

## Measuring Technique

### General

The production department for LEDs and displays has extensive measuring equipment. This guarantees reliable observation and monitoring of the high internal company standards which are reflected in our specifications and quality requirements.

Measurement of electrical variables such as forward voltage  $V_F$ , breakdown voltage  $V_R$ , junction capacitance  $C_j$ , is uncritical and corresponds to the usual measurement for all semiconductor components.

In addition, optical key parameters such as luminous intensity  $I_V$  and dominant wavelength  $\lambda_d$  (only for orange, yellow and green LEDs) etc. must be measured for all LEDs. The reproducibility of these results is guaranteed by the following measures:

- The result must be determined in accordance with standard specifications (DIN IEC 747).
- The result must be based on a calibrated standard.

The two criteria mentioned above, and the demands for high measuring speeds have led to the development of optoelectronic measuring methods and a graded measurement strategy for these parameters. This is explained in detail below.

The following measurement systems are used:

### Series Measurement

Each limit value specified by Vishay in the data sheet is checked on every component in the production department.

Rapid machine measurement with single pulses is performed which enables a throughput of several components per second.

Here, the measuring accuracy depends only on systematic errors.

### Random Sample Measurement

Samples of components are taken during the production process in accordance with a random sample plan. These components are measured again by means of a measuring method differing from series measurement. Here, the parameters of the components are compared with calibrated standards. The series measurement can thus be checked additionally.

### Measurement of Parameters with Typical Values

These parameters are generally defined by the technology used. The quality checks during production guarantee observation of the permissible tolerances. Measurement of these parameters is performed on random samples in a specially equipped testing laboratory.

### Calibration Measurements

Traceability to standards must be possible for measurement in accordance with 'Series', 'Random Sample' and 'Measurement of Parameters with Typical Values'. Reference components are checked at regular intervals for the above measurements in our calibration laboratory. In addition, random samples are compared with standards.

Components logged by the PTB (German Federal Standards Laboratory) or by recognized calibration institutes are available as calibrated standards for measurement comparison.

## Luminous Intensity

### Principle

The luminous intensity  $I_V$  (in mcd) is decisive for characterization of a light-emitting diode or an LED display, as it corresponds most closely to the application as an indicating component. It is defined as the luminous flux  $\Phi_V$  (in mlm) per solid angle unit  $\Omega$  (in sr), measured in the direction of the mechanical axis of the LED with a small measuring angle (compared with the radiation angle). Basically, the luminous intensity can be determined by measuring the radiant intensity  $I_e$  (in mW/sr) with a suitable detector (figure 1) and multiplying the measured value with the product of the photometric conversion factor  $K_m$  and spectral sensitivity factor  $V(\lambda)$  of the eye for daylight viewing (see DIN 5031, part 3), (figure 2). For a red LED (660 nm) with  $I_e = 0.1$  mW/sr, the luminous intensity is calculated as below:

$$I_V = I_e \cdot K_m \cdot V(\lambda) = 0.1 \text{ mW/sr} \cdot 683 \text{ lm/W} \cdot 0.061 = 4.2 \text{ mcd.}$$

## Luminous Flux

### Principle

For high intensity devices like TELUX, the characterization is carried out by a measurement of luminous flux, wavelength and forward voltage. The luminous flux is measured in a special test box which simulates an "Ulbricht" Sphere. The test box has five detectors, one in the optical axis and 4 at the device side. The luminous flux is measured indirectly after reflection at the wall of the box. This system is in a wide range only to calibrate to an Ulbricht Sphere.

The wavelength is measured in the optical axis with a spectrometer.

All optical measurements are carried out within 30 ms. The electrical measurements  $V_F$  and  $V_R$  are carried out within the first 10 ms.

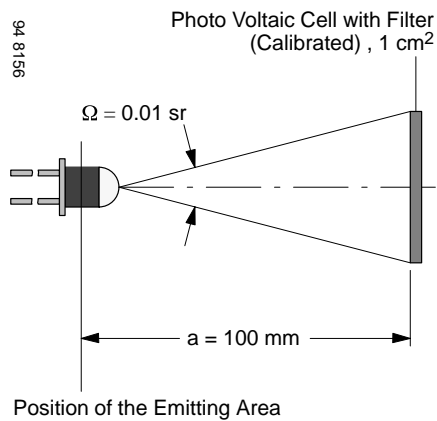


Figure 1. Radiant intensity measuring configuration

A silicon photo diode with a special filter is used for precise measurements as the wavelength of the emitted radiation of each LED to be measured must be known precisely for this method, and as the spectral bandwidth of the LED is not taken into account. Detectors with filters for measurement of wideband light sources (daylight, incandescent lamps) are not suitable as their spectral curve deviates by up to 50% above 640 nm from the standard value in the red range (figure 3).

