Fundamentals of Far-infrared

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Definition of Far Infra-red

- Far Infra-red, FIR, is a form of electromagnetic radiation similar to light, microwave and X-ray.
- The difference is the amount of energy each wave carries.
Where is Far-infrared?
Detail Classification in Infra-Red

The electromagnetic spectrum is divided into segments by wavelength.

- Cosmic Rays
- Gamma Rays
- X-Rays
- Ultraviolet
- Infrared + visible
- Microwaves

Wavelength (microns):
- Visible light: 0.4
- Near IR: 0.7
- Medium IR: 2.0
- Infrared: 4.0
- Far infrared: 1000
Our Atmosphere
Infra-red Transmission in Air

Most observation and detection are done in the 3-5 µm and 8-14 µm range.
Division of Infra-red

The International Commission on Illumination (CIE) defined the division of optical radiation into the three bands:

- **IR-A**: 700 nm–1400 nm; near-infra-red (NIR) region used mainly in optical communication, eye-safe security surveillance and night vision. Dominated by water vapour absorption.

- **IR-B**: 1400 nm–3000 nm; short wavelength infrared (SWIR) region used mainly for long distance optical communication. Dominated by water vapour absorption.

- **IR-C**: 3000 nm–1 mm; sub-divided into (i) Mid-wavelength infrared (MWIR) region [3-5µm] used for guided missile. (ii) Long wavelength infrared (LWIR) region, also known as far-infrared [8-15 µm], is the thermal imaging region. (iii) Far-infrared (FIR) [15-1,000µm] where FIR laser presently used.
Far Infra-Red Sources

- In principle, any object that absorbs light or other form of radiation can also emit radiation as its temperature increases above room temperature.
- The emission spectrum an object emits depends on the object temperature – colour temperature.
- In Physics, the emission spectrum is described mathematically by an equation: Planck’s Distribution or Blackbody Radiation.
- All thermal radiation sources, natural or artificial, obey this equation.
Blackbody Radiation

- 15,000 K star
- the Sun (5,800 K)
- 3,000 K star
- 310 K human

Graph showing the intensity (relative) of radiation at different wavelengths (nm) for different objects.

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Blackbody Radiation

- Blackbody is defined as a perfect emission object.
- Planck’s law describes the emission radiance of a blackbody at temperature, $T$:

$$I'(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.$$

- $1^\circ C = 273K$

(http://en.wikipedia.org/wiki/Planck's_law)
Power Percentage of Black Body Radiation

- The shape of black body radiation described by Planck’s law is independent of temperature.

- Therefore it is possible to represent the total radiance energy in percentage as a function of wavelength or frequency.

- For example, the Sun has temperature of 5778K then, the percentage of radiance as function of wavelength is,

<table>
<thead>
<tr>
<th>%</th>
<th>λ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>380</td>
</tr>
<tr>
<td>20%</td>
<td>463</td>
</tr>
<tr>
<td>25.0%</td>
<td>502</td>
</tr>
<tr>
<td>30%</td>
<td>540</td>
</tr>
<tr>
<td>40%</td>
<td>620</td>
</tr>
<tr>
<td>41.8%</td>
<td>635</td>
</tr>
<tr>
<td>50%</td>
<td>711</td>
</tr>
<tr>
<td>60%</td>
<td>821</td>
</tr>
<tr>
<td>64.6%</td>
<td>882</td>
</tr>
<tr>
<td>70%</td>
<td>967</td>
</tr>
<tr>
<td>80%</td>
<td>1188</td>
</tr>
<tr>
<td>90%</td>
<td>1623</td>
</tr>
</tbody>
</table>
Natural Sources

- The Sun is one of the natural sources.
- Moon and even the Earth are IR sources.
- Other natural hot objects e.g. volcanoes, hot springs are also IR radiation sources.
- These natural IR sources form the thermal (noise) background.
- Hot blooded living things e.g. human, animals are IR radiation sources and can be detected in thermography imaging.
The Greenhouse Effect

- Solar Radiation absorbed by Earth: 235 W/m²
- Directly radiated from surface: 40
- Thermal radiation into space: 195
- Heat and energy in the atmosphere: 324
- Greenhouse gas absorption: 350
- The Greenhouse Effect

Earth's land and ocean surface warmed to an average of 14°C
Artificial IR Sources

- Any heated materials can be IR sources.
- However, heat lost or unstable heat generation can make the radiation from some of the materials irregular.
- One of the stable IR source is a graphite rod with a cone hole in it and heated by a constant current source.
- Many lamps are IR sources e.g. incandescent lamp and various pressurised gas lamps.
- Modern stable heat source has sophisticated electronic feedback system to control the heating.
There are commercial FIR sources available. However calibration of these sources are not easy. All the IR sources are electrically powered and has good current control. In addition to the traditional IR emitter, LEDs are now available as IR source.
An example is SiC IR emitters from Oriel Co. The emitter spectra cover from 1-25 μm in wavelength.
Calibrated Source

Calibrated IR sources can be obtained from some of the commercial companies.

