Counterbalancing iridium coating stress for astronomical X-ray mirrors

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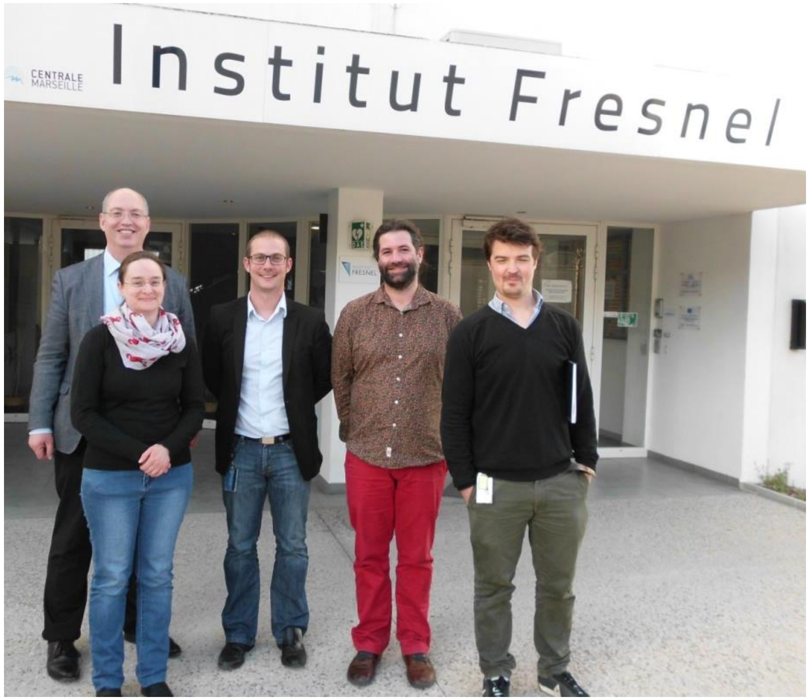

Agenda:

- Programmatic context
- Requirements for mirror coatings
- Experimental set-up
- The challenge of coating stress
- Measured iridium coating stress
- Stress compensation by SiO_2
- Stress compensation by Cr layer
- Summary and Outlook

Programmatic context

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The coating development at Aschaffenburg University is embedded in international collaborations with groups from other universities and institutes. For the results of the TRILAMICO-F project presented here bi-national funding by the Bavarian-French Academic Centre BFHZ has been granted.

TRILAMICO
Trilateral Mirror Collaboration

Funding agency:

Bayerisch-Französisches Hochschulzentrum (BFHZ)

Centre de Coopération Universitaire Franco-Bavarois

Introduction: New technology needed

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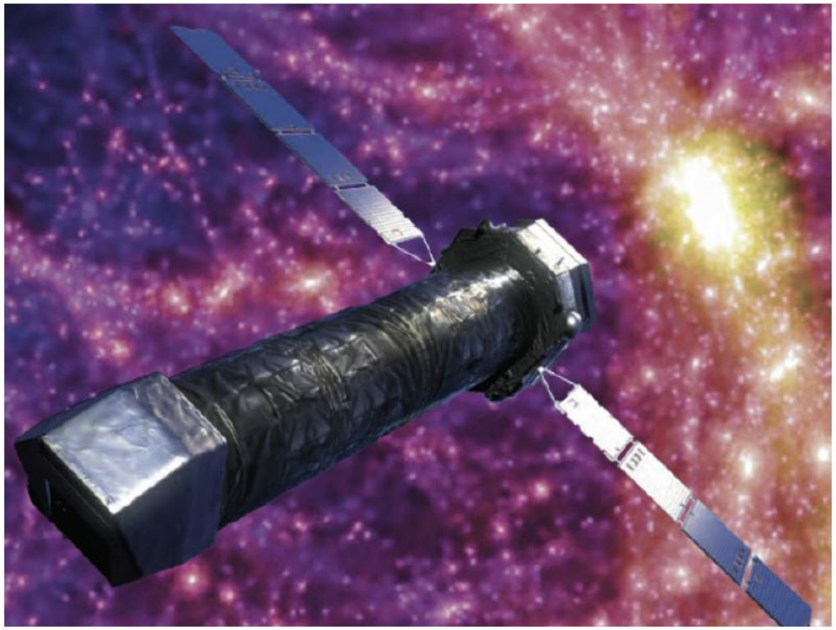
Next generation X-ray observatories require:

- apertures of several meters
- large effective areas
- good angular resolution
- stringent mass budgets



Source: www.cosmos.esa.int

Previously used mirror technologies are not able to fulfil the challenging requirements of future X-ray telescopes.

→ Development of new technologies for X-ray mirrors is needed.

