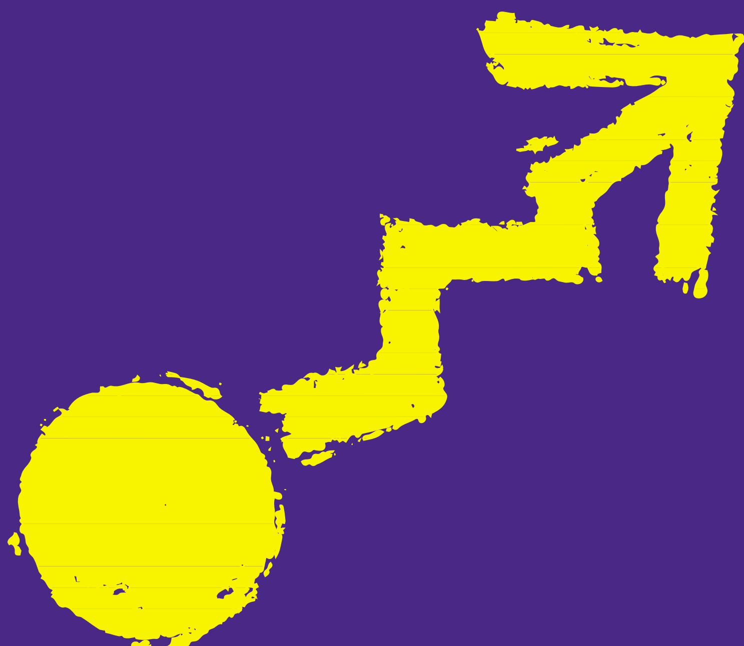
APPLICATION NOTE

No. 2

Applications of the Integrating Sphere Optical Power Measurement System in Laser Diode Characterization



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CAUTION

In all experiments described in this Application Note the laser diode assembly; including the laser diode, laser diode mount, and integrating sphere; should be fully covered for laser safety purposes. In addition, appropriate laser protective eyewear should be worn for protection against the emitted radiation.

AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION

Applications of the Integrating Sphere Optical Power Measurement System in Laser Diode Characterization

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Introduction

Integrating spheres are useful for measurement of divergent light emitted from laser diodes. Typically the laser diode is positioned very close to the internal port of the sphere (Figure 1) and light emitted from the front facet of the device is collected by the internal cavity of the integrating sphere which is coated with a highly reflective material. A baffle positioned between the input port and the detector port prevents the detector from directly viewing the emitting aperture of the laser. What the detector sees is a uniformly illuminated environment within the cavity of the sphere.

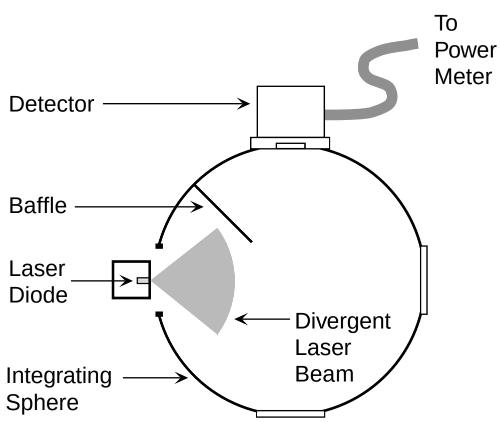


Figure 1. Schematic representation of the integrating sphere (top view), showing the principle of operation in laser diode output light measurement. Using an integrating sphere it is possible to collect all of the light emitted from the front facet of a device that has a highly divergent beam.

An integrating sphere and calibrated detector combination setup is suitable for accurate, absolute value light power measurement of laser diodes. Unlike when using simply a detector by itself, the measurements will be insensitive to errors caused by detector positioning or problems associated with overfilling or saturation of the active area of the detector.

In an integrating sphere the detected radiation flux is always a small fraction of the incident flux. This attenuation, caused by light reflecting many times before reaching the detector, makes the integrating sphere an ideal tool for measurement of output light power of high-power laser diodes.

Newport's Model 819S integrating spheres (Figure 2) are suitable for laser diode measurements because of their relatively thin walls, only a few millimeters thick, making it possible to position the laser diode very close to the internal cavity of the sphere. As a result every photon emitted from the front facet of the device finds its way into the cavity of the sphere. The choice of detector depends on the wavelength of emission of the laser diode. A variety of semiconductor detectors are available to cover the entire spectral range from about 200 nm up to 1800 nm. Newport's 818 Series family of semiconductor detectors include silicon, germanium, and InGaAs material based devices.

