023

TESTING WITH LED SOURCES

TECHNICAL NOTE

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As spectral resolution gets increasingly important in today's measurements, a better understanding of source spectral distribution characteristics is required. This article reviews the basics of light-emitting diodes (LEDs)–whether they are edge-emitting (EELED), surface-emitting, or super-luminescent diodes (SLEDs)–in test and measurement applications.

First, we will discuss the semiconductor design required to produce a LED and give examples of structures commonly available in commercial source products. Since a LED's emission wavelength depends exclusively on material compounds, the examples provided are valid for most spectral windows.

Next, we will briefly review some of the most important test applications using LEDs. From a passive-component-testing point of view, we are particularly interested in straightforward spectral insertion loss using an optical spectrum analyzer.

Testing with LEDs necessitates in-depth knowledge of their physical properties in order to cope with measurement uncertainties, especially when finer spectral resolution is required. By looking at the change in central wavelength with applied current, the long-term spectrum stability for different resolution bandwidths, and some qualitative measurement of the degree of polarization of LEDs over narrower spectral windows, we hope to provide helpful insight into LED testing. To illustrate these various elements, we will use EXFO's FLS-2200 Broadband Source.

What Is a LED?

At the basis of diode operation is the p-n junction. The semiconductor conduction band fills with electrons when a current is injected across the junction, generating light when the electrons and holes are recombined. The frequency of light emission depends on the composition of the material and on the relative proportion of the semiconductor constituents.

This recombination is mainly spontaneous; that is, an emission that is not very coherent. For a light-emitting diode (LED), the light emission is essentially made up of photons that do not have phase or frequency relations. The 3 dB bandwidth ranges from 25 to 100 nm (the 3 dB bandwidth of a source is also called full width half maximum or FWHM).

Different Types of LEDs

Edge-Emitting LEDs

An EELED (see Figure 1) produces light in the active layer of the p-n junction and emits the light from the side of the diode, in the shape of an elliptical cone. The angle that shapes this cone is typically 30 degrees perpendicular to the layers and 120 degrees at the active layer.

It is important to remember that the power in EELEDs increases with the current and that it is preferable to use high-intensity currents for these types of sources because they are not very efficient at low intensity. At the output, between 500 µW and 1 mW of total power can be obtained by this type of LED.

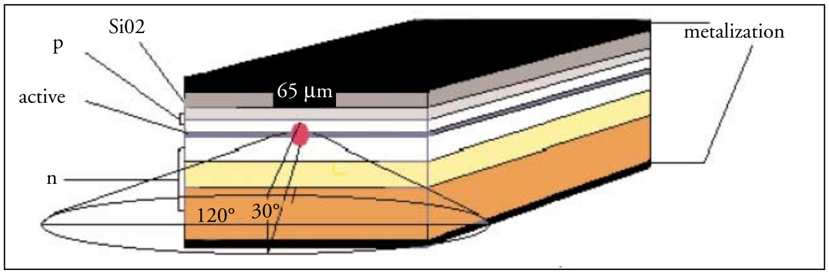


Figure 1 Schematic of edge-emitting LED 1

Surface-Emitting LEDs

In the case of surface-emitting light diodes (see Figure 2), the light beam is emitted from the top of the diode, and not from the side.

The guiding has a circular symmetry and the beam's emission cone is typically 120°. This large angle is caused by a difference in refractive index between the semiconductor (high index) and the fiber or the glass material used for coupling with the fiber (low index). The total output power is similar to that of the EELEDs; that is, between 500 µW and 1 mW.

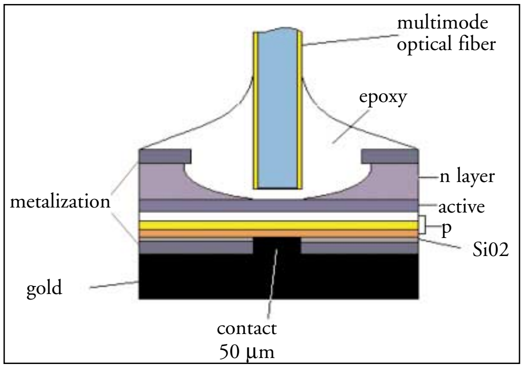


Figure 2 Schematic of surface-emitting LED 2

Superluminescent LEDs

SLEDs are different from EELEDs and surface-emitting LEDs in several ways. In an SLED, there is stimulated emission with amplification but insufficient feedback for laser oscillations to occur. Light coming from an SLED is more coherent and its degree of polarization is generally higher. The output beam is more directional, like a laser–which allows for better coupling in the fibers–and the spectral width is narrower.