Design principles for X-ray telescopes

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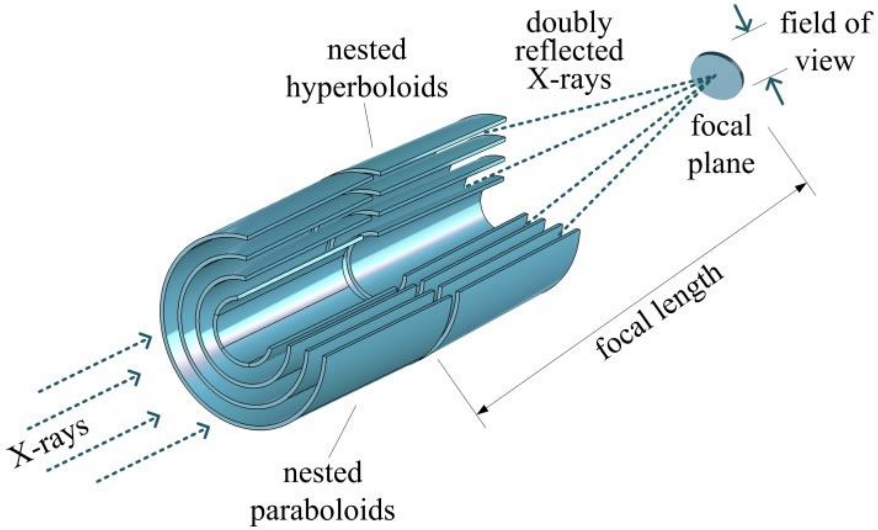
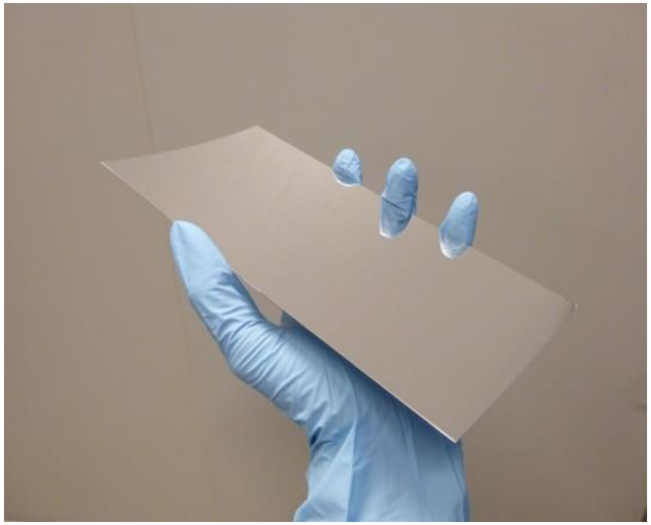
Wolter-I design: **Curved mirrors integrated in nested coaxial shells**





This design is followed up by the Max-Planck-Institute for extraterrestrial physics. Substrates of mirror segments are formed by indirect hot slumping of thin glass sheets.

Design principles for X-ray telescopes

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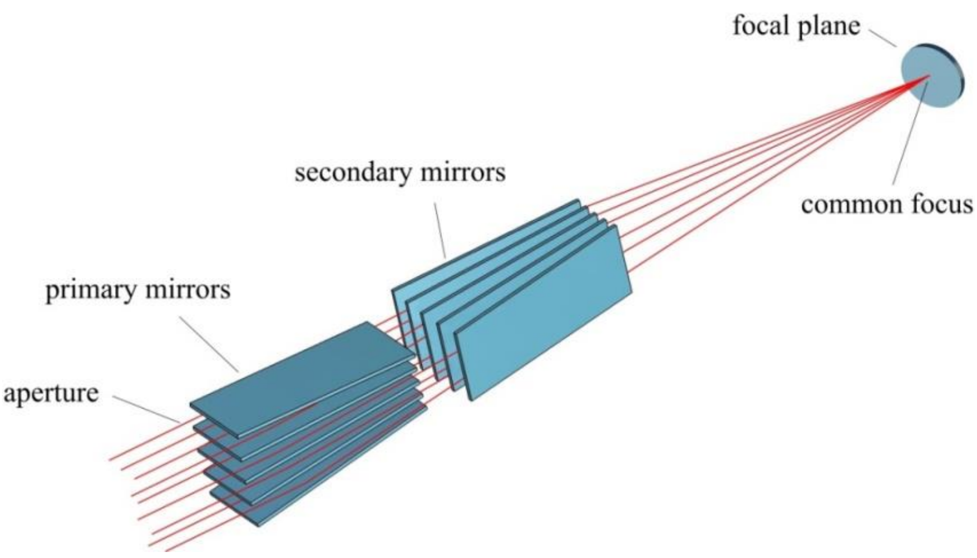
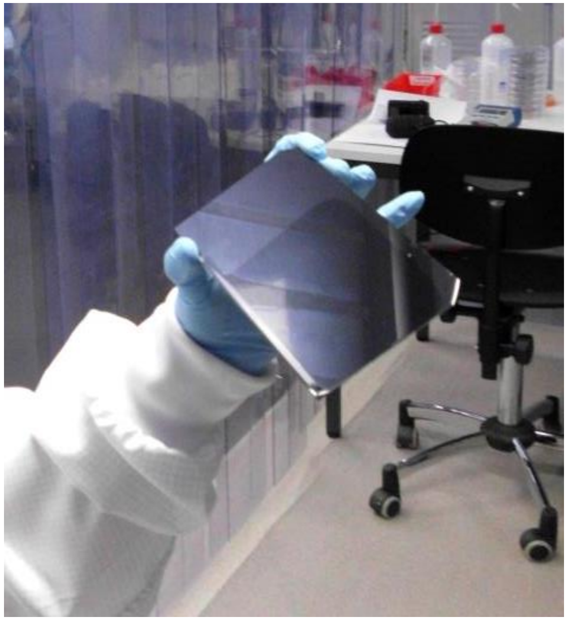
Lobster-Eye design: Flat silicon wafer substrates





