Oxygen diffusion characterization in ultrathin films by low energy ion scattering

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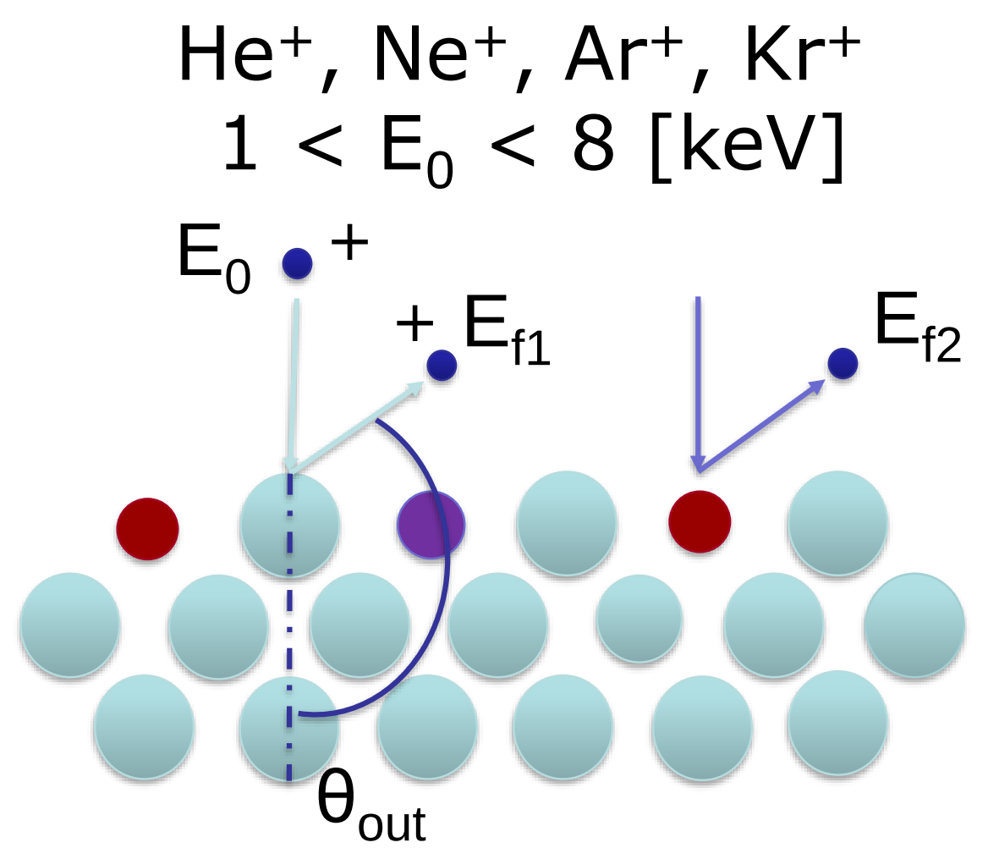
Abstract

Experimental determination of oxygen diffusion kinetic parameters for ultrathin films is of interest for applications as electronic devices and protective layers of extreme ultraviolet optics. Techniques usually applied to derive these data (XPS, SIMS) often lack details regarding surface chemistry and/or resolution. In this work, the oxygen diffusion in ultrathin films is analysed through LEIS, a technique that provides the possibility of correlating the selective analysis of the outermost atomic layer with high-resolution static depth profiling.

