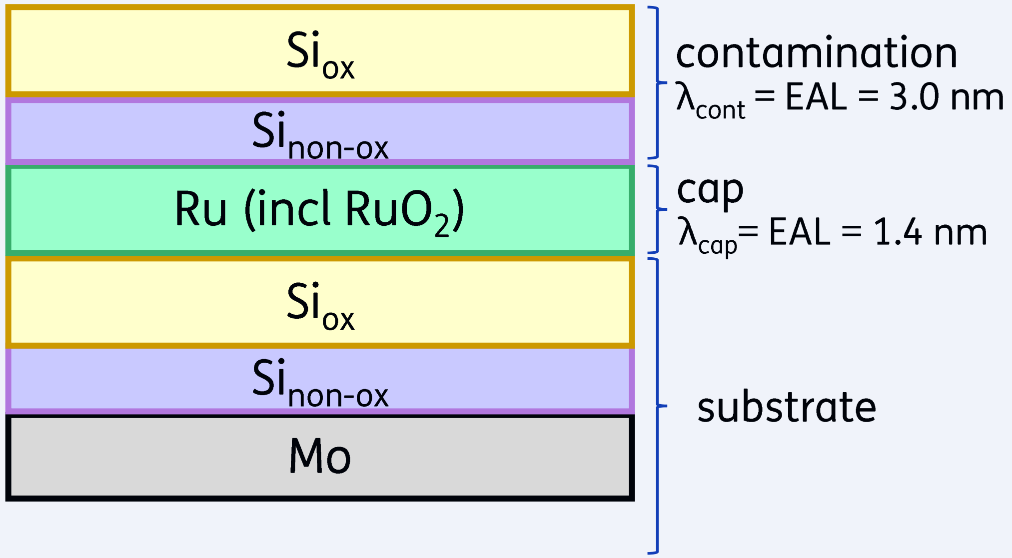
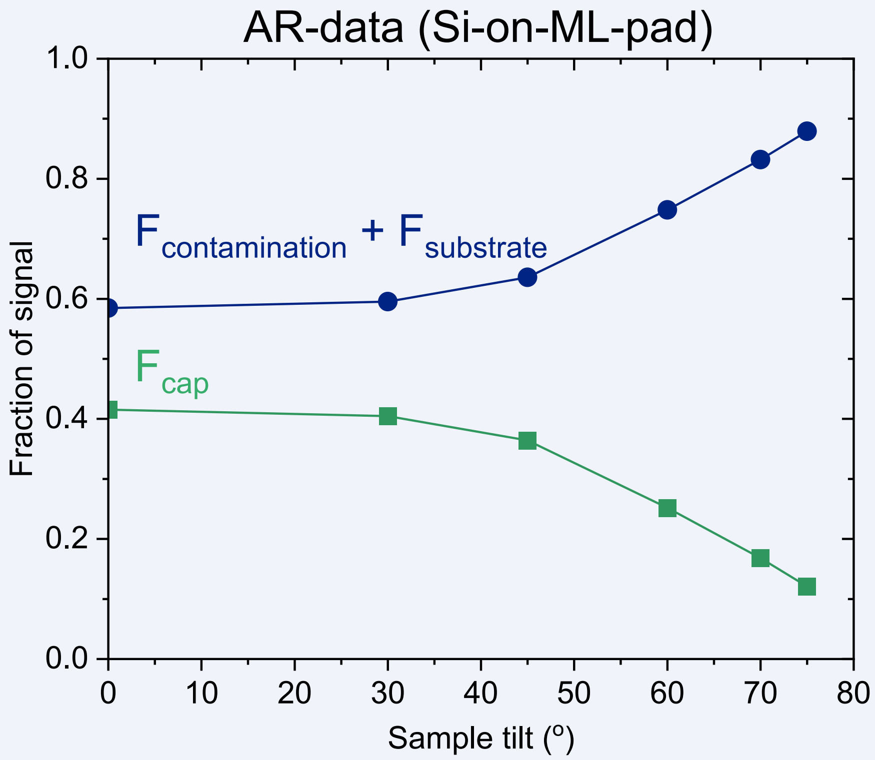
$Si_{ox,\,cont}$ + O, $Si_{non\text{-}ox,\,cont}$

$$F_{cont}(\theta) = 1 - F_{cap}(\theta) - F_{sub}(\theta)$$



Approach 1: AR-XPS



Mo, $Si_{ox, sub}$ + O, $Si_{non-ox, sub}$ $\quad F_{sub}(\theta) = \exp\left(-\frac{d_{cont}}{\lambda_{cont}\cos\theta}\right)\cdot\exp\left(-\frac{d_{cap}}{\lambda_{cap}\cos\theta}\right)$