This design is followed up by our partners of CVUT Prague. In a bionic approach the mirror arrangement adopts the focusing principle of a lobster eye.

Requirements for X-ray mirror coatings

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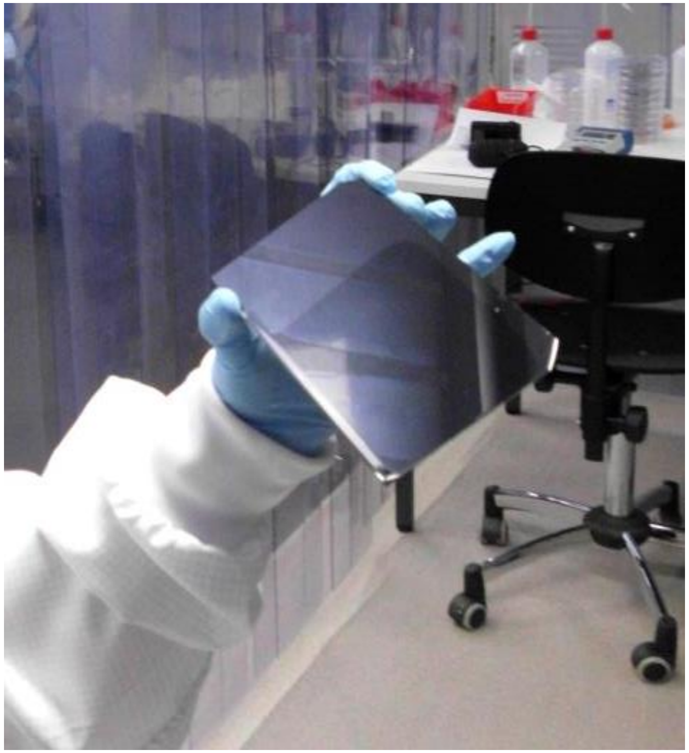
General requirements for grazing incidence X-ray mirrors coatings are:

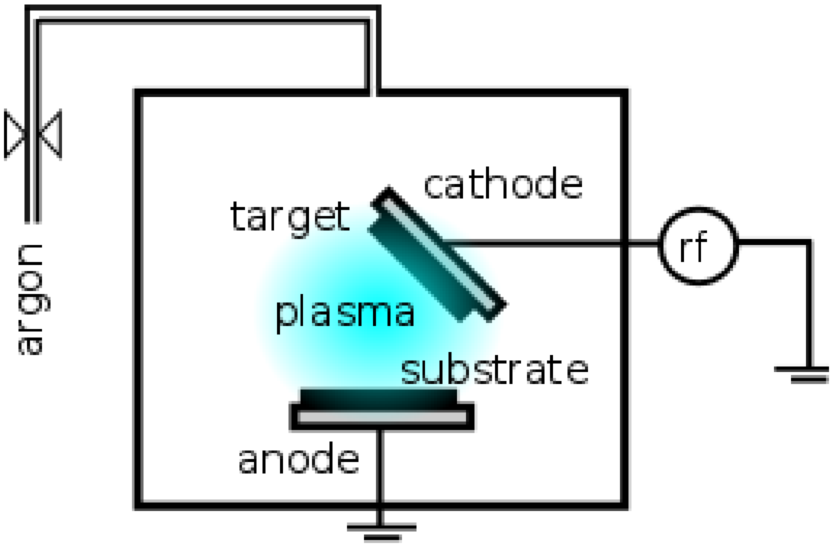
- high X-ray reflectivity
  → high-Z coating materials (→ Ir)
  → low roughness and high density
- no mirror shape deformation introduced by the coating
  → low coating stress
- no degradation of the mirrors during storage and in space
- coating process suitable for serial production



Iridium coated X-ray mirror

Experimental set-up

Sputtering chamber



Schematic set-up

Aschaffenburg University is using sputtering equipment for the coating development of iridium reflection layers for X-ray mirrors. The Institut Fresnel has similar - more industrial - equipment.