Low Energy Ion Scattering (LEIS)

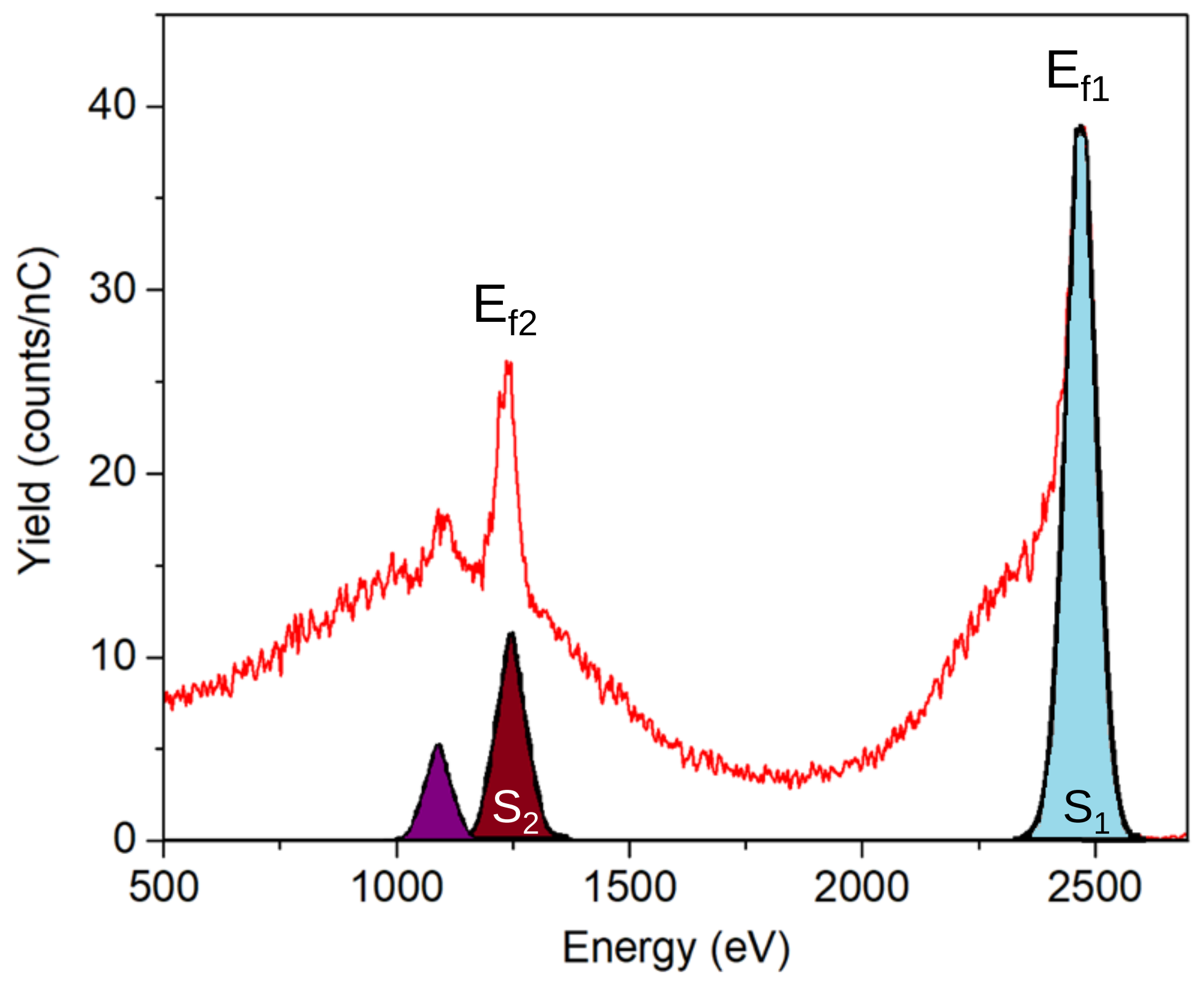
Sputter depth profile – Peak analysis

- ✓ LEIS peaks: outermost surface characterization
- ✓ Sensitive to scattered *ions*



