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Emissivity Measurement of Semitransparent Samples

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Summary:

The characterization of infrared optical properties of semitransparent samples between 6 µm and 25 µm and between 20 °C and 90 °C is hampered by the fact, that the apparent emittance, reflectance and transmittance are intertwined in the optical signals. We report on an approach for the simultaneous measurement of transmittance and reflectance of semitransparent samples, expanding PTB's established emissivity measurement facilities under air and under vacuum. Measurements of silicon were performed under air, evaluated, and, additionally, validated by independent measurements.

Keywords: Emissivity measurement, semitransparent materials, radiative transport, silicon, infrared optical properties

Introduction

The increasing interest in industrial and scientific applications of semitransparent materials demands the precise and comprehensive measurement of their infrared optical properties. For instance, the non-destructive testing of fiber-reinforced polymers (FRP) by passive or active thermography requires precise knowledge of the emittance of the material to quantitatively identify defects [1]. Semitransparent semiconductors are also widely used as transmitting and reflecting components in infrared optics. For high precision measurements in the infrared wavelength region, the emission of the semitransparent components must be accounted for.

However, infrared optical properties of semitransparent materials at temperatures between 20 °C and 90 °C are difficult to measure because the detected optical signal is a superposition of reflected, transmitted and emitted radiation. Furthermore, the apparent emittance, reflectance and transmittance depend on the sample thickness. Therefore, in a second step, the absorption coefficient and refractive index must be identified. To solve these problems, a new sample holder, a model of radiative transport, and an identification scheme were developed.

Measurement principle

The measurement principle is based on PTB's emissivity measurement of opaque samples [2]. It is a direct radiometric comparison of the observed sample radiance and the radiance of two reference black bodies, operated at different temperatures. Radiance is measured using

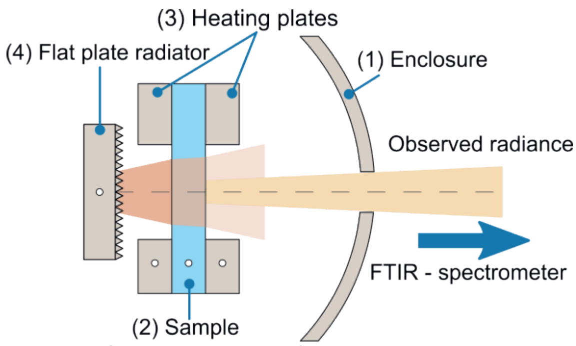

Fig. 1. Schematic view of the measurement setup. The enclosure (1), the sample (2), the heating plates (3), and the flat plate radiator (4) are visible in this sectioned side-on view.

a Fourier-Transform-Infrared (FTIR) spectrometer. The sample is placed in a separate sample holder [3], where it is thermally stabilized (see Fig. 1).

In contrast to opaque samples, where emittance is a surface property, emittance of semitransparent samples is a volume property. To achieve low uncertainties, the temperature not only on the surface, but throughout the entire observed volume must be known. For this purpose, the sample is placed between two annular heating plates which compensate radial temperature gradients, realizing a one-dimensional temperature distribution within the sample. Behind the sample, a temperature controlled flat plate radiator is positioned. The enclosure of the sample holder features a highly emitting coating. Like the radiator, its temperature is controlled as well. All components typically operate between 20 °C and 90 °C. Together, the enclosure and the radiator irradiate the sample with precisely known radiation.

For the simultaneous measurement of reflectance and transmittance, at least two independent measurements are required, which are realized by varying the temperature of the flat plate radiator and the enclosure. Because all sources of radiation are well defined, it is possible to explicitly consider reflection, transmission and emission of the sample.

Evaluation scheme

After correcting the background radiation and the spectral responsivity of the FTIR-Spectrometer, reflectance and transmittance are calculated from the observed spectra by a least squares approach. In a second step, the radiative transport equation [4,5] for isothermal samples is solved using the two-flux approach to derive expressions relating emittance, reflectance, and transmittance to the absorption coefficient and refractive index.

Results

Emissivity measurements of an optically polished sample of silicon were performed. The sample is 90 mm in diameter and 5 mm in thickness. The temperatures of the various components are summarized in Tab. 1.

Tab. 1: The nominal temperatures used for the emissivity measurement of silicon. The flat plate radiator was varied over three temperatures, while the temperatures of the sample and enclosure were kept constant.

Component	Temperatures
Enclosure	20 °C
Sample	60 °C
Flat plate radiator	40 °C, 70 °C, 90 °C

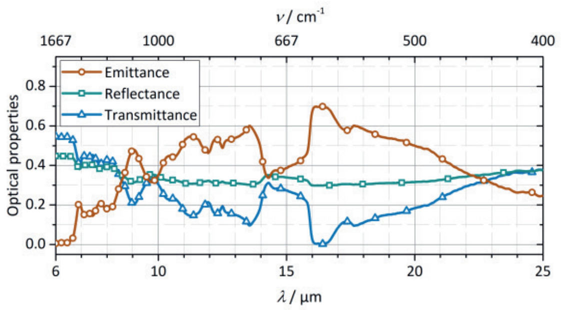

Fig. 2. Results for the apparent emittance (red), reflectance (green), and transmittance (blue) for an optically polished sample of silicon of 5 mm thickness at 60 °C.

Three measurements were performed from which the transmittance, reflectance, and emittance of the silicon sample were identified, the results of which are shown in Fig. 2. The unusually high emittance is due to the large thickness of the sample.

Finally, the setup was successfully validated by independent directional-directional reflectance measurements using a VW-setup and an FTIR spectrometer. The results of both, the direct radiometric comparison and the VW-setup, as well as the confidence interval of the VW-setup are shown in Fig. 3. The measured reflectance agrees within one sigma down to 7 µm, where after the offset is slightly above one sigma.

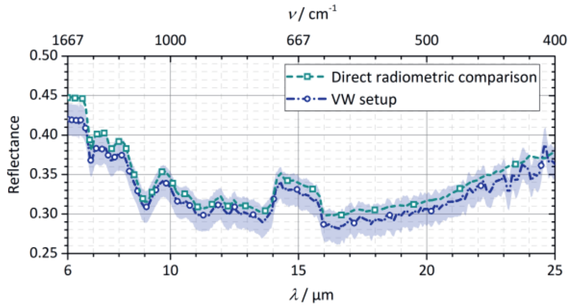

Fig. 3. Validation of the emissivity measurement of semitransparent samples by independent reflectance measurements.

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