Infrared Spectroscopy with LUXEON IR ONYX Broadband Emitter

Assembly and Handling Guidelines

Introduction

This application brief gives an overview of LUXEON IR ONYX broadband emitter behavior when used for spectrometry applications. Proper assembly and handling, as outlined in this application brief, ensures high optical output and long light output maintenance of LUXEON IR ONYX broadband emitters.

Scope

Spectroscopy is a very powerful tool used in numerous scientific and industrial fields; however, thus far, it's usage in daily life applications has been much more limited. This is mostly due to the size and cost of spectroscopy systems and sophisticated algorithms needed for data processing. Recent technological developments have substantially reduced the size and price of sensors and optics for spectroscopy. Combined with the computing power available in mobile applications, this opens the possibility of truly portable and affordable spectrometers. The last piece of the puzzle needed to enable miniaturized spectrometry systems is a compact light source; this application brief introduces the LUXEON IR ONYX broadband emitter, which enables infrared spectroscopy in the 700nm–1100nm range.

Table of Contents

1. Spectroscopy

1.1 Description

Spectroscopy is one of the most important tools for modern scientific and industrial applications, although, so far it's not very widespread in consumer applications. One of its most familiar forms is the ability of human eyes to distinguish color; an object illuminated by white light (e.g. from the sun) will absorb certain wavelengths and reflects the rest. Depending on the reflected wavelengths, the eye will perceive the object as having a certain color, based on which a person can decide whether a fruit is ripe or not.

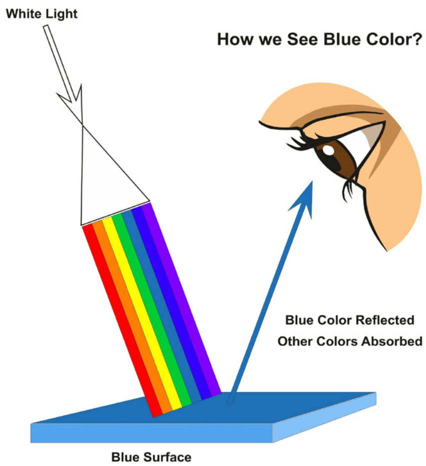

Figure 1. Color vision is a form of spectroscopy.

This kind of process can also be used for wavelengths outside the visible range, although, dedicated (near) infrared (NIR) sensors are needed. The concept stays the same, illuminate the object with a known spectrum, measure the light transmitted/reflected/scattered from it, and after some data processing it will be possible to measure the object's parameters (e.g. composition, concentration or whether contaminants are present).

For day-to-day spectrometry applications, the illumination used is typically visible (VIS) and NIR light, roughly covering the range of 400nm–2500nm.

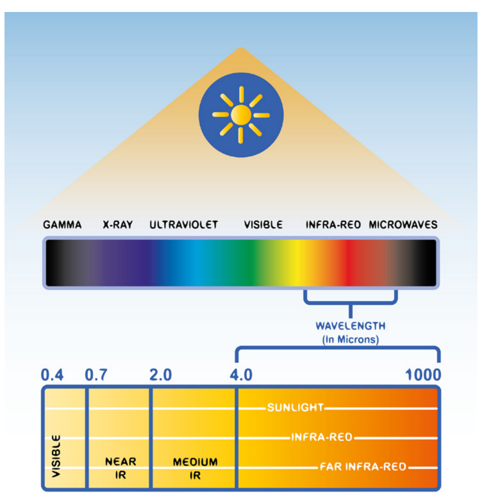

Figure 2. The electromagnetic spectrum.

The reason for using this wavelength range is related to the molecular composition of the sample being investigated and the way the bonds between the atoms within each type of molecule interact with light. The energy of a VIS/NIR photon is similar to the vibrational energy levels within a molecule; since each type of molecule has a specific combination of vibrational levels, the spectrum reflected/absorbed by it constitutes a "fingerprint" of that particular molecule. The Figure 3 below also illustrates why ultraviolet (UV) light is less used for spectroscopy – it tends to break down organic molecules.

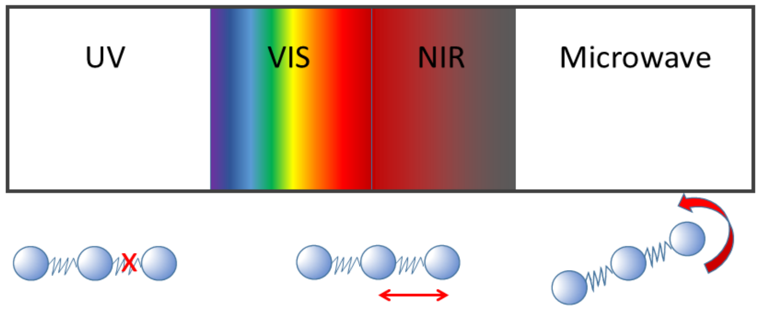

Figure 3. Molecule interaction with various wavelengths of light illustrating possible types of interactions (bond breaking with UV light, vibration with VIS/NIR and rotation with microwaves).

