Thin silicon carbide coating of a primary telescope mirror for an EUV imaging instrument of Solar Orbiter

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Abstract

We investigate the thermo-optical and vacuum-ultraviolet properties of thin silicon carbide (SiC) coatings on transparent substrates in view of their use for Solar Orbiter remote sensing UV instrumentation. We have made experimental studies with thin SiC coatings on quartz plates to evaluate their reflective properties in the EUV spectral range between 58 nm and 123 nm. We discuss the results in relation to the visible and near infrared optical properties of the samples. A thin SiC coating of 10 nm thickness is shown to be a very promising compromise between high VUV reflectivity and low vis/IR absorption. The absorption of the solar spectrum by such a mirror is less than 7 %. This will be beneficial for instruments requiring a large aperture due to diffraction and radiometric limitation, to cope with the thermal heat load during the Solar Orbiter mission.

Introduction:

Mirrors of silicon carbide (SiC) have been shown to be the material of choice for telescopes and spectrometers in space for their high reflectance at normal incidence in the wide spectral range between 50 nm and 160 nm.
High-resolution spectroscopy and imaging at vacuum-ultraviolet wavelengths requires apertures of several centimeters diameter to achieve the desired image quality and signal levels. The thermal environment of Solar Orbiter, however, sets very tight limits on the instrument's aperture size. To reduce the thermal heat load on the primary mirror, a dichroic design that does not absorb the solar visible and near infrared but preferentially reflects the VUV radiation can greatly relax such technical difficulties[1].
For this reason, we have produced samples of mirrors to study the thermo-optical and VUV reflective properties as a function of the thickness of the SiC coating. The results have been used to make a model calculation of the heat load due to the solar spectral irradiation in space.

Test setup:

Silicon carbide coatings of thicknesses of 4.6, 8.9, and 17.6 nm have been applied to three quartz samples at the Fraunhofer Institut für Angewandte Optik und Feinmechanik (IFO), and their transmission and reflectance curves between 200 nm and 1000 nm have been measured. From these photometric measurements the resulting absorption has been calculated over the entire spectral range. The reflectivity in the EUV/VUV has been measured and compared to a reference sample of bulk SiC-CVD coated SiC mirror at the wavelengths 58.4 nm, 73.5 nm, 104.4 nm, and 123.6 nm using the SUMER reflectometer chamber at MPS.
As a raddiation source the reflectometer has one open capilary discharge source, operated with the rare gases helium, neon, argon, and krypton. The output of the EUV source was better than 95% monochromatic after passing through a monochromator. The signal was detected with a photodiode (AXUV diode from IRD inc., USA) mounted on a rotatable arm, concentric with the rotation axis of the sample holder.

