LEDs and Displays Data Book 1996

TEMIC

Semiconductors

Contents

Contents (continued)

Explanation of Technical Data

TEMIC light emitting diodes and displays are generally designated in accordance with the TEMIC designation system:

TL... = Light emitting diode

TD... = Display

The following figures show how the components can be identified.

TEMIC Type Designation Code for LEDs

T	L	●	●	●	●	●	●

TEMIC

LED

Series
- B = Blink
- D = Double hetero
- H = High efficiency
- L = Low current
- M = Miniature
- P = Side view
- R = Resistor
- S = Symbol
- U = Universal
- V = Backlighting

Wavelength (typ. λ peak) / Color

	Wavelength (typ. λ peak)	Color
D, R, H	635...650	Red
T, L	635	Red (low current)
O, S	598...635	Orange
F	610	Orange (AlInGaP)
Y	585	Yellow
E	590	Yellow (AlInGaP)
A	585	Yellow (low current)
G	565	Green
C	565	Green (low current)
P	555	Pure green
B	470	Blue
V		Bi-color

Package Design

Series	
B, D, H, L, M, P, R, S, U, V	2 = 1.8 mm (stand-off) 4 = 3 mm (stand-off) 5 = 5 mm (stand-off) 6 = 5 mm (without stand–off)
M	2 = SOT23 3 = PLCC2 4 = Miniature SMD
S	2 = 2.0 x 5 mm 5 = 2.5 x 5 mm

Design Varieties

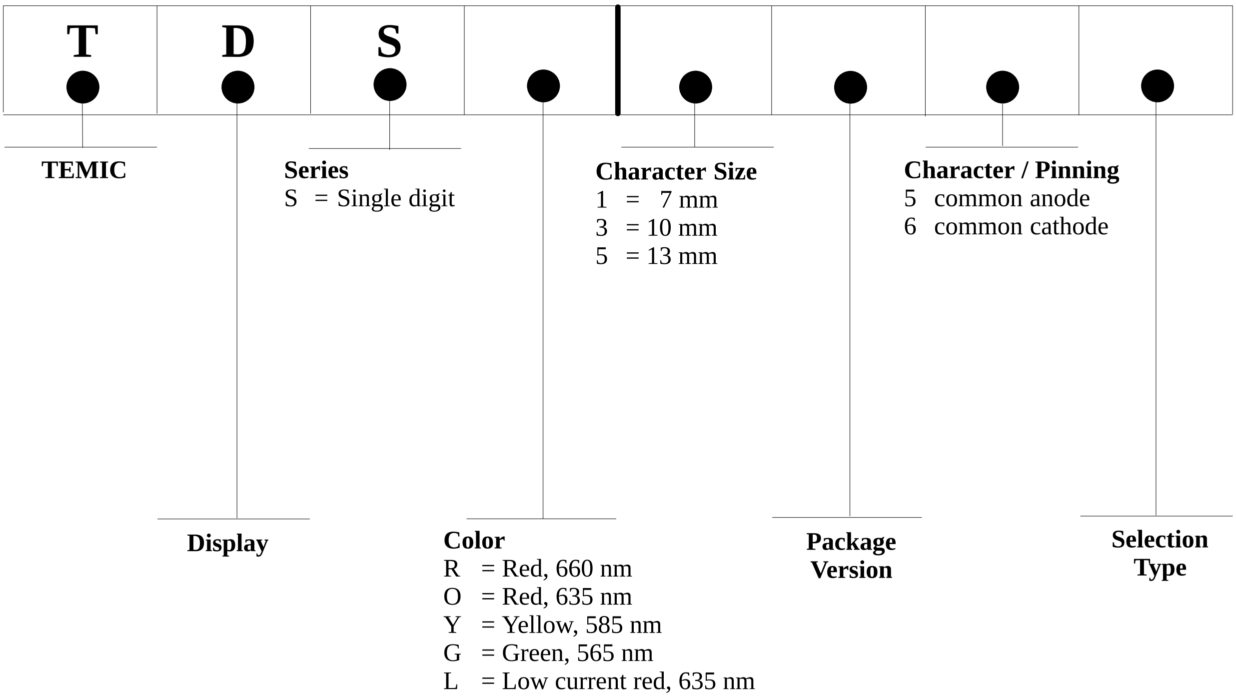
Series	
B, D, H, L, P, R, U, V	2 = Tinted, non-diffused 3 = Untinted, diffused 4,6 = Tinted, diffused 1,8,9 = Untinted, non-diff.
S	1 = Tinted top diffused
M	1 = Untinted, non-diffused 2 = Tinted, diffused 3 = Tinted, non-diffused 4 = Untinted, diffused 5 6

0...8 **Main Type**

0...8 **Selection Type**

Example: TLME3100 = PLCC2, yellow, AlInGaP-technology

TEMIC Type Designation Code for Displays



Example: TDSG5160 = digit green, 13 mm

For a few types, the old designations (e.g., CQX...) are used in accordance with the Pro Electron System.

Further designations (e.g., for taping) are provided by a further designation group, e.g.,: TLHR5401AS12.