The ability to do "fingerprinting" means that spectroscopy can be used to identify materials and quantitatively measure their composition, which makes it suitable for numerous applications, like identifying food and beverage contents, sorting different types of plastics and measuring blood oxygenation levels for medical & health applications.

1.2 Types of Measurements

Roughly speaking, there are two types of spectroscopic measurements, transmission and reflection (see Figure 4 below):

- In reflection configuration, the emitter and detector are on the same side as the sample, so quite often it's easy to make them part of the same device
- In transmission configuration, the sample is placed in between the emitter and detector
- An additional possibility for transmission measurements is to have a mirror on one side of the sample; this allows keeping the emitter and detector together; additional care is needed to prevent significant direct reflection from the sample

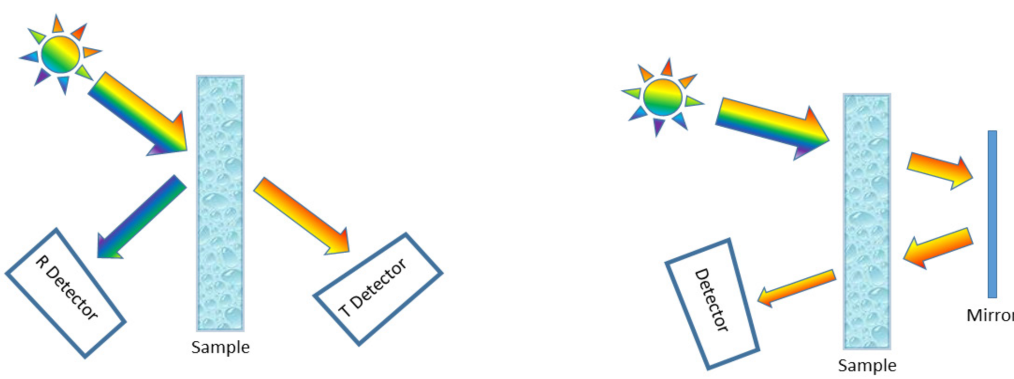

Figure 4. (Left) Schematics of typical reflection/transmission spectroscopy setup. (Right) Transmission setup using a mirror.

1.3 Building Blocks of a Spectrometry System

What are the components of a self-contained spectrometry system?

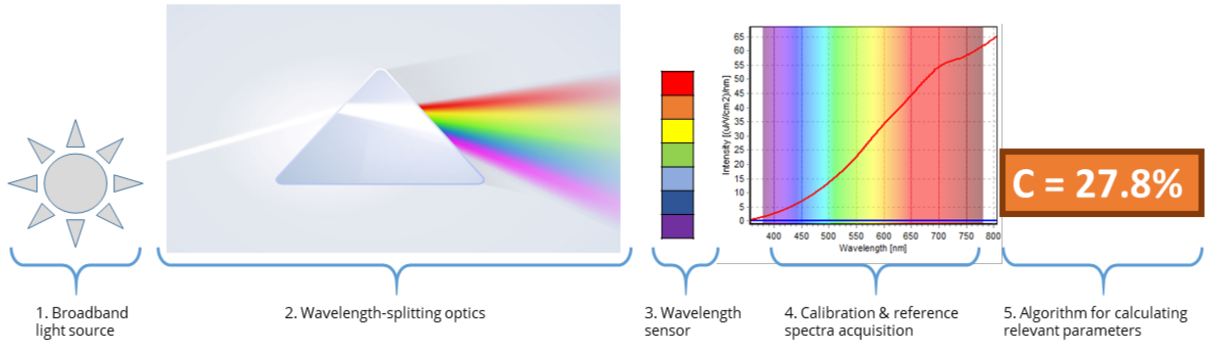

Figure 5. The main building blocks of a spectrometry setup.

As shown in Figure 5 above, there are five main parts:

1. A broadband light source (typically incandescent bulbs or arc discharge lamps).
2. Wavelength-splitting optics; this can be:
   a. Dispersive optics (as shown in Figure 5), which separates the wavelengths spatially.
   b. Absorptive optics: color filters placed on top of the sensor, which let through only certain wavelengths.
3. Wavelength sensor, typically a CCD-type with multiple pixels (arranged in an array or matrix).
   a. If dispersive optics is used, then each pixel "sees" only the wavelength that happens to fall on it.
   b. If absorptive optics is used, the full spectrum falls on all pixels, but each pixel has its own color filter, so the final outcome is the same: each pixel "sees" only one wavelength.
4. Acquisition of calibration/reference spectra; this part consists of all the hardware and processes needed to obtain an accurate transmission/reflection spectrum (e.g. measuring a reference spectrum against a calibrated surface).
5. Data processing/algorithms/machine learning: in many situations, measured spectra need additional data processing in order to calculate the parameters of interest (e.g. sweetness, fat content, etc.).