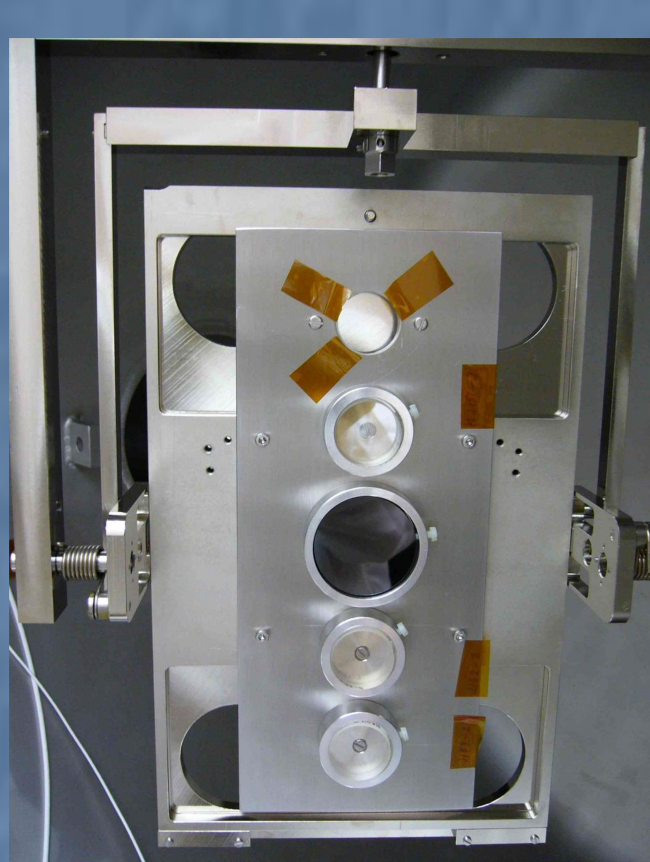

Figure 1 shows on the left the three quartz samples coated with thin SiC (transparent) and the solid SiC/CVD reference sample (black) in the middle of the sample holder. The figure on the right shows the sample holder manipulator inside the reflectometer. It allows sample movements with five degrees of freedom. A detector can be rotated independently around the centre of the chamber.

EUV reflectance results:

At the four EUV wavelengths the reflectance of the samples was measured at 6° angle of incidence and compared with the SiC/CVD reference sample and with an uncoated quartz sample. The SiC coating of 8.9 nm already shows very good reflectivity, while the sample with 17.6 nm thickness already reaches very close to the reflectance of the SiC/CVD reference. The results are shown in the table below:

sample\λ	58.4 nm	73.5 nm	104.4 nm	123.6 nm
blank quartz	4.3	5.4	3.3	4.7
SiC/CVD reference	22	31	37	39
#1 (17.6 nm)	18	29	35	38
#2 (8.9 nm)	18	26	32	34
#3 (4.6 nm)	15	21	25	26

Thermo-optical Properties of thin-coated SiC mirrors:

The photometric data between 200 nm and 1000 nm of the silicon carbide coated mirrors of thicknesses of 4.6, 9.1, and 17.7 nm have been used to calculate the thermo-optical properties under solar irradiation. A solar spectrum of the "Solar 2000 Model"[2] was used to calculate the transmission, reflectance, and absorption of the samples. Results are shown in Figure 2:

