Pyrometry

Objective

The objective of this laboratory is for you to explore the physics and practical aspects of temperature measurement by infrared pyrometry.

Preparation

Read the chapter from Speyer on heat transfer and pyrometry; and the first four pages of the article on pyroelectric detectors.

Equipment and samples

- Optical pyrometry station: small tube furnace, infrared lens, chopper, pyroelectric detector, glass and BaF2 windows.
- Sample cylinders made of aluminum and graphite. Both are 3" long and have 0.9" outer diameter. The graphite tubes have a hole on one end (with inner diameter 0.6"), and are closed on the other end. The aluminum rods have a polished end and a rough end.
- Computer, plotting software, computer-based oscilloscope

Introduction

Most materials processing occurs at elevated temperatures and accurate knowledge of the temperature is extremely important. Placing a thermocouple or other physical thermometry in contact with the material is often inconvenient or impossible. Measurements of the intensity and spectrum of electromagnetic radiation emitted by a material are often the only option for thermometry but accurate calibration of the pyrometer and accurate knowledge of the emissivity of materials is often challenging.

In this lab, infrared photons emitted from a hot surface are focused with a lens on an IR detector. The detector is made of a special type of dielectric crystal, a pyroelectric, that generates a voltage when heated.

Session 1: Calibrating an optical pyrometer

- With the black-body insert in the oven and the oven at an elevated temperatures, explore how the chopping frequency changes the signals generated by the pyroelectric detector. What is the optimal chopping frequency?
- You want to know what is the best lens placement. The source is larger than the detector so you probably want to demagnify the source.

- Calibrate the pyrometer with black body sample (a graphite well). Based on your knowledge of black body radiation and information about the equipment, determine an appropriate temperature range and temperature intervals. Heat up the sample and collect data as you vary the temperature. How does the result compare with Stefan-Boltzmann law?

- How sensitive is this calibration to the position of the black-body, lens, and detector? Be as quantitative as possible.

Session 2: The black-body spectrum and emissivity

- With the black-body in the furnace, repeat the calibration using a glass or silica window in front of the detector. How does the calibration change with the glass window? Analyze the results in terms of the known infrared transmission of the glass window and the temperature-dependent spectrum of black-body radiation.

- Remove the glass window and replace the black-body with an Al rod that extends to within 0.25 inch of the end of the furnace. Determine the emissivities, ε, as a function of temperature If time permits, repeat with a rough Al surface. (A rough surface typically increases the emissivity but you have to be careful not to place the rough surface where too much infrared radiation from the sidewalls of the furnace scatters into the detector.)

Instrument procedures

Optical chopper

The SDC-5000 optical chopper creates pulses of infrared radiation from a continuous emission source. This is essential for the operation of the pyroelectric detector. The chopper operates by rotating fan blades at a desired speed; the frequency range is 4 to 500 Hz for the ***Low Freq*** setting (which uses the inner aperture, closer to the center) and 40 to 5000 Hz for the ***High Freq*** setting (which requires outer aperture, further away from the center). The outer aperture has finer fan blade spacing to achieve the higher chopping frequency.

To operate the chopper, turn on the power switch (at the back, next to power cable) and check the controller to make sure ***Int*** mode is active. Choose an aperture and select the corresponding speed mode. Press and release the frequency set knob once and the least significant digit on the clock will blink. Turning the knob clockwise increases that digit by one for every click. Pressing and releasing the knob once again will cause the next least significant digit to blink. Continue and adjust each digit as necessary. Once you reach the most significant digit allowed, pressing the knob one more time will set the motor to the speed displayed and also store the value in memory. The Sync Output should be connected to the oscilloscope to provide the trigger.

Detector and oscilloscope

We use the SPH-CM-Test pyroelectric detector to measure the power of radiation emitted. The heart of the detector test box is a 5 mm diameter $LiTaO_3$ detector. The detector generates a voltage signal by detecting a temperature change due to incoming radiation with linear response up to 40,000 V/W. The detector test box has a BaF_2 window that is transparent to visible and IR radiation (up to 17.5 μm) to block air flow.

To collect the data, we use a DS1M12 oscilloscope. Turn on the detector and start the EasyScope II program. You want to trigger ***ChB*** with the sync output of the chopper. Adjust the T/Div and V/Div knobs to see a clear image of the signal. Adjust ***Gnd*** level if necessary. Pressing ***Meter A*** button will display useful readings, which you can customize by pressing configure.

Furnace

The Carbolite MTF 10 furnace is used to heat up the test samples to the desired temperatures. All of the samples are 3" long rods, and some have hole on one end. To ensure uniform temperature, you want to place the sample at the center of the heating tube, except when measuring emissivity, see below.

Before you start the heating, align the furnace with the lens/chopper/detector. Then, turn on the furnace with the green switch, press the button once so it displays SPoC (sample temperature), press the up and down arrow buttons to select the desired temperature, then press three more times to set the temperature. The LCD now displays the current temperature of the heating tube. To start the heating, flip the orange switch below the green power switch. The orange light will turn on indicating that the heating coil is on. The temperature will reach the set limit fairly quickly, and over-shoot (amount of over-shoot depends on heating rate) then come down to help the system to stabilize. The sample inside the furnace will take 10 to 15 minutes to stabilize; use the oscilloscope reading as a guide.

Note: Cooling the furnace down takes a long time. Using a fan will help, but not by much. Therefore, it is best to choose appropriate temperature steps and constantly increase the temperature during the experiment. Also, be gentle when changing temperature, as pushing the buttons too hard might shift the furnace and ruin the alignment.

Silicon lens

The silicon lens is used to focus IR radiation emitted by the source onto the detector. The lens only transmits radiation that has wavelength from 1 to 10 μm, with transmittance $T \geq 70\%$. It has focal length of f = 100mm. You should place the lens in between the furnace and the detector, and the distance to each is governed by the thin lens equation: $f^{-1} = d^{-1} + d'^{-1}$, where d is lens-to-furnace distance and d' is lens-to-detector distance. The ratio d/d' is the demagnification of the setup; the larger the number you set, the smaller the image of the source on the detector you get.