$$E_{fi} = k(\theta, m_{ion}, m_{target}) \cdot E_0$$

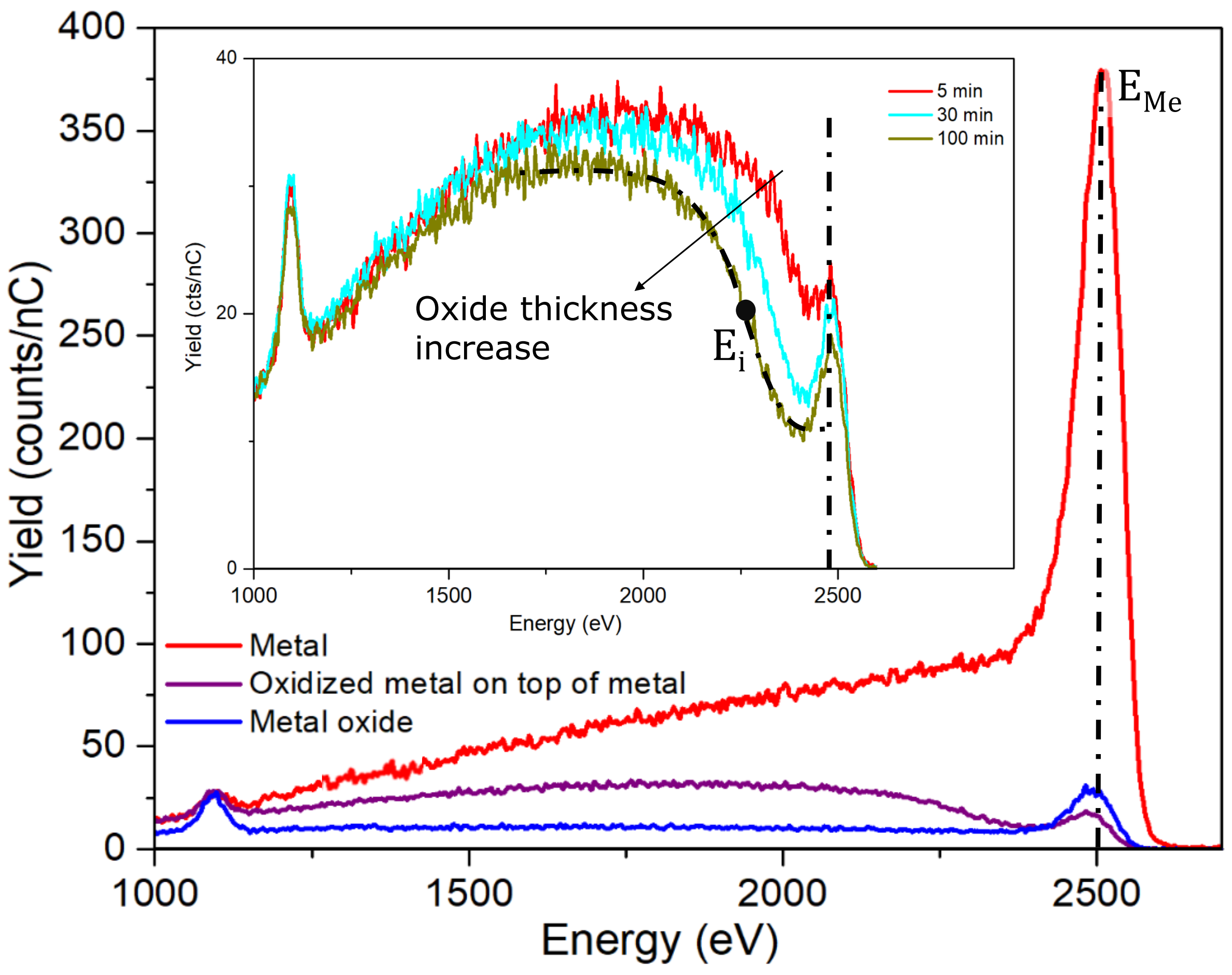
$$S_i \sim Atomic\ concentration$$



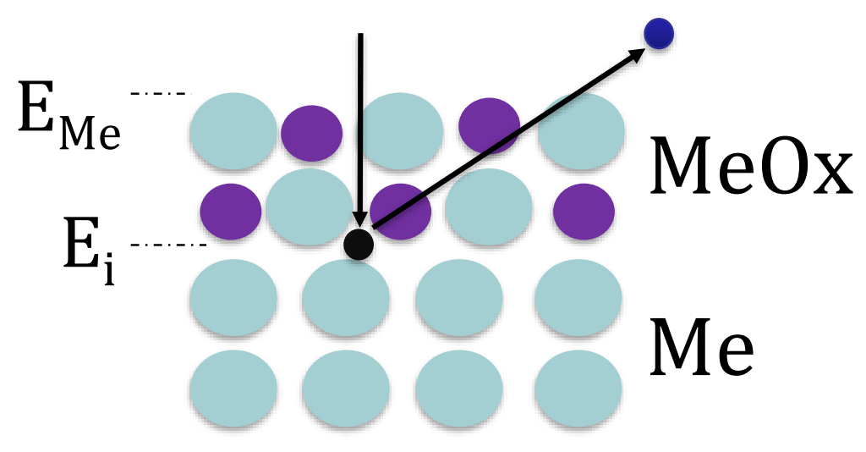
- ✓ Concentration of species with accuracy at each sputter step
- ✓ LEIS Sputter DP – determine change in *oxygen concentration* in *depth*

Static depth profile – Background signal analysis

- ✓ Species scattered at deeper layers may *reionize* at surface
- ✓ Ion/target interaction → Stopping Power (S)



Reionizied Particles = Background signal