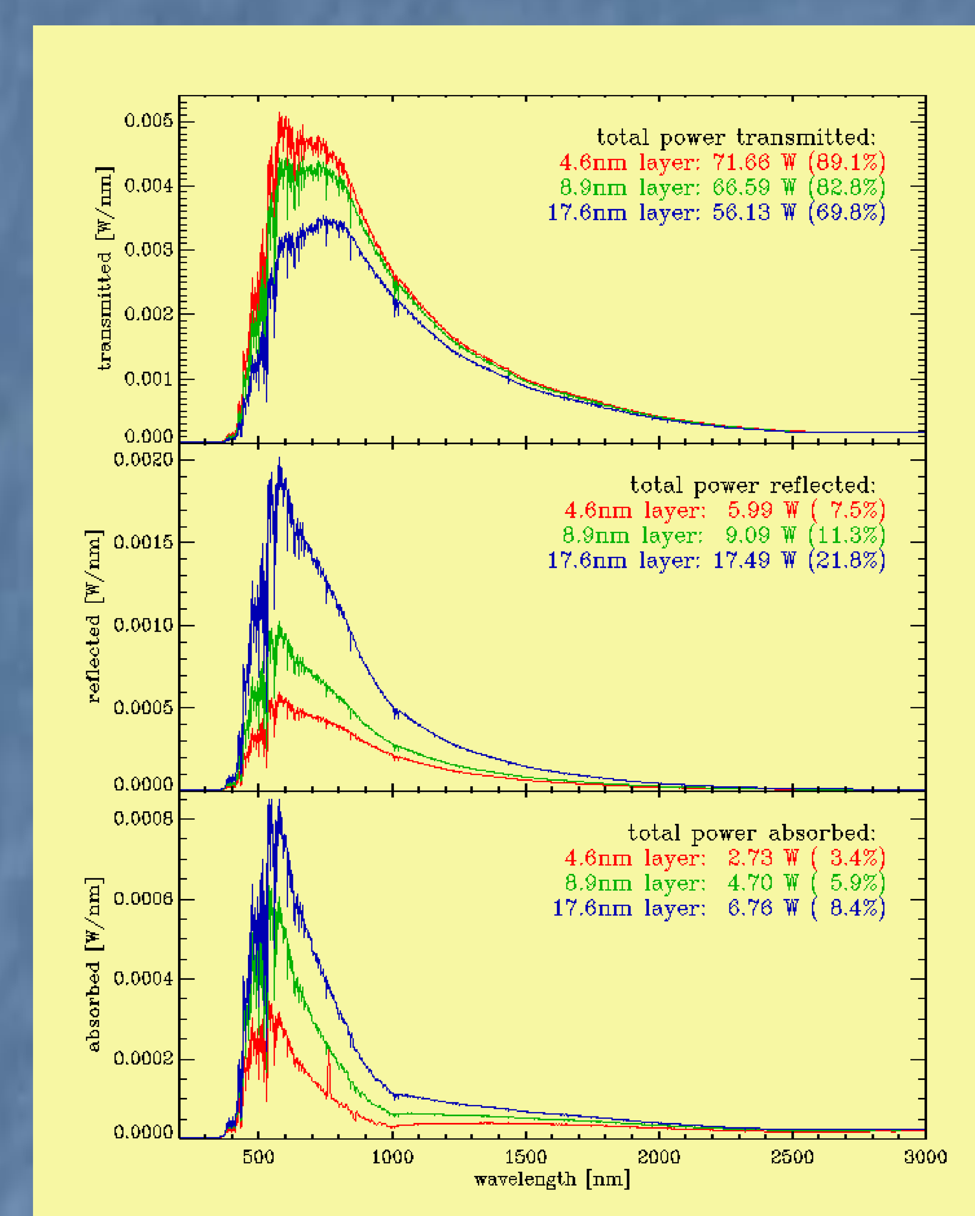

Figure 2: The transmission, reflectance, and absorption of the solar spectral irradiance of the three SiC mirror samples. The spectral curves were genrated from the measured photometric properties using a solar irradiance from the „Solar 2000 Model" spectrum of January 2000.

The important result is the total absorption of the solar power by the SiC coating. Using the coating with a thickness of 8.9 nm, the power absorbed is less than 6 %. A conservative estimation, taking into account the residual absorption of quartz in the near infrared (above 1000 nm), may increase this value to not more than 8 %.

Proposed mirror design for the Solar Orbiter EUS spectrograph:

The results of this assessment are very promising in fulfilling the thermal requirements set by the Solar Orbiter mission. A spectrograph without entrance filter can greatly benefit from this design using a primary mirror with low absorption of the solar spectrum. For the normal-incidence design of the EUS instrument such an in-band reflecting mirror will provide the needed EUV reflectance while absorbing only less than 7 % of the solar power.