A U-shaped cut in the active layer increases the density of the carriers, which improves the power efficiency (see Figure 3), reaching 18 or 20 mW.

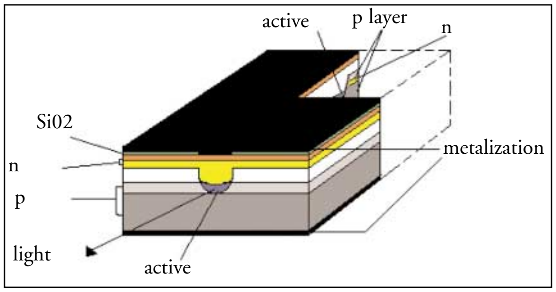


Figure 3 Schematic of SLED

A warmup time of 30 minutes is recommended before starting measurements.

For most accurate measurements with higher resolution, we suggest using two 1x2 switches and taking a reference before each measurement. Figure 4 illustrates the proposed setup.

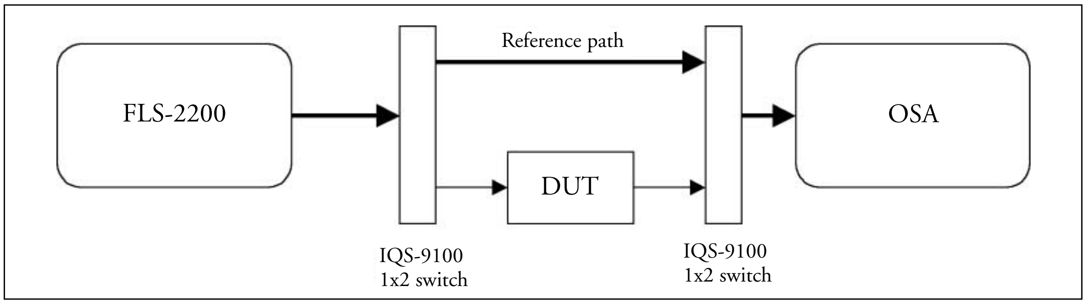


Figure 4 Proposed test setup to compensate for slow spectrum drift of the input signal for high-resolution, long-term test applications

Test and Measurement Applications for LEDs

LEDs are widely used in testing and measurement. The main application is the characterization of passive components that are massively used in fiber-optic transmission networks. For example, an optical spectrum analyzer (OSA) can be used to provide important information on different aspects of a filter as a function of wavelength.

Insertion Loss Measurement

In the following measurement, we have calculated the spectral insertion loss of a bandpass filter by first taking a reference trace from a LED with an OSA (Figure 5a) and then taking a measurement trace after the DUT has been added (Figure 5b). The IL is the difference between the two curves. In figure 6, the upper spectrum is the reference (flat black line); the lower spectrum is obtained with the filter inserted between the source and the OSA. If you subtract the lower spectrum from the upper one, you obtain the insertion loss of the filter (blue line in Figure 6 with values expressed in dB). LEDs have medium spectral density (especially when compared to amplified spontaneous-emission (ASE) sources), limiting the OSA's maximum measurable insertion loss.