Symbols and Terminology – Alphabetically

A
Anode, anode terminal

A
Radiant sensitive area
That area which is radiant sensitive for a specified range.

AQL
Acceptable Quality Level

C
Capacitance

C
Cathode, cathode terminal

°C
Celsius
Unit of the Celsius scale;
Symbols: T
T (°C) = T (K) – 273

cd
Candela
SI unit of luminous intensity I_v

C_j
Junction capacitance
Capacitance due to a PN-junction of a diode.
It decreases with increasing reverse voltage.

E_v
Illuminance, illumination
(at a specific point on a surface)
Quotient of the luminous flux incident on an element of the surface containing the point, divided by the area of that element.

$$E_v = \frac{d\Phi_v}{dA}$$

Unit: lx (Lux)

f
Frequency
Unit: Hz (Hertz)

I_F
Continuous forward current
The current flowing through a diode in the direction of lower resistance.

I_{FAV}
Average (mean) forward current

I_{FM}
Peak forward current

I_{FSM}
Surge forward current

I_R
Reverse current, leakage current
Current which flows when reverse bias is applied to a semiconductor junction.

I_v
Luminous intensity (of a source in a given direction)
Quotient of the luminous flux leaving the source propagated in an element of solid angle containing the given direction by the element of solid angle.

$$I_v = \frac{d\Phi_v}{d\Omega}$$

Unit: cd (candela), lm/sr

I_{vav}
Luminous intensity, average

K
Kelvin
The unit of absolute temperature T (also called the Kelvin temperature); can also be used for temperature changes (formerly °K).

lm
Lumen
SI-unit of luminous flux, Φ_V

L_V
Luminance (in a given direction, at a point on the surface of a source or a receptor, or at a point on the path of a beam).

Quotient of the luminous flux leaving, arriving at, or passing through an element of surface at this point. It is propagated in directions defined by an element of the solid angle containing the given direction, divided by the product of the solid angle of the cone and the area of the orthogonal projection of the element of surface on a plane perpendicular to the given direction.

$$L_v = \frac{d^2\,\Phi_v}{d\Omega \times dA \times \cos\theta}$$

Unit: cd/m^2

lx
Lux
SI-unit of illumination, E_v

M_v
Luminous exitance (at a specific point on a surface)
Quotient of the luminous flux leaving an element of the surface containing the point, divided by the area of that element.

$$M_v = \frac{d\Phi_v}{dA}$$

Unit: lm/m^2

P_{tot}
Total power dissipation

P_v
Power dissipation, general

Q_v
Quantity of light
Product of luminous flux and its duration

$Q_v = \int \Phi_v \times dt$
Unit: lm s (lumen-second)

R_{thJA}
Thermal resistance, junction-ambient

R_{thJC}
Thermal resistance, junction case

sr
Steradian
SI-unit of a solid angle Ω

T
Period (duration)

T
Temperature
0 K = –273.16°C
Unit: K (Kelvin), °C (Celsius)

t
Time

T_{amb}
Ambient temperature
If self-heating is significant:
Temperature of the surrounding air below the device, under conditions of thermal equilibrium. If self-heating is insignificant: Air temperature in the intermediate surroundings of the device.

T_{amb}
Ambient temperature range
As an absolute maximum rating:
The maximum permissible ambient temperature range.

TC
Temperature coefficient
The ratio of the relative change of an electrical quantity to the change in temperature (ΔT) which causes it, under otherwise constant operating conditions.

T_{case}
Case temperature
The temperature measured at a specified point on the case of a semiconductor device.
Unless otherwise stated, this temperature is given as the temperature of the mounting base for devices with metal can.

t_d
Delay time

t_f
Fall time

T_j
Junction temperature
The spatial mean value of temperature during operation.

t_{off}
Turn-off time

t_{on}
Turn-on time

t_p
Pulse duration

t_r
Rise time

t_s
Storage time

T_{sd}
Soldering temperature
Maximum temperature allowed for soldering at a specified distance from case and its duration.

T_{stg}
Storage temperature range
The temperature range at which the device may be stored or transported without any applied voltage.

$V_{(BR)}$
Breakdown voltage
Reverse voltage at which a small increase in voltage results in a sharp rise of reverse current. It is given in the technical data sheet for a specified current.

V_F
The voltage across the diode terminals which results from the flow of current in the forward direction.

V_R
Reverse voltage
Voltage drop which results from the flow of reverse current.

V_S, V_{CC}
Supply voltage

φ
The plane angle through which an emitter can be rotated in both directions away from the optical axis, before the electrical output of a linear detector facing the emitter falls to half the maximum value.

