An Introduction to InGaAs Over InGaAs Ratio Pyrometry

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Temperature is the most frequently measured physical quantity, second only to time. Infrared technology has been used for millennia in noncontact temperature measurements (fire was the target and the eye was the detector, observing how the color emitted by a flame varied based on temperature). Today, pyrometry is the primary technique of noncontact temperature measurement. Pyrometry is a method of calculating the temperature of an item remotely (sometimes at great distances) using measurements of a target's thermal radiation (infrared light).

The ability to measure temperature remotely using pyrometry is quite advantageous, especially when the measurement target is in an unreachable location or a hazardous environment, is moving, or is a dangerously hot temperature. Pyrometry can record temperatures within a fraction of a second, and from up to hundreds of kilometers away, depending on what light collection optics are used. Pyrometry measurements also have the advantage of being immune from electrical interference, and there is no mechanical contact between the target and sensor which could influence the temperature measurement.

How are these measurements made? Pyrometers are often handheld devices which are used to acquire light measurements and convert to a temperature reading. They make use of some common physical laws that we will discuss.

All physical objects are able to emit thermal radiation. This ability can be idealized as a blackbody (perfect emitter) using Planck's law:

$$M_e(\lambda, T) = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)}$$

where $M_e(\lambda, T)$ = spectral radiant exitance, λ = wavelength of measured light, *h* = Planck's constant, *k* = Boltzmann's constant, and T = temperature.

Real surfaces don't typically emit thermal radiation as well as a perfect blackbody source. Rather, they emit some fractional part of what a blackbody would emit, acting instead as a graybody. The ratio of the target's actual emitted radiation to that of a blackbody (at the same temperature) is known as its emissivity.

In standard pyrometers, the emissivity is used along with a light measurement to calculate temperature as shown in the Stefan-Boltzmann law:

$$M_e(T) = \varepsilon\sigma T^4$$

Where $M_e(T)$= target irradiance, ε = the emissivity of the target, σ = the Stefan-Boltzmann constant, and T= the target temperature.

Figure 1 shows a simplified diagram of a pyrometer. The goal is to collect the target's thermal radiation (irradiance) with collection optics and focus it onto a photodiode detector. The photodiode's output is a measurable current which is proportional to the incident optical power.

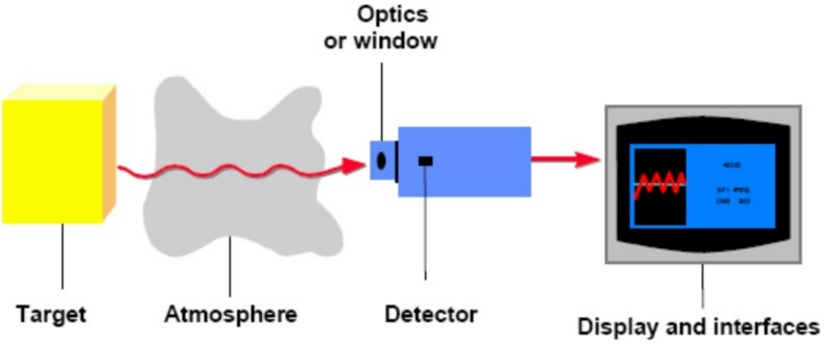

Figure 1: Pyrometer Schematic[i]

While standard pyrometry with a single detector has some distinct advantages over a contact measurement method like thermometry, there are some limitations to this process that can make it difficult or impractical. When light travels a long distance to reach the detector, it may pass through atmospheric gases, smog, and turbulence which can reduce the signal and skew or obstruct the measurement.

Another limitation is that for each measurement, the emissivity of the target must already be known in order to calculate the temperature. That means that the temperature measurement is most accurate only when the person performing the measurement knows precisely what material is being measured and can consult published tables to look up the emissivity of materials. This is cumbersome at best and limiting at worst.

These limitations are solved by using a subset of pyrometry called ratio pyrometry.

A ratio pyrometer uses two photodiode detectors stacked on top of each other. Light is incident on the top detector and the absorbed light generates a correlating measurable output current. A small portion of the incident light is transmitted through the top detector and is incident on the bottom detector, which outputs a smaller current. The ratio of the top detector current to the bottom detector current will vary depending on the target temperature.