A detector-filter combination, in which the red slope of the spectral sensitivity curve is matched precisely to the standardized curve of the human eye's sensitivity, is therefore used for LEDs from green to red (figure 4).

If blue LEDs are to be measured, a more expensive, high precision detector head which matches the total eye response curve has to be used.

In the case of standard, customary LED measuring instruments, the built-in photodiode-filter combination is calibrated only for a middle wavelength. A measuring error of around  $\pm 5\%$  must be expected here in the spectral range of normal LEDs (550 nm – 680 nm). This error is avoided by computer-controlled measuring systems which use a separate calibration value for each LED color.

The Physikalisch Technische Bundesanstalt (German Federal Standards Laboratory) in Braunschweig is responsible for calibration of detector masters.

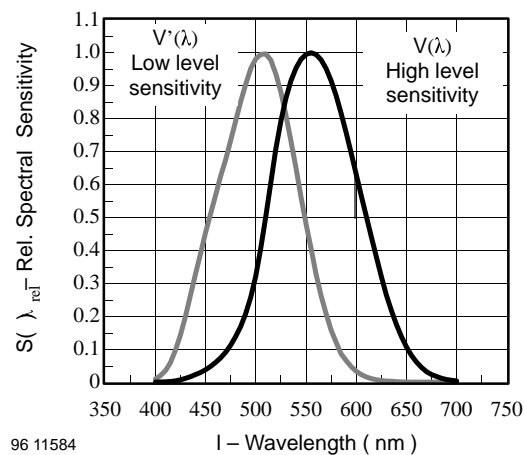


Figure 2. Relative spectral sensitivity of human eye

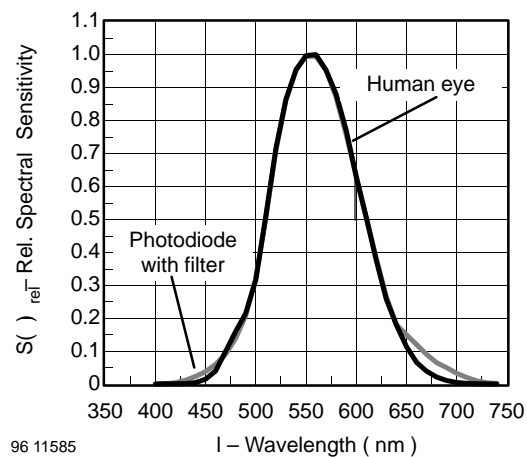


Figure 3. Correction filter

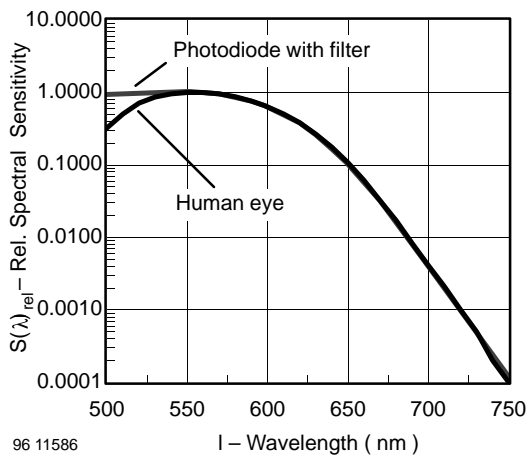


Figure 4. "Red photopic"