Parts 1, 2 and 3 above are hardware, part 5 is software, and part 4 can be a combination of hardware and software/algorithms.

Traditionally, spectrometry setups tended to be quite bulky, mostly due to the size of wave-splitting optics and of the broadband light source.

Recent advances in micro-optics technologies significantly reduced the dimension of the optics, which is now comparable in size with that of the sensor itself; actually, the optics and the sensor tend to be integrated together in one package.

Nowadays, the computing power needed for the data processing is available in any smartphone, with the added benefit of cloud connectivity for access to more extensive and permanently updated databases and calculation models.

Given the above remarks, it looks like a compact and robust light source would be the final ingredient needed to build a miniaturized spectroscopy system, assuming it can cover the spectral range(s) of interest. Phosphor-based light sources are a promising candidate for this application; the next section gives a short overview of their main characteristics.

2. Phosphor-Based Light Sources

Phosphor-based light source became mainstream during the last decade; they're mostly known as "white LEDs" and can be found basically everywhere, from public and home illumination, to cars and cellphone flash units. Their working principle is illustrated below; a blue LED is used to excite a phosphor, which in turn emits a broad spectrum.

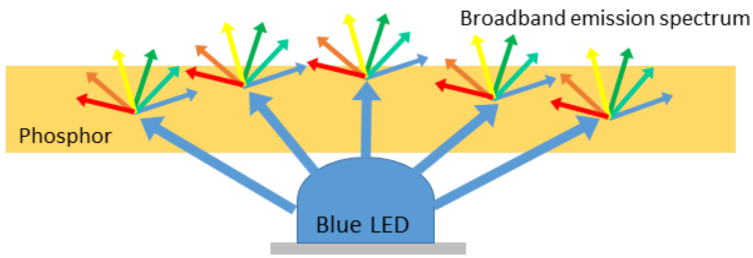

Figure 6. Working principle of a broadband LED emitter; a blue LED is used to pump a phosphor, which emits a wide spectrum. Some of the original blue light also goes through.

However, the emission spectrum of these light sources covers the range of 450nm–700nm; LUXEON IR ONYX expands the usable range into the NIR, adding the range of 700nm–1050nm and beyond.[1]

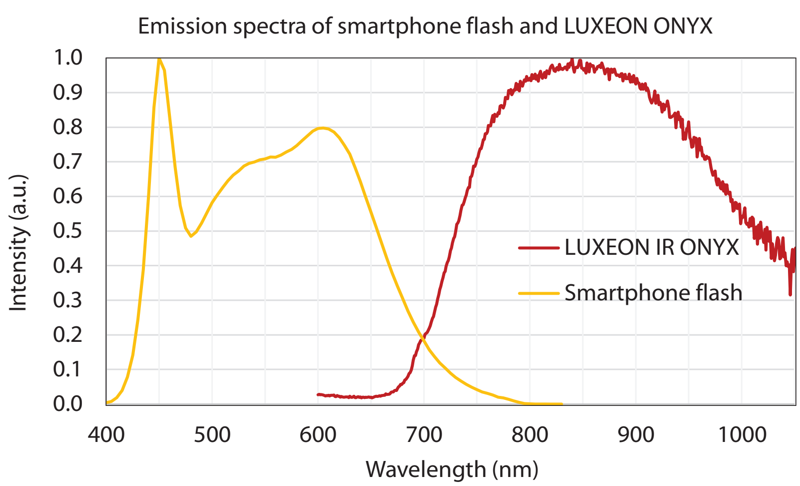

Figure 7. Normalized white and LUXEON IR ONYX broadband emitters spectra. NOTE: The 450nm peak is the blue pump LED.

As shown in Figure 6, a broadband emitter is actually a two-part light source, consisting of a blue pump LED and a phosphor, which converts the blue light into broadband white or IR. This means that the overall behavior of the emitter, like the dependence of output flux vs. ambient temperature, is driven by both components.