The challenge of coating stress

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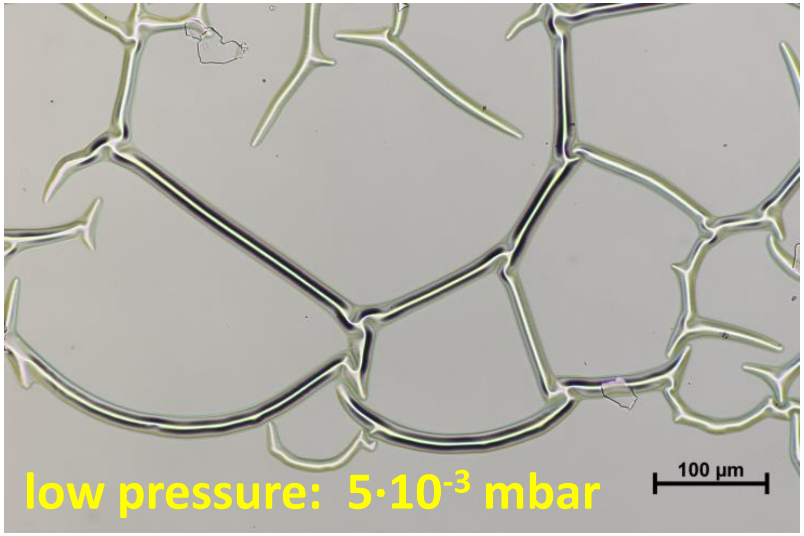
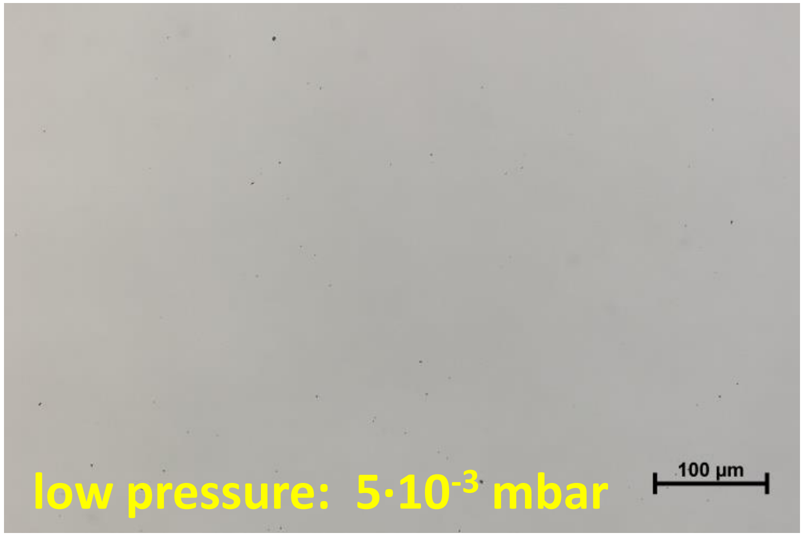


Micrograph with stress induced cracks in Ir - monolayer



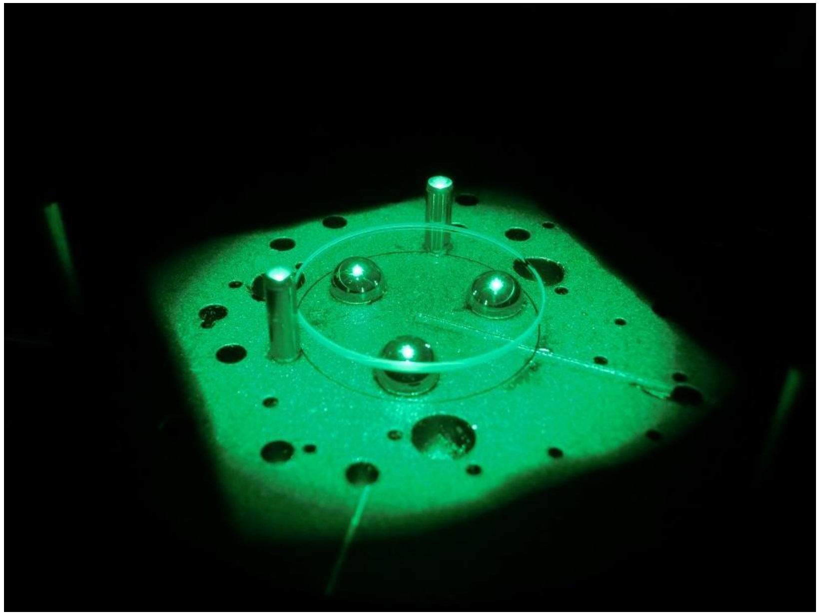
Micrograph of a Cr/Ir – bilayer without cracks

