Optical Characterization of Absorbing Coatings for Sub-millimeter Radiation

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For the development of quasi-optical instruments in the THz region absorbing surfaces are necessary to suppress stray light and standing waves. Here we will present experimental results on the specular and diffuse reflectance (BRDF) of a variety of sub-millimeter absorbing surfaces, obtained using an OPFIR laser at wavelengths of 118.8µm, 184.3µm, 496µm and 889µm. Although the emphasis of this study is on the development and characterization of absorbing coatings, intended for the HIFI and PACS spectrometers aboard the Herschel (FIRST) satellite, also some convenient materials for laboratory use are discussed.

Introduction.

Absorbing coatings for THz radiation ($100 < \lambda < 900$ µm) have been characterized using light from an OPFIR laser at wavelengths of 96.5, 118.8, 184.3, 496 and 889 µm.. The optical characterization of a surface starts with the study of the specular reflection (SR) as a function of the angle of incidence θ_i of the radiation. For good coatings also the BRDF is studied. This "Bi-directional Reflectance Distribution Function" describes the scattering properties of surfaces, and is defined as the reflectance per unit projected detector solid angle as a function of the azimuthal coordinates θ and ϕ. It is expressed in inverse steradians (sr^{-1}), usually measured in the plane of incidence (ϕ=180°) versus the non-specular angle Δθ:

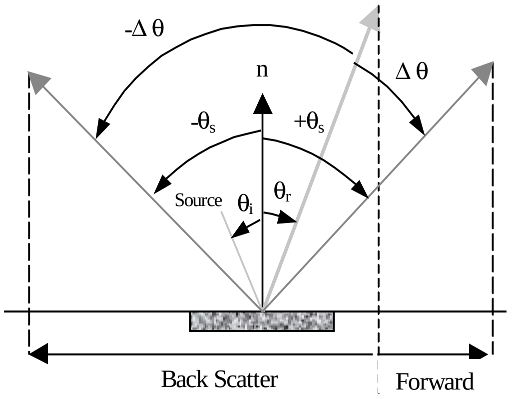


Fig.1 Definition of angles in the optical plane (in general perpendicular to the sample surface)

θ_i = Angle of incidence
θ_r (= θ_i) = Specular direction
$\Delta\theta = \theta s - \theta_i$ = Non-specular angle

p-pol: polarization in the plane
s-pol: perpendicular to plane

$$\mathbf{BRDF\ (\Delta\theta,\lambda,\theta_i) = P_s\ (\Delta\theta,\lambda,\theta_i)\ /P_0\ (\lambda,\theta_i)\ \Omega\cos\theta_s}$$

P_s is the power, diffusely scattered by the surface, in the direction θ_s, and P_0 the source power. The factor $\Omega\cos\theta_s$ ($\Omega \approx 10^{-2}$ sr) is the projected detector solid angle. For a Lambertian surface, i.e. a non-absorbing perfect diffuse scatterer, the BRDF is independent of direction and equals π^{-1}. The influence of variations in shape and intensity of the laser beam has been eliminated by comparing all samples with (near Lambertian) reference samples that have been characterized accurately. We present a selection of results on categories of coating samples: commercial available materials and “home made” absorbing surfaces.

Results

Commercial available materials.

Marconi LAO 5, carbon loaded soft open foam *microwave* absorber appears to be useful for the THz range too. It exhibits a low specular reflection for small θ_i (fig.2). In fig. 3 evidence of specular reflection for $\theta_i \geq 50^0$ is observed, i.e. a peak develops for $\Delta\theta = 0$. The BRDF value of 0.02-0.04 results in a Total Hemispherical Reflection (THR) of 6-12% (-12- -9 dB).

(Tessalating Terahertz) RAM from Thomas Keating Ltd., injection molded 25mm squares with sharp needles at the surface, formed in conducting plastic. The regular 1x1 mm^2 needle structure acts as a reflection grating, leading to peaks in the angular dependence of the reflection. (Not shown here, and only observed with the optical plane parallel to the needle rows.) For other directions a low reflection is observed, resulting in a THR of about –20dB.

SiC 60ppi open foam from ERG Materials and Aerospace Corp. A very hard material, that can be coated with Stycast 2850 FT to further decrease the reflectivity. Because of the good thermal conductivity, it might be useful for black body sources at cryogenic temperatures.

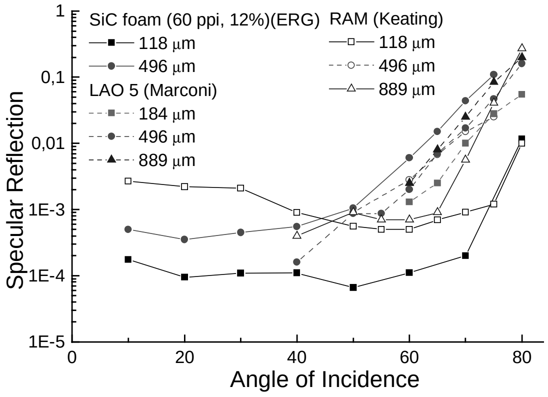


Fig.2 Specular reflection of commercial materials.