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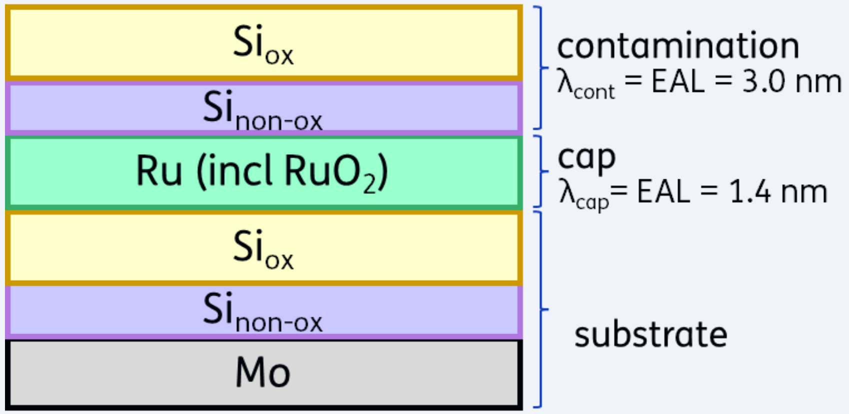
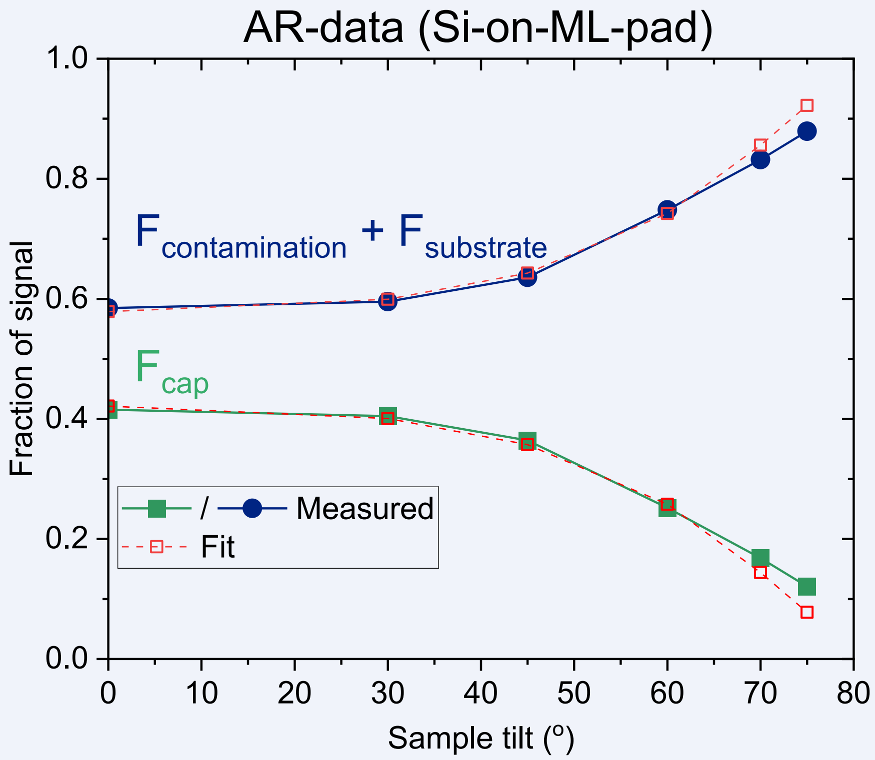
$Si_{ox, cont}$ + O, $Si_{non-ox, cont}$ $\quad F_{cont}(\theta) = 1 - F_{cap}(\theta) - F_{sub}(\theta)$

	Measured Fractions	
θ (°)	$F_{contamination}+F_{substrate}$	F_{cap}
0	0.58	0.42
30	0.60	0.40
45	0.64	0.36
60	0.75	0.25
70	0.83	0.17
75	0.88	0.12



