EUV induced degradation studies on reticles by X-ray photoelectron Spectroscopy (XPS)

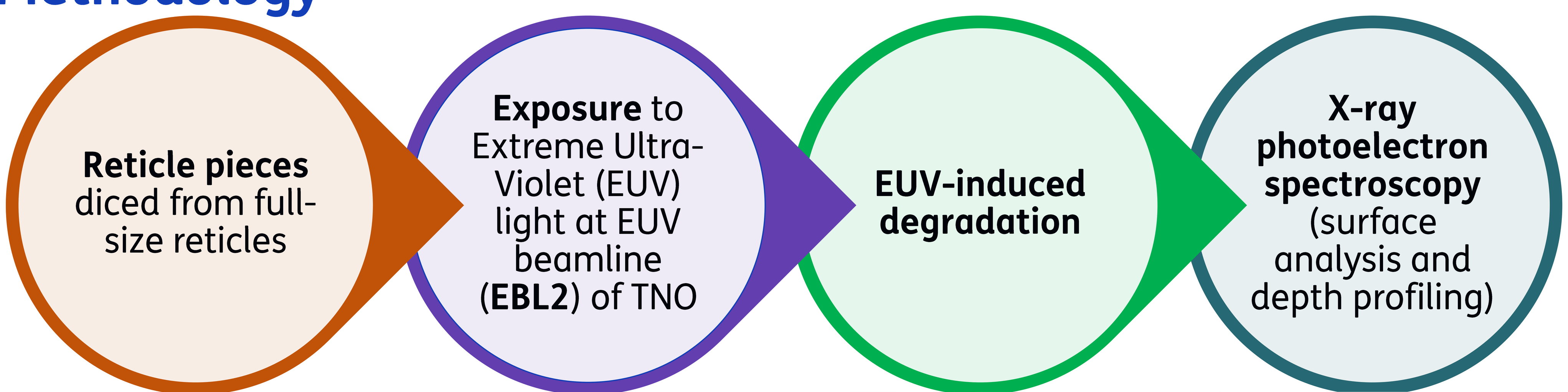
Shriparna Mukherjee, Alessandro Troglia, Véronique de Rooij-Lohmann

Netherlands Organisation for Applied Scientific Research (TNO), Stieltjesweg 1, 2628 CK, Delft, Netherlands

Introduction and Goal

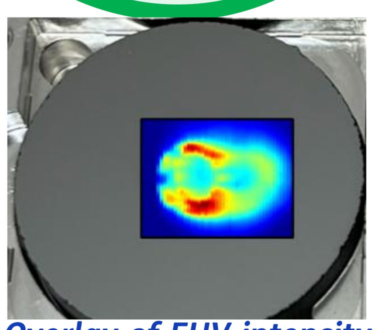
A reticle, also known as a photomask, is used to transfer patterns onto silicon wafers during the photolithography process. Reticles play a crucial role in semiconductor manufacturing since their quality directly impacts the resolution and accuracy of the transferred image, which, in turn, affects the performance and yield of the produced chips. Reticles are very costly and subject to degradation under the challenging scanner environment. Key degradation phenomena include surface contamination, oxidation, layer intermixing, and structural damage due to high-energy photon interactions and thermal cycling. These effects can compromise image fidelity, reduce throughput, and increase production costs. Better understanding of degradation mechanisms is therefore necessary to improve the designs and further increase the lifetime of the reticles [1,2].

Methodology



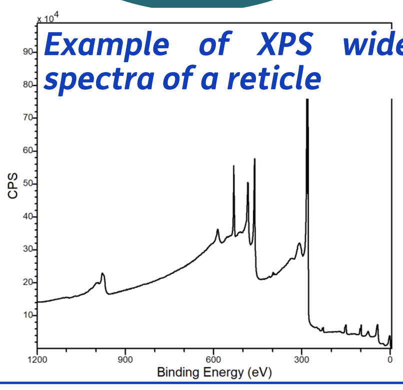
- Multilayer blank
- Patterned reticle

- Oxidative Gas conditions: 1.0E-4 mbar H_2O and 1.5E-5 mbar N_2-O_2 mixture
- Sample temperature ~50⁰C
- EUV dose: ~0.2-0.3 kJ/mm²



Overlay of EUV intensity profile on a reticle

Example of XPS wide spectra of a reticle



Extreme Ultraviolet Beamline 2 (EBL2) @TNO

Fig.1: EUV Beamline (EBL2) facility at TNO [3] .