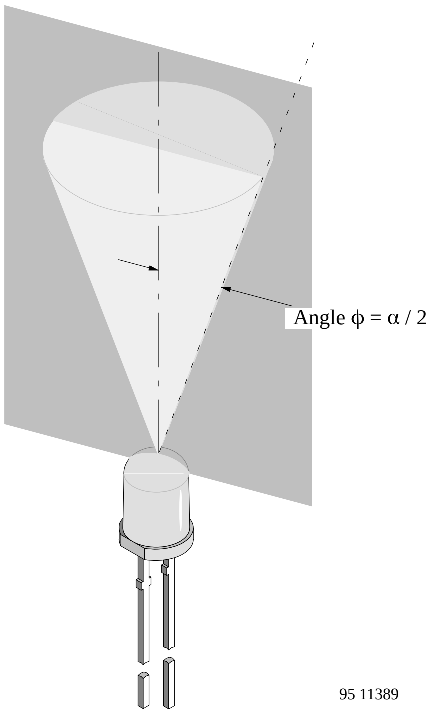


Figure 1. Angle of half intensity

λ
Wavelength
The wavelength of an electromagnetic radiation

$\lambda_{0.5}$
Range of spectral bandwidth (50%)
The range of wavelengths where the spectral sensitivity or spectral emission remains within 50% of the maximum value.

λ_d
Dominant wavelength
The dominant wavelength of a color stimulus is the wavelength of the monochromatic stimulus that, when additively mixed in suitable proportions with an achromatic stimulus, yields a color which matches the color stimulus in question.

λ_p
Peak wavelength
Wavelength of peak sensitivity or emission

$\Delta\lambda$
Spectral half bandwidth
The wavelength interval within which the spectral sensitivity or spectral emission falls to half peak value.

Φ_v
Luminous flux
Quantity derived from radiant power by evaluating the radiation according to its effect upon a selective receptor, the spectral sensitivity of which is defined by the standard spectral luminous efficiencies.

$$\Phi_v = \frac{dQ_v}{dt}$$

Unit: lm (lumen)

Ω
Solid angle
The space enclosed by rays which emerge from a single point and lead to all the points of a closed curve. If it is assumed that the apex of the cone formed in this way is the center of a sphere with radius r and that the cone intersects with the surface of the sphere, then the size of the surface area (A) of the sphere subtending the cone is a measure of the solid angle

$$\Omega = \frac{A}{r^2} \quad [sr]$$

There are 4π sr in a complete sphere. A cone with an angle of half sensitivity α forms a solid angle of

$\Omega = 2\pi\,(1 - \cos \alpha/2) = 4\pi \sin^2 \alpha/4$
Unit: sr (Steradian)

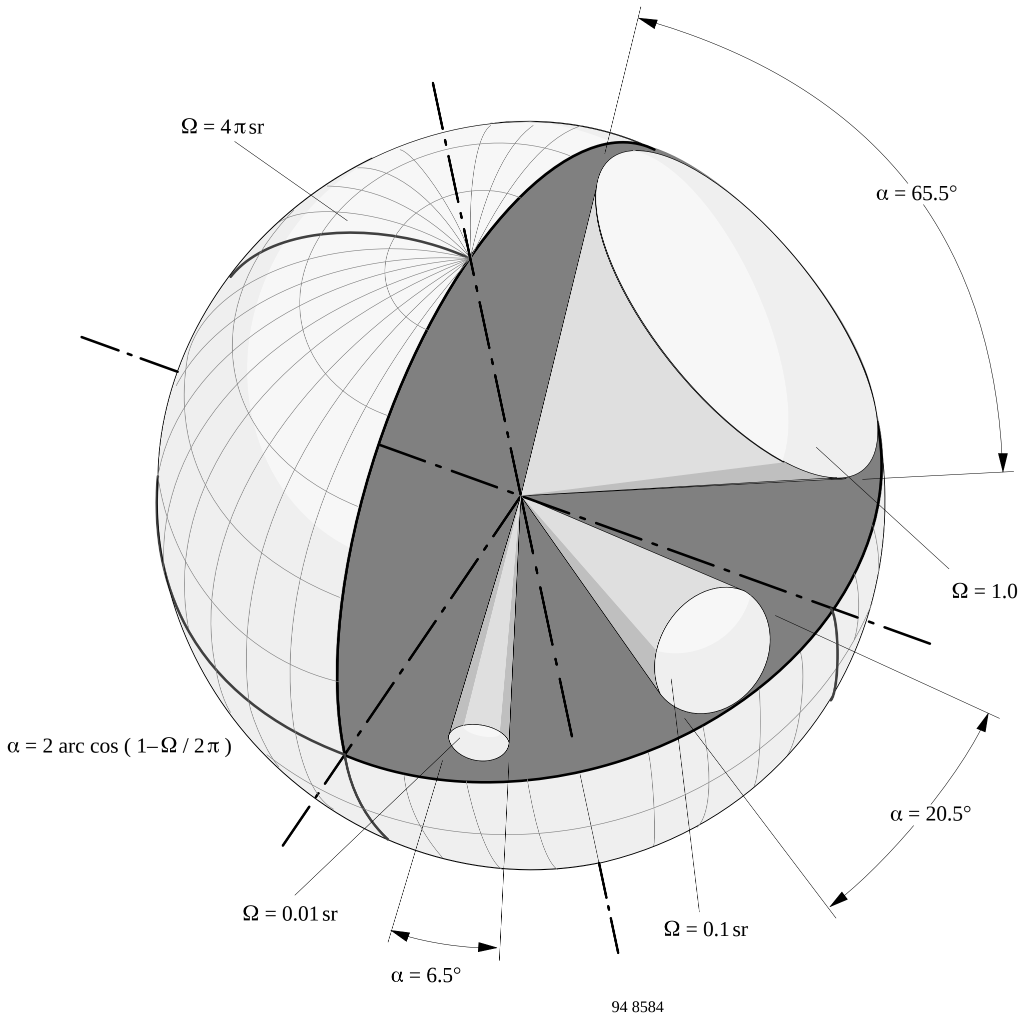


Figure 2. Solid angle

Data Sheet Construction

Data sheet information is generally presented in the following sequence:

- Description
- Features
- Applications
- Absolute maximum ratings
- Optical and electrical characteristics
- Typical characteristics (diagrams)
- Dimensions (mechanical data)

Additional information on device performance is provided if necessary.