Approach 1: AR-XPS



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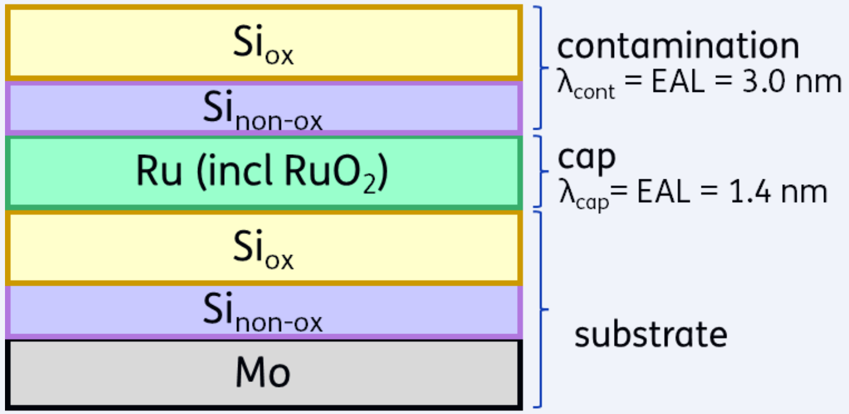
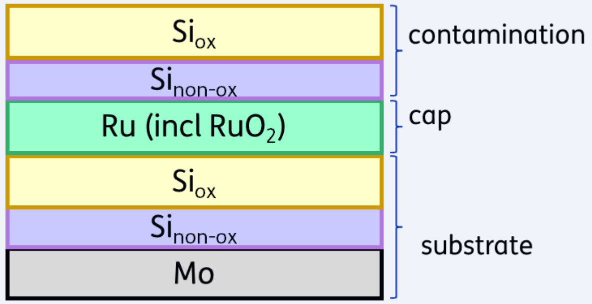
$Si_{ox, cont}$ + O, $Si_{non\text{-}ox, cont}$ $$F_{cont}(\theta) = 1 - F_{cap}(\theta) - F_{sub}(\theta)$$

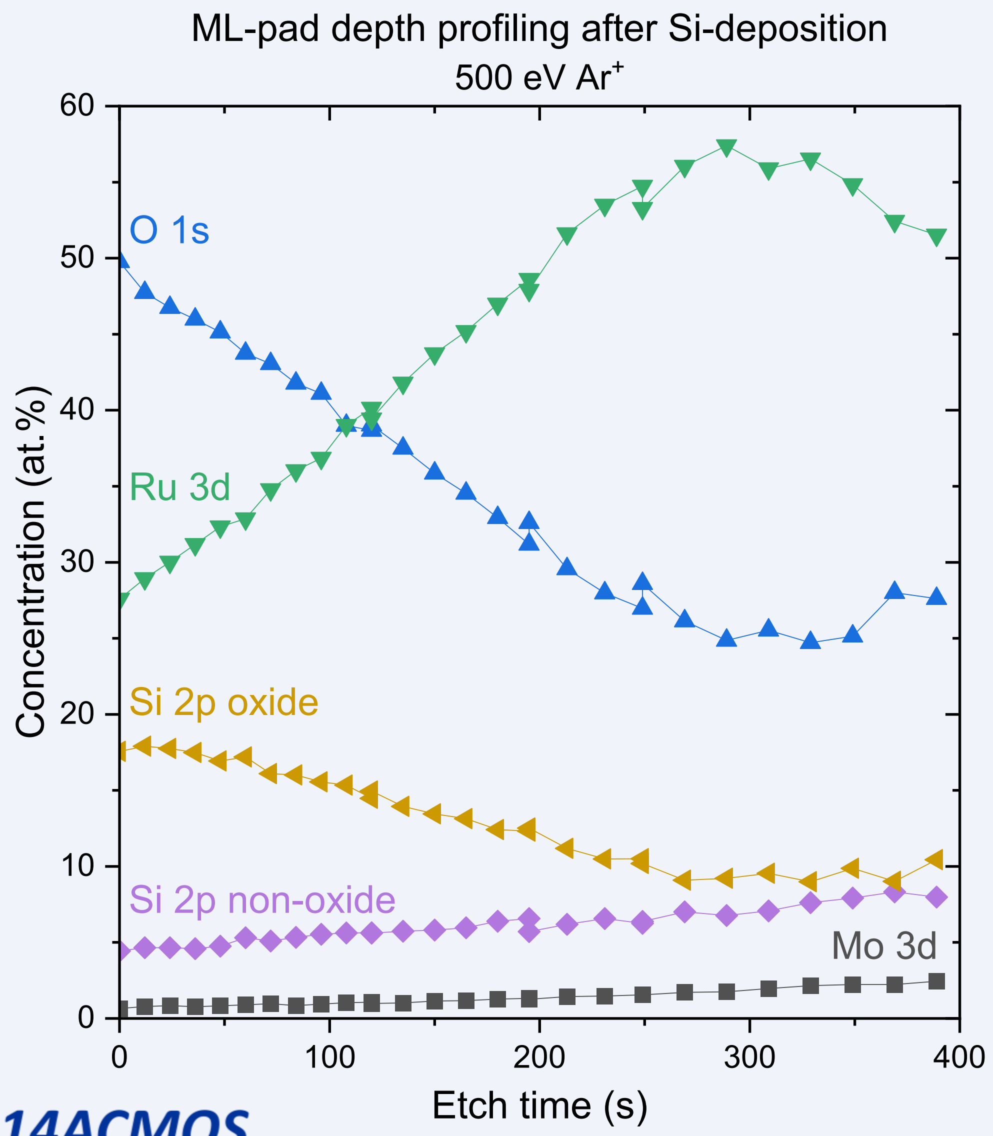
	Measured Fractions		Fitted Fractions		
θ (°)	$F_{contamination}+F_{substrate}$	F_{cap}	$F_{contamination}$	F_{cap}	$F_{substrate}$
0	0.58	0.42	0.48	0.42	0.09
30	0.60	0.40	0.53	0.40	0.07
45	0.64	0.36	0.61	0.36	0.04
60	0.75	0.25	0.73	0.26	0.01
70	0.83	0.17	0.86	0.14	0.00
75	0.88	0.12	0.92	0.08	0.00

