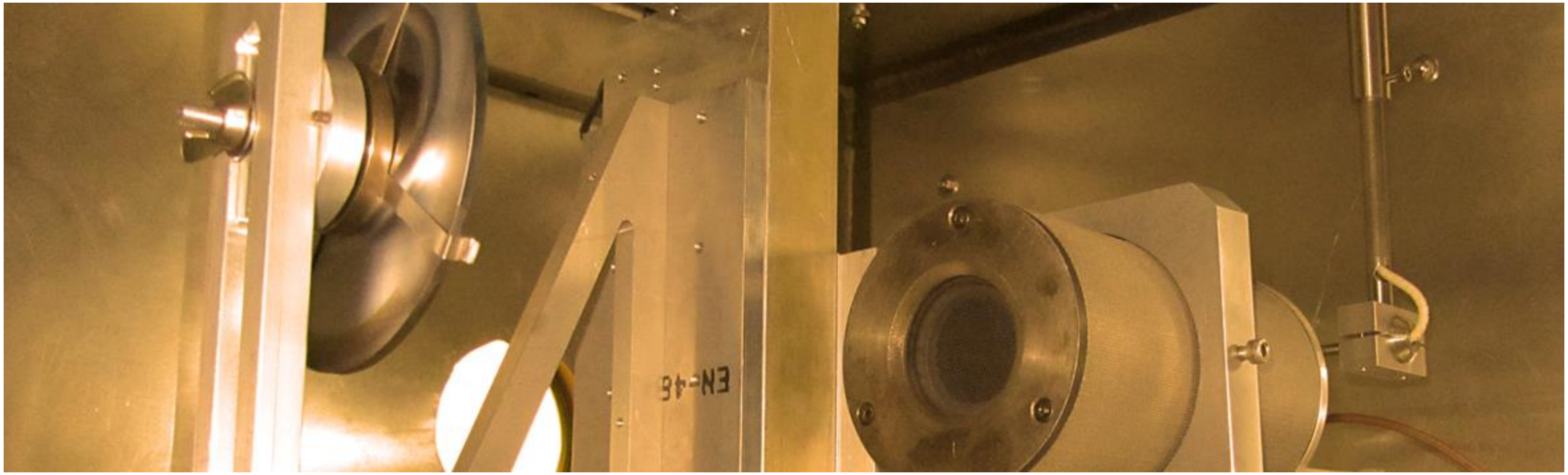


# Unravelling the systematics in ion beam sputter deposition of $SiO_2$

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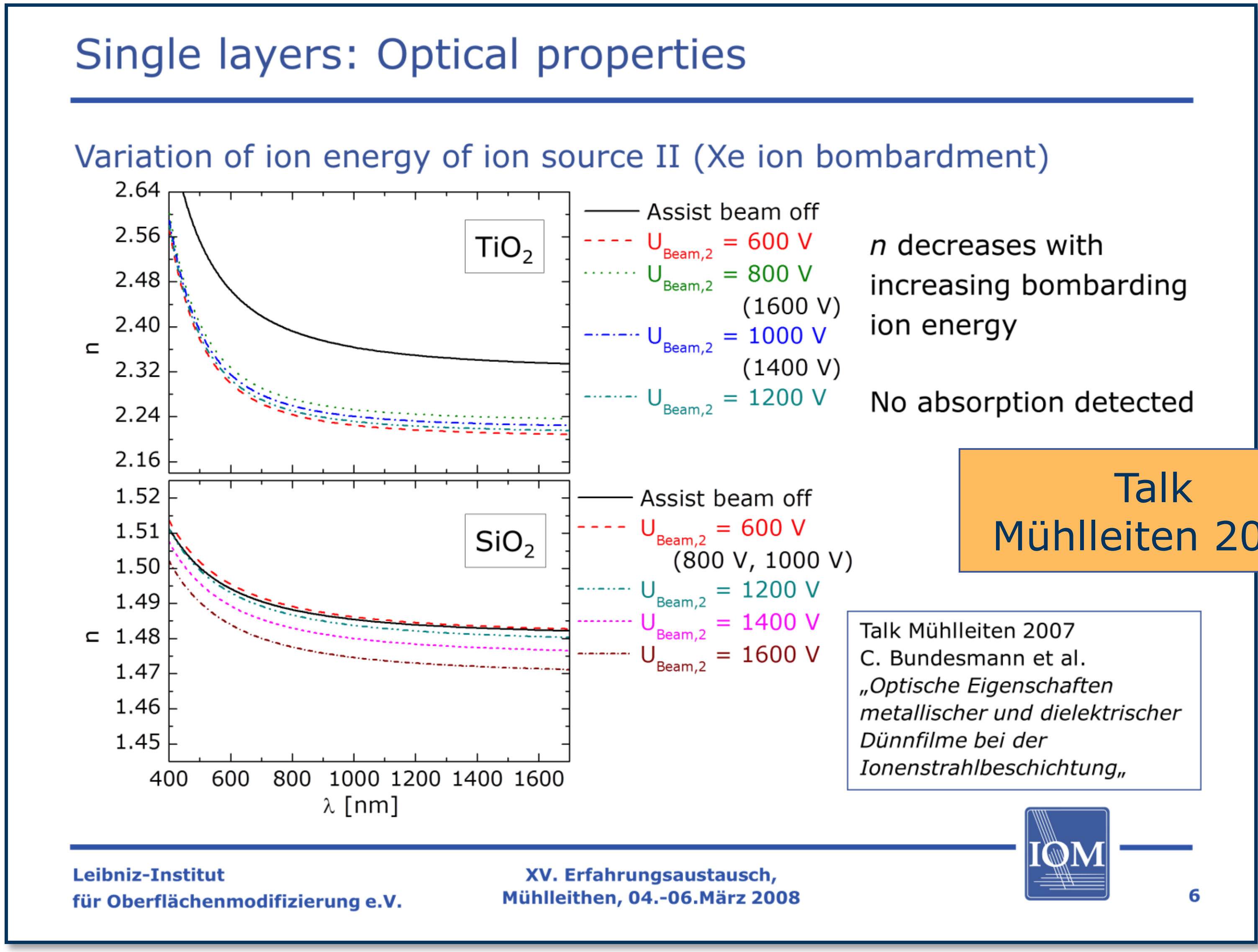
Mühlleithen, 07.-09.03.2017

IOM
Leibniz-Institut für
Oberflächenmodifizierung e.V.

# Outline

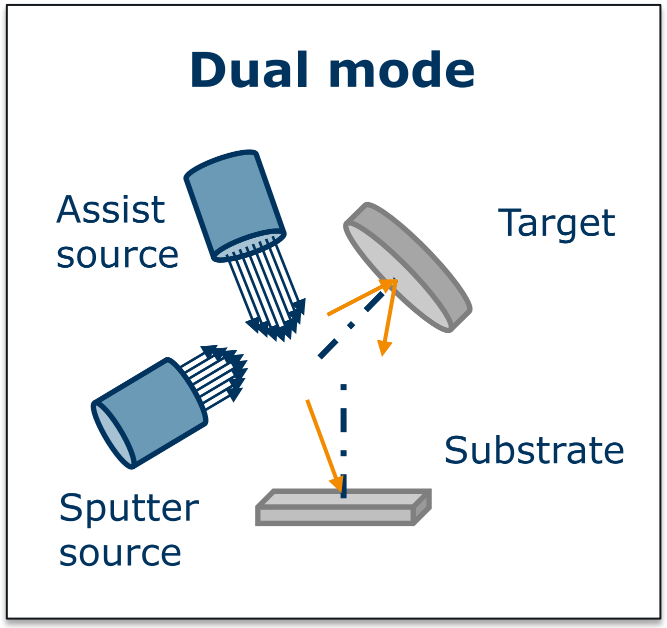
- Introduction
  - Motivation
  - Setup and growth parameters
  - Characterization techniques
- Experimental results
- Summary and outlook

# Motivation




Talk Mühlleiten 2008

- Refractive index changes upon assisting ion bombardment
- Questions:
  - Why?
  - Systematics?