Iridium layers often suffer from high coating stress. **In extreme cases, high stress levels can induce cracking or even delamination of the Ir coatings.** **The application of a thin Cr adhesion layer can overcome this problem.**

Substrate material for stress evaluation

In the presented approach the substrate material (only) for the stress evaluation is the well-known material fused silica:

Diameter of substrate: D_s= **25 mm**
Thickness of substrate: t_s= **1.00 ±0.05 mm**
Young modulus: E_s= **73 GPa**
Poisson coefficient: ν_s= **0.16**
Flatness: **≈ λ/4 @ 532 nm**



Stress measurement

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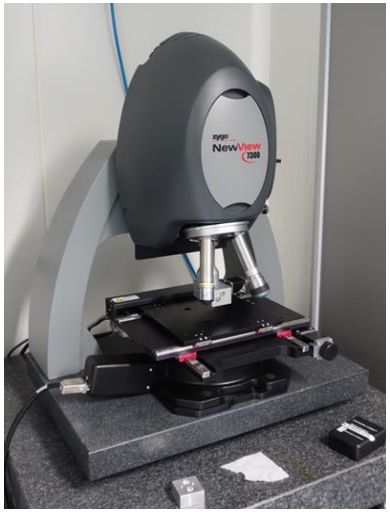
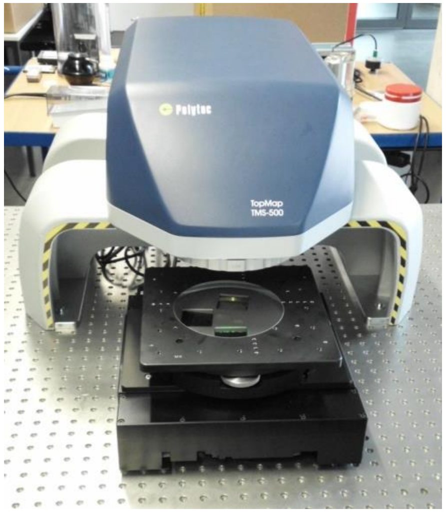
The change in the substrate radius of curvature was measured with two white-light interferometers. Thereby the cross-calibrated results of Aschaffenburg University and of Institut Fresnel are consistent.





Mechanical coating stress is calculated from substrate radius of curvature change before (R_s) and after (R_{s+f}) deposition using the Stoney equation, given here for a single layer coating with thickness t_f

$$\sigma = \frac{E_S {t_S}^2}{6t_f(1-\upsilon_S)}\left(\frac{1}{R_{S+f}} - \frac{1}{R_S}\right)$$

Iridium coating stress

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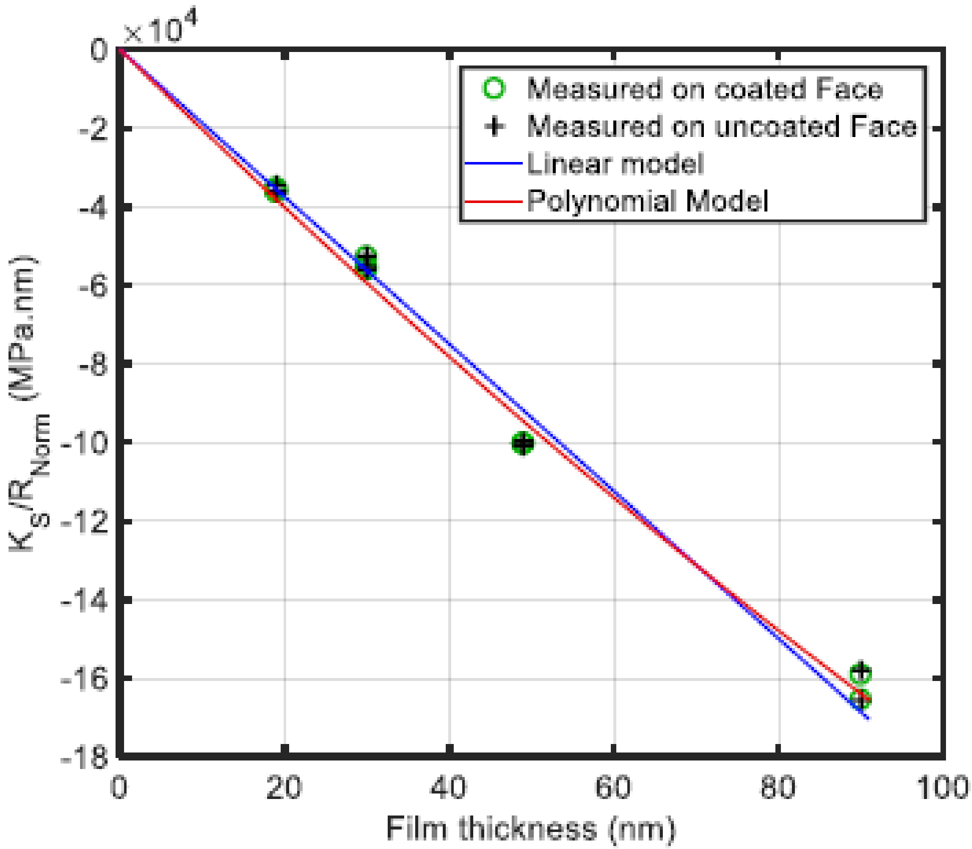
From modified Stoney equation:

$$\frac{K_S}{R_{Norm}} = \sigma t_f$$

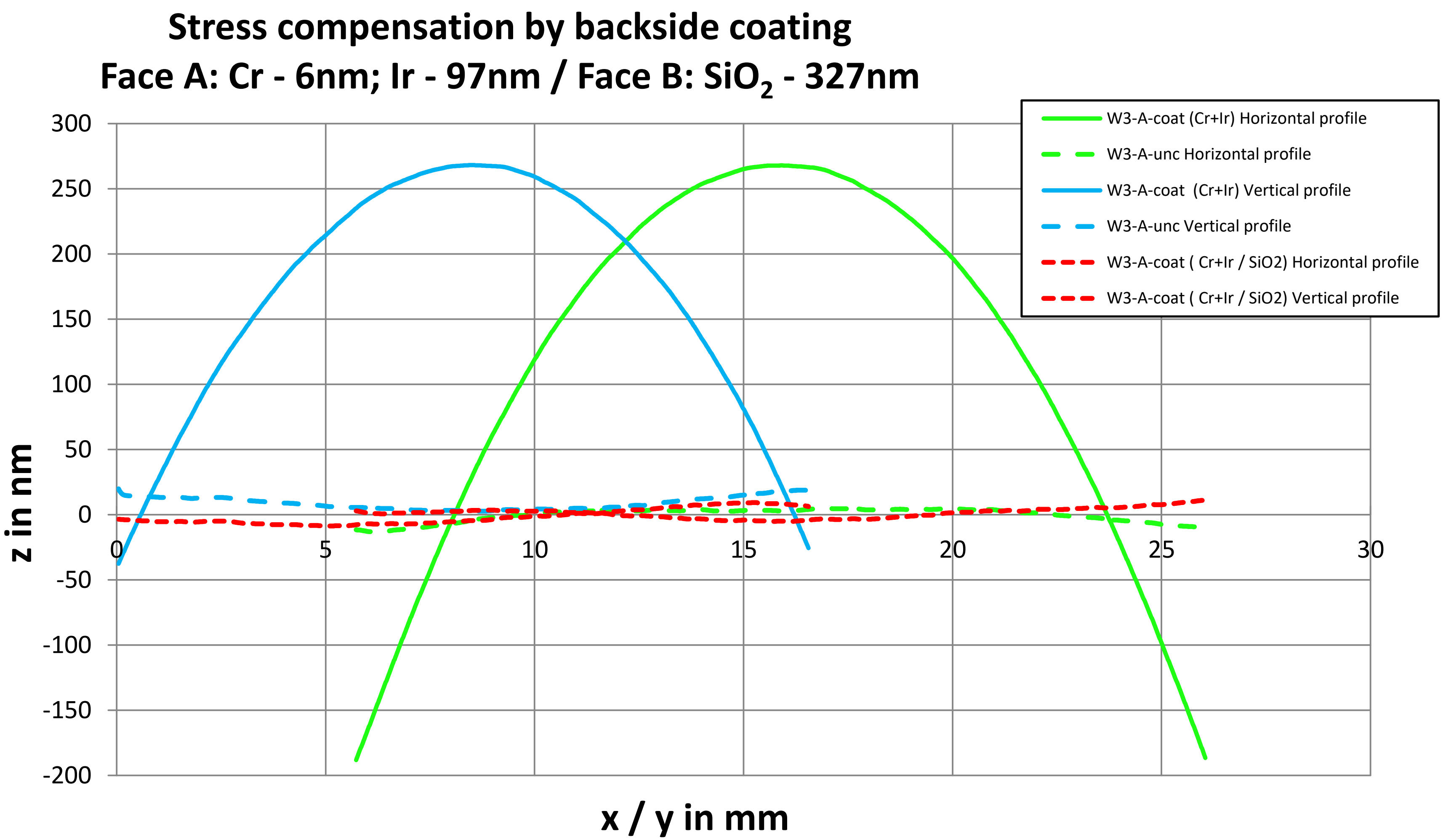
$$K_S = \frac{E_S}{6(1-\upsilon_S)}$$

$$R_{Norm} = \frac{R_S R_{S+f}}{t_S{}^2(R_S - R_{S+f})}$$



A linear relation is expected between the K_s/R_{norm} ratio and the film thickness t_f
Measured iridium coating stress (slope): about -1870 MPa