These are sources that have reliable known spectral irradiance that are calibrated against recognised standard from e.g. NIST.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Approximate NIST Uncertainty (%)</th>
<th>Approximate Newport's Uncertainty* (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>2.23</td>
<td>2.8</td>
</tr>
<tr>
<td>350</td>
<td>1.35</td>
<td>2.5</td>
</tr>
<tr>
<td>654.6</td>
<td>1.01</td>
<td>2.5</td>
</tr>
<tr>
<td>900</td>
<td>1.34</td>
<td>2.5</td>
</tr>
<tr>
<td>1300</td>
<td>1.42</td>
<td>2.5</td>
</tr>
<tr>
<td>1600</td>
<td>1.89</td>
<td>2.8</td>
</tr>
<tr>
<td>2000</td>
<td>3.29</td>
<td>2.8</td>
</tr>
<tr>
<td>2400</td>
<td>6.50</td>
<td>2.8</td>
</tr>
</tbody>
</table>

*Additional uncertainty due to calibration transfer.
Detecting Far-Infrared Radiation

As the Infra-red range is quite broad, hence different detectors are used to detect difference waveband.

- **Near infrared**: from 0.7 to 1.0 micrometers - silicon, CCD detector.
- **Short-wave infrared**: 1.0 to 3 micrometers - InGaAs covers to about 1.8 micrometers; the less sensitive lead salts (PbS) cover this region.
- **Mid-wave infrared**: 3 to 5 micrometers - covered by Indium antimonide[InSb] and HgCdTe and partially by lead selenide [PbSe]).
- **Long-wave infrared**: 8 to 12, or 7 to 14 micrometers: the atmospheric window (Covered by HgCdTe and microbolometers).
- **Very-long wave infrared (VLWIR)**: 12 to about 30 micrometers, covered by doped silicon and germanium.
Typical IR Detectors
Characteristics of Some IR Detectors

- Most IR detectors are semiconductors and need to operate in low temperature.
- But their response across the IR wavelength range is limited.
- Some non-semiconductor detectors have very broad response range.
- The only disadvantage is their responsivity is low.
Transmission of IR Materials
Applications

There is a broad areas of applications for IR radiation.

Some of the notable areas are

- Smart IR Heating
- IR communication
- IR curing
- IR Spectroscopy
In many manufacturing processes application of heat is needed

By knowing the optimum absorbing wavelength of a material, it is possible to adjust the IF heater temperature to maximise its emission in that wavelength.

This makes heating more efficient with higher process speed and minimum energy wastage.
IR Communication

- IR communication can be used in both indoor and outdoor medium to short range communication.
- In particular in-house communication in which household information, video, audio all can be streamed across the rooms in each house.
- There are competitors:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Transmission speed (Mbit/s)</th>
<th>Maximum transmission distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WiFi</td>
<td>11-248</td>
<td>30-100</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>1-10</td>
<td>10-100</td>
</tr>
<tr>
<td>IRDA</td>
<td>0.1-4</td>
<td>2</td>
</tr>
<tr>
<td>Ethernet</td>
<td>10-10,000</td>
<td>100</td>
</tr>
</tbody>
</table>
IR Curing

- IR heating can be used for curing of coating on a product.
- IR curing oven can be designed to optimise not only the temperature but also uniformity in curing.
- Through custom design of an IR oven, it is possible to reduce the labour cost significant (e.g. 30%).
- Rejects due to under and over-curing can be reduced to almost zero.

IR Spectroscopy

- Infrared vibrational spectroscopy is a technique which can be used to identify molecules by analysis of their constituent bonds.

- Each chemical bond in a molecule vibrates at a frequency which is characteristic of that bond.

- The vibrational frequencies of most molecules correspond to the frequencies of infrared light. Typically, the technique is used to study organic compounds using light radiation from 4000-400 cm\(^{-1}\), the mid-infrared.

- A spectrum of all the frequencies of absorption in a sample is recorded. This can be used to gain information about the sample composition in terms of chemical groups present and also its purity (for example a wet sample will show a broad O-H absorption around 3200 cm\(^{-1}\)).
Vibration of Molecules

Each molecular bond vibrates uniquely and different direction too. Some vibrational modes are wagging, stretching, scissoring.
Fourier Transform IR Spectroscopy

- **Fourier transform infrared (FTIR) spectroscopy** is a measurement technique for collecting infrared spectra.

- Instead of recording the amount of energy absorbed when the frequency of the infra-red light is varied, the IR light is guided through an interferometer.

- After passing through the sample, the measured signal is the interferogram and is subjected to a mathematical Fourier transformation.

- The transformation gives a spectrum identical to that from conventional (dispersive) infrared spectroscopy.
Schematic of FTIR Functioning
Commercial FTIR Products

FT-IR System

Optical Bench
The Spectrum™ 400 is a combined FT-IR spectrometer. The system combines optimum performance in both the Mid-IR and Far-IR regions with sampling versatility in a single instrument.

Spectrum BX Systems are designed to meet the high validation standards set by QA/QC, method development and analytical service laboratories.
Conclusion

- Infra-red, Far Infra-red technology continue to enable a broad range of applications in industry and in academic sector.

- IR, FIR products include manufacturing, health, environmental monitoring, and analysis etc.

- Through better understanding on Physics of IR and FIR, better and new applications will emerge.

- Understanding of the science leads to new engineering – that is the essence of science & technology.