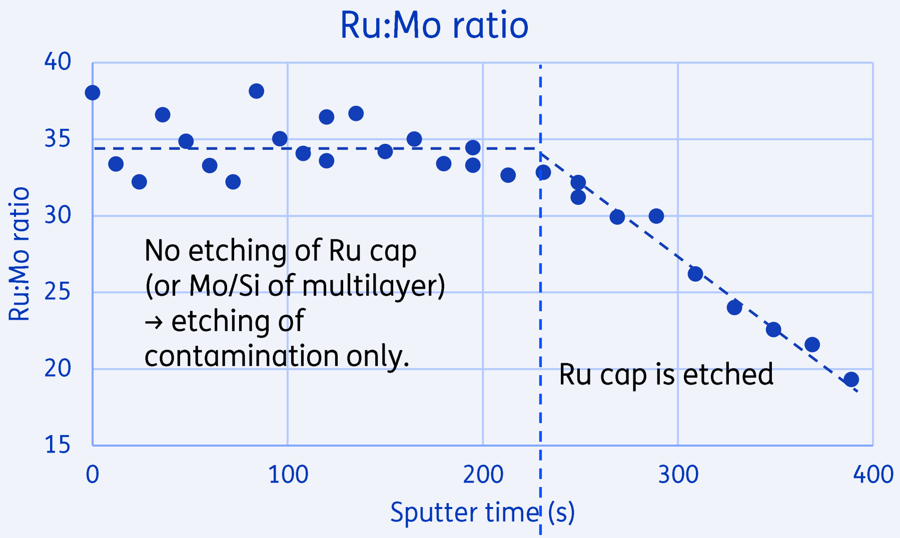


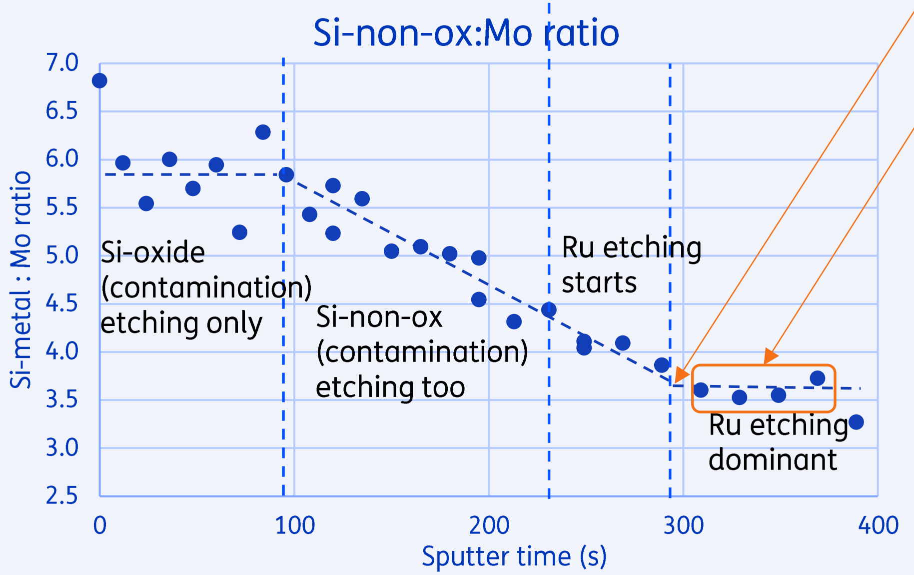
Obtained thicknesses	
$d_{contamination}$	d_{cap}
2.0 nm	2.4 nm

Approach 2: sputter depth profiling







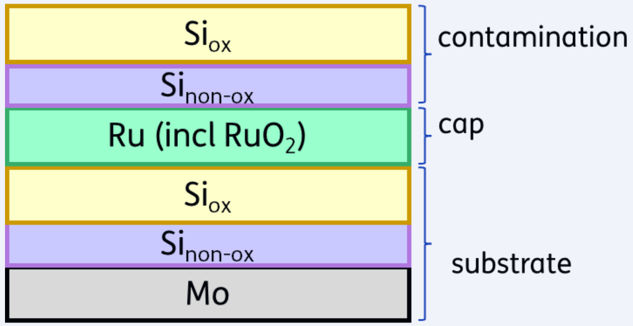