### Measuring Configuration

The measuring configuration is a light-proof box, lined on the inside with black material (figure 5), in which the LED and the detector are arranged axially and opposite each other. An aperture B in the beam path prevents stray light from reaching the detector, but without limiting its angle of entry. The distance *a* between emitter and detector should (in agreement with DIN 5032) be at least ten times as large as the diameter of the emitter and as the diameter, *d*, of the light-sensitive surface *A*. For practical applications, a measuring solid angle of  $\Omega = 0.01$  sr (corresponding to a plane full angle of  $6.5^\circ$ ) has proved suitable, as the following condition is (almost) fulfilled at this value:

$$a = \sqrt{A/\Omega} = (d/2) \times \sqrt{\pi/\Omega} = 8.86 \times d.$$

If the detector has a light-sensitive surface of  $A = 1 \text{ cm}^2$ , the distance becomes

$$a = \sqrt{1 \text{ cm}^2/0.01} = 10 \text{ cm}$$

Special holders are required which guarantee precise location of the components for precise and reproducible luminous intensity measurement.

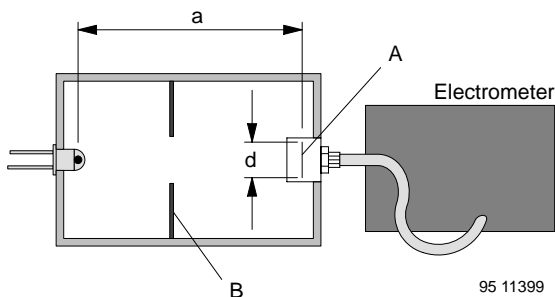


Figure 5. Luminous intensity measurement

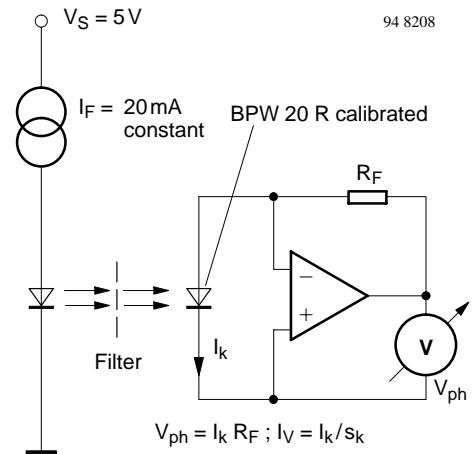


Figure 6. Test circuit with FET operational amplifier

In order to determine the luminous intensity of the LED, the short-circuit current  $I_k$  of the detector (normally less than 100 nA) is measured with an electrometer or an FET operational amplifier circuit (figure 6). Another method which has proved useful is to connect a measuring resistor of approximately 100 k $\Omega$  in parallel to the detector and to measure the voltage drop (less than 10 mV) with the aid of a highly sensitive digital voltmeter (figure 7).

If the photosensitivity of the detector filter-combination used is calibrated in A/lumen, the light flux arriving at the detector can be calculated from the measured short-circuit current:

$$\Phi_v = I_k/s.$$

After this, the light flux value can be calculated up to the standard solid angle (1 sr):

$$I_v = \Phi_v/\Omega = \Phi_v/0.01\text{sr}.$$

If, in contrast, the calibration value *s* is specified in A/lx, the illumination on the detector surface can be determined by  $E_v = I_k/s$ . The luminous intensity is obtained by multiplying  $E_v$  with the square of the distance *a* (in m):  $I_v = E_v \cdot a^2 = E_v \cdot 0.01 \text{ m}^2$ .

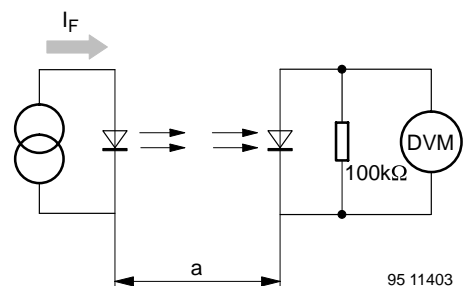


Figure 7. Configuration with a sensitive digital voltmeter

**Measuring Angle**

With a small measuring angle such as 0.01 sr, even LEDs with a very narrow emission angle ( $\pm \varphi < 10^\circ$ ) can be measured precisely. This means that the component's mounting must be mechanically precise. A further advantage is that the precise position of the light emission point on the LED is uncritical at the relatively large distance of 10 cm. It is therefore possible to measure LEDs with differing case shapes without changing the distance. If only LEDs with a wide radiation angle are measured, it is also possible to use a larger measuring angle such as 0.1 sr (corresponding to a plane full angle of  $20.5^\circ$ ). Then, the electrical signal at the detector is 10 times larger and the requirements for mechanical precision of the measuring mounting are reduced. Measurements on LEDs with non-uniform radiation characteristics are therefore easier to reproduce, as the larger measuring angle ensures that the individual peaks are averaged.