When it comes to compact/portable/mobile spectrometry applications, the overall requirements for a suitable light source are:

- Broadband emission spectrum
- Smooth spectrum – emission peaks should be avoided since it forces short integration times for the detector in order to avoid saturation at the peak wavelength, which leads to low and noisy signal at other wavelengths
- Stability of spectrum over time – long life time
- Tolerance to wide temperature range – it can operate in a variety of environments without active cooling / minimal passive cooling
- Small size

- High Wall Plug Efficiency (WPE) – this has two main benefits:
  - Allows operation on battery power
  - Creates less waste heat, which in turn helps keep the overall device small (no active cooling required)
- Fast modulation capability, so that the emitter can be synchronized with the sensor; the ability to switch off the light source when the sensor is off means less power consumption overall and longer battery life

3. LUXEON IR ONYX Broadband Emitter

3.1 General Properties

The LUXEON IR ONYX broadband emitter is available in an industry-standard 2720 package. For a detailed description of its mechanical, electrical and optical characteristics, view the datasheet on the LUXEON IR ONXY product page.

The typical emission spectrum is shown in Figure 8 below; note that a significant amount of the blue pump light is transmitted through the phosphor. Since the distribution of the blue light is roughly the same as the IR light, and the infrared is basically invisible to the human eye, the blue light can be used to "aim" the IR illumination in the right direction. For the situation where the blue light is not needed or deemed too intrusive, it can be blocked by a Long Pass filter that lets through only IR light.

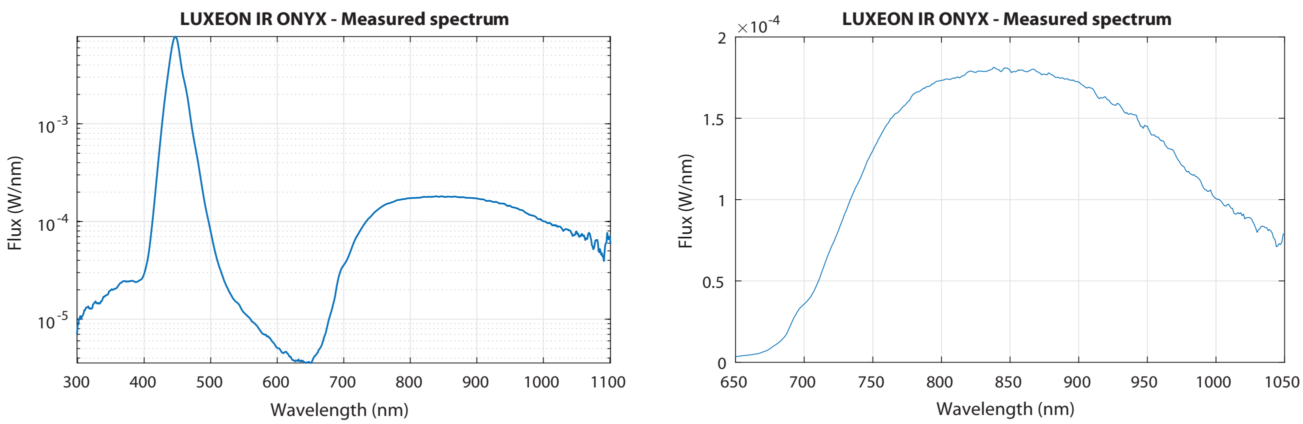

Figure 8. Typical output spectrum of the LUXEON IR ONYX broadband emitter at 350mA drive current and 25°C case temperature. Left: Full spectrm on log scale, including blue light. Right: IR spectrum.

For a drive current of 350mA, the typical output flux is 50mW, with a spectral power density of 50–180 uW/nm in the range of 700nm–1050nm.

3.2 Output Flux and Spectrum Dependence on Temperature

As shown in Figure 6, a broadband emitter is made of two parts, a blue pump LED and a wavelength-converting phosphor. Blue LEDs efficiency (and, by consequence, the amount of emitted blue light) and phosphor's conversion efficiency are lower at higher temperatures,[2] which has an impact of the output flux, as shown in Figure 9 below.

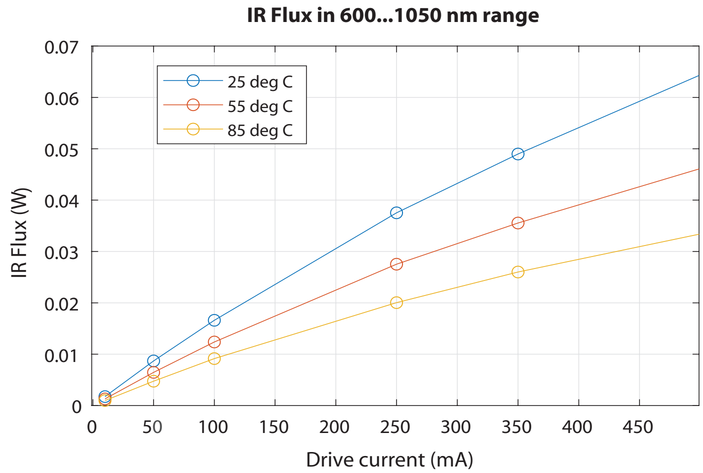

Figure 9. IR flux output of LUXEON IR ONYX vs. drive current at different case temperatures.

