# Low-density coatings for enhanced X-ray reflectivity of astronomical telescope mirrors


Thorsten Döhring[1]*, Johannes Stadtmüller[1], Manfred Stollenwerk[1], Vincenzo Cotroneo[2], Giovanni Pareschi[2], Eugenio Gibertini[3], Luca Magagnin[3]

[1] Technische Hochschule Aschaffenburg, Aschaffenburg (Germany)
[2] INAF – Osservatorio Astronomico di Brera, Merate (Italy)
[3] Politecnico di Milano, Milano (Italy)

mailto:thorsten.doehring@th-ab.de



High reflectivity grazing incidence mirrors of astronomical X-ray telescopes are usually coated with thin layers of iridium, gold, or platinum. Due to a series of absorption edges, these noble metals have low reflectivity in the 2 - 4 keV band. We present the development of innovative material combinations using chromium and an additional layer of polydopamine for enhanced reflectivity X-ray coatings.


## 1 Introduction

X-ray telescopes usually operate in space and they are quite different from astronomical telescopes for visible light. For normal angles of incidence, optical light is reflected on the mirror surface, whereas X-rays are either transmitted or absorbed. However, also high reflectivity X-ray mirrors are possible here, when the incident rays direction is almost parallel to the mirror surface. Such grazing incidence mirrors are usually coated with thin layers of high-Z materials like iridium, gold, or platinum, as this result in high X-ray reflectivity. These noble metals offer a wide range of reflection up to high photon energies, but, due to a series of absorption edges, have low reflectivity in the 2 - 4 keV band and below. It has already been proposed to use carbon (also in diamond-like form) or $B_4C$ overcoatings on top of the metal layers in order to increase the reflectivity around the absorption edges of the metal layer below [1] [2]. This contribution presents the development of innovative material combinations based on thin layers of iridium and chromium, followed by an additional layer of a carbon-based material, especially polydopamine [3] [4] [5]. We also discuss a dip coating process as production method for enhanced reflectivity mirror coatings of future X-ray telescopes like ATHENA (figure 1).

***Fig. 1*** *Illustration of the ATHENA X-ray observatory.* (Source: www.the-athena-x-ray-observatory.eu)

## 2 Innovative coating approach

Although the current baseline coating for the ATHENA mission is iridium, it has been shown recently that a thin layer of chromium on top can enhance the reflectivity over the band of 2 - 4 keV [5] [6]. Such Cr-Ir-Cr trilayer coatings are our baseline for the application of an additional poly-dopamine overcoating. This organic layer shows good reflectivity in the low energy range, but gets transparent for higher photon energies were the metallic coatings are reflecting instead. Thereby the disturbing absorption edges are covered (figure 2).

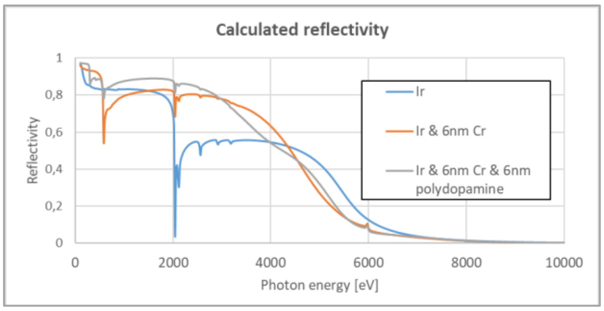


***Fig. 2*** *Calculated X-ray reflectivity for Ir, Ir&Cr, and Ir&Cr&polydopamine* (Source: https://henke.lbl.gov)

The developed novel type of overcoatings is based on the concept of "dip" deposition, i.e. it can be realized by immersing a substrate (or, when possible, also the finite optics) in a precursor solution, and letting the coating material deposit on the surface [7]. Thereby the challenge is to keep the surface micro-roughness of this overcoating low. Film thickness can be controlled by means of two different mechanisms, according to the film material: self-assembling mono-layers, which grow ordered structures with definite thickness or, in alternative, indefinite-growth coatings, for which the sedimentation of structures happens continuously and the final structure of the film is regulated by the characteristics of the precursor solution, by the


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deposition conditions and time. The "dip" coatings considered here belong to the second category.