- All contamination-Si has been removed
- Mo:Si-metal and Mo:Si-oxide are representative for the ML

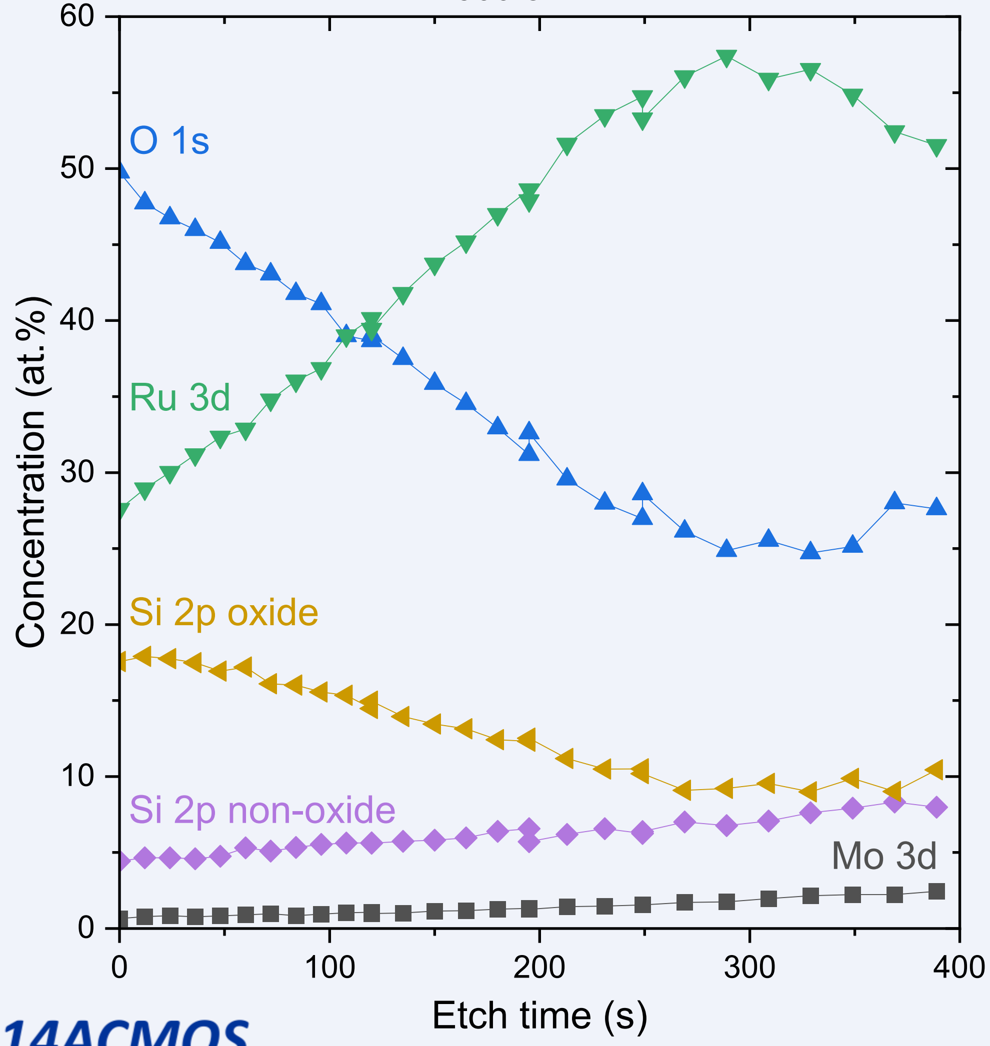
Si-metal:Mo	Si-oxide:Mo	Si-metal:Si-oxide
3.60	4.37	0.83