A more subtle effect of temperature increases is a change of the spectrum shape. This is due to the fact that, in order to broaden the IR emission spectrum, the phosphor is made out of two components, which respond differently to temperature changes, as shown in Figure 10.

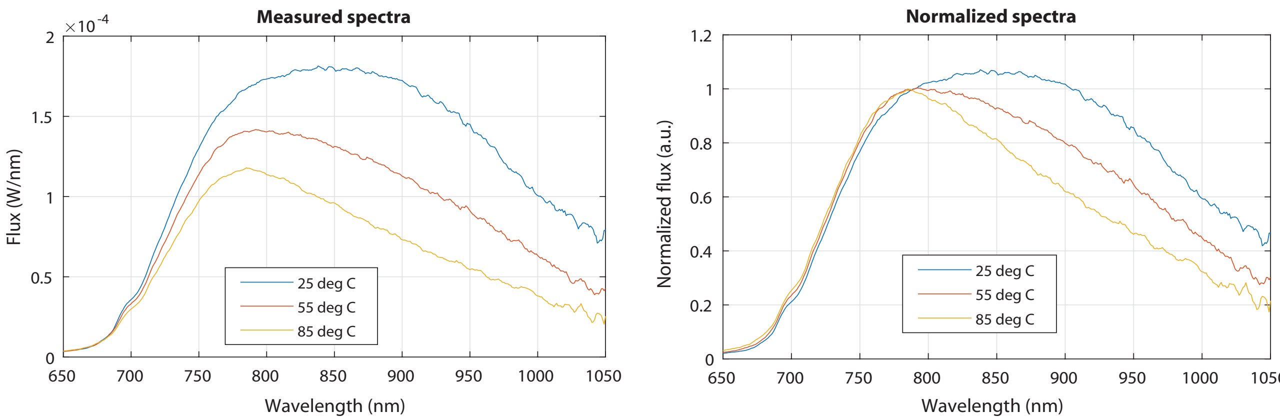

Figure 10. Output spectrum of LUXEON IR ONYX at different case temperatures. Drive current = 350mA.
Left: Measured spectra. Right: Spectra normalized to their value at 790nm, in order to make shape comparison easier.

So far in this document, "temperature" has meant ambient/case temperature; however, during operation, the LED itself produces heat, which leads to an increase in junction temperature and, as discussed earlier, a decrease in emitted blue flux. Depending on the geometry and heat management capabilities of the printed circuit board (PCB) on which the LED is mounted, this may lead to an increase in phosphor temperature, too. In the end, the effective temperature of the junction is determined by the ambient temperature and the amount of heat generated.

Two factors that have a direct impact on the junction temperature are the drive current (higher current means more heat is generated) and, when operating in pulsed mode, the pulse length/duty cycle, a lower duty cycle would allow heat removal between pulses, thus decreasing the junction temperature.

Both parameters can be used to control the amount of light emitted within a given time span; this is especially interesting in spectrometry applications, where the amount of light needed for a good measurement is not always known before the measurement.[3] The amount of light collected can be controlled either by increasing the flux of emitted light (via the drive current) or by increasing the exposure time of the sensor, which also means an increase in the pulse length, since the light source needs to be on during this time.

The impact of these two factors on spectrum shape will be examined in more detail in the next two sections.

3.3 Spectrum Dependence on Drive Current

Increasing the drive current leads to an increase in output IR flux of the LUXEON IR ONYX; however, Figure 11 shows that the overall shape of the spectrum doesn't change significantly.