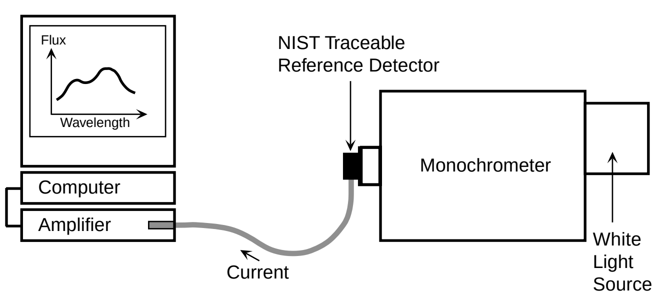
Figure 2. A 6 inch diameter and 4 inch diameter Model 819S integrating spheres equipped with 818-SL silicon detectors and the related stand assemblies and post hardware components (optional accessories). The stand assemblies shown here consist of: SP-2 (2 inch post), VPH-3 (3 inch post holder), B-3 (sliding base plate for the 6 inch sphere), and B-2 (sliding base plate for the 4 inch sphere).

Newport's integrating spheres and low-power detectors can be configured as a system to measure diverging light inputs. The assembly generally consists of a Model 819S integrating sphere with one of the 818 Series low-power semiconductor detectors, and is calibrated to NIST traceable standards. The calibration information is captured in the calibration module compatible with most of Newport's Optical Power Meters (Figure 3). A fiber optic connector port and fiber pigtailed collimator are optional accessories. The model number for the integrating sphere and detector combination shown in Figure 3 is: 819S-OPT-06-SL-CM-DV (stand assembly not included). The stand assembly consists of a 2 inch post (Model SP-2), 3 inch post holder (Model VPH-3), and a sliding base plate (Model B-3).

Figure 3. A 6 inch diameter Newport Model 819S-IS-6 integrating sphere, equipped with an 818-SL silicon detector, fiber pigtailed collimator and port adaptor, demonstrated with a Newport Model 1835-C optical power meter.

Calibration Technique

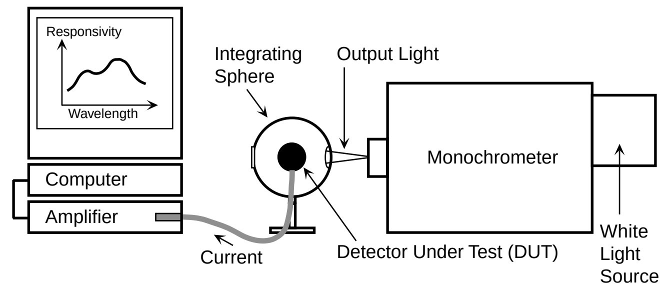
A double grating monochrometer and a NIST traceable reference detector are used to calibrate the integrating sphere and detector combinations. As a first step, the NIST traceable detector is placed in front of the monochrometer and its output current is measured for a specific range of wavelengths (Figure 4). For example, in the case of a Model 818-SL silicon detector this spectral range is from 400 nm to 1100 nm. This is done before every calibration run. The current values measured in this fashion are divided by the responsivity of the NIST traceable detector in order to determine the radiation flux from the monochrometer incident on the NIST traceable detector. Responsivity is defined as the ratio of electric current generated by the detector to the unit light power detected.



$$\text{Radiation Flux from Monochrometer (W)} = \frac{\text{Current from NIST detector (A)}}{\text{Responsivity of NIST detector (A/W)}}$$

Figure 4. Schematic diagram of the experimental laboratory setup used in the calibration of the Integrating Sphere Optical Power Measurement Systems. First a NIST traceable reference detector is placed in front of a monochrometer and the flux versus wavelength curve is obtained.

As a second step, the integrating sphere and detector combination setup is placed in front of the monochrometer and the output current from the detector is measured (Figure 5). These values are then divided by the radiation flux values obtained using the NIST traceable detector to determine the responsivity of the integrating sphere detector combination under test. The unit of responsivity is Amperes per Watt (A/W). The responsivity versus wavelength curves (Figures 6 and 7) basically tell us exactly how much current flows from the detector for each unit of power detected at each specific wavelength. These values are tabulated and plotted on a calibration data sheet provided with each integrating sphere detector combination. In most cases a second similar calibration is performed with an attenuator placed between the detector and the integrating sphere. In this manner the power measurement range of the entire setup is expanded. The calibration information is then captured in the calibration module which serves as the interface between the detector and the power meter.



$$\text{Responsivity of DUT (A/W)} = \frac{\text{Current from DUT (A)}}{\text{Radiation Flux from Monochrometer (W)}}$$

Figure 5. The integrating sphere equipped with semiconductor detector is positioned in front of the output port of a monochrometer and the responsivity versus wavelength data is measured.