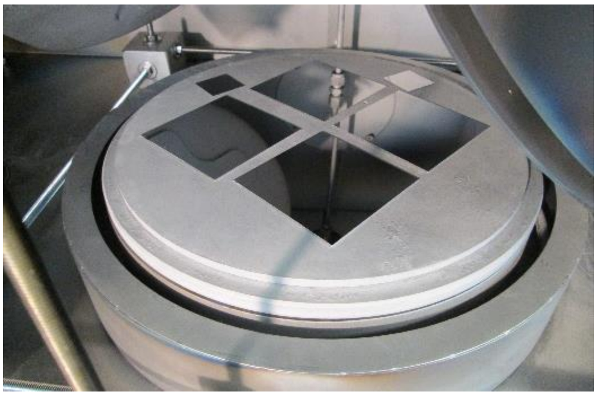

***Fig. 3*** *SPO wafer plates after coating with Cr-Ir-Cr layers in the vacuum chamber at Aschaffenburg University.*

The coatings selected for the liquid-phase deposition on top of the Cr-Ir-Cr coatings (figure 3) were polydopamine. This material have a known compatibility with the underlying material, showing features of good adhesion and smooth surface. They are commonly used in a broad range of research and industrial applications; biotechnologies, electronics, MEMS, among others [7].

We have deposited polydopamine overcoatings on Cr-Ir-Cr coated substrates using different immersion times. Polydopamine coatings are obtained by dopamine ($C_8H_{11}NO_2$) auto-polymerization or oxidative polymerization in alkaline solution. Here, polydopamine coatings were obtained according to a procedure adapted from literature. A 20 mM dopamine hydrochloride solution and 20 mM ammonium persulfate in 10 mM TRIS-buffer (pH 8.5) was prepared and samples were immersed in solution at ambient temperature. Density is usually around 1 g/cm$^3$. Times between 4 hours and 2.5 days were used to develop the deposition process. Film growth was apparent from the change of discoloration towards a brownish color.

## 3 Results and conclusion

We have deposited iridium-chromium trilayer coatings on substrates representative for X-ray mirrors, like the wafer plates that will be used for the ATHENA silicon pore optics (SPO), measuring surface topography for each layer and extracting PSD information over a broad range of spatial frequencies. While roughness slightly increases (as expected) along the layers stack, it is shown that all layers maintains an acceptable roughness, with chromium layer having a rms below 4 Å, over $10^{-2}$ to $10^{2}$ µm$^{-1}$ frequency range, and 6.4 Å over a broader frequency range (down to $2 \cdot 10^{-3}$ µm$^{-1}$) with a rather flat PSD in the central part of the spectral range under investigation. The roughness values are in good agreement with the rms roughness of 3 - 5 Å estimated from an X-ray reflectivity fit.

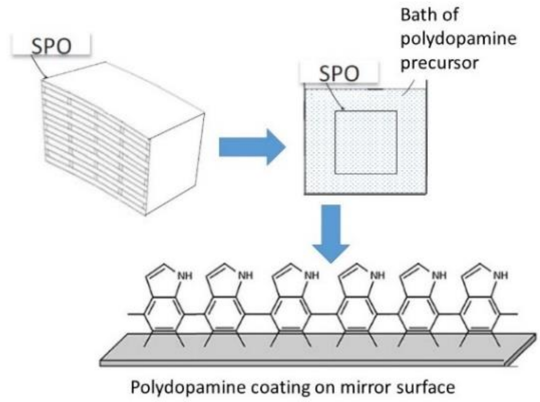


***Fig. 4*** *Proposed process of the polydopamine deposition on an ATHENA SPO X-ray mirror module.*

The coating shows uniform structure on the largest scales (AFM over 100 µm scale and 10x optical profilometer). The thickness was evaluated by measuring steps on masked areas by means of optical profilometry and AFM, confirming that film thickness can be controlled in the valid range (5 - 10nm) by varying the deposition time. The collected PSD data will be used to model the scattering properties and infer the X-ray properties. We plan to characterize the coated samples in X-rays after a more detailed characterization of the film properties.

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