In the case of LEDs with a narrow emission angle ( $< \pm 5^\circ$ ), exact measurement of the axial luminous intensity is influenced as follows: On clearly encapsulated LEDs with aspherical lenses, the luminous surface of the semiconductor chip may be imaged on the detector together with the non-luminous "bonding spot" in the center of this chip. This causes a luminous intensity minimum on the sensitive area of the detector. For this reason, no reliable, reproducible values are obtained from measurement of LEDs with a very narrow measuring angle ( $\ll 0.01 \text{ sr} = 6.5^\circ$  plane angle). The reproducibility of these readings is improved with an increasing measuring angle.

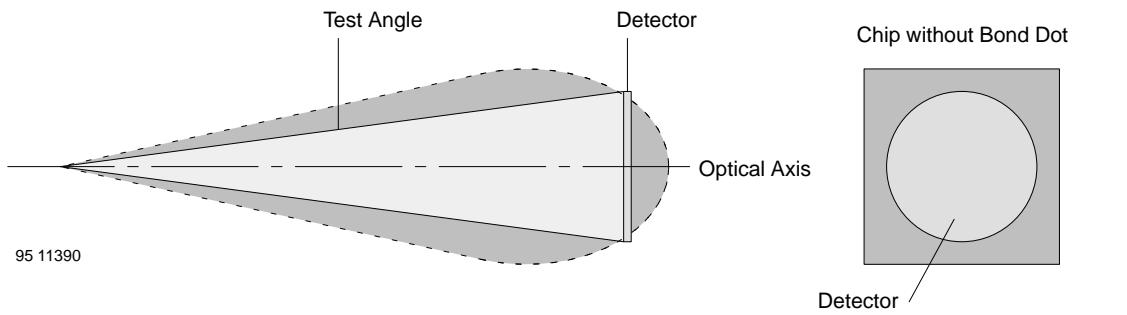


Figure 8. Simplified radiation characteristic

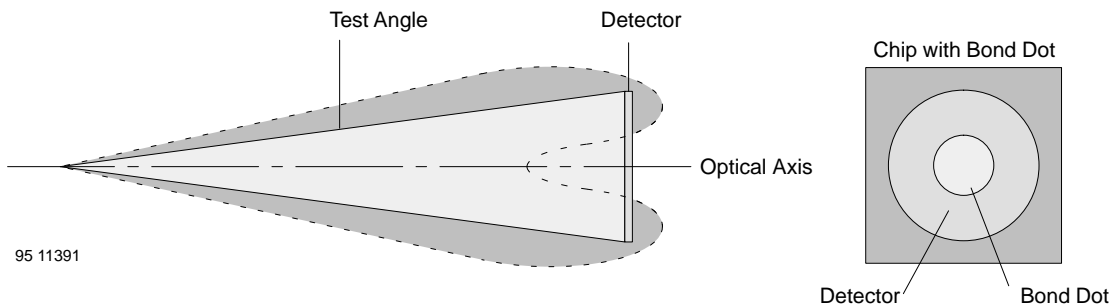


Figure 9. Radiation characteristic with bond dot

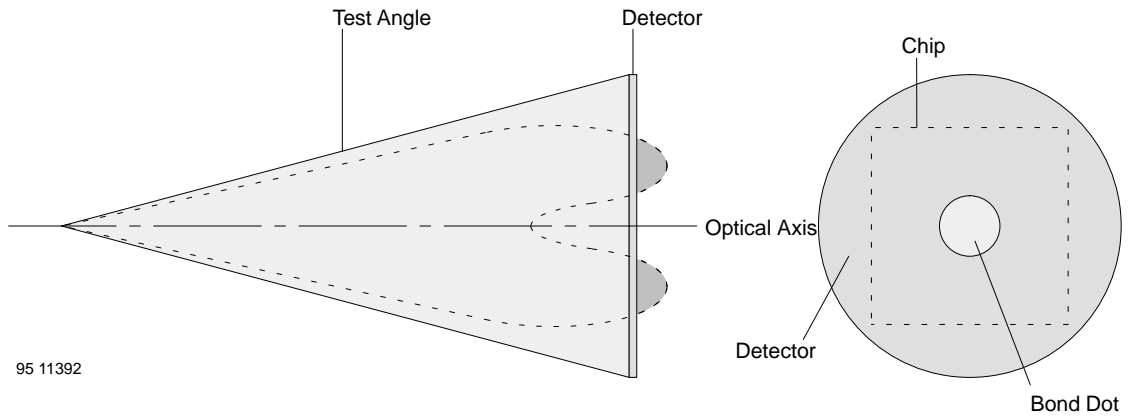


Figure 10. Large test angle



Figure 11. Deviation between optical and mechanical axis

In the previous remarks, a symmetrical arrangement of the emission characteristic around the mechanical axis of the LED was assumed. However, the emission characteristic is frequently asymmetrical in practice.

In addition, it should be taken into account that the reflector into which the chip is mounted in the LED housing is imaged as a concentric ring. The relative luminous intensity of this ring depends greatly on the distance between the LED and detector only in the near field (< 50 mm).

The mean value of the luminous intensity within the measuring angle is now indicated. This deviates greatly from the axial luminous intensity value if the measuring angle chosen is larger than the emission angle.