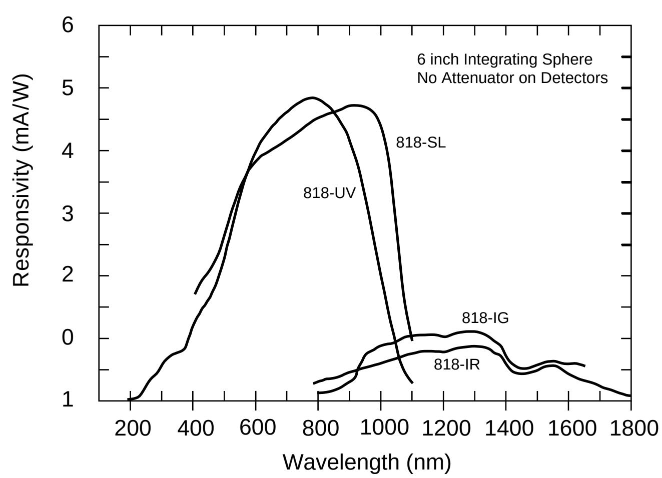


Figure 6. Typical example of an experimentally obtained responsitivity vs. wavelength information associated with a ***6 inch*** *diameter Model 819S integrating sphere and variety of four semiconductor detector combinations without the use of an attenuator positioned between the detector and the sphere.*

The measurement results shown in Figures 6 and 7 are associated with four flavors of semiconductor detectors, all of which are also available as stand alone products. The Models 818-UV and 818-SL are silicon based detectors. When mounted onto the 819S Series of integrating spheres the system as a whole is calibrated from 190 nm up to 1100 nm in the case of the 818-UV detector and 400 nm to 1100 nm in the case of the 818-SL detector.

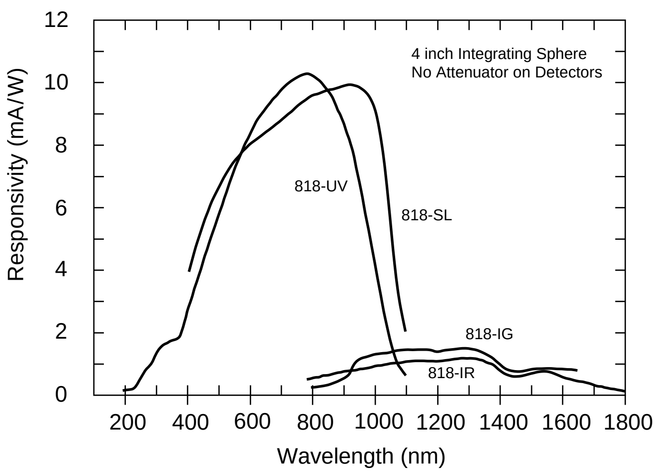


Figure 7. Typical example of an experimentally obtained responsivity vs. wavelength information associated with a ***4 inch*** *diameter Model 819S integrating sphere and variety of four semiconductor detector combinations without the use of an attenuator positioned between the detector and the sphere.*

The 818-IG detector is a germanium based detector and the integrating sphere detector combination in this case is calibrated from 800 nm to 1650 nm. The 818-IR detector is based on the InGaAs material system and the calibration for this integrating sphere detector combination is performed in the range of 780 nm to 1800 nm. Each of the detector and integrating sphere combinations mentioned is suitable for different applications depending on the wavelength of emission that is to be measured.

Laser Diode Optical Power Measurement Applications

The 819S family of integrating spheres can be used with a variety of laser diodes and laser diode mounts, depending on the application. For example, Figure 8 shows a 6 inch diameter 819S integrating sphere positioned in front of a Model 762 high-power laser diode mount that is typically used in high-power laser diode bar applications. Such laser diode bars typically emit light at a wavelength

Figure 8. A 6 inch diameter 819S integrating sphere equipped with an 818-SL detector. The laser is mounted on Newport's Model 762 air cooled high-power laser diode mount. This assembly is used for optical power measurements of a CW high-power laser diode bar.

of about 808 nm with CW output powers in excess of 30 Watts. The detector attached to the sphere, in this case, is a Model 818-SL silicon based semiconductor device. An attenuator is mounted on the detector. Calibrations in this case are performed both with the attenuator and without the attenuator.