Description

The following information is provided: Type number, semiconductor materials used, sequence of zones, technology used, device type and, if necessary, construction.

Also, short-form information on the typical applications and special features is given.

Absolute Maximum Ratings

These define maximum permissible operational and environmental conditions. If any one of these conditions is exceeded, this could result in the destruction of the device. Unless otherwise specified, an ambient temperature of $25 \pm 3°C$ is assumed for all absolute maximum ratings. Most absolute ratings are static characteristics; if they are measured by a pulse method, the associated measurement conditions are stated. Maximum ratings are absolute (i.e., interdependent).

Any equipment incorporating semiconductor devices must be designed so that even under the most unfavorable operating conditions, the specified maximum ratings of the devices used are never exceeded. These ratings could be exceeded because of changes in supply voltage, the properties of other components used in this equipment, control settings, load conditions, drive level, environmental conditions and the properties of the devices themselves (i.e., ageing).

Some thermal data is given under the heading ‘Absolute Maximum Ratings’ (e.g., junction temperature, storage temperature range, total power dissipation). This is because it imposes a limit on the application range of the device.

The thermal resistance junction ambient (R_{thJA}) quoted is that which would be measured without artificial cooling, i.e., under worst-case conditions.

Temperature coefficients, on the other hand, are listed together with the associated parameters under ‘Optical and Electrical Characteristics’.

Optical and Electrical Characteristics

The most important operational optical and electrical characteristics (minimum, typical and maximum values) are grouped under this heading, together with associated test conditions supplemented with curves. An AQL-value is also quoted for particularly important parameters.

Typical Characteristics (Diagrams)

Besides the static (dc) and dynamic (ac) characteristics, a family of curves is given for specified operating conditions. Here, the typical independence of individual characteristics is shown.

Dimensions (Mechanical Data)

In this section, important dimensions and connection sequences are given, supplemented by a circuit diagram. Case outline drawings carry DIN-, JEDEC or commercial designations. Information on angle of sensitivity or intensity and weight completes the list of mechanical data.

Note:

If the dimensional information does not include any tolerances, then the following applies:

Lead length and mounting hole dimensions are minimum values. Radiant sensitive or emitting area respectively are typical, all other dimensions are maximum.

Any device accessories must be ordered separately and the order number must be quoted.

Additional Information

Preliminary specifications

This heading indicates that some information given here may be subject to slight changes.

Not for new developments

This heading indicates that the device concerned should not be used in equipment under development. The device is, however, available for present production.

Physics of Optoelectronic Devices

Light-Emitting Diodes

This section deals with the principles and characteristics of the technically most important types of visible emitters which are formed, without special lateral structures, as whole-area emitters.

Materials for LEDs

The materials for light-emitting diodes in the visible spectrum (400 - 700 nm) are semiconductors with bandgaps between 1.8 and 3.1 eV, with E_g (eV) = hν = 1240 /λ (nm). In order to permit effective recombination, the materials should have direct band-to-band transitions or permit other recombination paths with high efficiency. Neither of these requirements are fulfilled by the well-known semiconductors silicon and germanium, as their bandgaps are too small and they are indirect by nature.

As a further requirement, the materials have to enable manufacturing in the form of monocrystals (volume crystals or at least epitaxial layers) and sufficiently developed technology must be available for processing.

Element combination from groups III and V of the periodic element system results in semiconducting compounds with bandgaps between 0.18 eV (InSb) and approximately 6 eV (AlN); see figure 3.

I	II	III	IV	V	VI	VII	VIII
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar
K	Ca Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr Cd	In	Sn	Sb	Te	J	Xe

III	V: N	P	As	Sb
Al	AlN 6.0	AlP 2.45	AlAs 2.15	AlSb 1.65
Ga	GaN 3.4 *	GaP 2.26	GaAs 1.42 *	GaSb 0.73 *
In	InN 1.95 *	InP 1.34 *	InAs 0.36 *	InSb 0.18 *

Figure 3. Periodic system of elements and III-V compounds

For every composition the bandgap is given in eV. Direct semiconductors are denoted by an asterisk. The largest direct bandgaps are found in the group III – nitrides GaN and InN. These nitrides will supercede silicon carbide as semiconducting material for blue light emitting diodes within the next few years. Gallium arsenide has a direct bandgap of 1.42 eV and is not only important for light emitting diodes, but is also a significant substrate material.