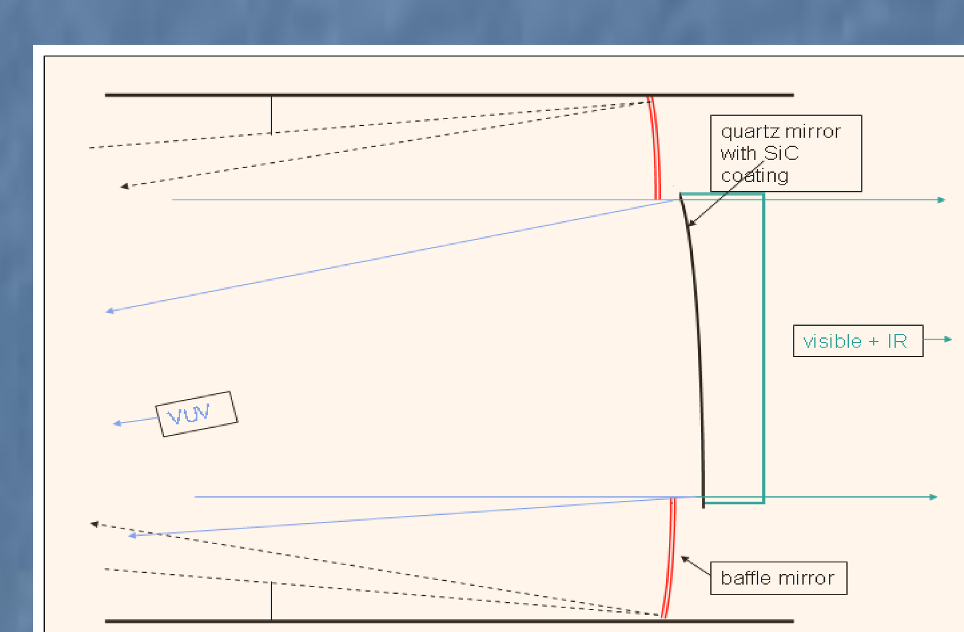

Figure 3: Proposed heat rejection scheme of the primary mirror of a EUV spectrograph using the thin SiC coating on a quartz mirror substrate. Note that the rear surface of the mirror can be figured independently with optical power if needed.

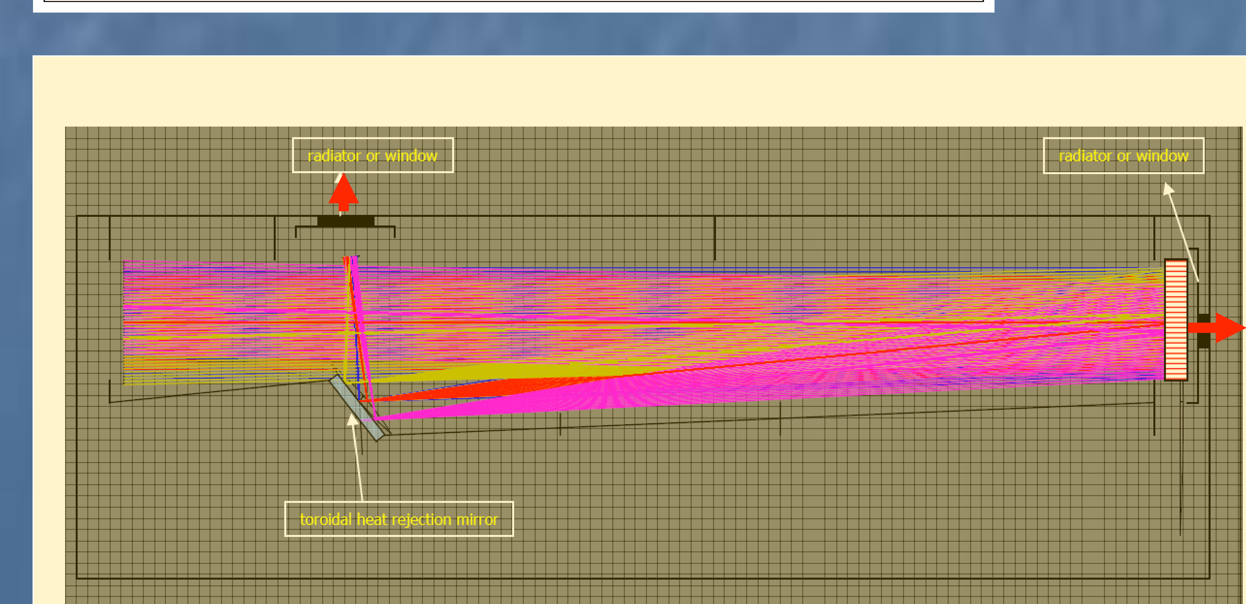

Figure 4: Proposed heat rejection scheme for the telescope section of the EUS instrument

[1] The original idea has been brought to our attention by David Windt of RXO ltd.
[2] W. K. Tobiska, T. Woods, F. Eparvier, R. Viereck, L. Floyd, D. Bouwer, G. Rottman, O. R. White, Journal of Atmospheric and Solar-Terrestrial Physics 62, 1233-12

U. Schühle, Solar Orbiter Workshop II, Athens 16. – 20. October 2006, Poster P.010