In addition to a calibrated integrating sphere optical power measurement system, the testing of laser diodes requires other instrumentation. An optical power meter, laser diode driver, laser diode temperature controller, and laser diode mount onto which the device is placed are some of the necessary equipment. A computer could also be used to automate the instrument control and data acquisition process. Figure 9 shows the schematic diagram of a typical laser diode experimental test setup used in the laboratory.

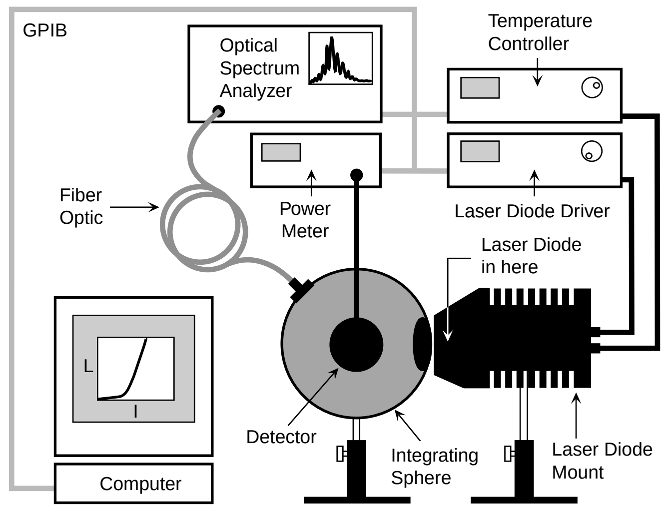


Figure 9. Schematic representation of a typical computer controlled laser diode test and characterization setup in which an integrating sphere is used to simultaneously measure both the output light power and the spectrum of a laser diode.

Figures 10 and 11 show the photographs of the actual test setup in an application involving light measurement of a laser diode with output power of up to about 3 Watts. With the exception of the computer, all instrumentation and components shown are offered by Newport. These include: optical power meter, integrating sphere optical power measurement system, laser diode driver, laser diode temperature controller, laser diode mount and connecting cables, and LabVIEW drivers for each instrument. For detailed information, technical specification, and pricing associated with each item refer to Newport's Photonics Catalog or contact one of Newport's Application Sales Engineers. Equipment and model numbers are listed in Table 1. Typical output light versus input current characteristic curves, generated using the experimental setup of Figure 10, is shown in Figures 12 and 13.

Figure 10. Test setup for output light power measurement of a laser diode with output power of up to about 3 Watts.

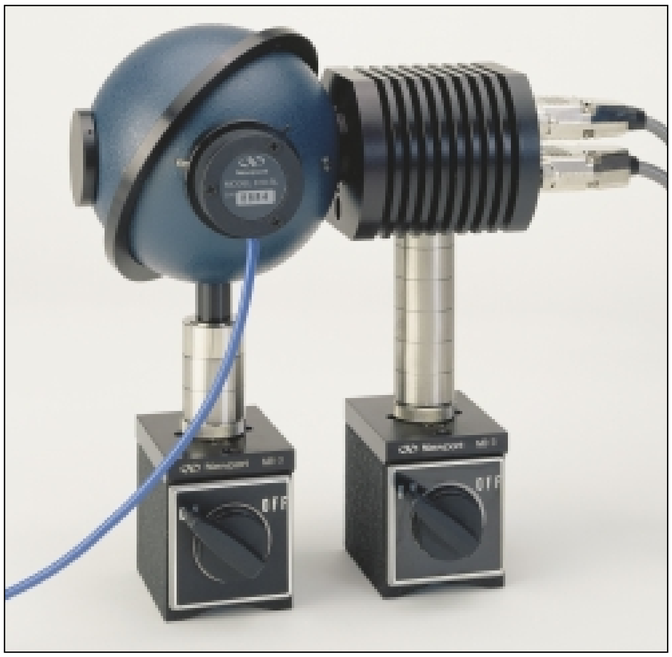


Figure 11. Close-up view of the calibrated 4 inch diameter integrating sphere and silicon detector assembly (Model 819S-04-SL-CM-DV) and laser diode mount (Model 760) used in the laser diode experimental setup of Figure 10.