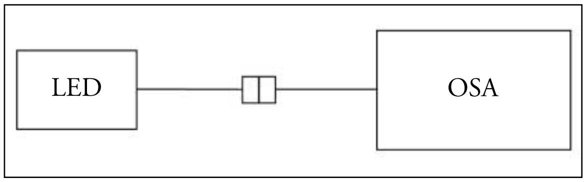


Figure 5a Reference trace

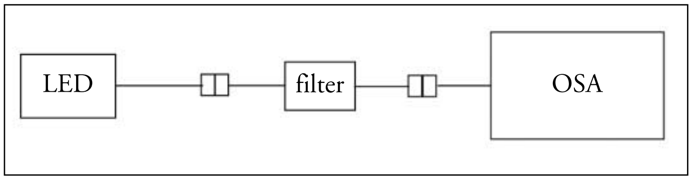
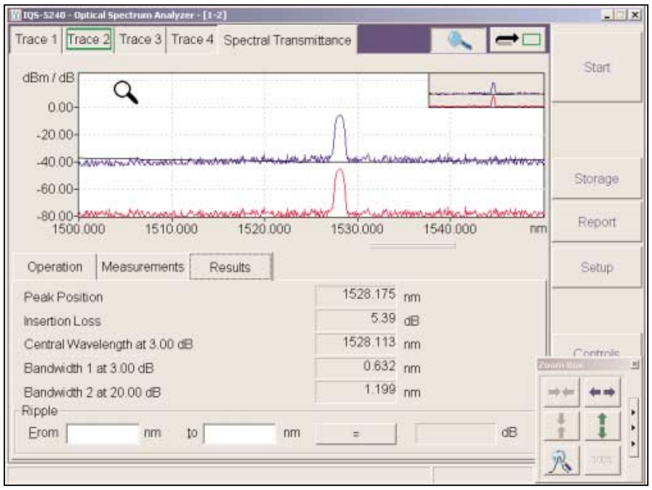


Figure 5b Measurement trace



Peak Position 1528.175 nm
Insertion Loss 5.39 dB
Central Wavelength at 3.00 dB 1528.113 nm
Bandwidth 1 at 3.00 dB 0.632 nm
Bandwidth 2 at 20.00 dB 1.199 nm
Ripple
From nm to nm = dB

Figure 6 Reference trace (straight black line), measured (bottom, red line) trace and calculated spectral insertion-loss measurement (top, blue line) over a bandpass filter

PMD Measurement

For component manufacturers, another key application is PMD measurement based on the interferometric method. The main characteristic for a broadband source when performing a PMD test is its large spectral range. Having a broad spectrum (and, therefore, low coherence) is important in order to measure small PMD values, as it allows for repeatable measurements and ensures that the following measurements will be similar to the previous ones. The output power spectrum of EXFO's FLS-2200 allows the user to calculate PMD in all ranges, as it is available in all bands (1300, 1485, 1550, 1620 nm).

Combined with EXFO's passive depolarizer (M9700), these sources provide a depolarized signal of up to 2 dBm, which is required for very small PMD measurement (even down to 20 and 10 fs with EXFO's FPMD-5600).

Optional Low-Coherence Reflectometry

As for optical low-coherence reflectometry (OLCR) measurements, LEDs are extremely useful. When a source has a large spectral width, it enables two very closely spaced reflectance events to be separated. The larger the spectral width of a source, the lower the coherence; a wide-source bandwidth is a must in OLCR measurements. The power of the source should also be considered because high power will make the detection of weak reflectance events easier.

Characteristics of LED Sources

LED sources are mainly characterized by the following: central wavelength, bandwidth, ripple, power stability, degree of polarization, as well as the relation between emitted power and current intensity.

Central Wavelength and 3 dB Bandwidth

An important specification for a LED is the central wavelength, which can be calculated in two different ways. The first method is to take the most intense point on the spectrum (peak wavelength), and the second method involves calculating the 3 dB width and identifying the wavelength at the center of this range (see Figure 7). The latter, using the full width at half maximum (FWHM), is probably the most common because it takes possible curve deformities into consideration. The central wavelengths of EXFO's FLS-2200 models are as follows:

- 980 nm ± 10 nm
- 1300 nm ± 20 nm
- 1485 nm ± 15 nm
- 1550 nm ± 10 nm
- 1610 nm ± 15 nm

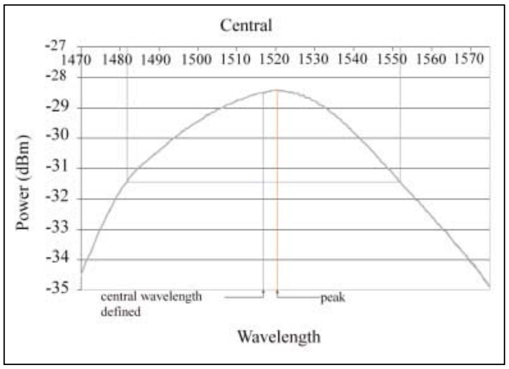


Figure 7 Central wavelength measurement based on two methods
(mid-point-wavelength of 3 dB bandwidth and peak-emission-point measurements)

Spectral Modulation

An aspect that should not be neglected is the possible presence of spectral modulations (ripple). These modulations are very apparent when the resolution of the spectrum analyzer used is increased (see Figure 8). Such a modulation generally comes from an undesirable Fabry-Perot etalon present between the LED's front facet and the input fiber. Better control of internal reflections reduces the Fabry-Perot effect. It is interesting to note that the length of the Fabry-Perot etalon (L) is equal to c/2Dn, where c is the speed of the light, n is the refractive index of the material, and D is the modulation period expressed in Hz. Typically, L is around 1 mm, which is equivalent to the distance of the interface created by the LED output and the fiber input or lens facets used for coupling in the fiber.