Total sputter duration is equivalent to 1.5 nm Ta_2O_5 .

Approach 2: sputter depth profiling



ML-pad depth profiling after Si-deposition
500 eV Ar^+



Normalized to 100 at.% with all elements excl C

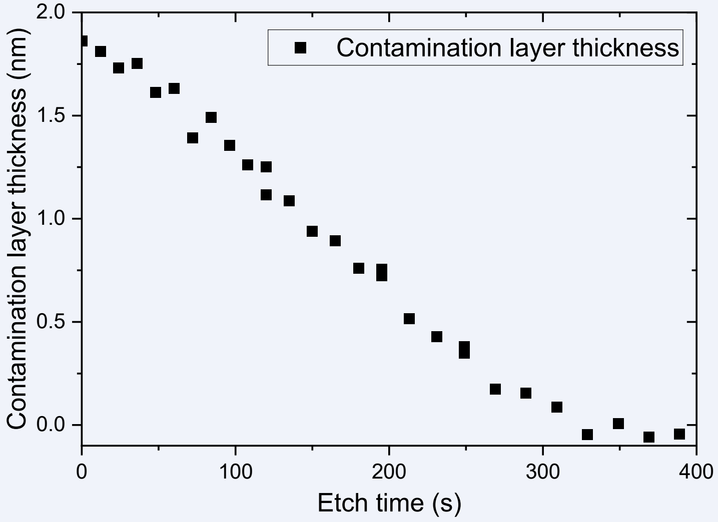
Etch time (s)	Mo 3d	O 1s	Ru 3d (cap)	Si non-ox (at.%)	Si ox (at.%)
0	0.65	49.8	27.6	4.4	17.6

- Multilayer ratios:

Si-non-ox:Mo	Si-oxide:Mo
3.60	4.37

Splitting ML-Si and Contamination-Si

at.%				Multilayer-Si		Contamination Si	
Etch time (s)	Mo 3d	O 1s	Ru 3d (cap)	Si non-ox	Si oxide	Si non-ox	Si oxide
0	0.65	49.8	27.6	2.3	2.8	**2.1**	**14.7**



Contamination layer	
Si+corresponding O	**Thickness**
46.2 at.%	1.9 nm

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Total sputter duration is equivalent to 1.5 nm Ta_2O_5.