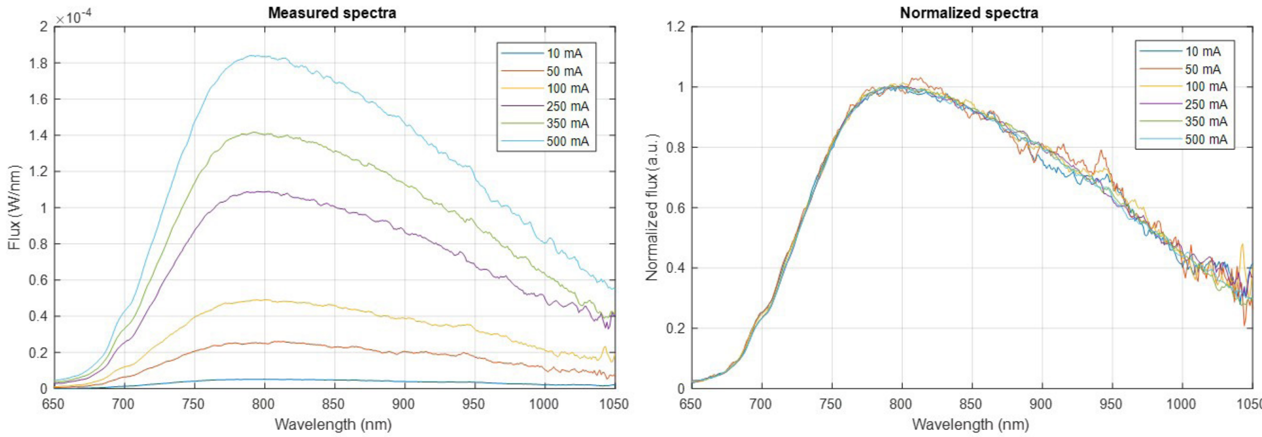

Figure 11. Output spectra of LUXEON IR ONYX at different drive currents. Case temperature = 55°C. Left: Measured spectra. Right: Spectra normalized to their value at 790nm, in order to make shape comparison easier.

3.4 Spectrum Dependence on Pulse Length (Pulsed Regime)

A common approach for making sure that the sensor collects enough light is to increase the integration time, while keeping the drive current of the light source constant.4 This means that the light source is on as long as the sensor collects light.

The plots below show the shape of the spectrum at different ambient/case temperatures (25, 55 and 85 degrees Celsius, respectively) for three integration times/pulse length (0.2ms, 3ms and 20ms). The 0.2ms and 3ms measurements were done with repetitive pulses (50 Hz repetition rate), while the 20ms measurement was single pulse.[5]

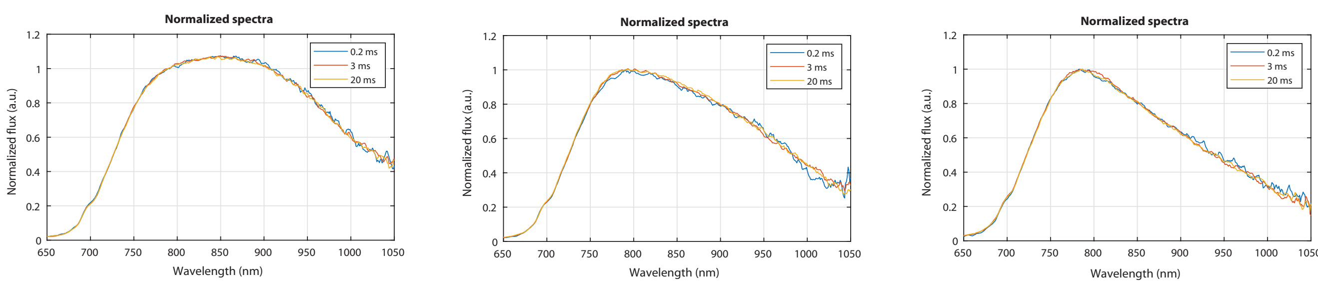

Figure 12. Normalized output spectra of LUXEON IR ONYX at different pulse lengths. Case temperature: left = 25°C, center = 55°C and right = 85°C. Spectra are normalized to their value at 790nm, in order to make shape comparison easier.

For a given ambient temperature, the shape of the spectrum stays the same, regardless of the pulse length.

3.5 Heat Management Considerations—Type of PCB

The results presented so far were obtained with a LUXEON IR ONYX mounted on a Metal Core (MC) PCB. No additional heat management (e.g. heatsinks, active cooling and forced convection) was used, besides the PCB intrinsic heat transfer capabilities.

As a "worst case" situation, an additional measurement was done with the emitter mounted on a standard FR4 PCB, using different pulse lengths at a drive current of 400mA.

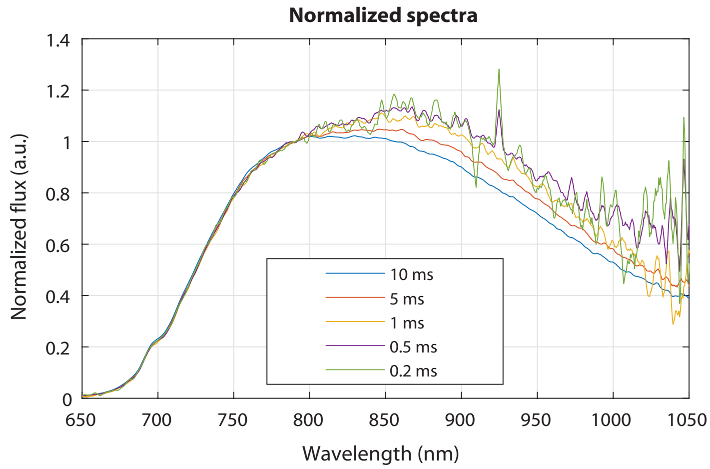

Figure 13. Normalized output spectra of LUXEON IR ONYX mounted on a FR4 PCB at different pulse lengths and repetition rate of 20 Hz. Case temperature = 25°C, drive current 400mA. Spectra are normalized to their value at 790nm, in order to make shape comparison easier.