The potential detrimental effect of the presence of ripple along the spectrum is counteracted by the fact that this ripple is very repeatable over time, as with EXFO's FLS-2200 Broadband Source. The reference performed before a series of insertion loss measurements will ensure that the ripple does not affect any subsequent measurement.

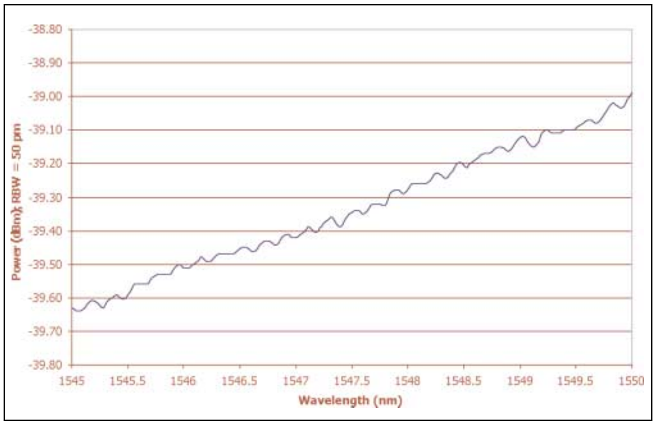


Figure 8 Presence of low-amplitude but repeatable spectral modulation of the FLS-2200-SCL around 1550 nm with a resolution bandwidth set at 0.05 nm

Output Power

Since output power varies with injected current, the relation between the two must be known. The FLS-2200 Broadband source has been designed so that the user can select the current flowing through each single source (even for dual-source models). The minimum current has been set to 50 mA. As seen in Figure 9, power increases with current, but saturation occurs at high current. In this particular case, the power saturates at around 210 mA. For the FLS-2200, each SLED has its own limit, generally around 200 to 300 mA.

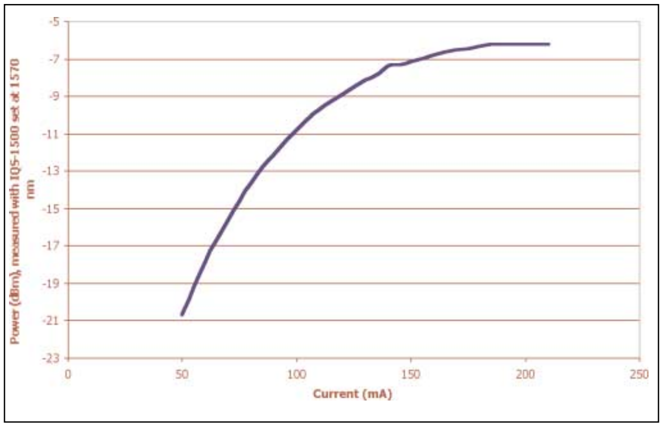


Figure 9 Typical L-I (light vs. current) curve for the FLS-2200-SCL, with only one active SLED

The variation of the current can also produce spectral displacement. For the SLED tested in the example below, the spectral displacement, measured with the width at mid-height (at –3 dB), is around 6.5 nm (see Figure 10). Also, the spectral width obtained with a low-intensity current is less significant than the width obtained with a high current. Therefore, to obtain the full capacity of the SLEDs, it is preferable to set the maximum current, as it will produce greater spectral width and power.

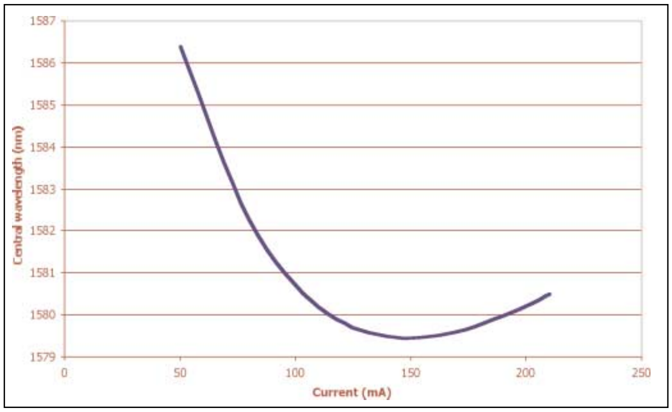


Figure 10 Typical wavelength shift for the FLS-2200-SCL, with only one active SLED