C. Bundesmann et al., Thin Solid Films 516 (2008) 8604.

# Motivation

Ion beam and geometrical parameters → Energy and angular distribution of sputtered and scattered particles → Film properties

- Extend systematic investigations to $SiO_2$
  $SiO_2$ has many applications: multilayer coatings, semiconductor devices, …
- Similarities and differences to ion beam sputter deposition of $TiO_2$ (Ag, Ge)

Ag:
R. Feder et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 316 (2013) 198.
R. Feder et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 317A (2013) 137.
C. Bundesmann et al., Thin Solid Films 551 (2014) 46.
C. Bundesmann et al., Contrib. Plasma Phys. 55 (2015) 737.

Ge:
R. Feder et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 334 (2014) 88.
C. Bundesmann et al., Thin Solid Films 589 (2015) 487.

$TiO_2$:
T. Lautenschläger et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 385 (2016) 30.
C. Bundesmann et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 395 (2017) 17.
C. Bundesmann et al., Appl. Surf. Sci., in press.



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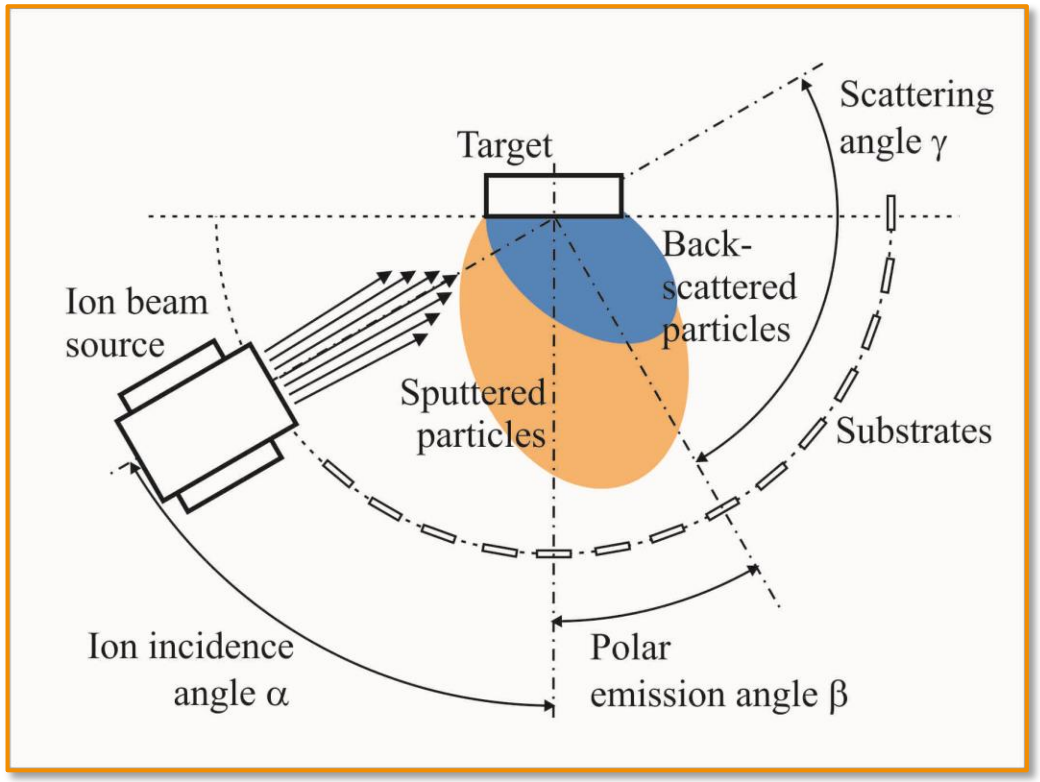
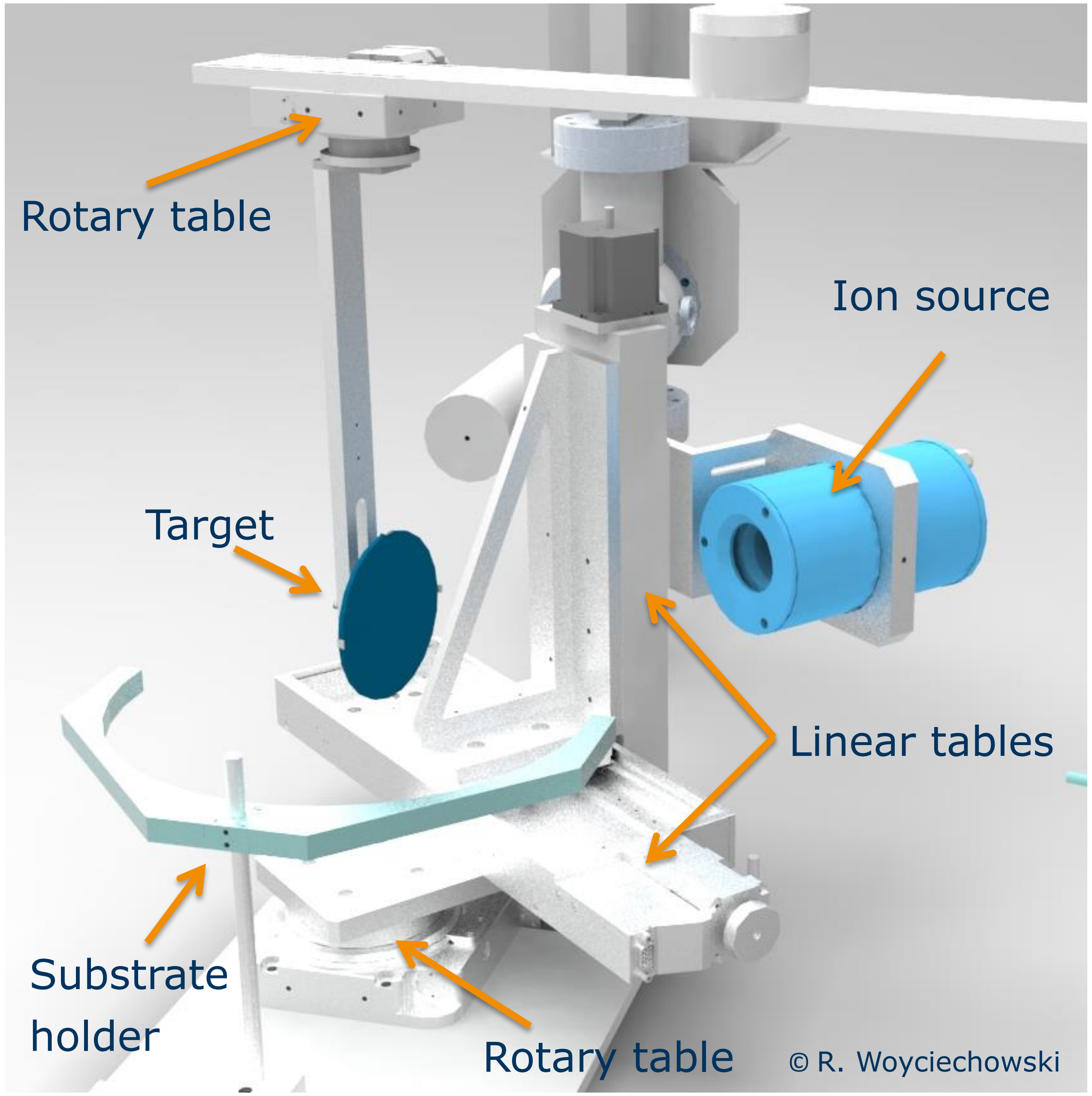
# Setup and growth parameters