$$< \Delta E > = \int_x S(E,x)dx$$

$$d_{ox} = \frac{E_{Me} - E_i}{2.2 \cdot S}$$

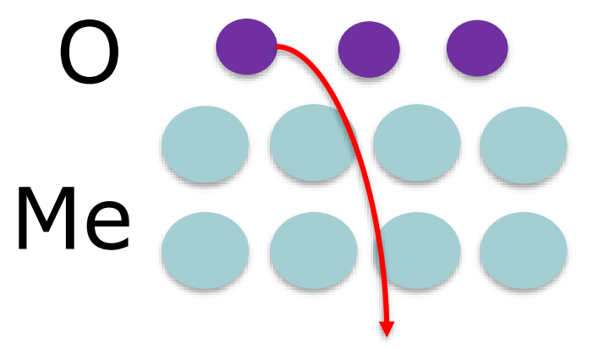
Geometrical factor

- ✓ Metal and oxide: differences in electronic stopping powers
- ✓ Thicker oxide: higher ΔE between surface peak and interface
- ✓ LEIS Static DP – Change *oxide thickness* with *oxygen exposure time* in a non-destructive way

Methodology

- 3 keV He^+ → Ru, Zr and Mo – single layers (15 nm)
- Atomic O: RT, 10^{-4} mbar

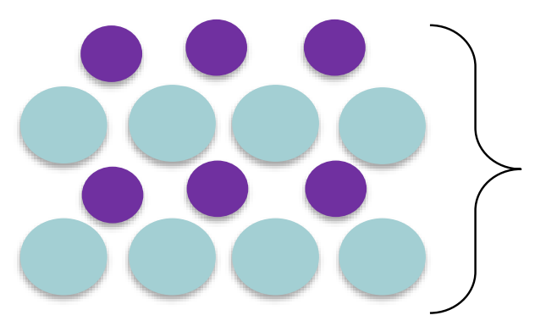
Sputter Depth Profile



Diffusivity (D)