Newport Model Number	Description
5030	Laser Diode Driver (3.0 Amp)
500-04	Laser Diode Driver/Mount Cable
3040	Temperature Controller
300-04	Temperature Controller/Mount Cable
760	Laser Diode Mount
TPS3	3 inch Laser Diode Mount Post
SS-1-A	(1/4)x20 to 8-32 Thread Adaptor
MB-3	Magnetic Base
1835-C	Optical Power Meter
819S-OPT-04-SL-CM-DV	Calibrated Integrating Sphere Optical Power Measurement System. (Includes an 819S-IS-4 integrating sphere and 818-SL silicon detector)
TPS1	1 inch Post
TPS.5	0.5 inch Post
SS-1-A	(1/4)x20 to 8-32 Thread Adaptor
MB-3	Magnetic Base

Table 1. List of key equipment, and part numbers, used to setup the test and measurement system shown in Figures 10 and 11 (not including the laser diode). Note that the Model 760 Laser Diode Mount does not come with a built-in TEC option. However, it has the cabling connections so that a TEC Controller can be used to drive a TEC built into the laser diode package itself.

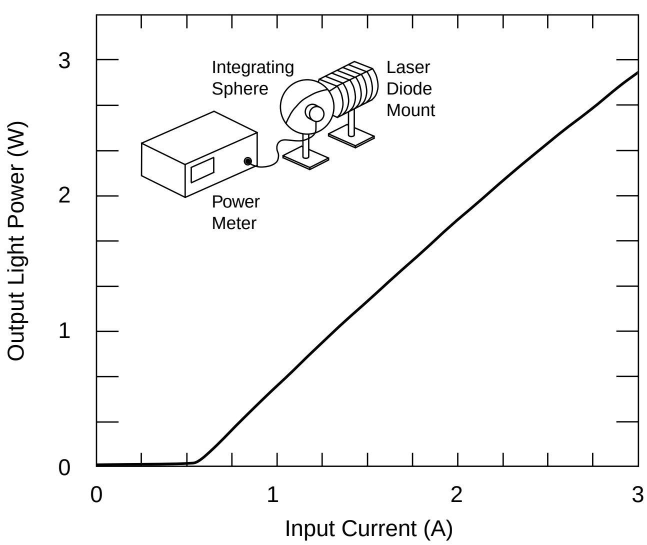


Figure 12. Output Light versus Input Current characteristic curve, also known as L.I. curve, associated with a laser diode tested using the experimental setup shown in Figure 10.

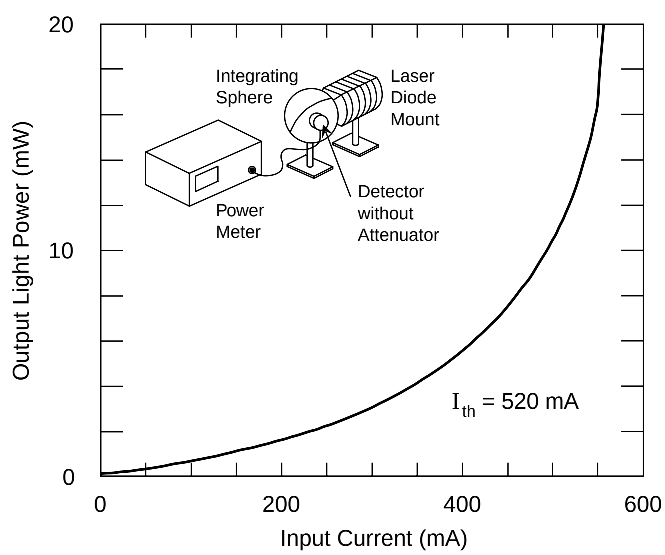


Figure 13. L.I. curve of the laser diode in the region below threshold current. For this measurement the attenuator was removed from the detector in order to increase the responsivity of the integrating sphere detector combination. The experimental setup used is the one shown in Figure 10.

Figures 14 and 15 show an experimental setup similar to the one shown in Figure 10. However, the setup shown in Figures 14 and 15 is suitable for applications involving high-power laser diodes emitting output powers in excess of 30 Watts. Such devices could require a water cooled laser diode mount such as Newport's Model 762W high-power laser diode mount. Table 2 lists equipment and components needed to setup this test and measurement system. Figure 16 shows the L.I. curve of a high-power laser diode tested and measured using the experimental setup shown in Figures 14 and 15.

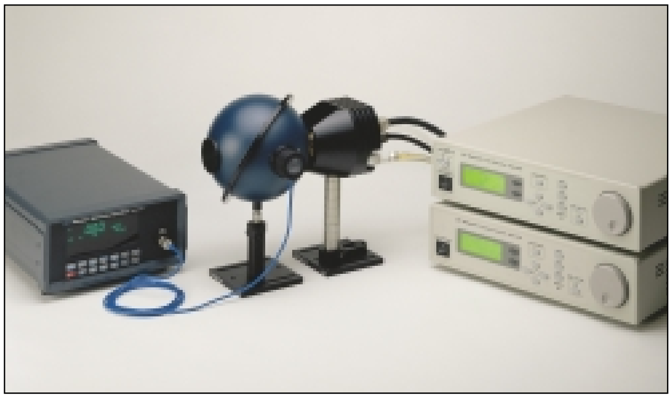


Figure 14. Test setup for output light power measurement of high-power laser diode bars.