III–V compounds can form mixed crystals with properties between those of the binary compounds. The most important mixed crystal systems pertaining to LEDs are GaAs–AlAs, GaAs – GaP, InP – GaP – AlP.

The bandgap and the lattice constant of $Ga_{l-x}Al_xAs$ and $GaAs_{l-x}P_x$ are shown in figure 4. The direct region is shown as a solid line and the indirect region as a dashed line. Up to x = 0.44 (band gap 1.96 eV), $Ga_{l-x}Al_xAs$ is direct, and the lattice constant changes only slightly over the whole mixture range. The highest direct bandgap for $GaAs_{l-x}P_x$ is 1.99 eV (x = 0.45). In the indirect region of $GaAs_{l-x}P_x$, the efficiency of radiating recombination can be increased considerably by doping with nitrogen (isoelectronic center). This reduces the effective bandgap by approximately 0.06 eV (second dashed line).

The bandgaps required for common LED colors are marked at the top of figure 4. Whereas red emission can be achieved with $Ga_{0.6}Al_{0.4}As$ or $GaAs_{0.6}P_{0.4}$ (both direct), the indirect $GaAs_{l-x}P_x$:N is used for the other colors.

In figure 5, the bandgaps and lattice constants of InGaAlP are presented. In this diagram, binary compounds are shown as points, ternary compounds as lines, and the quaternary mixed crystal InGaAlP as a shaded area. The binary crystals InP, GaP and AlP form the apecies. Their characteristic form is a result of the complex nature of the band structure and the transition from the direct to the indirect region and vice versa. The diagram shows which InGaAlP compositions are direct and which mixed crystals are lattice matched to a given substrate material. Both are necessary prerequisites for the manufacture of particularly bright light emitting diodes. The vertical dashed line drawn through the direct bandgap region shows the compositions that are exactly lattice matched to, and can be manufactured on a GaAs substrate. The corresponding notation $In_{0.5}(Ga_xAl_{l-x})_{0.5}P$ gives the ratio of the amounts of atoms in the crystal lattice. The bandgap is direct if the aluminium concentration is below x = 0.7. The spectral region from red via orange and yellow to green can be covered by variation of x in InGaAlP. Extremely high luminescent effiencies for orange and yellow are obtained in double heterostructures of InGaAlP situated on a Bragg reflector on a GaAs substrate.

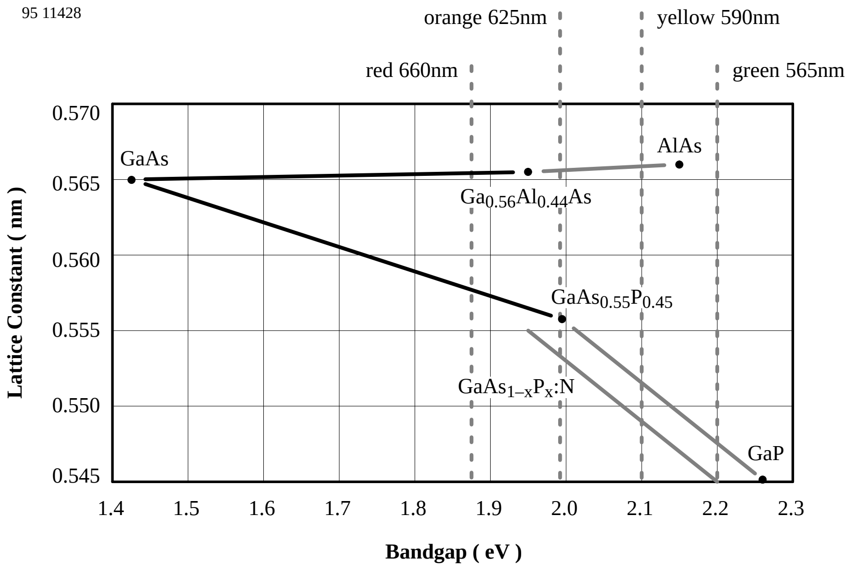


Figure 4. Bandgaps and lattice constants

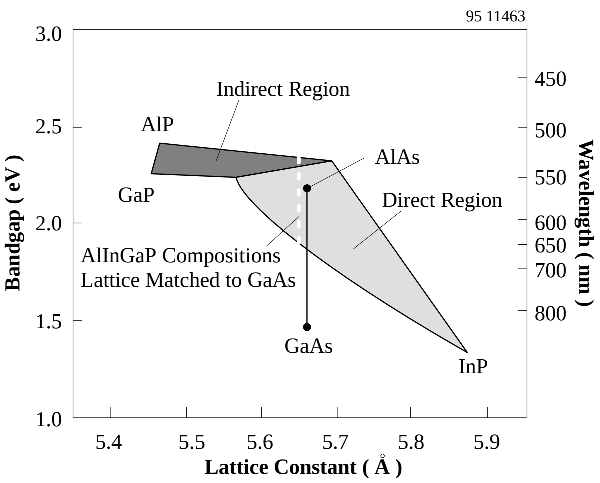


Figure 5. Bandgaps and lattice constanst for InGaAlP

LED Versions

The figures below show two structures on a GaAs substrate: figure 6, standard red and figure 7, DH-red. Standard red consists of $GaAs_{0.6}P_{0.4}$ which was deposited with a $GaAs_{l-x}P_x$ buffer layer on a n-GaAs substrate by vaporphase epitaxy. The element is manufactured in a planar process with masked Zn diffusion. The substrate is opaque in this case. This means that the rear contact can be provided over the complete area.