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

Static Depth Profile



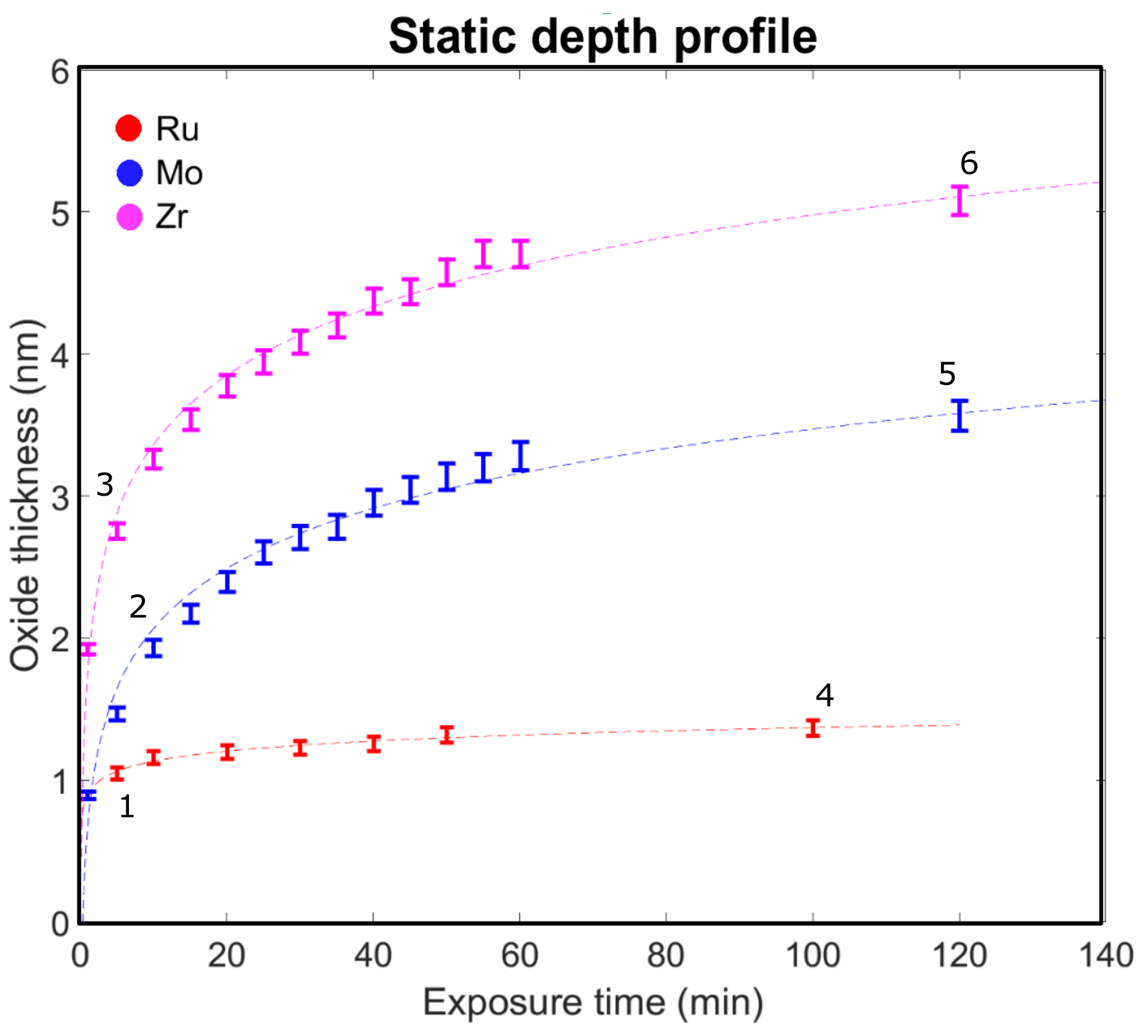