By using this ratio as the indicator of the temperature, the limiting factors discussed earlier are reduced or eliminated. Any absorbing or turbulent gases in between the target and the ratio pyrometer affect the top and bottom detector equally, and the effect is cancelled out. Similarly, the effect of the target’s emissivity on the measured temperature is also severely reduced since it affects the measurements from both detectors equally. Thus, the ratio between the two detector outputs will remain almost constant at a given temperature, even when in the presence of absorbing gases or if moving to a target material with a different emissivity.

Two-color or “sandwich” photodiode detectors are a core component of ratio pyrometers, as they take the incoming optical signal and convert it to an electrical signal. GPD Optoelectronics provides two-color sensors consisting of two stacked InGaAs photodiodes. InGaAs absorbs light in the shortwave infrared (SWIR) spectrum. The 2C2-N17N17-T39 (formerly GAP9099) detector shown in Figure 2 contains a 2 mm diameter InGaAs chip over a second 2 mm InGaAs chip. Each photodiode is axially aligned to the center of the TO-39 package.

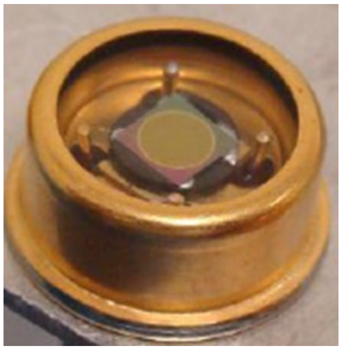

Figure 2: 2C2-N17N17-T39 detector from GPD Optoelectronics

The top detector is exposed to a wider spectrum of light than the bottom detector, which only contends with a smaller spectral range transmitted through the top InGaAs chip. A user will typically attach a long-wave pass (LWP) filter to block out any ambient light at lower wavelengths than the wavelength of interest. This minimizes signal noise which could degrade the accuracy of the measurement. It is also important to reduce noise by ensuring that the diameter of the incoming light is smaller than the detector diameters.

Figure 3 illustrates the spectral responsivity in A/W vs. incident wavelength for both photodiodes in the 2C2-N17N17-T39 detector. A 1500 nm LWP filter was attached to the window to improve the signal to noise ratio. The target's radiant exitance is collected by each photodiode and subsequently processed with suitable electronics to provide an output signal ratio related to the target's radiance.

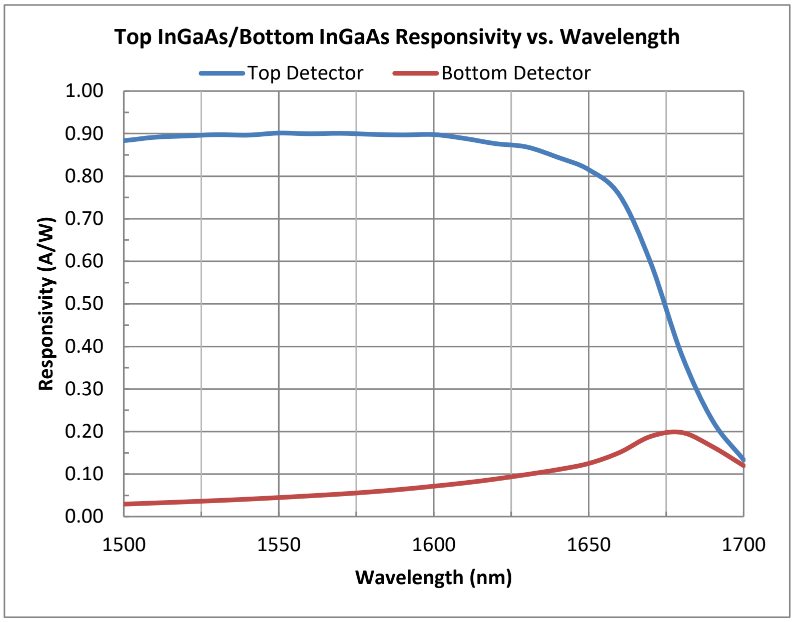

Figure 3: InGaAs/InGaAs Responsivity vs. Wavelength

As mentioned earlier, the ratio of the photodiodes' output current is used to determine the target temperature. To assign a given ratio to the correct temperature (degrees Celsius or Kelvin), a physical temperature measurement of the target or a laboratory blackbody source is used for calibration. Figure 4 shows a standard blackbody test station.