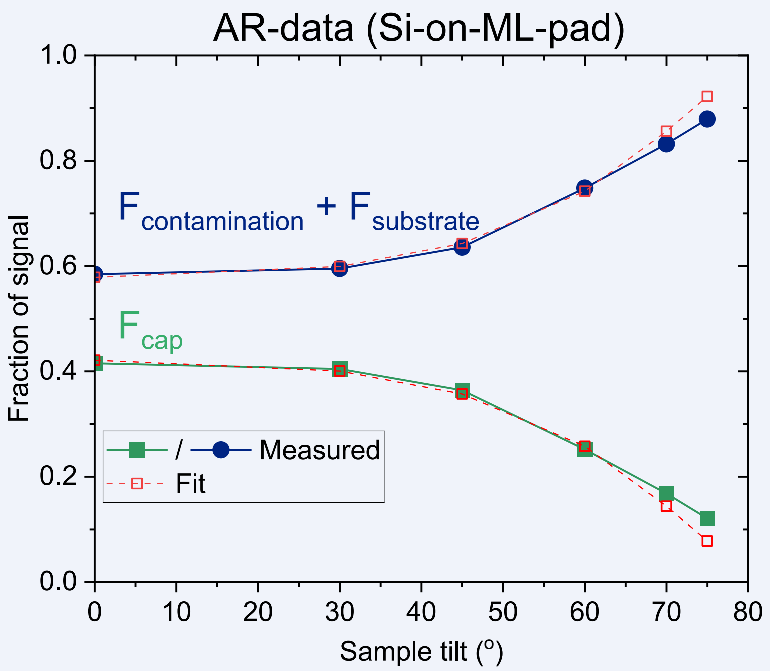
Conclusions and Outlook

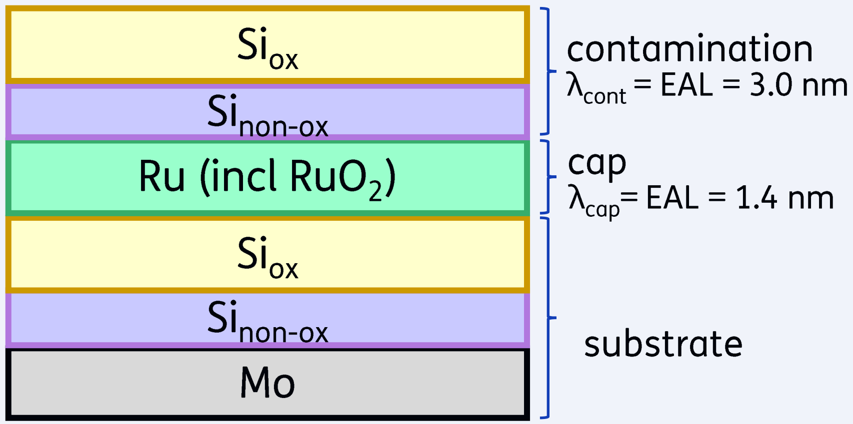
Conclusions

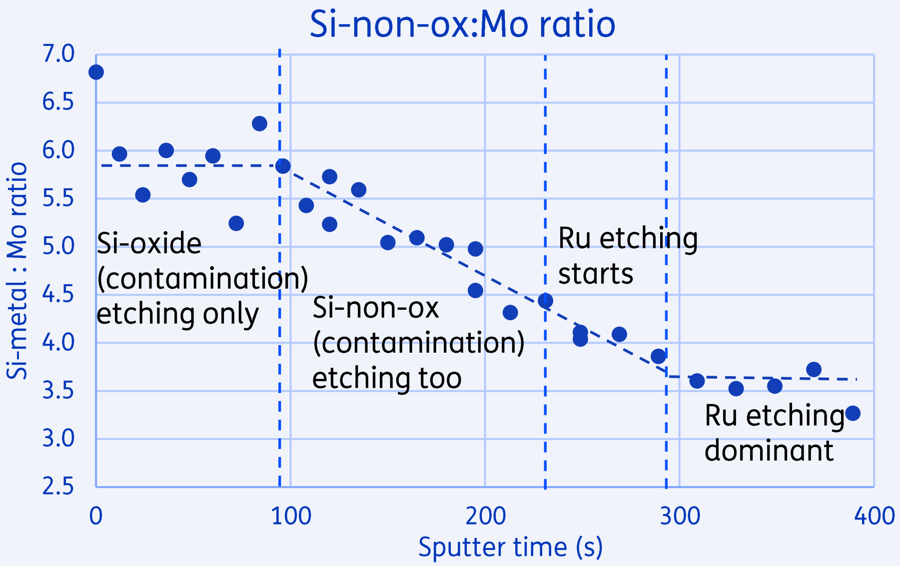
- With XPS, it is possible to discriminate between the contamination-layer and the sub-surface layer, even when it consists of the same elements
- Both AR-XPS and XPS-depth profiling with surface reconstruction are suitable method *and* yield the same result.

Outlook

- Apply both methods to a Si-contaminated patterned reticle (lines & spaces)







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Acknowledgments:

Rik Jonckheere (imec, Belgium) - providing the reticle sample

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