Oxidation
$d_{ox}(t)$

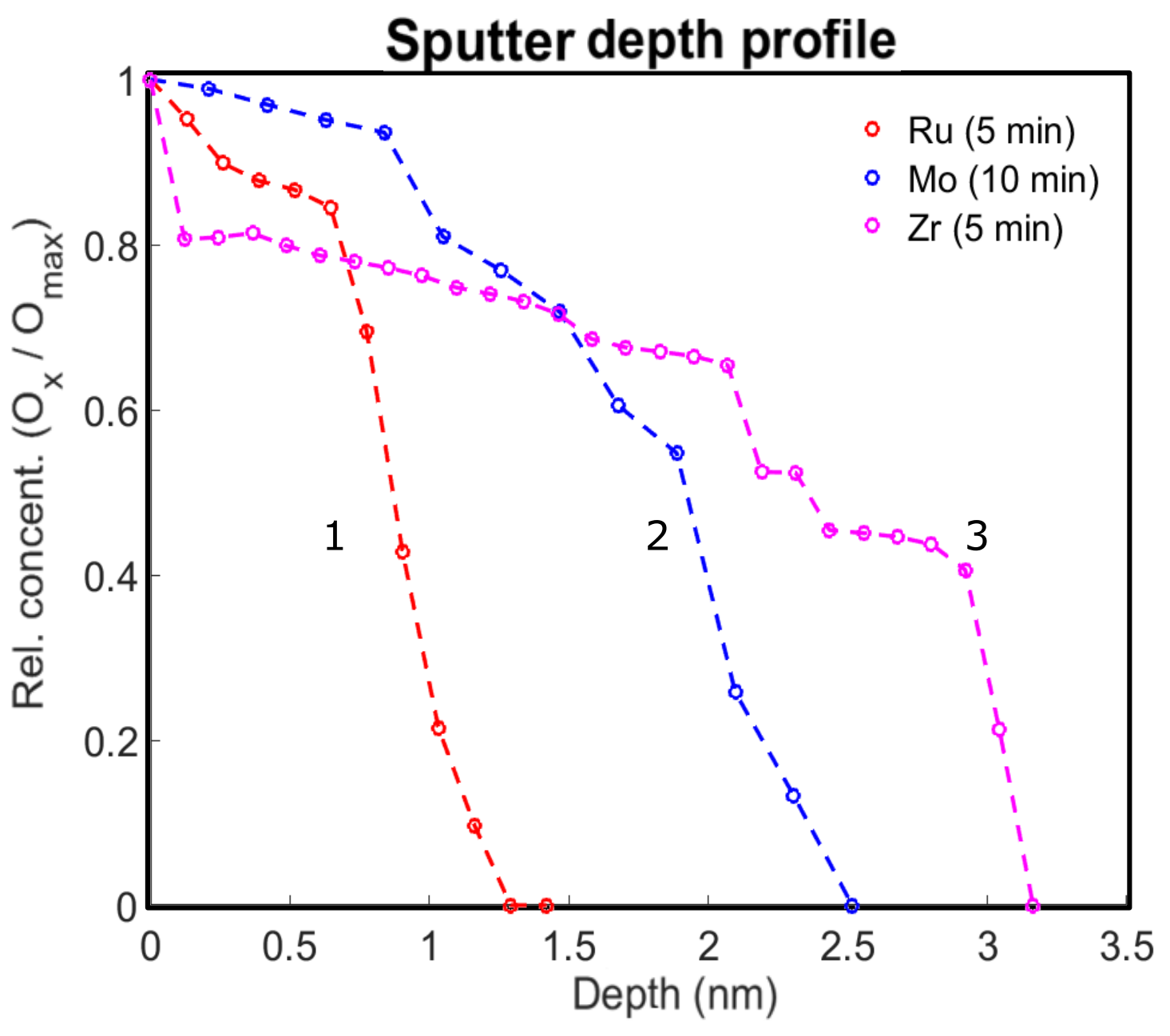
- ✓ Mechanisms and kinetics of oxide growth of thin films