Figure 15. Close-up view of the calibrated 6 inch diameter integrating sphere and silicon detector assembly (Model 819S-06-SL-CM-DV) and water cooled laser diode mount (Model 762W-xx-TE) used in the laser diode experimental setup of Figure 14. This laser diode mount has a built-in TEC.

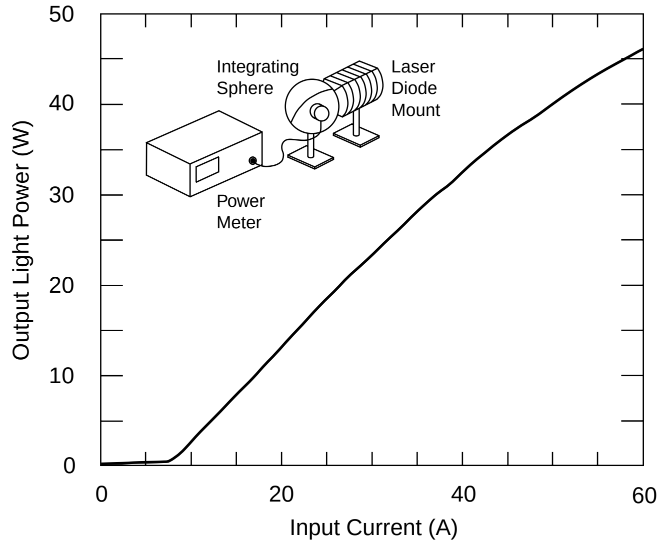


Figure 16. The L.I. curve of a high power laser diode bar emitting at a peak wavelength of 808 nm.

Newport Model Number	Description
5600-OPT-65	Laser Diode Driver (65 Amp)
5600-04	Laser Diode Driver/Mount Cable
3150	Temperature Controller
300-04	Temperature Controller/Mount Cable
762W-xx-TE	Water Cooled Laser Diode Mount with Thermoelectric Cooler
TPS3	3 inch Laser Diode Mount Post
TPS2	2 inch Laser Diode Mount Post
SB-TPS	Sliding Base Clamp
B-3	Sliding Base Plate
1835-C	Optical Power Meter
819S-OPT-06-SL-CM-DV	Calibrated Integrating Sphere Optical Power Measurement System. (Includes an 819S-IS-6 integrating sphere and 818-SL silicon detector)
SP-2	2 inch Post
VPH-3	3 inch Post Holder
B-3	Sliding Base Plate

Table 2. List of key equipment and part numbers used to setup the test and measurement system shown in Figure 14 (not including the laser diode). The recirculating water chiller used was a Model RTE 100 unit from NESLAB.

In addition to the 819S family of integrating spheres Newport offers the Model 818-IS-1 Universal Fiber Optic Detector, a small diameter integrating sphere with 2 detectors. This integrating sphere and detectors combination is most suitable for test and measurement of fiber pigtailed laser diodes typically used in telecommunication applications. The Model 818-IS-1 uses a dual detector design giving it a wavelength measurement range of 400 nm up to 1650 nm. This makes it suitable for use in accurate polarization independent measurements from all fiber optic sources. The Model 818-IS-1 can be used for measurement of input optical power levels of up to 200 mW. Figure 17 shows an experimental setup for measurement of the output light power of a fiber pigtailed, butterfly package style, telecom laser diode. Table 3 shows the list of necessary items to put together such experimental setup. Figure 18 shows the measured L.I. curve of the laser diode using the experimental setup of Figure 17. Figure 19 shows the collection of fiber optic connector adaptors included with Model 818-IS-1.