- Ion energy: 0.5 / 1.0 / 1.5 keV
- Ion species: Ar, Xe
- Incidence angle: 0°, 30°, 60°
- Emission angle: -40° … 80°

# Characterization techniques

Done

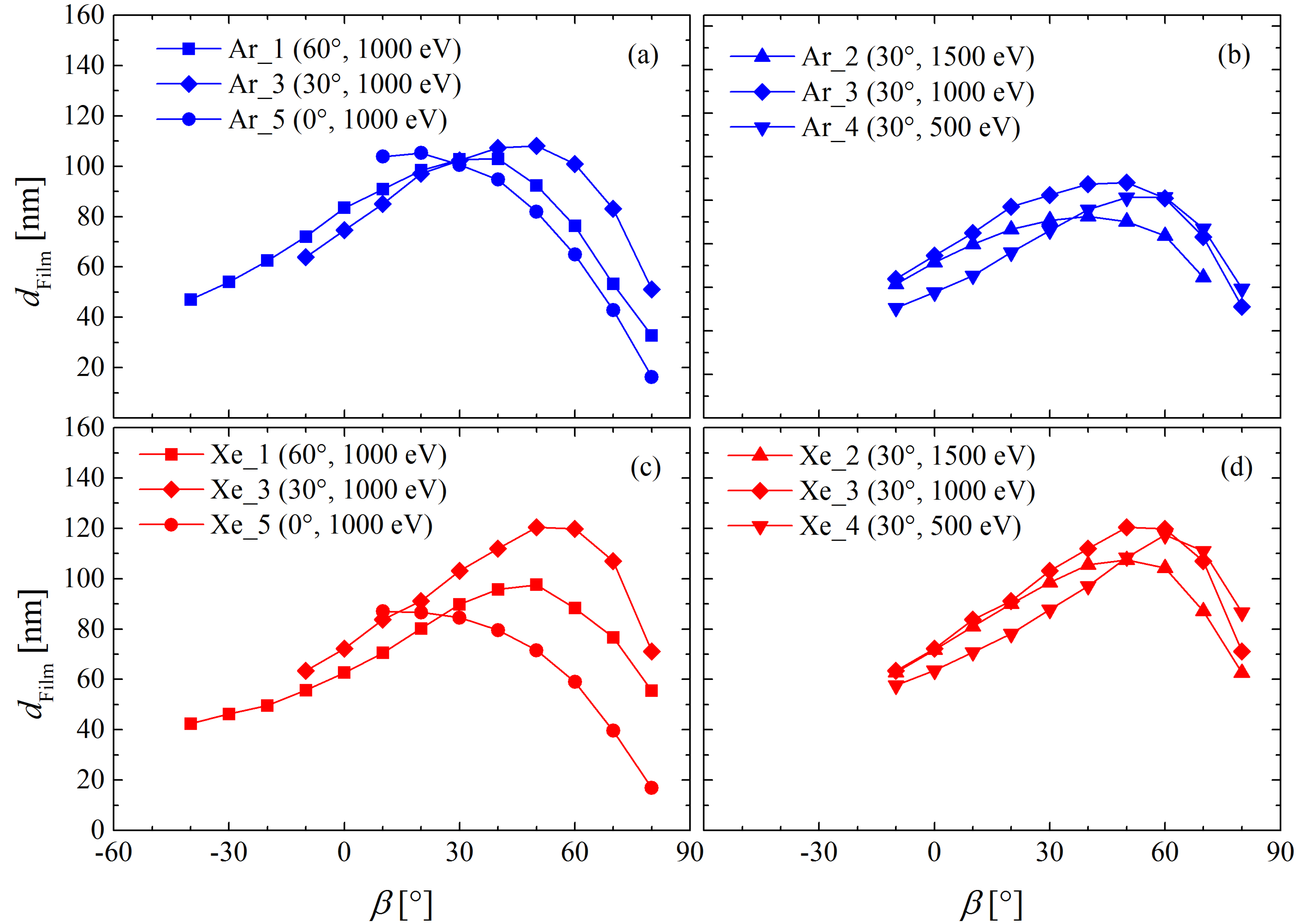
- Spectroscopic ellipsometry (SE) … Film thickness, growth rate
  optical properties
- RBS … Composition
- AFM … Surface roughness

In progress

- XRD … Crystallinity
- XRR … Mass density

# Film thickness (SE)

Ion incidence angle varied    Ion energy varied




- Aim: Maximum film thickness ~ 100 nm
- Maximum at polar emission angle between 40° and 60°



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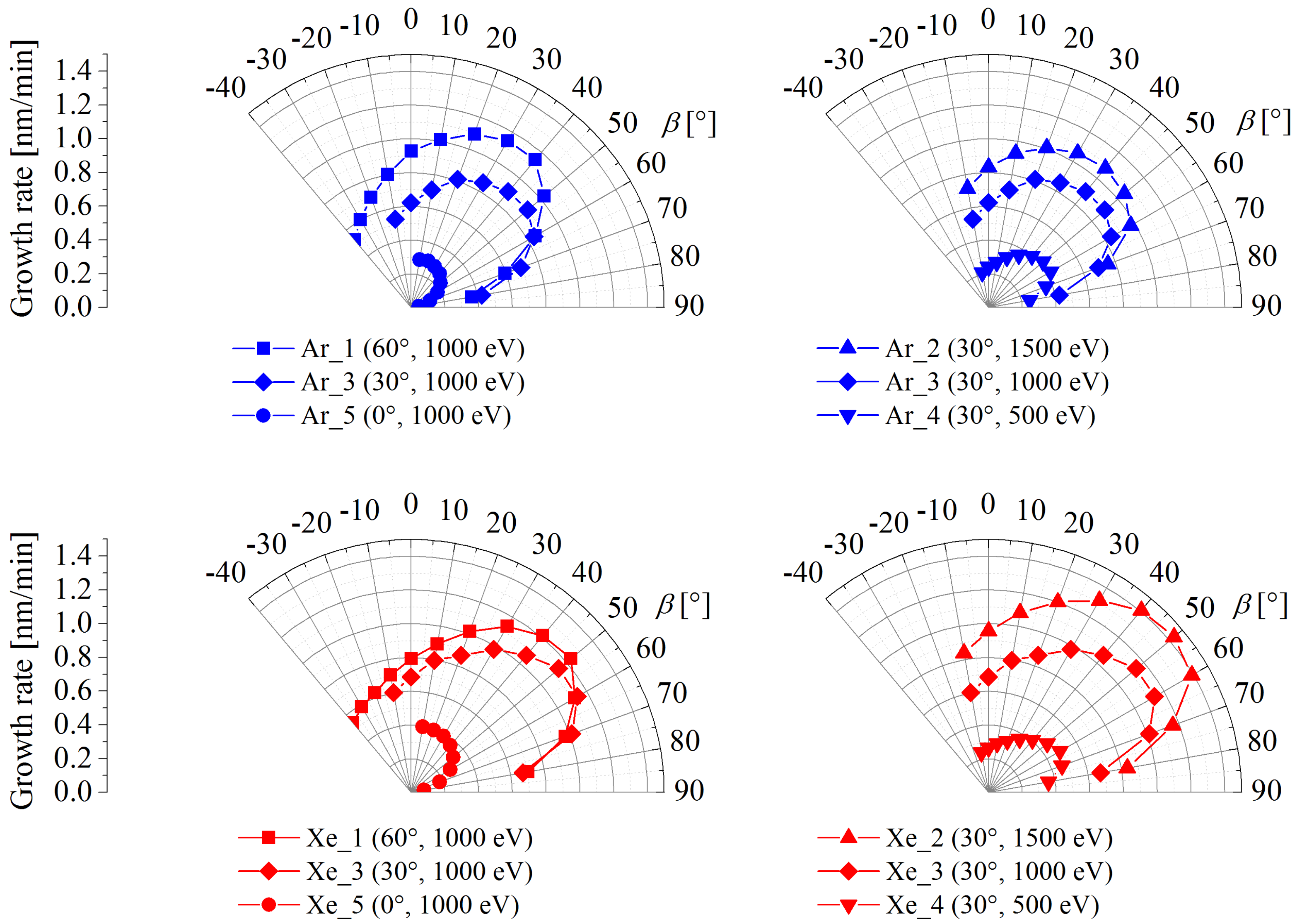
# Growth rate (SE)