Stress compensation by backside coating



Stress compensation by backside coating

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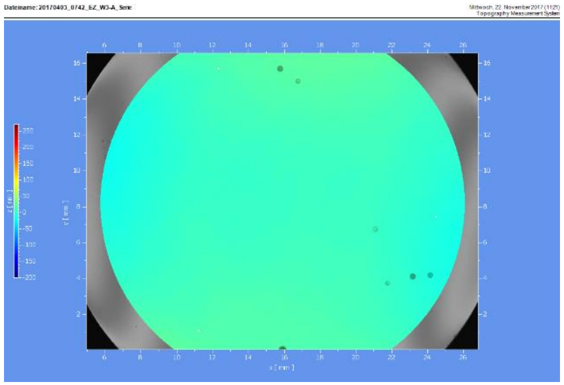
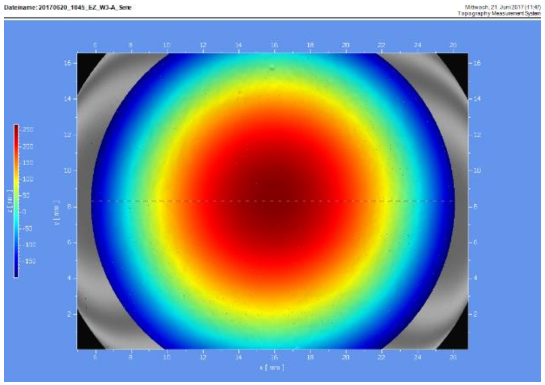
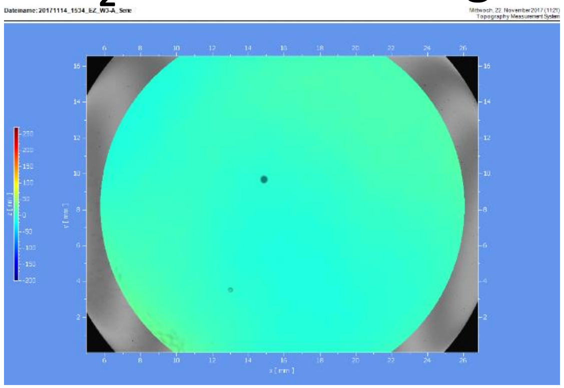
Uncoated substrate



Coated with Cr+Ir



Stress compensation with SiO_2 backside coating



A coating of the substrates backside with a thickness adapted SiO_2 layer is able to compensate the coating stress of the reflecting iridium layer.

Variation of chromium thickness

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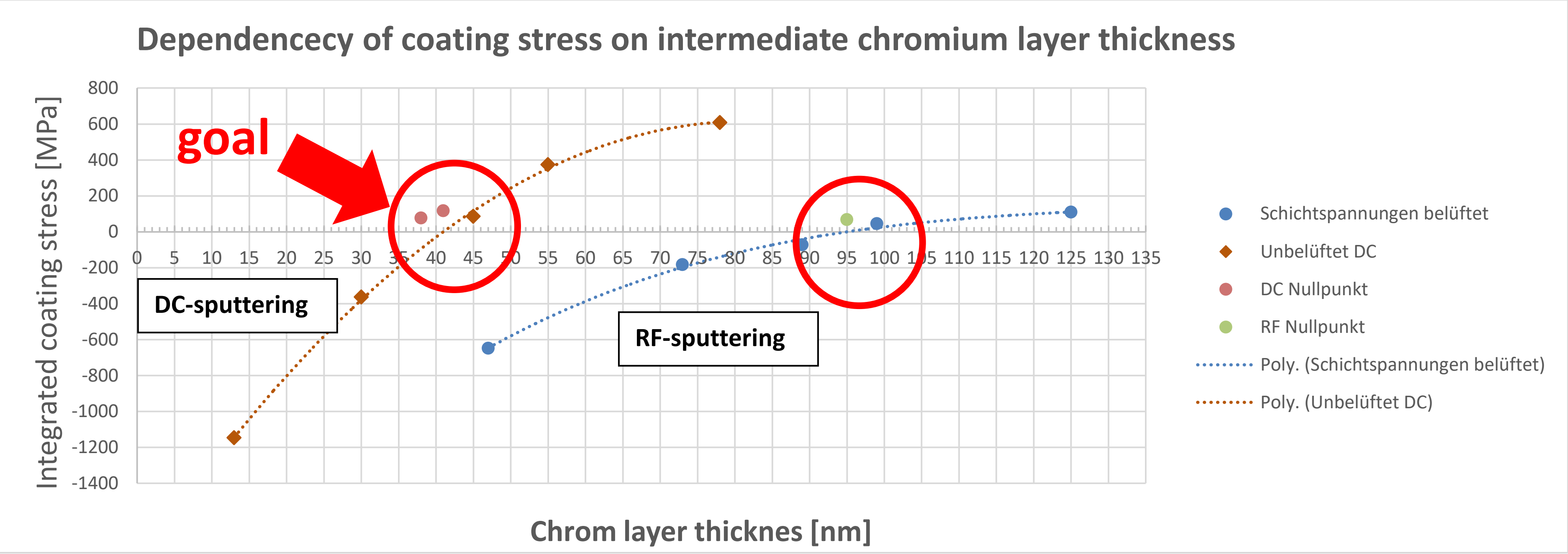