A slight deviation of the chip on the lead frame (< 100  $\mu\text{m}$ ) and of the frame in the plastic case (< 100  $\mu\text{m}$ ) leads to deviations of the optical axis (with respect to the mechanical axis) of several degrees in the case of highly focusing lenses. The bonding wire in the middle of the chip, which connects the upper side contact of the chip with the anode terminal of the LED, is responsible for small deviations.

This leads to interferences with the  $I_V$  measurement. In the case of a narrow emission angle, the measured values and their reproducibility is influenced as follows:

In the case of a narrow measuring angle (i.e., small detectors), the measured  $I_V$  values can be small or large. The reproducibility is therefore very poor.

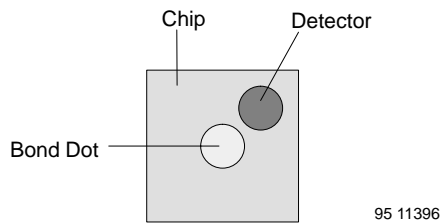


Figure 12. Small detector area

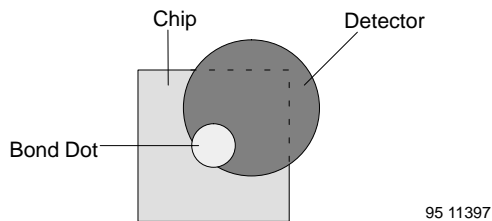


Figure 13. Middle detector area

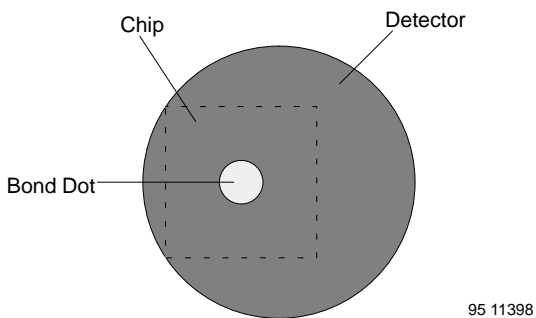


Figure 14. Large detector area

In the case of a medium measuring angle (i.e., detector size), the values of the  $I_V$  measurement are medium. The reproducibility is sufficient.

In the case of a large measuring angle (i.e., detector size), the values of the  $I_V$  measurement are too small (compared with the  $I_V$  main value). The reproducibility is good.

## Pulsed Operation

At low currents, the luminous intensity of LEDs rises faster than the forward current of the LED (start-up range). Pulsed operation therefore produces increased luminous intensity at the same average current. At higher currents, the slope becomes flatter (saturation area). This is caused primarily by the heating of the LED chip. This saturation effect is therefore less intense in pulsed operation than in DC operation. The reduction increases as the pulses become shorter and the duty cycle becomes longer.