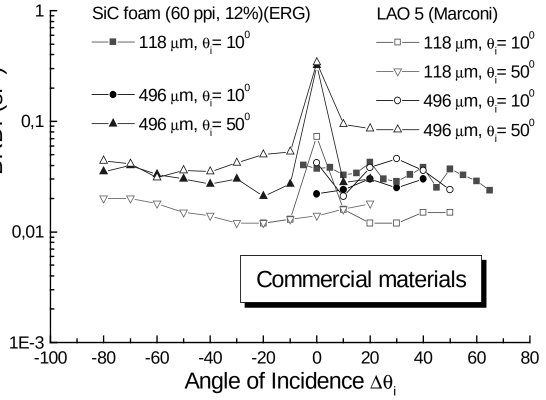
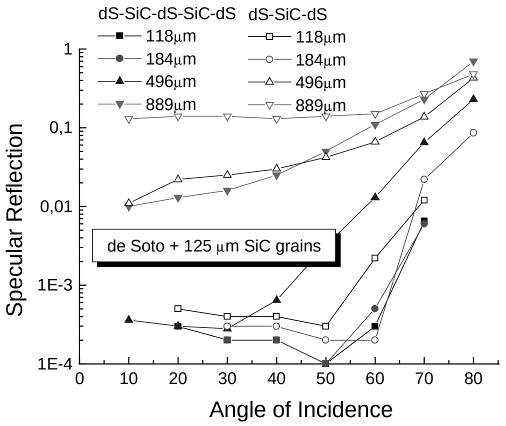


Fig. 3 BRDF of commercial materials

MPI coatings for PACS.

Coatings, meant for the PACS instrument aboard the Herschel (FIRST) satellite, are fabricated on Aluminium substrates, coated with a layer of Nextel Primer, and then coated with one or more layers of DeSoto Gunship Black (or Nextel Suede Coating) and 100 μm size SiC grains. Results for coatings with 5 and 3 layers (0.9mm and 0.5mm thick respectively), given in fig.’s 4 and 5, show that these absorbers perform well in the 100-200 μm range needed for PACS. The BRDF≈0.02 sr^{-1} corresponds to a THR of about 6% (–12dB). Nextel Suede coatings, data not shown here, perform slightly better [1].



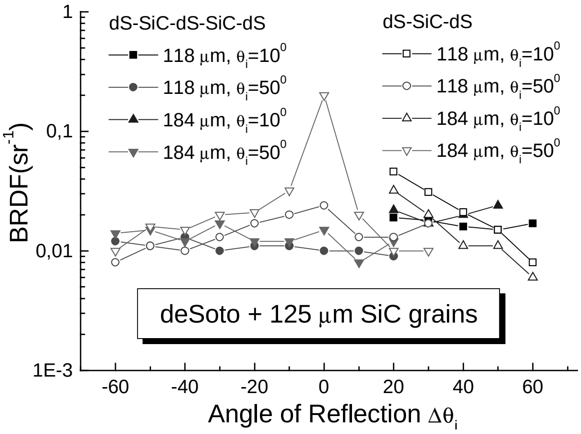
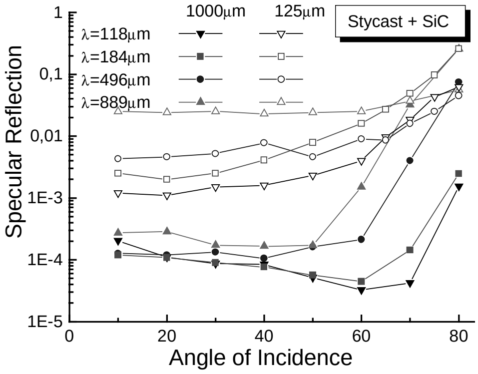


Fig.4 Specular reflection of two PACS coatings **Fig.5** BRDF of two PACS coatings

3. Delft/SRON coatings for HIFI.

For this second Herschel spectrometer, the coatings need to absorb wavelengths up to 650 μm. On an Aluminium substrate a thin layer of Stycast 2850 FT and subsequently a mixture of Stycast 2850 FT and SiC grains (sizes range from 125 to 1000μm) is applied**.** In fig.'s 6 and 7 it is seen that a large surface roughness (large SiC grains) is needed for a low specular reflection at long wavelengths. The best coating (BRDF≈0.02) **-** 1000μm SiC grains and a 1:4 Stycast/SiC weight ratio - passed successfully a number of qualification tests: thermal shock and cycling and vibration at T=70K. Concern about the possibility of grains getting loose from this very rough surface, triggered the fabrication of coatings with a better embedding of the SiC grains. Some results on these new coatings are shown in fig.'s 8 and 9. Again, larger grain size coatings perform better; a Stycast layer on top of the surface for better fixation of grains leads to an increase in specular reflection (fig.8). A few experiments have shown that these coatings also perform well at cryogenic temperatures, be it that at the longer wavelengths side, performance is reduced. This effect is directly related to the decrease of the absorption coefficient towards longer wavelength. Although this effect does not result in a clear wavelength dependence of the reflection properties at room temperature, the further decrease of absorption coefficient towards low temperature apparently leads to a reduction of absorption for $\lambda \geq 500$ μm. To solve this problem, a



