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Fourier Transform Spectrometer for Spectral Emissivity Measurement in the Temperature Range between 60 and 1500ºC

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Abstract. A new spectral emissivity measurement system has been developed at Harbin Institute of Technology (HIT) by using a Fourier transform infrared (FTIR) spectrometer. The spectral range between 0.6 and 25 µm was covered by a photovoltaic HgCdTe and a silicon photodiode detector. A SiC heater with a black hole was employed for heating the sample. The temperature of the sample can be controlled in a range between 60 and 1500ºC with an error of less than 1ºC. The system was calibrated against two high quality reference blackbodies: a low temperature heat-pipe blackbody operated in the temperature range between 60ºC and 300ºC and a high temperature blackbody with SiC heater operated in the temperature range between 300ºC and 1500ºC. Several tests were done for this new system. The estimated uncertainty of emissivity measurement is better than 3%.

1. Introduction
The emissivity is an important parameter describing the thermal radiative property of material. It plays an essential role in the temperature measurements made by a pyrometer, in the analysis of the radiative heat transfer between objects, in the guidance of an infrared missile and hiding of military targets and so on. In spite of the simplicity of its definition, many problems in measuring emissivity confront us, such as low accuracy, narrow spectral band and small temperature range etc.

It is well known that the emissivity value can change greatly with surface conditions of materials. It depends strongly on the surface roughness, the surface oxidized film and temperature and so on. For this reason, emissivity values in literature usually lack information on data reliability and the measurement uncertainty is not clear for most measurement methods.

The Fourier transform infrared (FTIR) spectrometer is a powerful instrument for measuring spectral emission with a high spectral resolution and high accuracy. Many research works on using FTIR to measure spectral emissivity of materials have been done in recent years [1-9]. However, most instruments can only work at low temperature. It is obviously not enough to meet needs of many practical applications.

In this paper, we constructed a FTIR spectrometer system for the normal spectral emissivity measurement of solid materials in a temperature range from 60 to 1500ºC and in the spectral range from 0.6µm and 25µm.

Several tests were performed to check the characteristics of the system. At the end, a sample with black paint was measured over wide spectral range and wide temperature range. The estimated accuracy of emissivity measurement is better than 3%.
2. Instrument descriptions
By using a Fourier transform infrared (FTIR) spectrometer, a new system for measuring spectral emissivity of materials with high accuracy has been developed in HIT in 2004 (see in Fig.1). The spectrometer uses a simple Michelson interferometer that consists of a corner cube mirror and a KBr beam splitter. The spectral range between 0.6\textmu m and 25\textmu m is covered by a photovoltaic HgCdTe and a silicon photodiode detector.

A chamber with circulating water was designed for supporting the heater. We formed the heater with SiC material, on the heater there is a black hole on the opposite side of the sample supporter for simulating a blackbody. The sample was heated by passing a controlling current through the heater. Both thermocouple and pyrometer were employed for monitoring the temperature of the heater and the sample. Two reference blackbodies were used to calibrate and compensate the linearity and shift of the system.

3. Calibration and test
Assuming linearity of the spectrometer response to the incident spectral radiance, the radiometric properties of the spectrometer can be given by

$$S(\lambda) = R(\lambda) \left[ L_b(T(\lambda)) + L_o(\lambda) + L_a(\lambda) \right]$$

Where $R(\lambda)$ is the spectral response characterized with the properties of optical and electrical component, $L(\lambda)$ is the spectral radiance of sample, $L_o(\lambda)$ is the background spectral radiance emitted by the inner wall of instrument, $L_a(\lambda)$ is the background spectral radiance emitted by surrounding objects.

The purpose of calibration is to determine the spectral response function $R(\lambda)$ and background emission $L_o(\lambda)$ and $L_a(\lambda)$.

In the conventional calibration procedures for the FTIR spectrometer, the blackbody was controlled at different temperatures to be a reference radiation source. If the spectra $S_i(\lambda)$ and $S_j(\lambda)$ of blackbodies with different temperature $T_i$ and $T_j (T_j>T_i)$ were measured, two equations for the two unknown parameters are obtained as follows:

$$S_i(\lambda) = R(\lambda) \left[ L_b(T_i, \lambda) + L_o(\lambda) + L_a(\lambda) \right]$$

$$S_j(\lambda) = R(\lambda) \left[ L_b(T_j, \lambda) + L_o(\lambda) + L_a(\lambda) \right]$$

Where $L_b(T, \lambda)$ is the spectral radiance of the blackbody at the temperature $T$. These two equations can be solved yielding the FTIR response functions and

$$R(\lambda) = \frac{S_j(\lambda) - S_i(\lambda)}{L_b(T_j, \lambda) - L_b(T_i, \lambda)}$$

Figure 1. Diagram of system
When another two spectra \( S_s(T,\lambda) \) and \( S_b(T,\lambda) \) were against the sample and opposite its black hole. Another two equations are gotten as follows:
\[
S_s(\lambda) = R(\lambda) \left[ L_s(T,\lambda) + L_{e}\right] \\
S_b(\lambda) = R(\lambda) \left[ L_b(T,\lambda) + L_{e}\right] 
\]

Then
\[
L_s(T,\lambda) = \frac{S_s(\lambda)}{R(\lambda)} - L_{e}\lambda \\
L_b(T,\lambda) = \frac{S_b(\lambda)}{R(\lambda)} - L_{e}\lambda \\
\varepsilon(T,\lambda) = \frac{L_s(T,\lambda)}{L_b(T,\lambda)}
\]

Where \( \varepsilon(\lambda) \) is spectral emissivity of sample.

In practice, a heat-pipe blackbody operated in the temperature between 60ºC and 300ºC was used to measure the background radiance.

Several tests were performed. For instance, size-of-source and linearity of the response. Removable plates of various aperture sizes were attached in front of a large area target coated by black paint. We measured the spectral radiance of the sample at 200ºC. In figure 2 the horizontal and vertical axes represent the aperture diameter and the observed radiance differences, respectively.

It is seen that the effective size of the detector image on the target is broadened in comparison with the designed image size, 5 mm diameter. However, the effect of the size-of-source of the FTIR spectrometer was negligibly small for a target larger than 20 mm diameter. Since our sample size is 30mm diameter, the effect of size-of-source can be neglected.

We measured the normal spectral emissivity of a black paint surface at the temperature 300ºC. The spectral emissivity curve is plotted in Figure 3.
4. Conclusion
We described the spectral emissivity measurement system based on the FTIR spectrometer in the temperature range between 60°C to 1500°C and in the spectral range between 0.6μm to 25μm. After several calibrations and tests, Measurement of the spectral emissivity of a black paint was demonstrated with this system. It seems that the system works well. The uncertainty of emissivity measurement is estimated less than 3%.

There are several things that remain to be finished about this system, for instance, analyses of absorption of atmosphere, comparison with literature and so on. We will finish these as soon as possible and present those in future.

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