In this case (FR4 PCB) the pulse length does have an influence on the shape of the spectrum for pulses longer than several milliseconds.

3.6 Calibrating the Spectrum—Reference Measurements

As discussed in the first section, very often spectrometric measurements rely on a reference measurement; this is because reflection/transmission measurements are relative measurements, where the spectrum reflected/transmitted by an object is compared against a reference spectrum. For a reflectivity measurement, this requires measuring first the reflectivity of a known surface, which means that, besides the spectrometer itself and the light source, additional accessories (e.g. calibrated reflectors) are needed. This is not an issue in a laboratory setting, where measurements can be done in controlled conditions. The influence of various parameter on light sources output flux and spectrum shape still needs to be accounted for in the design of the spectrometry system, in order to make sure that it will provide adequate illumination under all circumstances, but, as long as a reference spectrum can be measured, knowing the actual emission spectrum of the light source for each measurement is not necessary.

However, this might not be the case for some consumer applications, where the end-user usually does not have the expertise needed to acquire a reference spectrum. On top of that, carrying around additional accessories for reference measurement is impractical. In such cases, knowing the actual spectrum emitted by the light source in different circumstances (ambient temperature, pulse length, drive current, etc.) would simplify the end-user experience, since it would eliminate the need for a reference measurement.

Measuring the emitted flux is relatively straightforward; a photodiode that "sees" a small part of the total flux is enough to determine the overall amount of light emitted by the LED.

However, measuring the shape of the emitted spectrum is a different matter. The previous sections indicated that ambient/case temperature is the factor with highest impact on spectrum shape.

So, assuming ambient temperature is known, would it be possible to calculate the flux and spectrum shape of the emitted light? A straightforward approach is to use measured spectra at different temperatures to make a linear fit for output flux at each wavelength vs. temperature; this model can then be used to predict the output spectrum at any temperature. The outcome of this approach is shown in Figure 14 below.

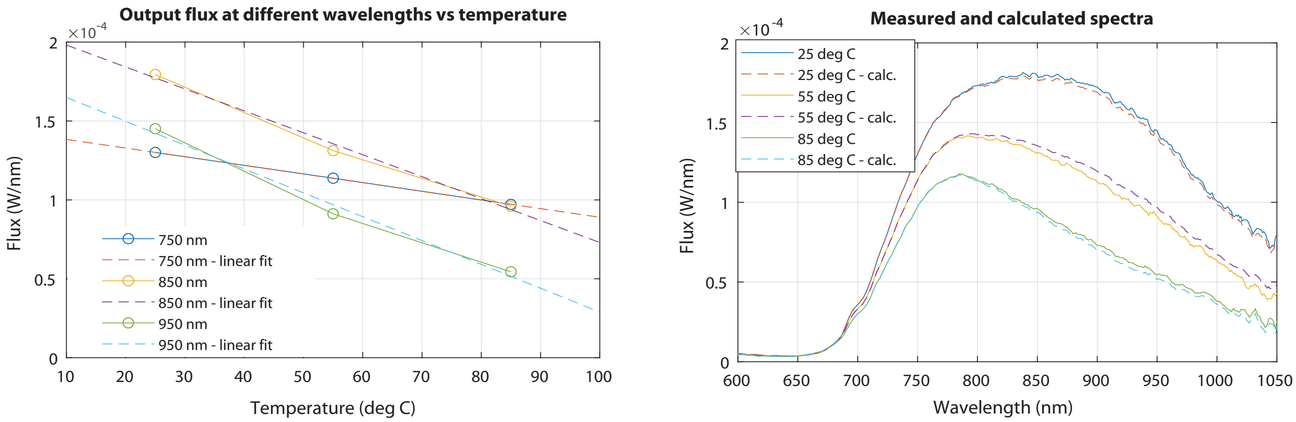

Figure 14. Left: example of linear fitting measured data at 3 different wavelengths (full lines–measured flux at each wavelength, dashed lines–linear fit). Right: Measured (full lines) and calculated based on the linear fit (dashed lines) spectral output of LUXEON IR ONYX at different ambient/case temperatures. Drive current = 350mA.