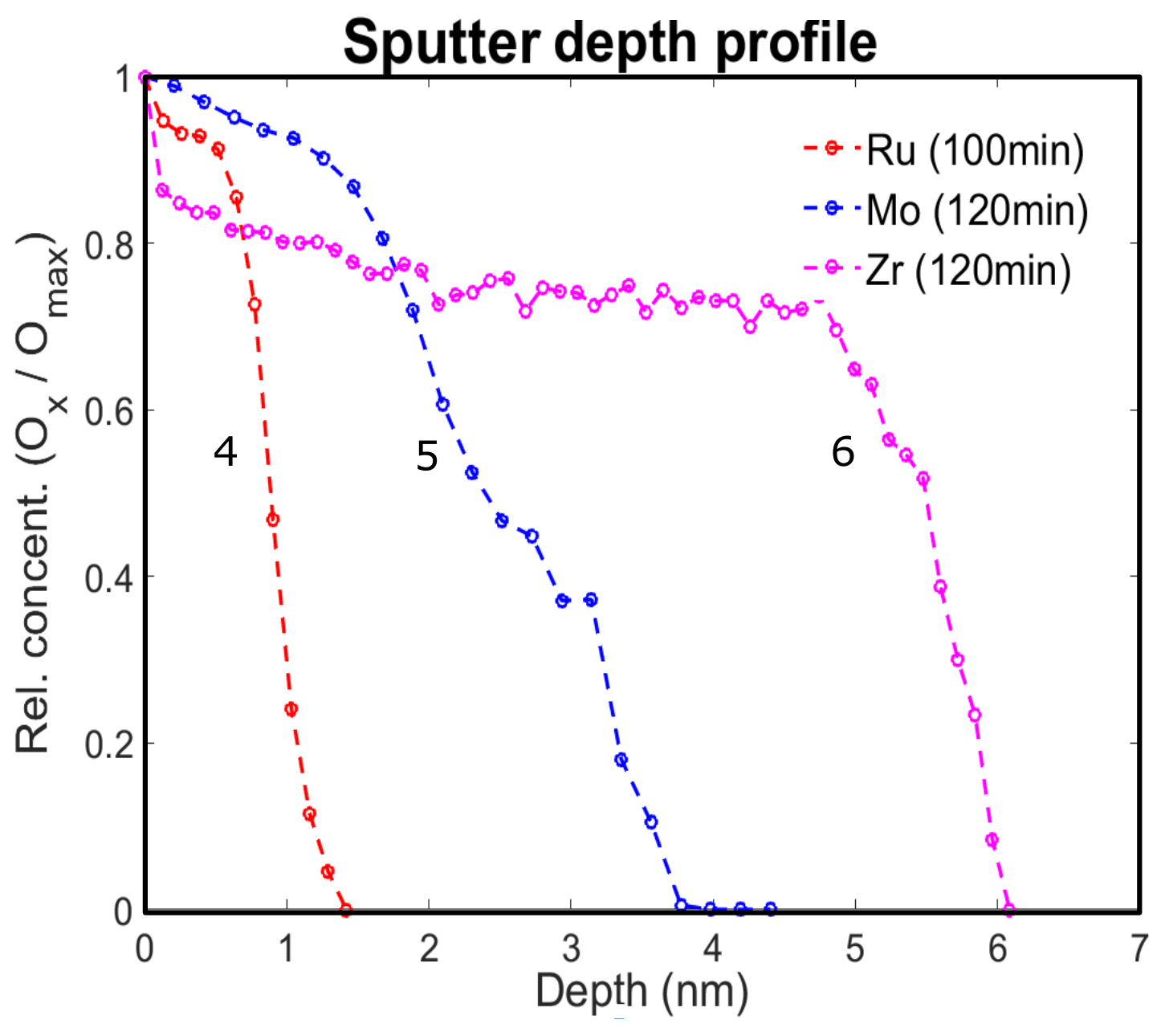
Results

Oxide growth through Sputter and Static depth profile

- ✓ **Static DP:** *oxide thickness* with accuracy and *non-destructively*


Static depth profile


Sputter depth profile


Sputter depth profile

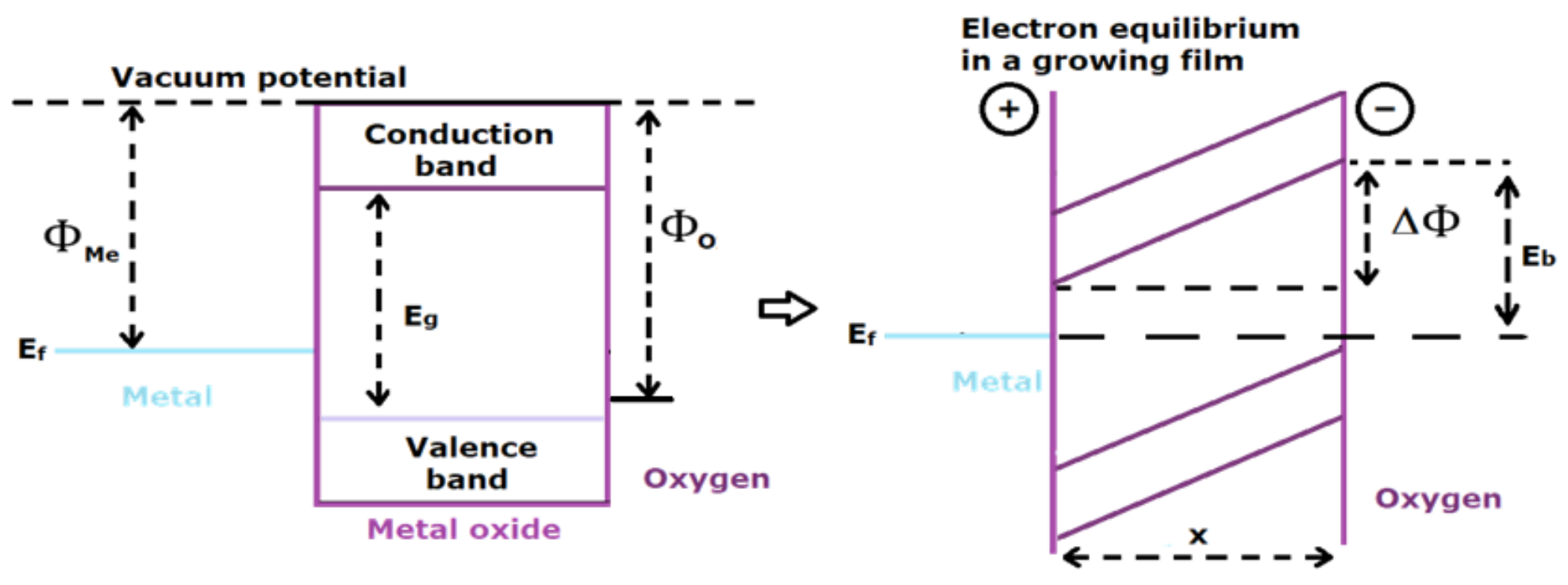
- ✓ **Sputter DP**: O concentration follows *non-linear diffusion*

RT thin film oxidation - Cabrera-Mott mechanism

- ✓ Rapid formation
- ✓ Saturation thickness with time
- ✓ Inverse logarithmic growth

$$\frac{1}{d_{ox}} \propto A(\Phi, d) \cdot \ln(t)$$

Metal oxide work function — *Metal oxide thickness*



- ✓ Adsorbed oxygen layer + Metal = Potential:

$$V_M = e^{-1}(\Phi_{Me} - \Phi_{o-})$$

- ✓ Generating a field:

$$E_b = -{V_M}/{d_{ox}(t)}$$

  - ✓ Driving force of oxide growth
  - ✓ Effective while potential drop in unit cell is comparable to diffusion activation energy

Conclusions and next steps

- ✓ LEIS Static DP: Fast and non-destructive way to determine oxidation of ultrathin films
- ✓ Static + Sputter DP: complete picture of thin-film oxidation
- ✓ Thin films (Ru, Zr, Mo) oxidation at RT: Cabrera-Mott theory
- ✓ Apply evaluation to different systems (varying T, materials)

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Literature

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2. N. Cabrera and N.F. Mott (1949). *Rep. Progr. Phys.* **12**, 163-184.