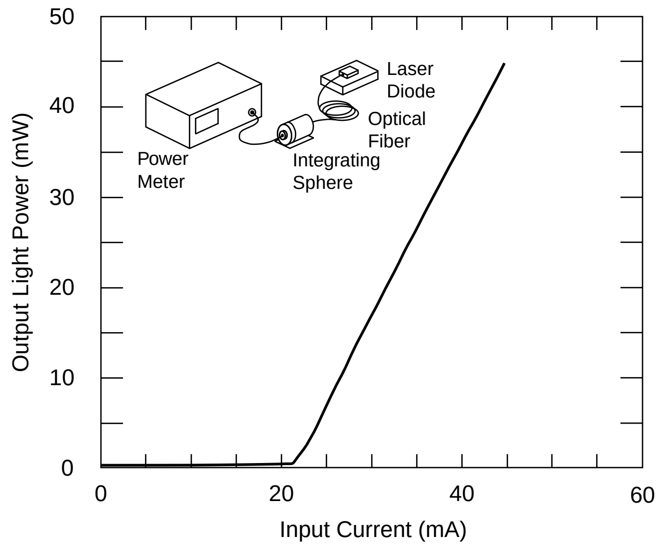


Figure 18. The L.I. curve of a telecommunication butterfly laser diode operating at about 1550 nm wavelength. The measurement was performed using the setup shown in Figure 17.

Figure 17. The experimental setup used to measure the output light power of a fiber pigtailed telecom laser diode. A small size diameter integrating sphere, Model 818-IS-1 Universal Fiber Optic Detector is shown with a 744-TEC Series Telecom Laser Diode Mount and Model 8008 Modular Laser Diode Controller.

Newport Model Number	**Description**
8008	Modular Laser Diode Controller
8605.8C	Combination LDD (500 mA) & TEC Module (up to 8 modules can be loaded in the 8008 controller)
744-TEC	Butterfly Telecom Laser Diode Mount with TEC.
500-04	LDD/Mount Cable
300-04	TEC/Mount Cable
818-IS-1	Universal Fiber Optic Detector (small diameter integrating sphere design)
1835-C	Optical Power Meter

Table 3. The list of key components used in the test and measurement system shown in Figure 17 (not including the laser diode).

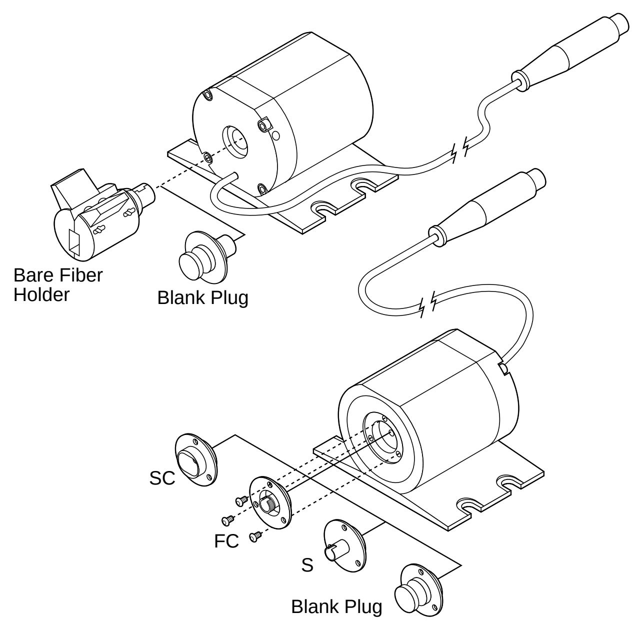


Figure 19. The Model 818-IS-1 Universal Fiber Optic Detector, includes a bare fiber holder and various fiber optic connector adaptors.

Laser Diode Spectral Measurement

In addition to measuring the output light power of laser diodes it is often necessary to perform spectral measurements too. The most convenient way to do this is to guide the laser output light to an optical spectrum analyzer using an optical fiber and a collimator. The collimator is a Graded Index (GRIN) lens assembly that is aligned and attached to an optical fiber. The collimator can then be positioned in front of the laser diode to collect the light and channel it to the optical spectrum analyzer which measures and displays the spectrum of the light emitted from the laser diode and determines the peak wavelength.

By attaching the fiber pigtailed collimator to the integrating sphere it is possible to perform both power and spectral measurements simultaneously. Figure 20 shows the schematic representation of this concept. In this manner each laser diode can be characterized more rapidly. In addition it eliminates the need to have the integrating sphere moved from its position in order to place the collimator in front of the laser, between the power and spectral measurements. Consequently there will be no need for operator interaction or the use of automatic motorized stages and controllers. In the case of an integrating sphere equipped with a fiber pibtailed collimator, it is best that the calibration of the integrating sphere and detector combination is done with this accessory attached. Figure 21 shows the experimental setup in which an integrating sphere equipped with a fiber pigtailed collimator is used for laser diode power and spectral measurement applications. The experimentally obtained spectral measurements are shown in Figure 22.