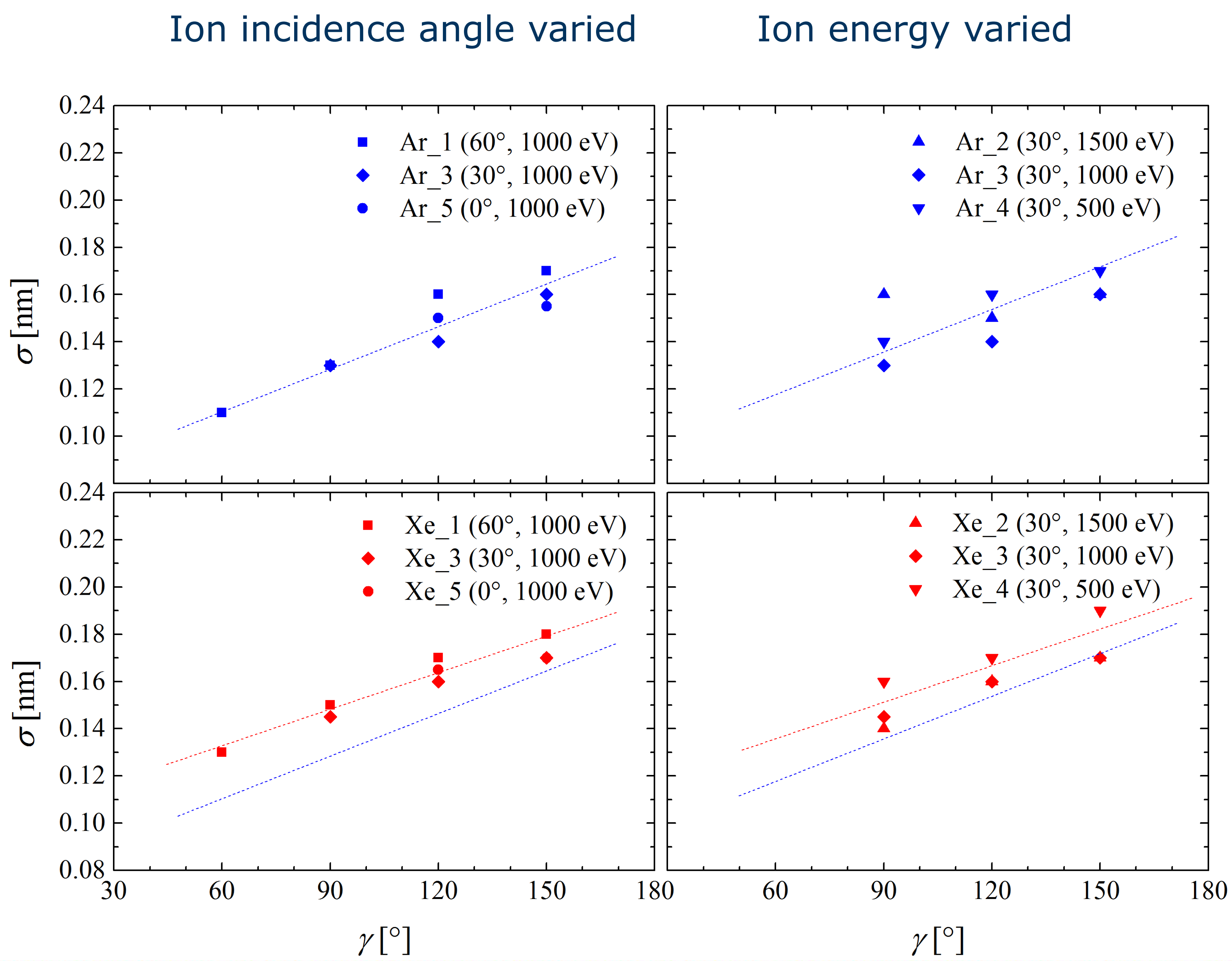
Ion incidence angle varied

Ion energy varied




- Increases with increasing ion energy or ion incidence angle, higher for sputtering with Xe than for sputtering with Ar (Total sputter yield)
- Over-cosine angular distribution, tilted in forward direction (anisotropy effects)

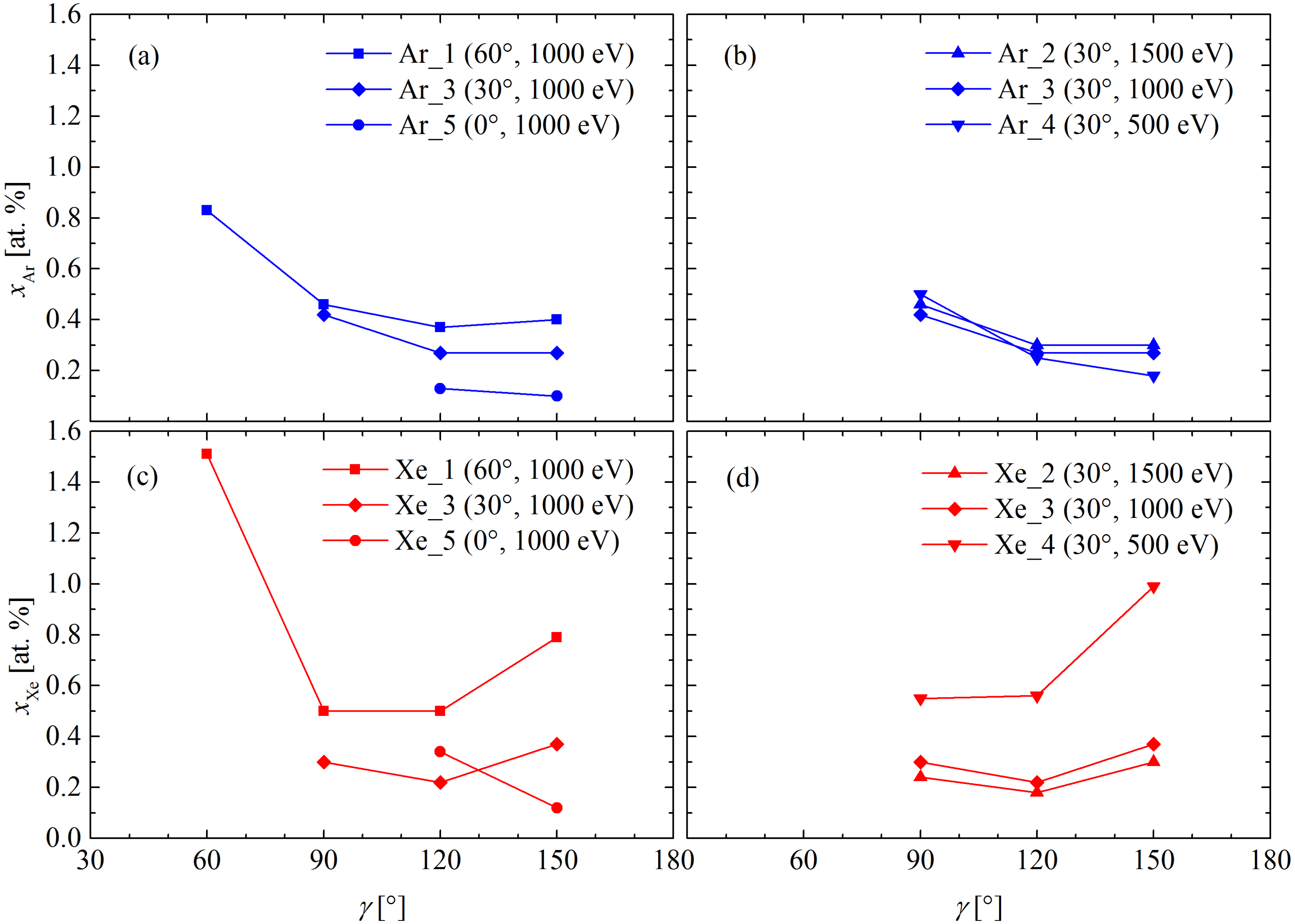
# Surface roughness (AFM)