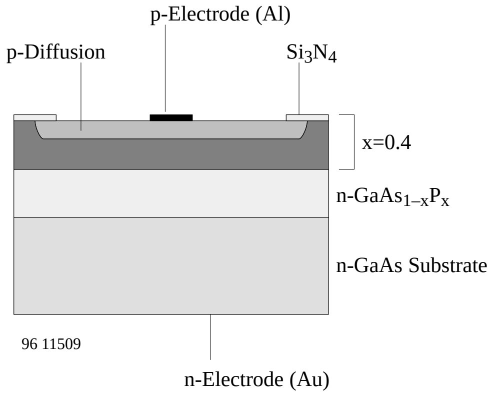


Figure 6. Standard red

The DH-red element consists of three epitaxial layers on p-GaAs substrate. The active layer with 35% Al-content is manufactured between two layers of $Ga_{l-x}Al_xAs$ of $>60\%$ Al content.

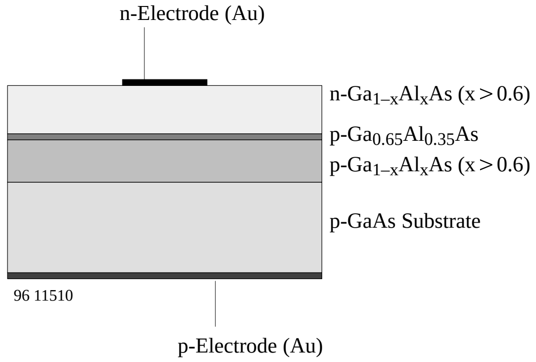


Figure 7. DH-red

Other standard LEDs are shown in figures 8 and 9. The chips for orange and yellow are similar to the standard red type. Due to the large amount of P, 0.6 or 0.85, the material is deposited with suitable buffer layers on the transparent GaP substrate, and a reflective rear contact is provided. The green element consists entirely of GaP and can therefore be manufactured with liquid-phase epitaxy. The grown PN junction is divided by mesa etching in this example to enable measurement of individual chips on the wafer.

A new type of LED for applications where a particularly high brightness is required is shown in figure 10. The structure is similar to that of a DH-red element. A double heterostructure is arranged on a light-absorbing GaAs substrate. A combination of a Bragg reflector between the substrate and DH-structure and window layer on the DH-structure effect an extremely high luminescent efficiency in this type of LED.

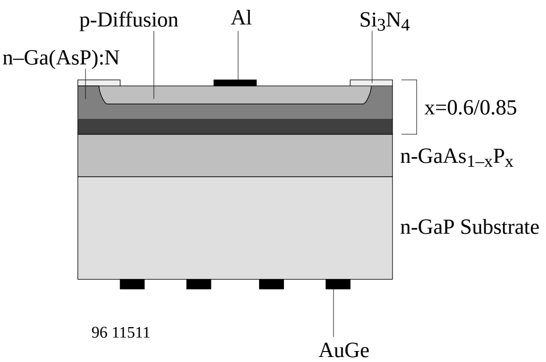


Figure 8. Orange and yellow

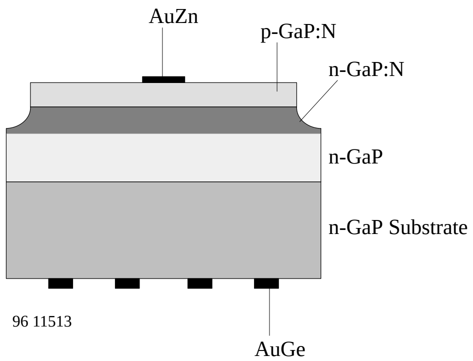


Figure 9. Green

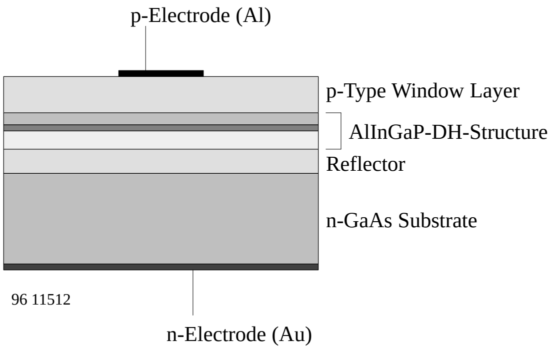


Figure 10. AlInGaP technology

LED Characteristics

The most important characteristics of the LEDs dealt with here are summarized in table 1. The emission of LEDs is almost monochromatic and can be characterized by a peak wavelength (column 4) and a spectral half bandwidth (column 6). The lowest spectral half bandwidth is generated by LEDs with direct band-to-band recombination, while other mechanisms and material inhomogeneities lead to wider emission. Here, it is evident that the efficiency drops as the wavelength is reduced.