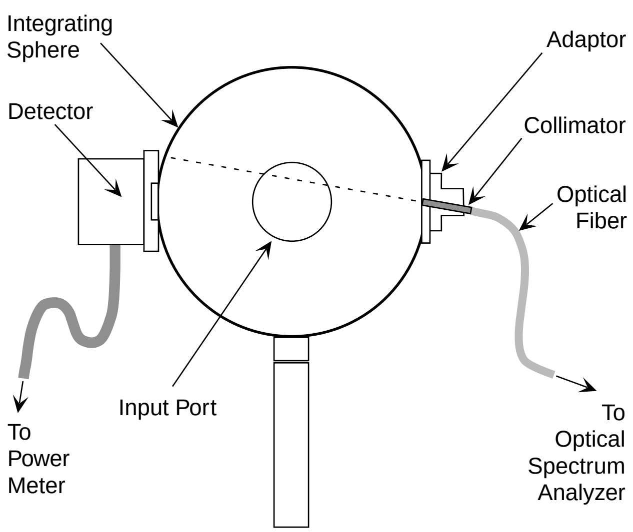


Figure 20. Schematic drawing of a fiber pigtailed collimator attached to an integrating sphere (front view). A special collimator-to-sphere adaptor is required for this purpose. The adaptor is designed in such fashion as to point the collimator slightly away from the detector surface and towards a highly reflective area of the sphere's interior wall in order to collect as much light as possible. The collimator-to-sphere adaptor is available through Newport.

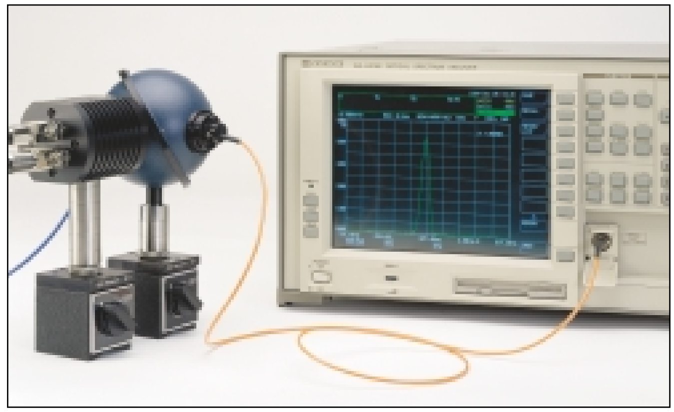


Figure 21. The use of an integrating sphere equipped with a fiber pigtailed collimator makes it possible to perform simultaneous output light power and spectral measurements of laser diodes. The fiber pigtailed collimator used here is Newport's Model F-COL-50-85. The optical fiber is a multimode version with a 50 µm diameter core. The one shown here is terminated at one end with a FC/PC connector and covered with a protective jacket. The fiber chosen for this purpose should have a specified center wavelength that is compatible with the wavelength of emission of the laser diode.

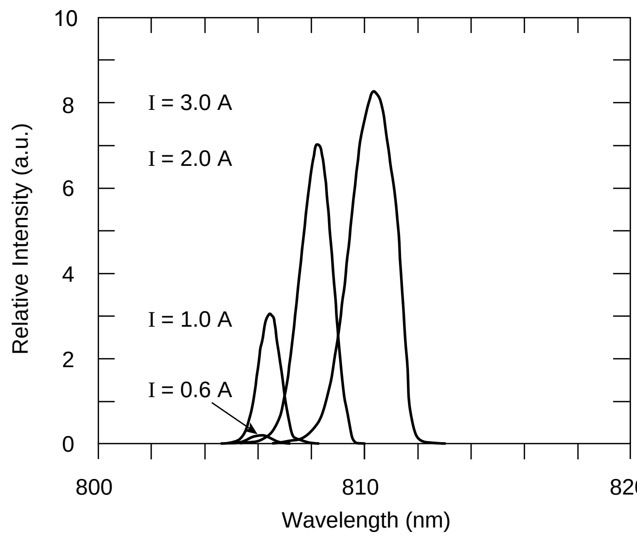


Figure 22. Spectral measurements of a laser diode at various operating currents, obtained using the experimental setup shown in Figure 21. The laser diode used here is the same device whose L.I. curve is shown in Figure 12.

Conclusion

Integrating spheres are very useful in light power measurements of sources with highly divergent output beams. These could include laser diodes with free space beams as well as fiber pigtailed devices. Depending on the type of device, its wavelength of emission, and the particular application in which it is being used, a variety of integrating sphere and detector combinations are available through Newport. These integrating sphere optical power measurement systems are fully calibrated (NIST traceable) to ensure precise, repeatable, and rapid laser diode output light power measurements suitable for use both in R&D and industrial settings.

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