- Films are very smooth
- RMS roughness (σ) increases with increasing scattering angle
- Small differences between sputtering with Ar or Xe
- Mainly influenced by scattering geometry
- Related to energy of secondary particles, affects surface mobility

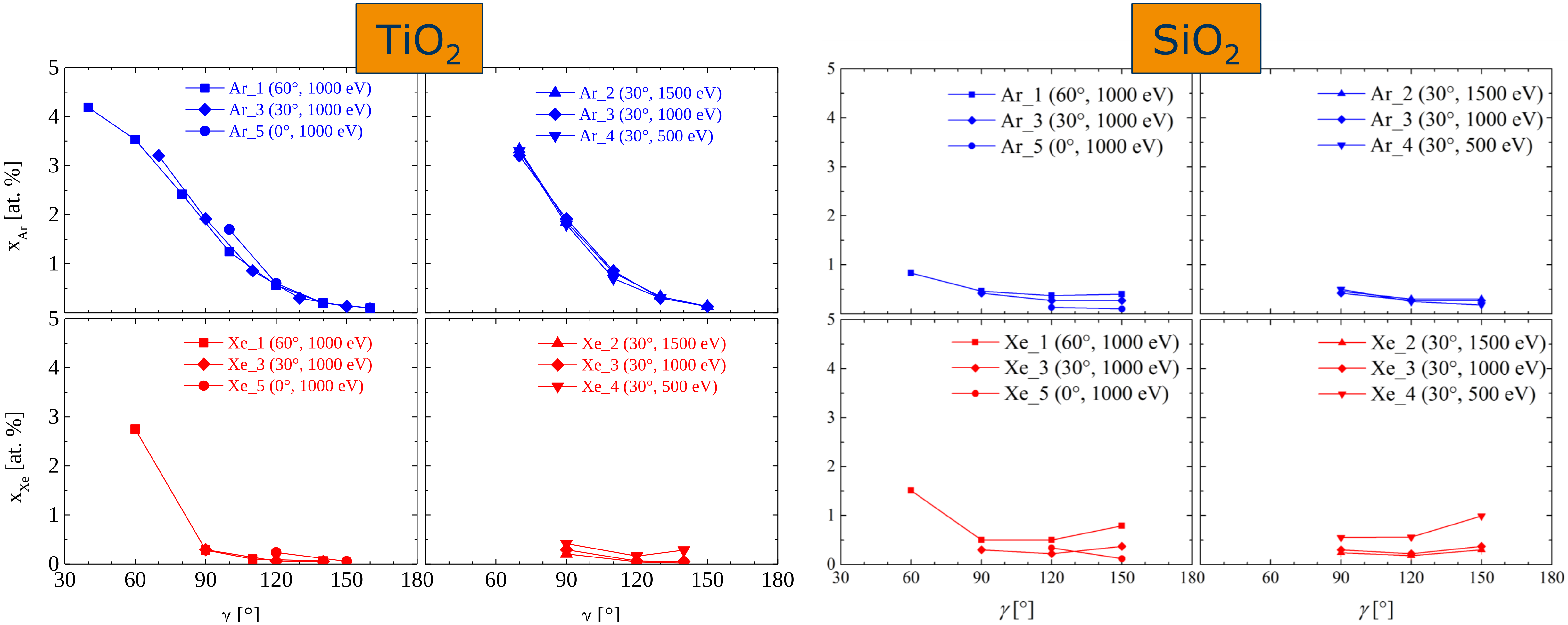
# Composition (RBS)

Ion incidence angle varied | Ion energy varied




- Films are stoichiometric (Si:O ~ 1:2)
- Incorporation of primary particles (correlated with scattering angle)
- Similar for Ar and Xe

# Composition (RBS)




- Higher amount of inert gas particles in $TiO_2$ films than in $SiO_2$ films, especially for Ar

C. Bundesmann, et al., Appl. Surf. Sci., in presss, DOI: 10.1016/j.apsusc.2016.08.056.



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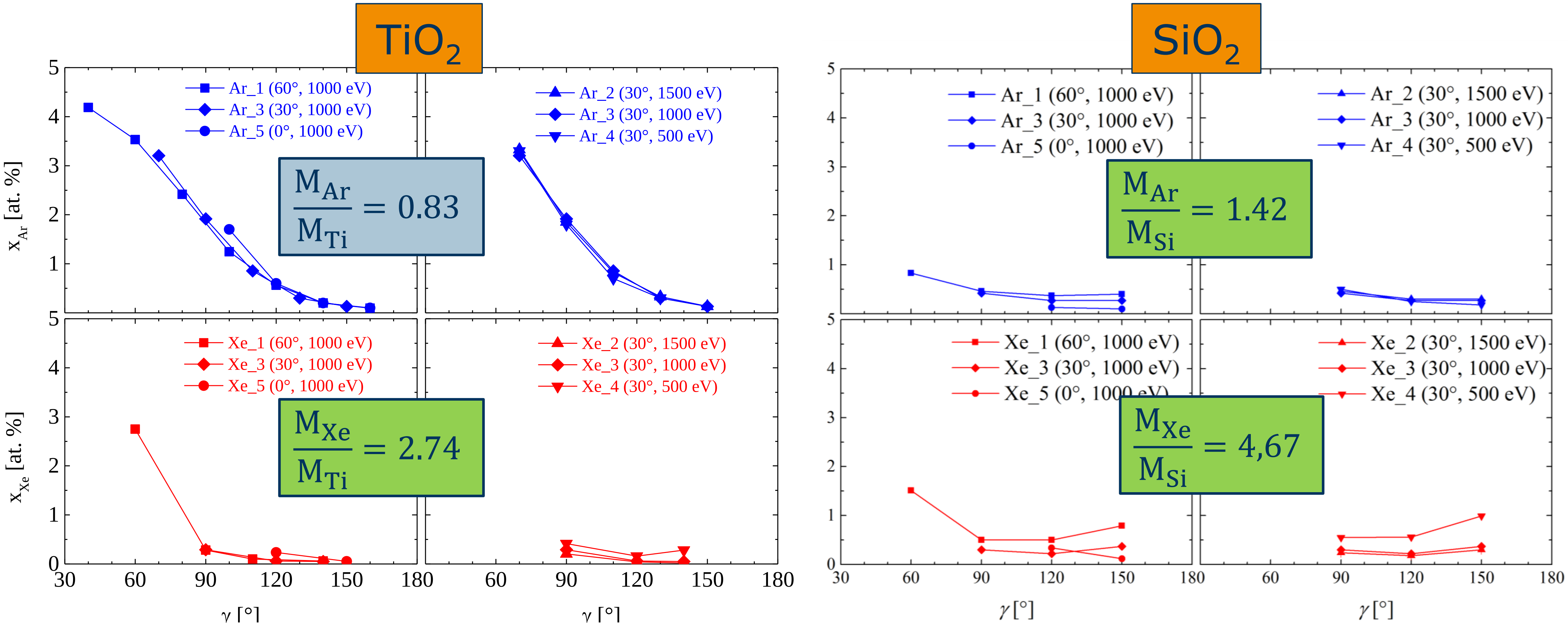
# Composition (RBS)