Properties	EBL2
EUV source	Ushio-Sn-LDP
Standard Rep. rate	1.5 – 3.0 kHz
Peak intensity (13.5 nm 2% BW)	>2 W/mm² @ 3 kHz
Process gasses	H_2, He, Ar, H_2O, XCDA, O_2, N_2, C_xH_y
Sample size	Arbitrary, max. 152x152x20 mm³

Key features: Tin-based EUV source of Ushio, full size reticle/pellicle exposure possible, scanner-like gas environment, tuneable power, flexible sample size, known plasma conditions.

Metrology: in-vacuo XPS, in-situ ellipsometry, in-situ thermal infrared thermometry, and residual gas analysis (RGA).

Accessibility: commercially available, used by ASML, Carl Zeiss & key partners/suppliers.

Multilayer blank

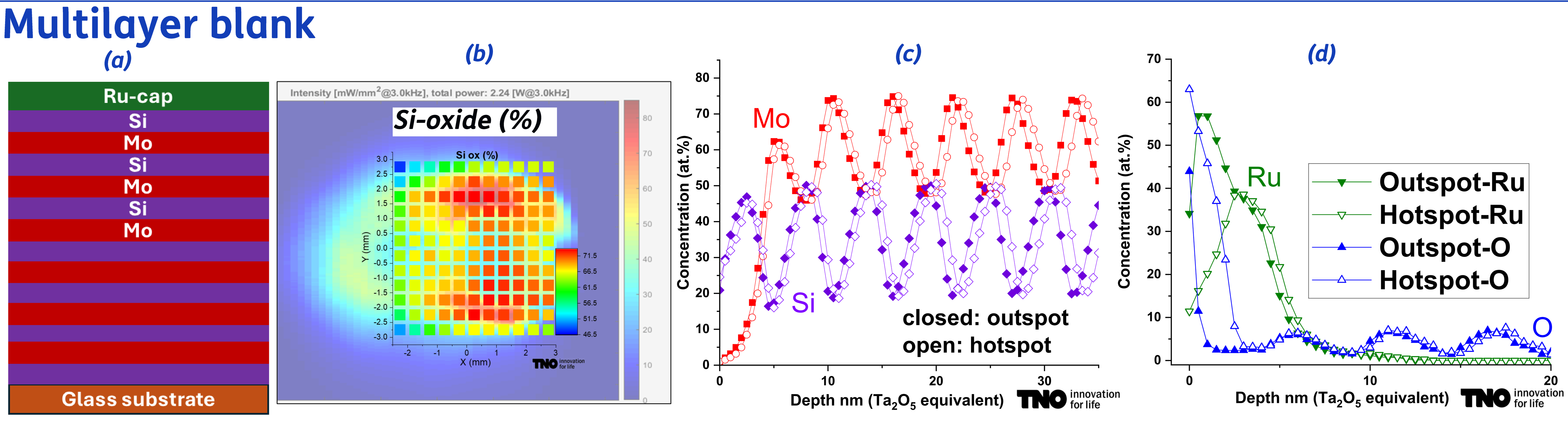
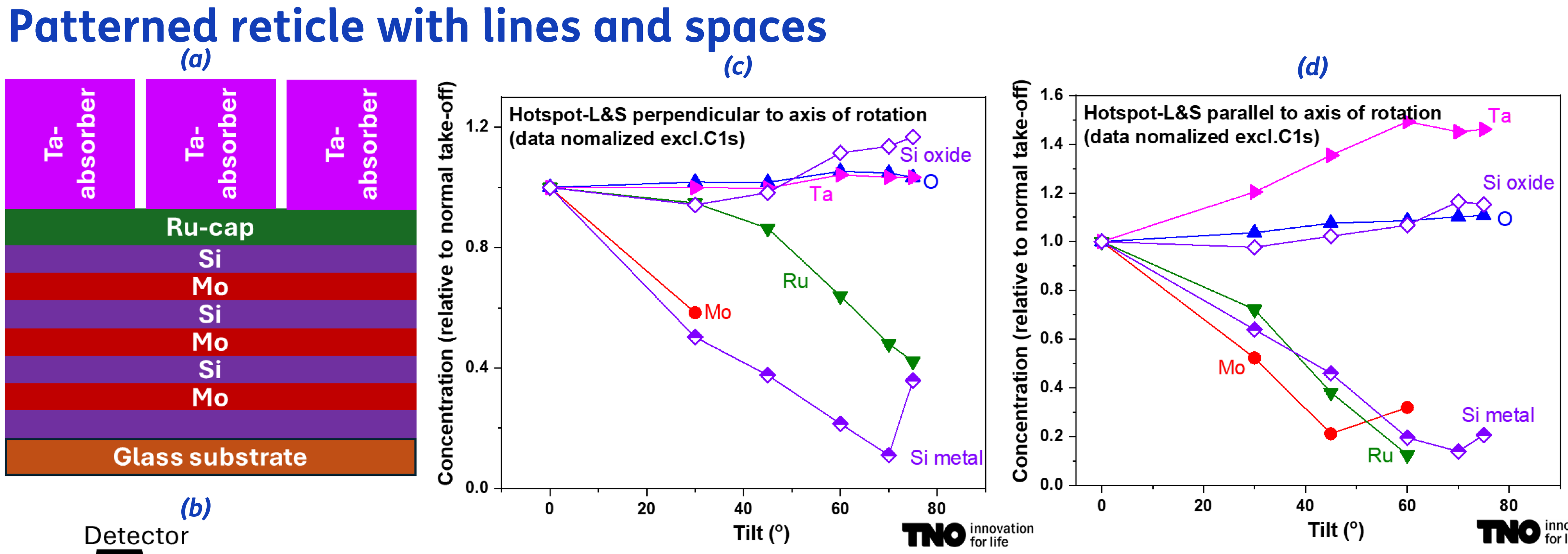