Liquid-phase elements generally have a higher efficiency than comparable vapor-phase elements. For applications in which a Si detector is to be used as a receiver, for example, the emitted radiated power ϕ_e is important. If, however, the receiver is the human eye, the light flux ϕ_v is decisive.

Figure 11 shows the sensitivity of the human eye in accordance with DIN 5031. The maximum value is 683 lm/W at 555 nm. Green LEDs are close to this maximum value, while the curve for red emission drops rapidly. An orange LED (630 nm), for example, appears approximately 5 times brighter than a red LED (660 nm) at the same efficiency.

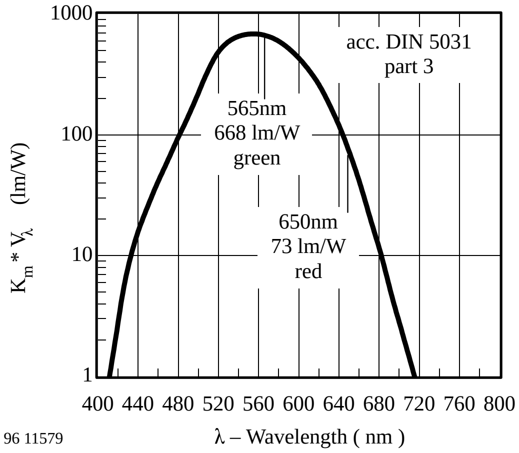


Figure 11. Human eye sensitivity diagram

Electrically, LEDs are ordinary PN diodes (except for SiC). The most important parameter for normal operation is the forward voltage V_F. (Table 1, third column from the right) where the numerical value in V corresponds approximately to the bandgap of the semiconductor used. The speed of LEDs is characterized by their switching time (last column); red LEDs made of direct materials are fastest, while indirect types are considerably slower due to the special recombination mechanism. Generally, LEDs are robust and their lifetimes (more than 10^5 hours) are more than sufficient for practically all applications.

Due to the rapid current rise in the forward direction, LEDs are always connected in series with a current limiting element. Figure 12 shows how the working point is set with a series resistor. If the supply voltage varies greatly, a constant current source is used. Digital displays and similar devices are often operated in multiplex mode. The seven data lines carry the information for the digits in a time-staggered manner. Each LED is operated for one-quarter of the time with four times the current in order to achieve the same intensity as in continuous operation. In displays with larger numbers of LEDs, it is advisable to reduce the number of driver stages and connecting leads. Due to the diode characteristics of LEDs, a large number of LEDs can be operated with only a few leads if the circuit is designed accordingly.

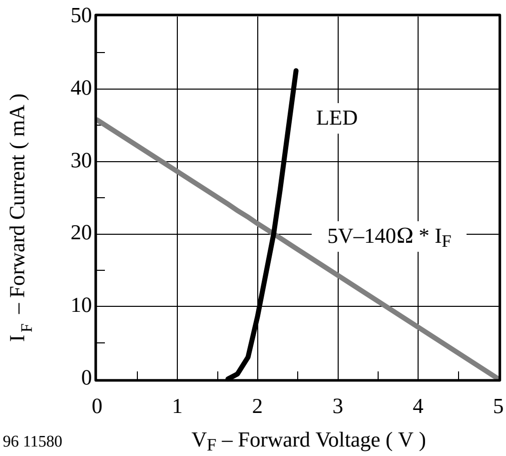


Figure 12. LED operating point

Table 1. LED characteristics at I_F = 10 mA

Color	Technology	TEMIC Type	λ_p	λ_d	$\Delta\lambda$	ϕ_v	ϕ_e	V_F	t_r	t_f
			nm	nm	nm	mlm	mW	V	ns	ns
DH-red	GaAlAs on GaAs	TLMD3100	650	648	20	45	0.7	1.8	100	100
High efficiency red	GaAsP on GaP	TLMH3100	635	620	45	25	0.17	2.0	300	150
Soft orange	GaAlAs on GaP	TLMO3100	605	605	40	25	0.15	2.0	300	150
AlInGaP-soft orange	AlInGaP on GaAs	TLMF3100	610	605	17	150	1.1	1.9	45	30
Yellow	GaAsP on GaP	TLMY3100	585	590	45	25	0.05	2.0	300	150
AlInGaP-yellow	AlInGaP on GaAs	TLME3100	590	588	15	125	0.25	1.9	45	30
Green	GaP on GaP	TLMG3100	565	570	25	35	0.05	2.0	450	200
Pure green	GaP on GaP	TLMP3100	555	560	22	12	0.02	2.0	450	200
Blue	SiC on SiC	TLMB100	467	480	75	1.0	0.013	3.1	–	–

Conversion Tables

Table 2. Corresponding radiometric and photometric definitions, symbols and units.