A simple linear fit allows a very good estimation of output spectrum versus temperature; this approach might be suitable for most real-life applications.[6] The fit can be implemented either by providing the linear fit parameters at each wavelength (as shown in Figure 14), or via a pre-generated lookup table.

3.7 Measurement Example

Figure 15 below shows an example of transmission spectrum measurement—a LUXEON IR ONYX emitter driven at 300mA was used as a light source and an Avantes ULS2048 spectrometer as a detector.[7] The detector was placed 2cm away from the light source and a reference measurement was taken. Then a small crucible (1cm in the direction light was travelling) filled with the test liquid (water and ethanol respectively) was inserted in the optical path and another spectrum was measured. Basically, this is the transmission setup described in Figure 4. The transmission spectra were calculated by dividing the second spectrum by the reference spectrum.

For both spectra, absorption features typical to both liquids are clearly visible (at 970nm for water, 910nm and 1040nm for ethanol).

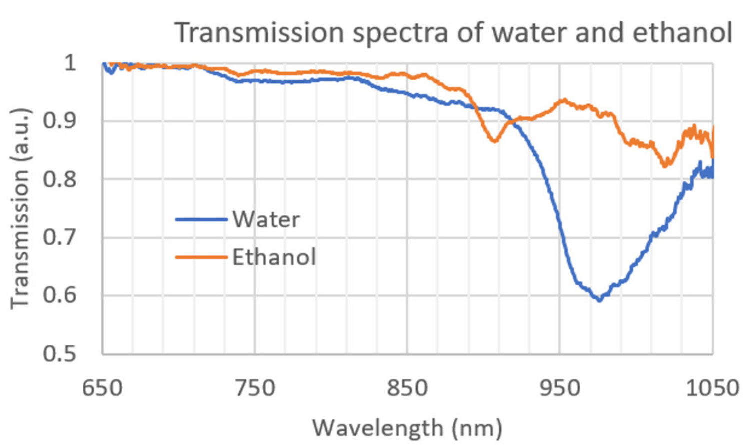

Figure 15. Transmission of water and ethanol, measured using an LUXEON IR ONYX emitter as light source. Optical path length through the liquid: 1cm. Spectra were normalized to transmission value at 670nm.

4. Conclusions and Recommendations

LUXEON IR ONYX is a compact, robust broadband emitter that extends the emission range of phosphor-based LEDs beyond 700nm. Its flat and smooth emission spectrum makes it especially suitable for spectrometry applications. Keeping in mind the following “rules of thumb” when designing your spectrometry system will help to maximize its performance and simplify the measurement procedure; of course, in the end, actual requirements for each particular application will determine which trade-offs are optimal in each case:

- Having an ambient temperature sensor on the same PCB allows for a more accurate estimation of output flux and spectrum
- Building in heat transfer capabilities always helps, especially for applications that require a high stability of spectrum
- If heat management is difficult for a particular application, keeping pulses short also leads to a more stable output spectrum
- The default emission profile of the LUXEON IR ONYX is Lambertian, covering a wide output angle. For applications that require a narrower angle, secondary optics can be used to increase the emitted intensity in forward direction by a factor of 5, which would allow decreasing drive current and/or pulse length

5. References

1. The emission spectrum of LUXEON IR ONYX extends to 1200nm; the sensitivity of silicon detectors is very low at wavelengths above 1000nm, and it drops to 0 above 1100nm, so a different type of detector would be needed to access this wavelength range.
2. This is a general property of LED emitters and phosphor converters, regardless of wavelength.
3. The amount of light needed depends on the material being measured, whose properties might be unknown.
4. Keeping the current constant has the additional benefit of simpler electric driver compared to the one required for a tunable current.
5. The measurements shown in this document are single 20ms pulse, unless otherwise stated.
6. Especially given that, with some thermal management, spectrum shape does not depend on pulse length and drive current.
7. Light was coupled in the spectrometer via a Cosine Corrector and optical fiber.

About Lumileds

Companies developing automotive, mobile, IoT and illumination lighting applications need a partner who can collaborate with them to push the boundaries of light. With over 100 years of inventions and industry firsts, Lumileds is a global lighting solutions company that helps customers around the world deliver differentiated solutions to gain and maintain a competitive edge. As the inventor of Xenon technology, a pioneer in halogen lighting and the leader in high performance LEDs, Lumileds builds innovation, quality and reliability into its technology, products and every customer engagement. Together with its customers, Lumileds is making the world better, safer, more beautiful—with light.

To learn more about our lighting solutions, visit lumileds.com.

lumileds.com