An intermediate chromium layer with adapted thickness is able to compensate the coating stress of a 30 nm thick reflecting iridium layer.

Summary and Outlook

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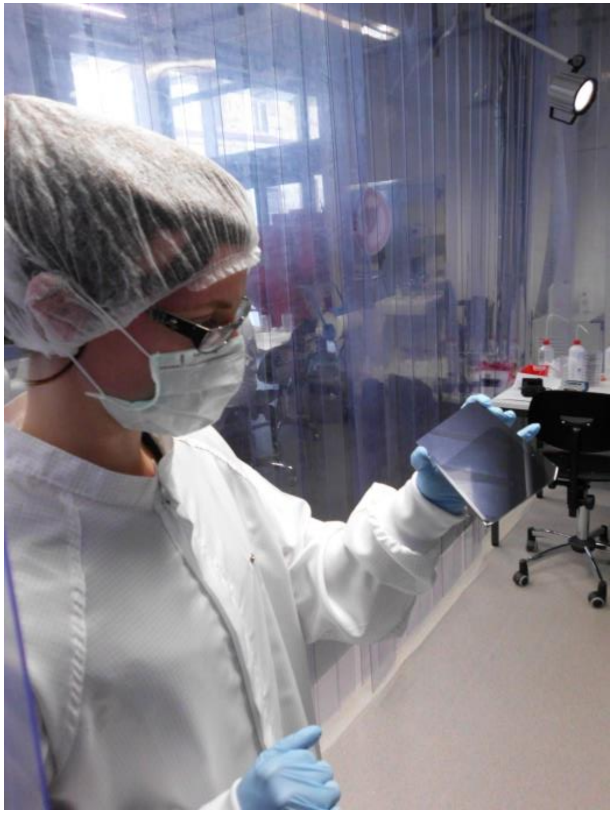
- Programmatic context of TRILAMICO-F.
- Requirements for X-ray mirror coatings.
- Challenge of low stress iridium layers.
- Intermediate chromium adhesion layer are needed for proper iridium coatings.
- Backside coatings of SiO_2 are able to compensate the iridium coating stress.
- An adapted chromium layer thickness is able to compensate the high iridium coating stress.



Acknowledgement: The TRILAMICO -F project is funded by BFHZ. Additional financial support came from the Bavarian State Ministry for Education and Culture, Sciences and Art, BAYHOST, and BFHA.

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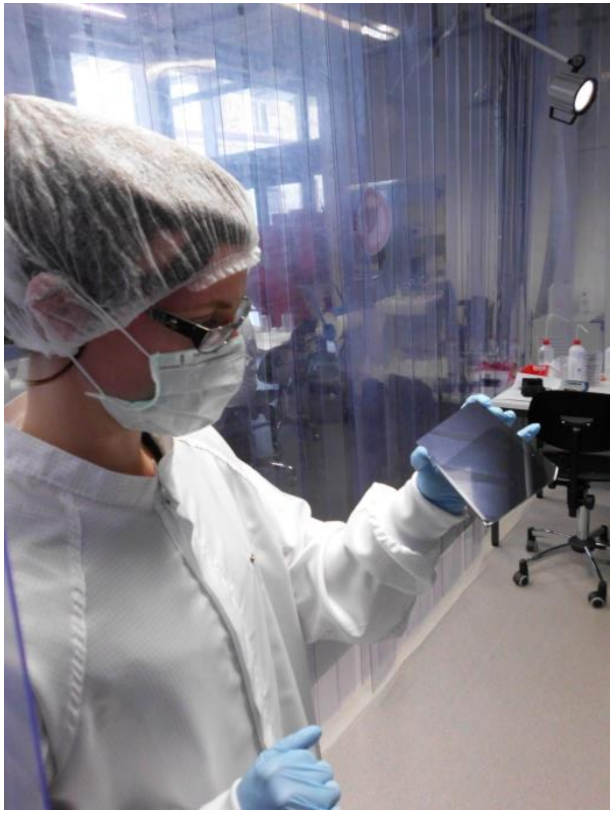

Thank you for your attention.

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