The luminous intensity under pulsed operation is measured either repetitively as a mean value or as a peak value with single pulses (single shot). For series measurements, it is usual to carry out all measurements on LEDs (including the luminous intensity) at high and low currents and the forward voltage with single current pulses in order to keep the measuring times short. If LEDs or displays are used for display purposes in multiplex operation, the pulsed luminous intensity values (specified in the data sheet) must be multiplied by the duty cycle. This is because as the human eye "sees" the mean luminous intensity value  $I_{VAV}$  if the repetition rate is sufficiently high. If LEDs are to be used in light barriers, the pulsed luminous intensity is decisive for the maximum possible range. The current range in which pulsed operation results in a gain in luminous intensity can be determined from the shape of the curve of the relative luminous intensity  $I_{Vrel}$ .

## Temperature Behavior

The luminous intensity of light-emitting diodes decreases as the temperature rises, by approximately 1.5% per degree in the case of standard red and orange-red, by approximately 0.7% per degree in the case of yellow, and approximately 0.5% per degree in the case of green, whenever measured in the range around 25°C. For high brightness AlInGaP 0.7% /degree for red and 0.9% /degree for yellow is detected, while for InGaN it is very low with 0.3% /degree. This reduction is practically undetectable by the human eye. However, in applications in light barriers and for data transmission, it may be necessary to compensate for this reduced light intensity in specific circuits which increase the forward current.

The accuracy of the luminous intensity measurement is influenced by the temperature behavior of the LEDs. On the one hand, the luminous intensity of the LED to be measured may fluctuate as a result of changing room temperature. On the other hand, "handling" of the LEDs has an influence on accuracy.

In order to reduce measurement inaccuracies, the measurements must be performed in air-conditioned rooms. The components must be touched only with tweezers, if at all.

In order to obtain reproducible results, the measuring current must not be connected to the LED until just before the measurement is to be carried out. The length of the current pulses up to measurement must be defined and always be the same. This can be achieved most simply by means of computer-controlled pulse measurement.

In the case of precision measurements, the forward voltages are also recorded for given forward currents. These are an exact measurement of the temperature on the chip. Both the radiant intensity  $I_e$  and emission spectrum are temperature-dependent. This means that the luminous intensity  $I_v$  is even more temperature-dependent because it depends on both of these.

## Radiation Angle

### Principle

Depending on the shape of the lens, the light emitted by LEDs is focused more or less in the halfspace (figure 15). Even a slightly reduced angle leads to a clear increase in the luminous intensity, namely by approximately 50% per 5° reduction of the angle of

half-intensity in the medium-angle range. For this reason, the luminous intensity values should be compared only together with the radiation angles when selecting an LED type.