Fig.2: (a) Schematic (not-to-scale) showing the multilayer blank with Ru cap and Mo/Si stack, (b) Overlay of XPS map for Si-oxide with EUV intensity profile and (c-d) XPS depth profile on ML blank showing Mo/Si periodicity, Ru cap layer within first 0-8 nms and Oxygen profile at EUV hotspot and outspot locations.

- The EUV imprint is visible in the XPS map (for Si-oxide).
- The sputter rate is calibrated using Ta_2O_5 film; hence depths reported herein are Ta_2O_5 equivalent.
- The amplitude of Mo/Si oscillations clearly visible both at the outspot as well as the EUV hotspot.
- The XPS depth profile shows thicker oxide layer at the EUV hotspot location compared to the outspot.
- Si-oxide (fig 2c) is higher at the hotspot. This is consistent with the EUV exposure gas conditions that were selected to provoke oxidation.
- Peak in Ru shifts to higher depths at the EUV hotspot compared to the outspot. This shows possible intermixing or diffusion of Si and/or Ru.

Patterned reticle with lines and spaces



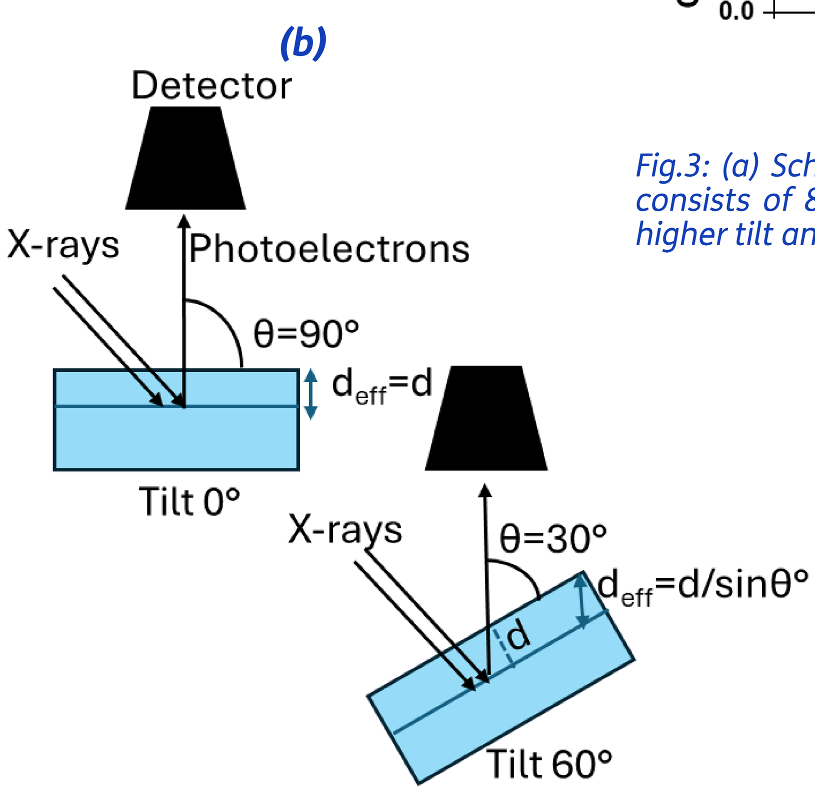


Fig.3: (a) Schematic (not-to-scale) showing a patterned Mo/Si stack reticle with Ru cap and Ta-based absorber; the pattern consists of 88 nm of lines and spaces (b) Schematic of angle resolved (AR-)XPS which has greater surface sensitivity at higher tilt angles and (c-d) AR-XPS for the patterned reticle.

- When L&S is perpendicular to the axis of rotation:
  - Mo is no more visible after 30⁰.
  - Ru cap is visible at higher angles unlike in parallel configuration.
- When L&S is parallel to the axis of rotation:
  - higher Ta observed at greater tilt angles reconfirming it is the absorber on the surface.
  - Ru is no more observable after 60⁰.
- Si-oxide is observed at tilt > 60⁰.
  - Because no Ru (or Mo) are detected there, it cannot be the Si from the multilayers. So, this might be due to Si-contamination on the surface.
  - It is also possible that the Si contamination is on the side of the absorber walls.

- AR-XPS was performed on the patterned reticle with 2 orientations of the lines and spaces- perpendicular and parallel to axis of rotation.
- XPS depth profiles performed at hotspot and outspot locations in patterned reticle.
- Despite of the patterning, XPS depth profiling is feasible and yields valuable information.
- From the depth profile, Ta-based absorber along with the Mo/Si oscillations can be observed.