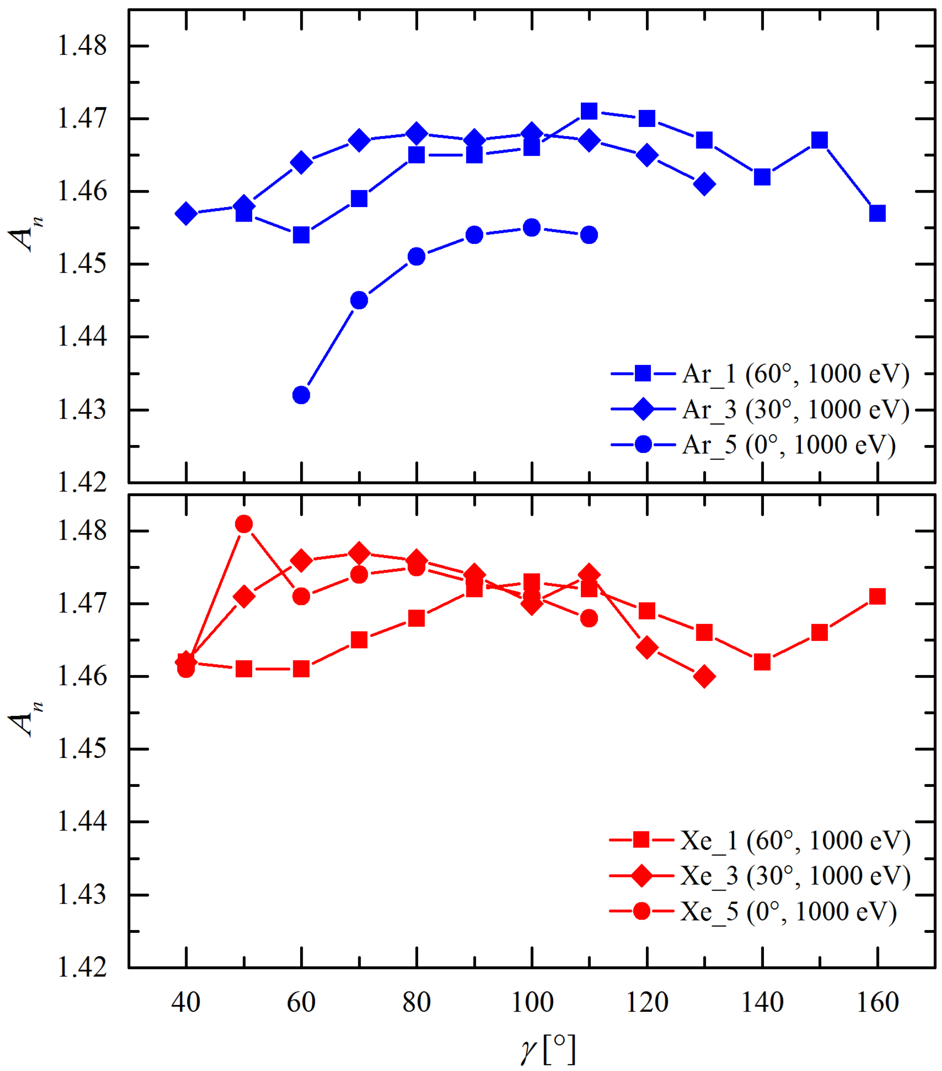



- Higher amount of inert gas particles in $TiO_2$ films than in $SiO_2$ films, especially for Ar
- Possible reasons: - different mass ratio of interacting particles
  - binary Rutherford scattering becomes less important

C. Bundesmann, et al., Appl. Surf. Sci., in presss, DOI: 10.1016/j.apsusc.2016.08.056.

# Optical properties (SE)

Ion incidence angle varied

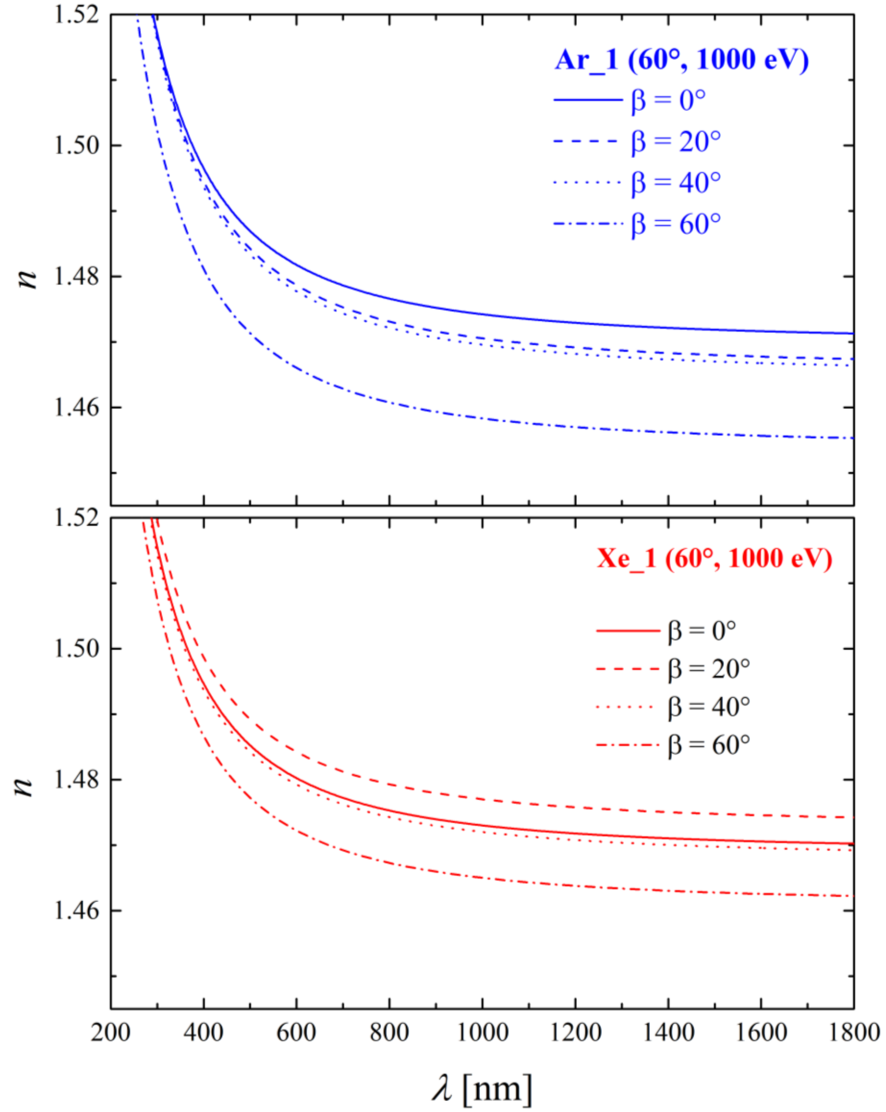



- Cauchy model:

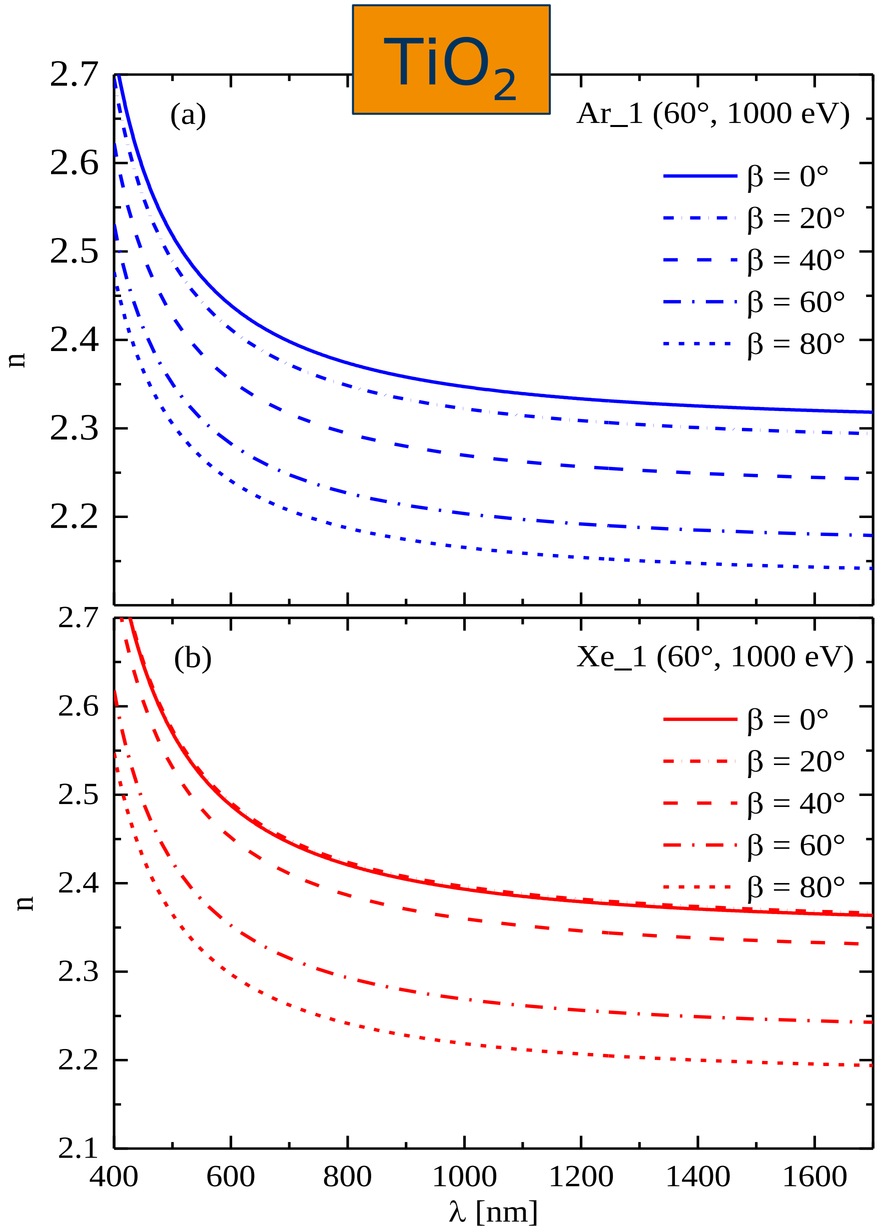
$$n(\lambda) = A_n + \frac{B_n}{\lambda^2} + \frac{C_n}{\lambda^4}$$

- Index of refraction (and $A_n$) almost constant
- Barely affected by ion species and ion incidence angle