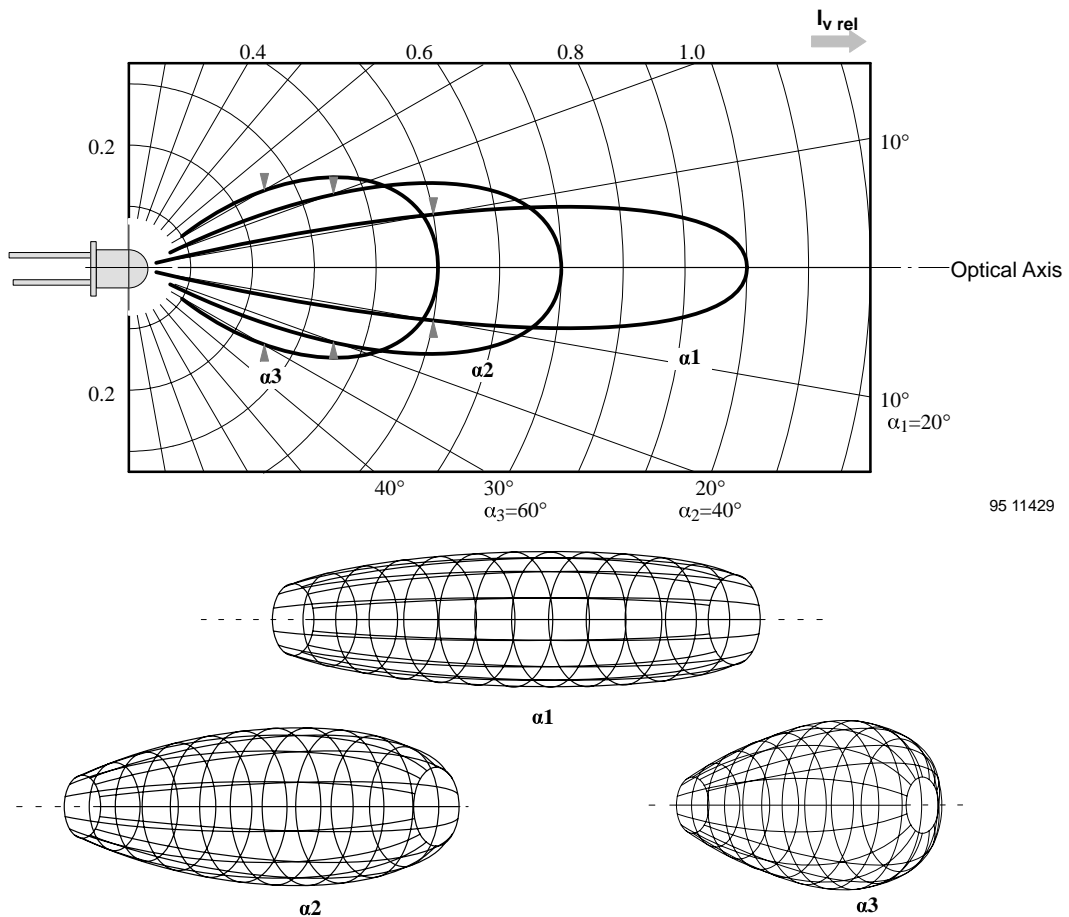


Figure 15. Radiation angles with corresponding angles of half intensity

## Measurement

A similar fixture as for luminous intensity measurement is used for manual measurement of the radiation angle. Instead of a rigid, axially arranged mounting for the LED to be measured, an externally rotary mounting with angle scale is installed. After measurement of the axial luminous intensity  $I_V$  (angle setting  $0^\circ$ ), the mounting is turned left and right until the luminous intensity values drop to half of this basic value. The two angles of half intensity can then be read off from the angle scale. A photo diode array can be used for rapid automatic measurement; this is arranged in a circular shape around the LED to be measured. Evaluation of the data is then carried out with the aid of a microcomputer.

## Forward Voltage

### Measurement

The forward voltage can be measured either with a curve tracer or statically as shown in figure 16. A constant current source generates the specified forward current for the LED. The voltage across the component is measured with a digital voltmeter. The use of separate contacts for current and voltage avoids measuring errors resulting from contact resistances.

### Temperature Behavior

The forward voltage of LEDs drops as the temperature increases, just as in silicon diodes. The temperature coefficient for LEDs of all colors is between  $-1.5$  and  $-2.5$  mV/degree.

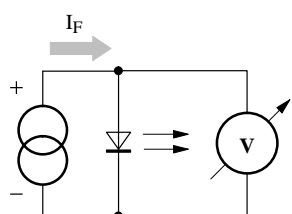


Figure 16. Forward voltage measuring

## Breakdown Voltage

For most LEDs,  $V_{(BR)}$  is specified at  $10 \mu\text{A}$  reverse current. In this case, either an extremely high impedance voltmeter has to be used for measurement, or the current consumption of the DVM has to be calculated and added to the specified current. A second measurement step will give correct readings.

It should be noted that measurement of breakdown voltage, if performed without special care, may destroy the device being tested. Only a precision current source will be fast enough to deliver a constant current into the LED without spikes. Constant voltage sources in current limiting mode are not applicable at all. AllnGaP LEDs in particular are prone to breakdown failure. Therefore, the compliance voltage of the current source must be limited to a maximum of 10 V.

If the actual value of breakdown voltage is of little interest, a reverse current measurement at a fixed reverse voltage is recommended. On the other hand, it is rather difficult to get stable readings with standard test equipment because reverse current values of LEDs normally lie in the nanoamp or even picoamp range.

## Color

### Wavelength Definition

In order to specify the color of an LED, three different wavelength specifications are generally used:

- a) Peak wavelength  $\lambda_P$ :  
the maximum point of the spectral curve
- b) Main wavelength  $\lambda_S$ :  
the main point of the spectral curve (identical with  $\lambda_P$  in the case of a symmetrical spectral curve)
- c) Dominant wavelength  $\lambda_d$ :  
The dominant wavelength  $\lambda_d$  (in accordance with DIN 5033 part 3) is a measure of the hue perceived by the human eye.