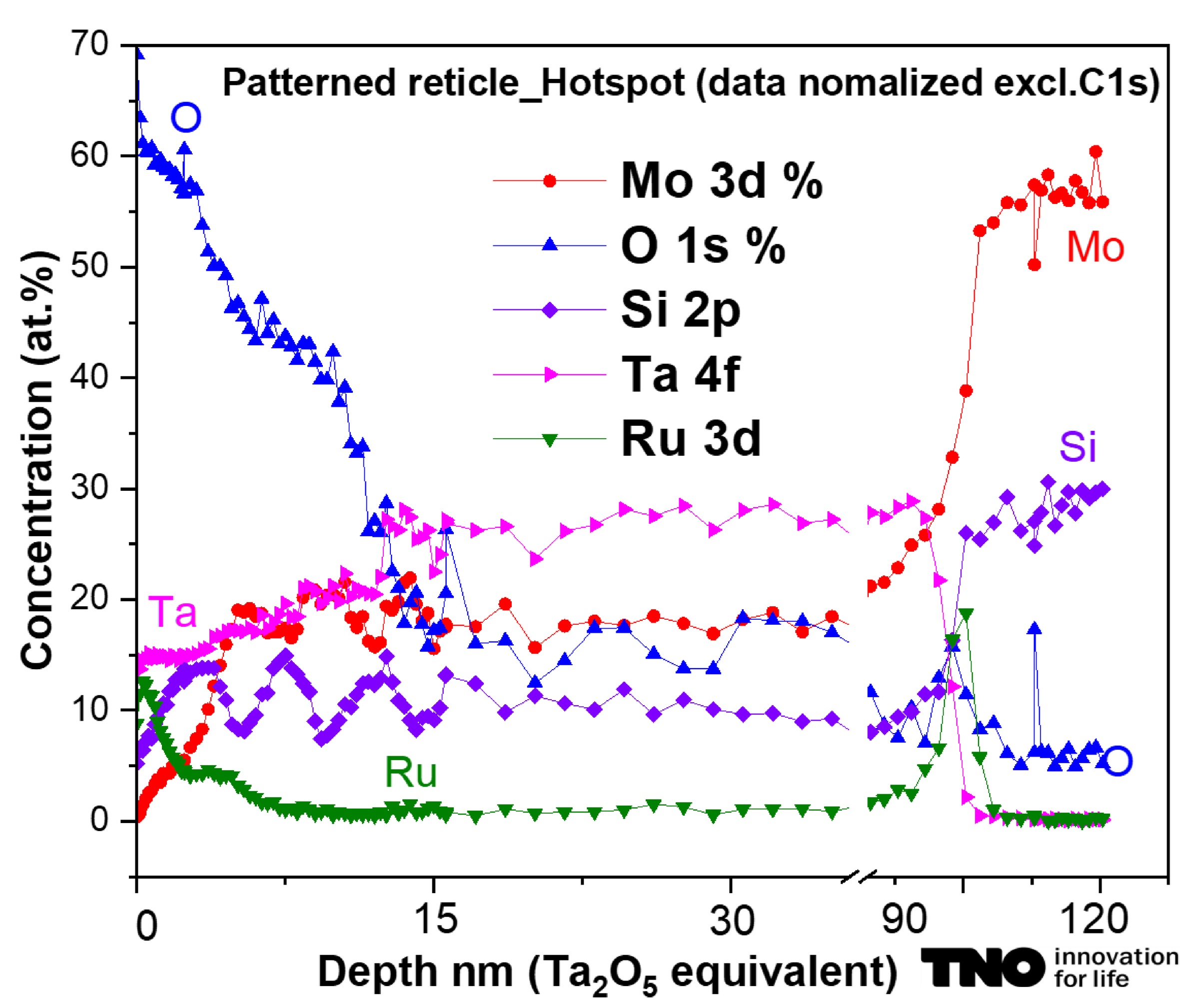


Fig.4: XPS depth profile on the patterned reticle; the depth scales are indicative only as the sputter rate is material dependent.

Summary and Conclusions:

1. AR-XPS and XPS depth profiling proves to be an effective technique for characterizing Mo/Si multilayer reticles, including those with patterned structures.
2. On the multilayer blank:
   - At the EUV hotspot location, there is clear indication of EUV induced oxidation in the first ~5 nm.
   - Comparison of the Ru depth profiles between outspot and hotspot locations suggests potential intermixing or diffusion of Si and/or Ru at the EUV hotspot.
3. On the patterned reticle with lines and spaces:
   - After ~80 nm (Ta_2O_5 equivalent), no more Ta is observed. This agrees well with the designed Ta layer thickness of ~70 nm.
   - The Mo/Si oscillations are visible in spite of the patterning as well as thick Ta layer initially.
   - After 30 nm, the Mo/Si stack is not clearly visible might be due to sputter induced roughening due to prolonged sputtering.

References:

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shriparna.mukherjee@tno.nl