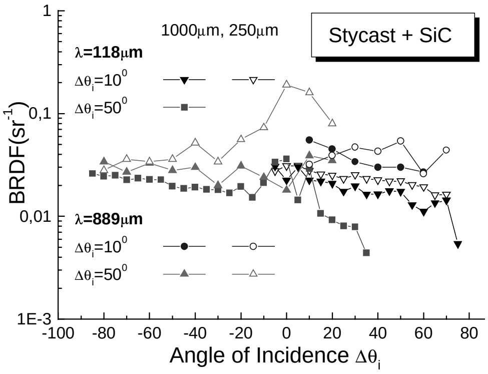


Fig. 6 Specular reflection of HIFI coatings **Fig.7** Diffuse scattering of HIFI coatings

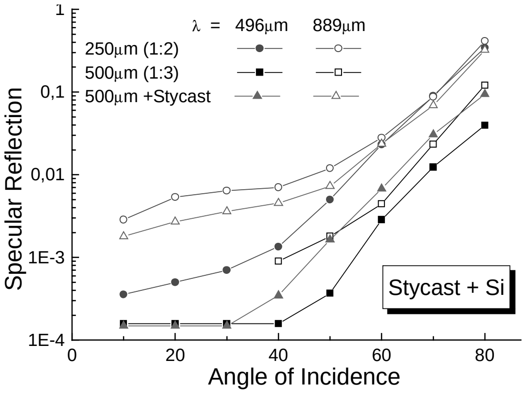


Fig.8 Specular reflection of first series of improved HIFI coatings

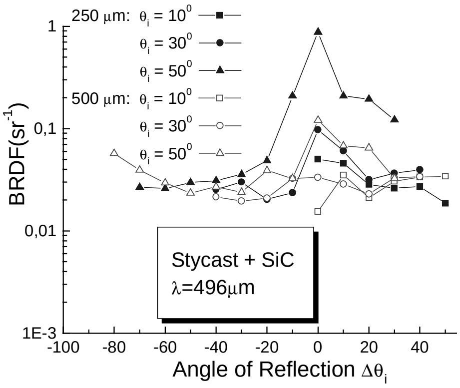


Fig.9 BRDF of first series of improved HIFI coatings.

second series of improved coatings was made with 500 μm SiC grains with a 1:3 Stycast/SiC ratio, with additional top layers of Stycast, to enhance the long wavelength absorption. In order to prevent the increase of specular reflection, resulting from the reduction of surface roughness due to the additional top layers (see fig 8), a different application technique was used. After the application of a thin layer of Stycast at 60^o C, before drying, the surface was blown was pressurized air to prevent the "valleys" at the surface to be filled with Stycast, and thereby reducing the roughness. The results shown in fig.'s 10 and 11, indicate that this process was successful; the sample with three additional layers does not show an increased specular reflection, and even seems to exhibit a slightly lower BRDF (≈ 0.02 – 0.03) than the standard sample.

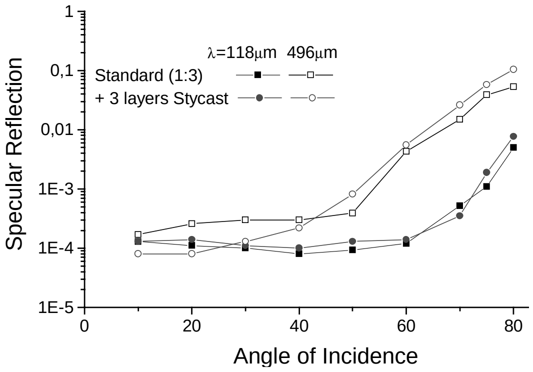


Fig. 10 Specular reflection of second series of improved HIFI coatings.

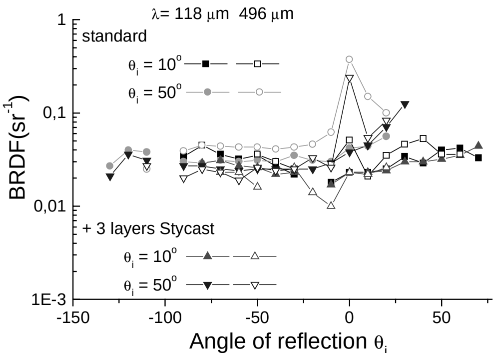


Fig. 11 BRDF of second series of improved HIFI coatings.

References.

[1] T.O. Klaassen, M.C. Diez, J.H. Blok, C. Smorenburg, K.J. Wildeman, G. Jakob, Proceedings of the 12th International Symposium on Space Terahertz Technology, Feb. 14-16, 2001, San Diego, USA.

Acknowledgements. Part of this work is supported by The Netherlands Agency for Aerospace Programs (NIVR) under contract NRT nr. 2901 TU.