Spectral Stability

During long-term testing, and when high resolution (<1 nm) is needed for the measurement, spectral density stability is extremely important. To provide an order of magnitude for this stability, Figures 11 and 12 show examples of spectra generated by the FLS-2200-SCL Broadband Source, which covers the 1460 to 1625 nm range. The spectra in these examples were acquired using an OSA with two different resolution bandwidths (0.05 nm and 1 nm). As shown, with an RBW of 0.05 nm, the maximum power density is around –36 dBm and may vary up to 0.3 dB in 16 hours. With 1 nm RBW, the maximum power becomes –23 dBm and only varies by 0.05 dB in the same 16-hour period. It is therefore advisable, when performing tests over a long period of time, that a resolution window of at least 0.1 to 1 nm be used.

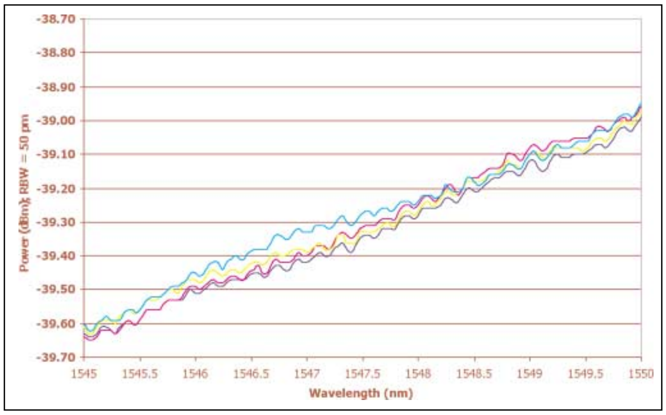


Figure 11 Zoom of the spectral stability of FLS-2200-SCL source over 16 hours, RBW set to 0.050 nm

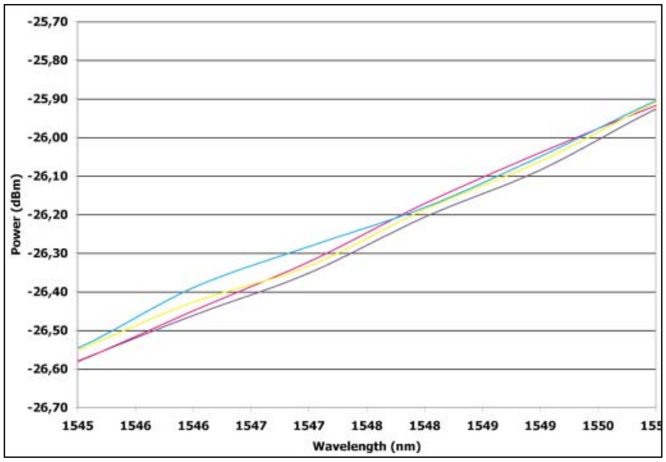


Figure 12 Same source (FLS-2200-SCL), spectral stability over 16 hours, RBW set to 1 nm

Coherence of Emitted Light

LEDs are commonly said to be incoherent, but even if the level of coherence is low, rectangular guiding structures typically make the output beam partially polarized, especially for SLEDs. The degree of polarization will vary with the RBW selected to measure this parameter. When testing devices with high PDL, it is good practice to use a passive or active depolarizer right after the source. The degree of polarization (DOP) will be reduced close to zero, even for SLEDs. However, if we start looking at smaller slices (smaller RBW), a residual degree of polarization of 10 to 30%, or even 90% in some cases, can cause measurement errors, especially when the polarization dependency of the DUT itself and of the optical spectrum analyzer used to perform the measurement are important.

Conclusion

As explained above, the optical performance of LEDs in the testing and measurement of passive components is of major concern, as LEDs can significantly affect measurement quality and accuracy. Overall, SLEDs are cost-effective source products, but their use is best for applications that require average dynamic range since they are typically 15 dB less powerful than ASE sources. However, this is greatly compensated by the fact that they do cover a wide wavelength range–about 100 nm–and they are available at various wavelength ranges along the telecommunication transmission bands.

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