The user optically aligns a ratio pyrometer to the output beam of the blackbody thermal cavity. The user then adjusts the temperature of the blackbody and records the resultant output current of each photodiode and calculates their ratio. The blackbody source emits thermal radiation (spectral radiant exitance) that is dependent on temperature and wavelength, while the sensor's responsivity is a function of wavelength and independent of the target's temperature.

Figure 4: Blackbody Test Station[ii]

Figure 5 shows the photodiodes' signal ratio vs. the incident blackbody temperature, the result from integrating the radiance with the responsivity. Eight discrete temperatures were used as calibration points, and an x-y linear regression analysis was performed to generate the target's surface temperature with respect to the ratio signal at the calibration points. The resultant trend line is used to indicate the temperature from measured ratios that fall between the calibration points.

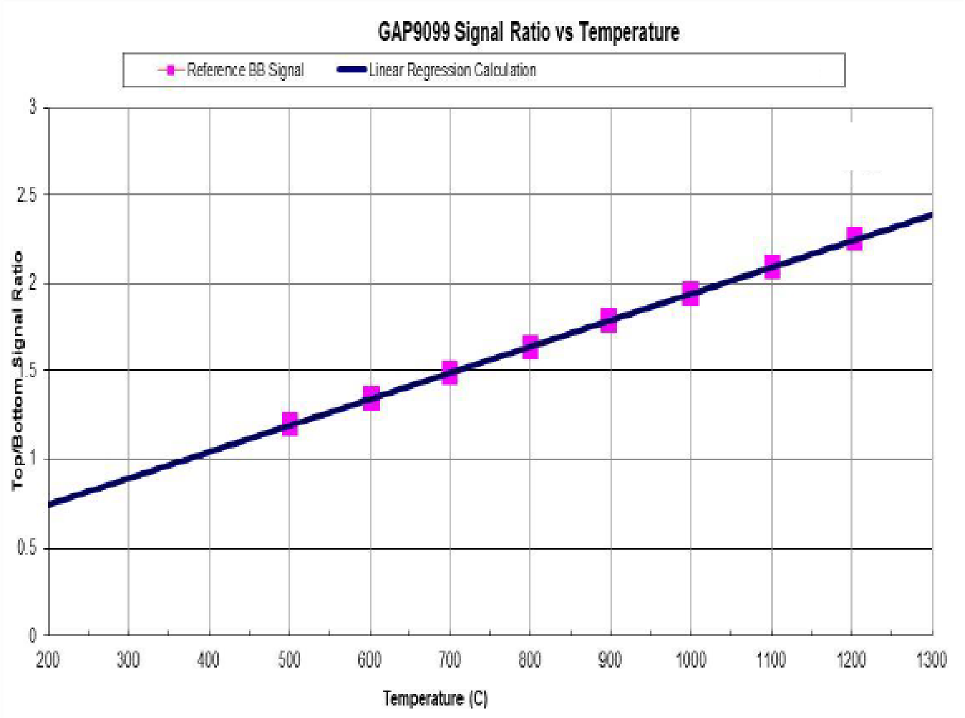

Figure 5: Signal Ratio vs. Blackbody Temperature

Ratio pyrometry in the SWIR spectrum is a powerful tool in noncontact temperature measurement, especially where measurement via contact thermometry is not possible or practical. The ability of ratio pyrometry to minimize the impacts of atmospheric disturbances and target emissivity differences offer a distinct advantage over standard single-detector pyrometry. These advantages over the past century allow us to perform accurate non-contact temperature measurements in ways that were prohibitively challenging in earlier times.

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[i] Gruner, Raytek GmbH, "Principles of Non-Contact Temperature Measurement," Oct. 2001. Available: https://www.vortex.com.br/notas/irprinciples_en2.pdf

[ii] Oriel Instruments, "Light Sources," 67030 Blackbody datasheet.

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