Emission angle varied

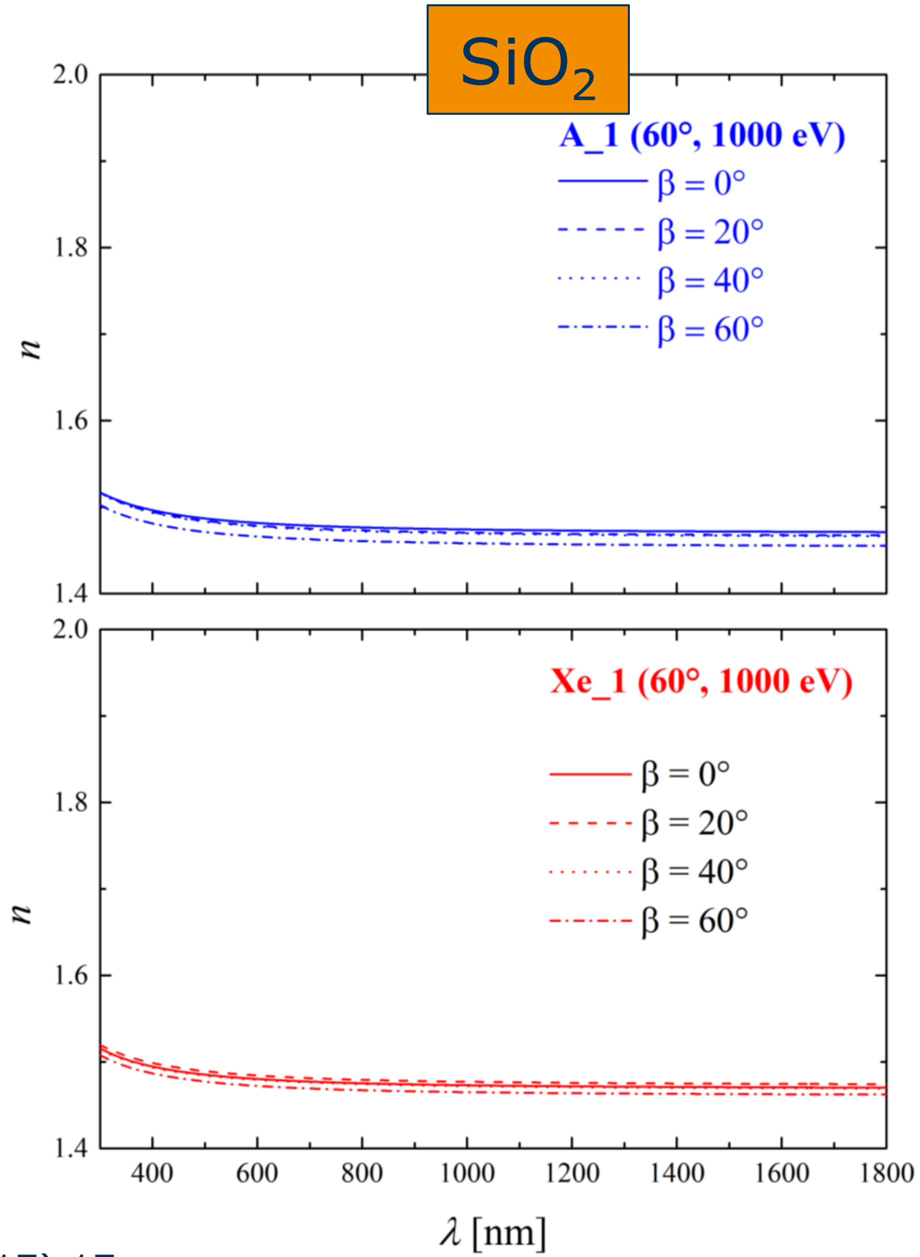


# Optical properties (SE)




Refractive index of $SiO_2$

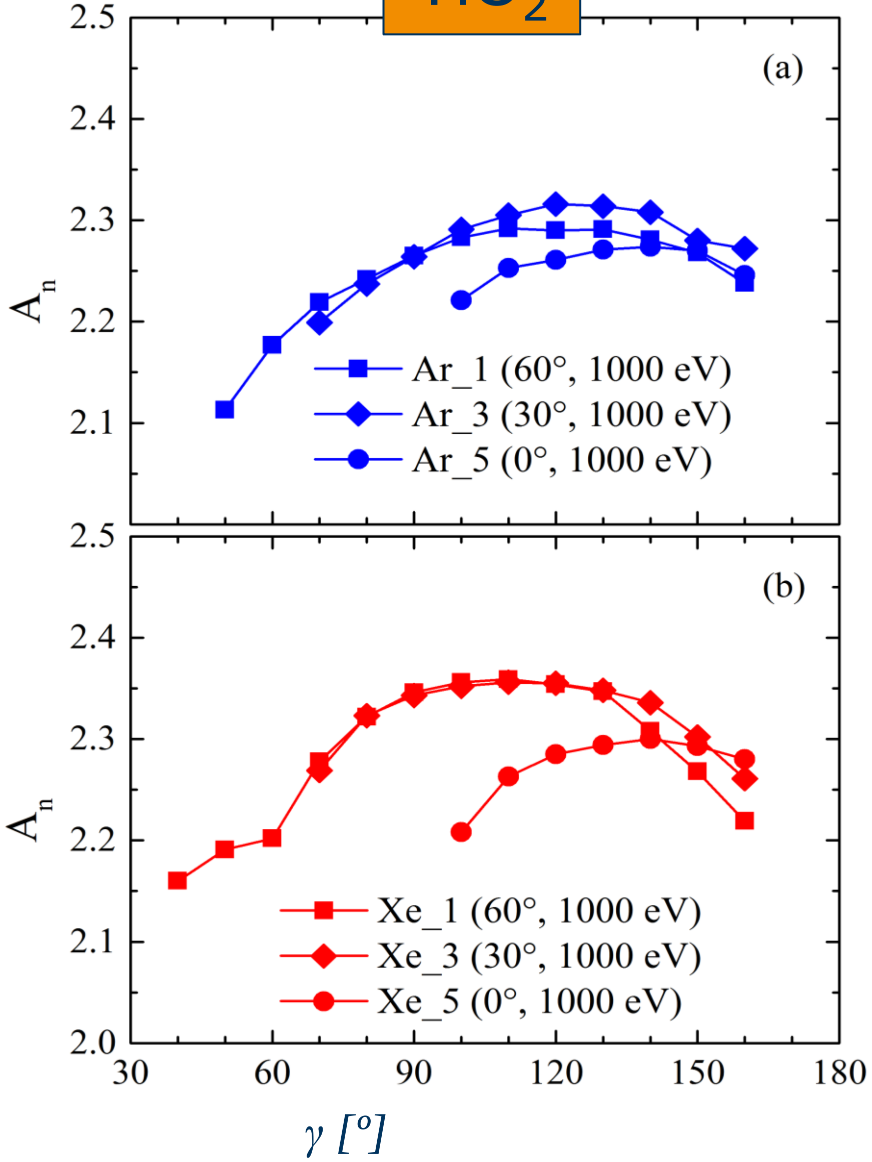
- Smaller changes than for $TiO_2$




C. Bundesmann, et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 395 (2017) 17.

# Optical properties (SE)

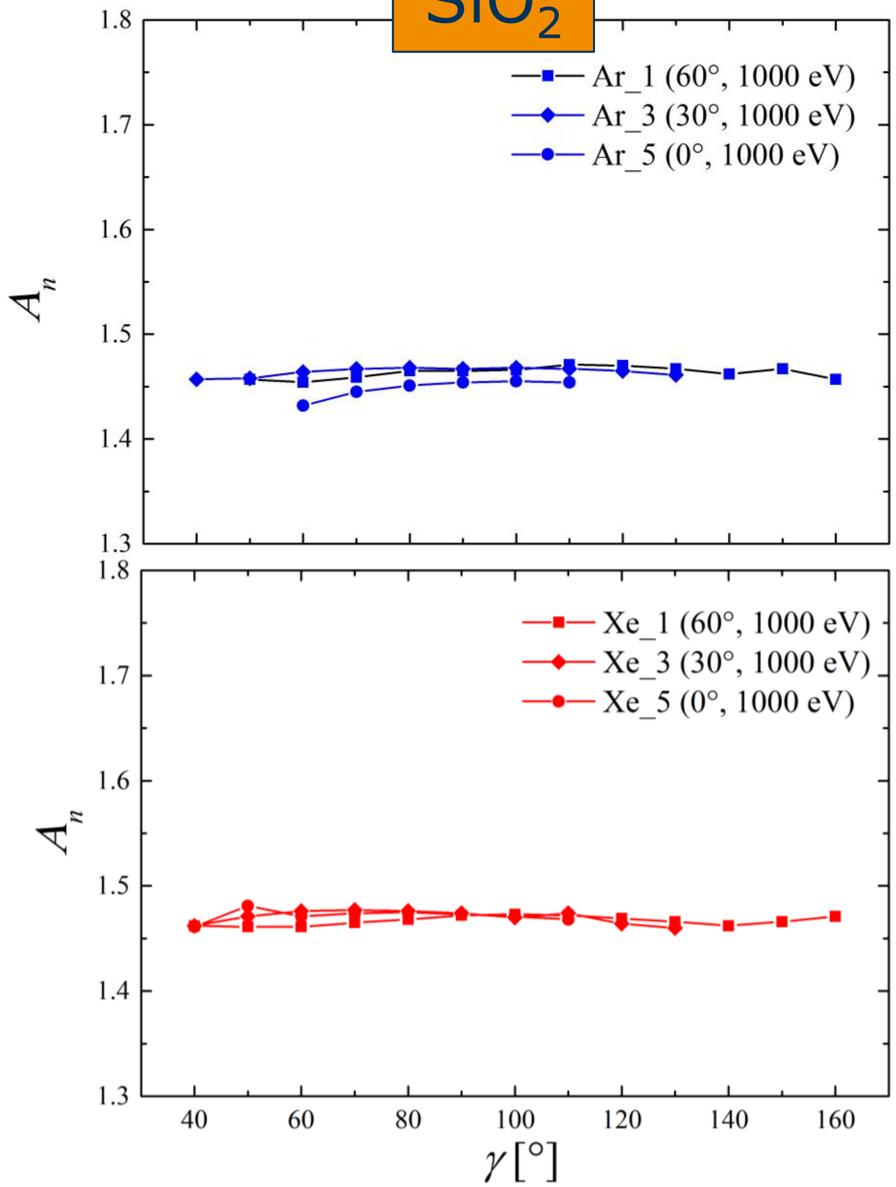
$TiO_2$




Refractive index of $SiO_2$

- Smaller changes than for $TiO_2$
- probably caused by smaller variation in mass density

$SiO_2$




C. Bundesmann, et al., Nucl. Instrum. Methods Phys. Res., Sect. B, 395 (2017) 17.

# Summary and outlook

- Film properties of $SiO_2$ depend systematically on process parameters: surface roughness, composition, optical properties
- Mainly influenced by scattering geometry; impact of ion energy and ion species is rather small
- Results show similar systematics as $TiO_2$ films, but variations are much smaller
- Differences may be caused by lower mass density variations of $SiO_2$

- Further film properties (XRR, XRD, …) → mass density, structure
- Properties of secondary particles (ESMS)
- Applications: e.g. amorphous $Ti_xSi_{1-x}O_2$ films for waveguide or photonic devices

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# Thank you for your attention!