The chromaticity  $x$  (red) and  $y$  (green) are determined using the 3-color method. The dominant wavelength can then be graphically determined from the chromaticity diagram. For this purpose, a straight line is drawn from the white point (achromatic point)  $W$  through the color locus  $S(x, y)$  until this line intersects with the spectral color curve (curve for 100% color saturation). The value of the dominant wavelength can be read off there. Since the light emitted by LEDs (exception: blue) has a color saturation of almost 100%, the color locus  $S$  is very close to the spectral curve.

In addition, the spectral bandwidth  $\Delta\lambda$ , i.e., the width of the spectral curve between the 50% points, is also specified (figure 17).



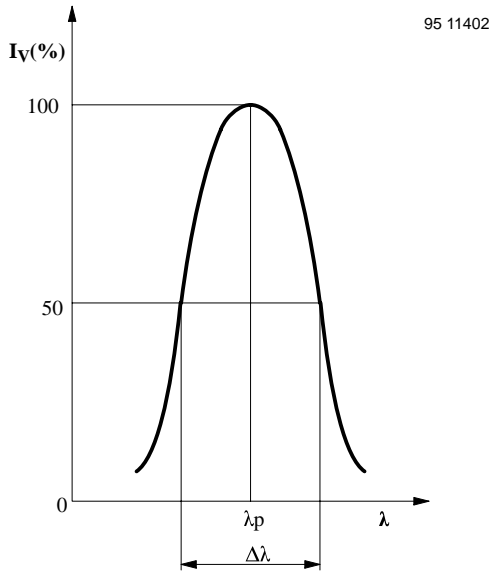
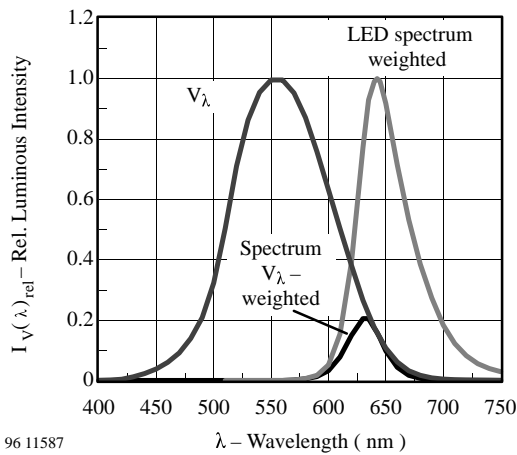


Figure 17. Spectral bandwidth



96 11587

Figure 18. LED spectral curve weighted by  $V(\lambda)$

### Spectral Measurement with Monochromator

A monochromator in a test configuration is used for precise determination of the emission spectrum. The specified amount of light emitted by the LED is focused through an optical system onto the inlet window of the monochromator. The part of the light (which is not absorbed) arrives at a calibrated detector, whereby external and reflected light must be carefully screened. Peak wavelength is obtained by tuning the monochromator until the meter indicates a maximum value. In order to determine the center and dominant wavelengths, the total spectral curve must be recorded. As the transmission factor of the monochromator and the spectral sensitivity of the detector is not constant over the spectral range of the LED, the measured values must be corrected accordingly.

### Color Measurement with Filter

In series measurements of orange, yellow and green LEDs, the dominant wavelength is determined by means of a rapid 3-color method.

By using a detector-filter combination, the red (x) and green (y) color contents in the spectrum of the LED can be measured. The blue content (z) of these LEDs is insignificant and does not have to be measured. The green color part is given by the luminous intensity measurement with a silicon detector-filter combination matched to the  $V(\lambda)$  curve. A cut-off filter matched to the LED color is additionally fitted for measurement of the red color part. This arrangement is permeable only for the red content of the LED spectrum.

The ratio of the red content and the luminous intensity provides exact and easily reproducible values from which the dominant wavelength is determined by the computer, with the help of programmed calibration curves. Measured values, accurate to  $\pm 1$  nm, are obtained with this method as long as the spectral pattern of the LED used for calibration largely agrees with that of measured objects.

### Temperature Behavior

As the temperature rises,  $\lambda_{dom}$  shifts to larger wavelength.

A shift of approximately +0.05 to 0.1 nm/k is typical for all technologies.