

Antireflection treatment of Thickness Sensitive Spectrally Selective (TSSS) paints for thermal solar absorbers

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Abstract

There are several methods to produce solar absorbers, and one cheap alternative is painted absorbers, preferably painted with a spectrally selective paint. The optical properties of Thickness Sensitive Spectrally Selective (TSSS) paints are, however, limited by the thickness of the paint layer. In this study it is shown that the solar absorptance of two commercial TSSS paints can be increased between 0.01 and 0.02 units with an antireflection treatment using a silicon dioxide layer deposited from silica-gel. It was found that the thermal emittance (100 °C) did not change significantly after the treatment.

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1. Introduction

Painted solar absorbers have always been a cheap alternative to more sophisticated surface treatments such as (electro-) chemical conversion or different choices of chemical or physical vapour deposition. The paint is preferably applied by a spray coating technique, for example on to metallic substrates such as aluminium (Solec Solar Energy Corporation, 2006; Orel, 1999; Orel and Gunde, 2001). It can be deposited manually or in large coil-coating processes. The types of paint can be categorised as Non-Selective (NS), Thickness Insensitive Spectrally Selective (TISS) or Thickness Sensitive Spectrally Selective (TSSS). It is possible to obtain a high solar absorptance of about 0.95 for all three types of paint, but with significant differences in thermal emittance (at 100 °C): 0.95 for NS paints (Meinel and Meinel, 1976), 0.5 for TISS paints (Orel et al., 2007)

and 0.2 for TSSS paints (Orel and Gunde, 2001). For a TSSS paint the solar absorptance (and thermal emittance) increases with the paint layer thickness. To obtain a solar absorptance of about 0.95, a paint thickness of about 3–4 µm is required. A further increase in thickness will only yield an emittance increase. Exceeding a solar absorptance of 0.95 could be possible by lowering the paint surface reflectance by application of an antireflection (AR) coating with a refractive index of 1.3, which will match between the refractive index of the silicane binder in the paint (about 1.6 (Teschfamiel et al., 1999)) and that of air. The Fresnel formalism for incoherent surface reflectance (i.e. no thin film interference and neglected bulk scattering) according to

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 \quad (1)$$

can be used to estimate the front reflectance of the paint as well as of an antireflection coating on the paint at normal angle of incidence, where n_1 is the refractive index of the

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first medium and n_2 is the refractive index of the second medium. Multiple reflections are neglected and the materials are considered non-absorptive ($k = 0$). Using the refractive indices given above, we have estimated that the absorptance can be increased from about 0.95 for the plain paint surfaces to 0.97 by adding an AR layer. Bulk scattering in the paint can reduce the AR effect, since a larger penetration of light into the bulk due to a lower surface reflection increases the bulk back scattering if it has the same magnitude as the absorption. The aim of this study is to investigate if it is possible to obtain an effective AR treatment of real paints. We have in the present stage only made an empirical study, using two commercial TSSS paints and a commercially available silica-gel for AR treatment.

2. Experimental procedure

2.1. Sample preparation

The two commercial TSSS absorber paints are Solarect-Z and Solkote HI/SORB-II, developed in Slovenia and the US, respectively. TSSS paints consist of a resin binder, pigments, curing agents and adhesion promoters admixed in a solvent (Orel, 1999).

The paints were applied on aluminium substrates. The aluminium was first cleaned from grease by a surfactant and thereafter etched in phosphoric acid to clean the surface from aluminium oxide. The paints were diluted with solvents according to the instructions from the manufacturers and then applied to the substrates by use of a conventional manual paint spray gun. This technique makes it difficult to control and repeat exactly the same coating thickness. Samples were therefore selected for further studies according to their solar absorptance and thermal emittance (see further in Section 2.2). The samples were heat treated according to the manufacturers' instructions to cure the paint.

The painted samples were AR treated by a dip coating technique. The coating was performed at room temperature and the AR solution comprised silica sol (Bindzil 40/130), deionised water, ethanol (99.5%) and surfactant (detergent). According to the product data the AR films consist of silicon dioxide nanoparticles of an average diameter of 25 nm. The thickness of the AR layer was controlled by the rate of withdrawal from the bath: a higher rate gives a thicker film. A withdrawal rate of 5 mm/s was used. The results were found to be insensitive to the rate in an interval between 2.5 and 10 mm/s.

When applied on glazing, the sol-gel films are usually baked in high temperatures to cure the coating and improve the attachment of the film to the glazing as well as the long-term stability of the material. A solar absorber, on the other hand, is not directly exposed to physical wear due to the cover glass of the solar collector. Baking the AR coating can therefore be avoided without risking long-term stability and keeping the high absorptance. The samples in

this study were not routinely cured, but some samples were baked again after AR treatment to investigate the influence on the optical properties. The absorptance of the Solkote samples was unaffected by the additional baking, while Solarect showed degradation at 250 °C. This indicates deterioration of the paints when exposed to high temperatures for longer periods.

2.2. Optical measurements

Optical measurements were made on the samples after being painted and after AR treatment. In the wavelength interval 0.3–2.5 μm the normal reflectance was measured with a Perkin–Elmer Lambda 900 spectrophotometer, equipped with a standard Labsphere 150 mm Spectralon integrating sphere. In the infrared wavelength range, 2.5–20 μm , a Bruker Tensor 27 FTIR (Fourier Transform InfraRed) spectrophotometer was used, also equipped with an integrating sphere. The measurements were combined in one reflectance spectrum. The reflectance (ρ) at near normal angle of incidence is used for analysing absorptance (α) in the solar wavelength range and emittance (ε) in the infrared wavelength range using the relation for opaque samples:

$$\alpha(\lambda) = 1 - \rho(\lambda) \quad (2)$$

and Kirchhoff's law for the relation between emittance and absorptance:

$$\varepsilon(\lambda) = \alpha(\lambda). \quad (3)$$

A single value for the absorptance in the solar wavelength range and emittance in the infrared wavelength range is obtained when calculating the normal absorptance, α_{sol} , and normal emittance at 100 °C, $\varepsilon_{\text{therm}}$, as average values weighted with the solar spectrum (I_s) and blackbody spectrum (I_b), respectively (Wäckelgård et al., 2001):

$$\alpha_{\text{sol}} = \frac{\int_{0.3 \mu\text{m}}^{4 \mu\text{m}} (1 - \rho(\lambda)) I_s(\lambda) d\lambda}{\int_{0.3 \mu\text{m}}^{4 \mu\text{m}} I_s(\lambda) d\lambda}, \quad (4)$$

where $\alpha(\lambda)$ is the absorptance, $I_s(\lambda)$ is the solar intensity spectral distribution and $\rho(\lambda)$ is the reflectance, all at wavelength λ . Similarly, the thermal emittance is calculated using the blackbody intensity spectral distribution, $I_b(\lambda)$, and the emittance, $\varepsilon(\lambda)$, at wavelength λ according to:

$$\varepsilon_{\text{therm}} = \frac{\int_{2.5 \mu\text{m}}^{20 \mu\text{m}} (1 - \rho(\lambda)) I_b(\lambda) d\lambda}{\int_{2.5 \mu\text{m}}^{20 \mu\text{m}} I_b(\lambda) d\lambda}. \quad (5)$$

The cut-off at 20 μm will give a small error in the emittance value.

Samples with a solar absorptance exceeding 0.9 were selected for the study. As described above, the samples were produced by spray coating by hand, a technique that is not suitable for obtaining very thickness uniform layers.

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