	Radiometry			Photometry		
Definition		Symbol	Unit		Symbol	Unit
Power	Radiant flux (radiant power)	Φ_e	Watt, W	Luminous flux (luminous power)	Φ_v	Lumen lm
Output power per unit area	Radiant emit-tance/exitance	M_e	W/m^2	Luminous exitance	M_v	lm/m^2
Output power per unit solid angle	Radiant intensity	I_e	W/sr	Luminous intensity	I_v	candela, cd
Output power per unit solid angle and unit emitting area	Radiance	L_e	W/m^2∗sr	Luminance	L_v	cd/m^2
Input power per unit area	Irradiance	E_e	W/m^2	Illuminance	E_v	Lux, lx lx = lm/m^2
Energy	Radiant energy	Q_e	Ws	Luminous energy (quantity of light)	Q_v	lm ∗ s
Energy per unit area	Radiant exposure (irradiation)	H_e	(W∗s)/m^2	Light exposure	H_v	(lm∗s)/m^2

Table 3. Luminance Conversion Units (DIN 5031 part 3)

Unit		cd ∗ m^{-2}	asb	sb	L	cd ∗ ft^2	fL	cd ∗ in^{-2}	Notes
1 cd*m^{-2}	=	1	π	10^{-4}	π∗10^{-4}	9.29*10^{-2}	0.2919	6.45*10^{-4}	
1 asb (Apostilb)	=	1/π	1	1/π∗10^{-4}	10^{-4}	2.957*10^{-2}	0.0929	2.054*10^{-4}	
1 sb (stilb)	=	10^4	π∗10^4	1	π	929	2919	6.452	
1 L (Lambert)	=	1/π 10^4	10^4	1/π	1	2.957*10^2	929	2.054	
1 cd*ft^{-2}=	=	10.764	33.82	1.076*10^{-3}	3.382*10^{-3}	1	π	6.94*10^{-3}	ft=foot
1 fl (Footlam-bert) =	=	3.426	10.764	3.426*10^{-4}	1.0764 *10^{-3}	1/π	1	2.211* 10^{-3}	
1 cd*in $^{-2}$ =	=	1550	4869	0.155	0.4869	144	452.4	1	in = inch

Table 4. Illuminance Conversion Units

Unit		lx	lm ∗ cm^2	fc	Notes
1 lx	=	1	10^{-4}	0.0929	instead of lm*cm^{-2}, formerly Phot (ph)
1 lm*cm^{-2}	=	10^4	1	929	
1 fc (footcandle)	=	10.764	10.764*10^{-4}	1	

Special Notes and Conversion Diagrams

a) At standard illuminant A:
1 klx ≈ 6.1 mW/cm^2 or 1 mW/cm^2 ≈ 164 lx

b) At 555 nm it is valid: 683 lm ≈ 1 W
634.5 lm/ft^2 ≈ 1 mW/cm^2

c) 1 lumen/ft^2 = 1 footcandle
4 π candlepower = 1 lumen (lm)

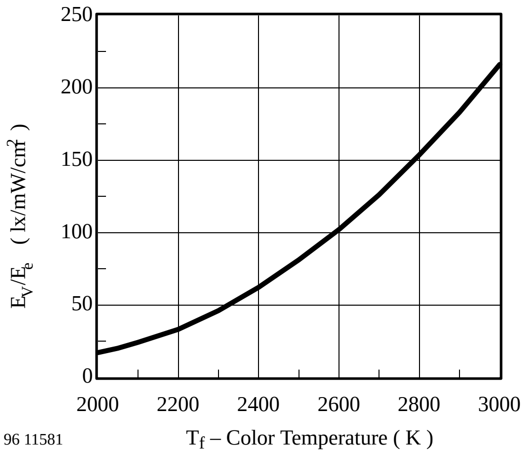


Figure 13. E_V/E_e (T_f)

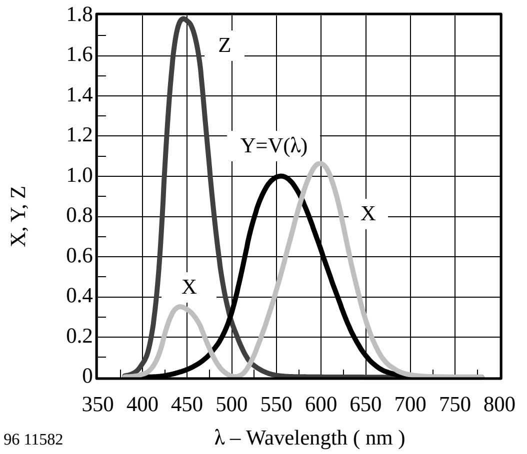


Figure 14. Color matching functions acc. to CIE 1931

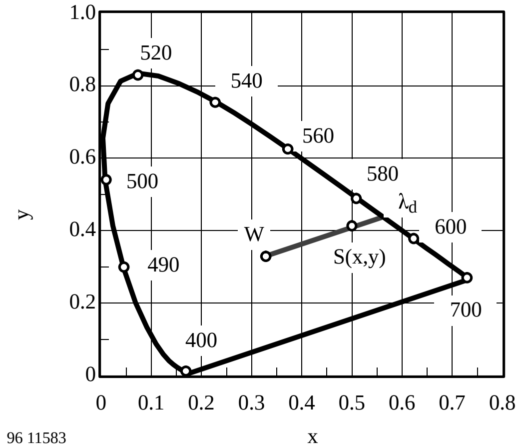


Figure 15. Chromaticity diagram acc. to CIE 1931

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 λ_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 TEMIC 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 Φ_V (in mlm) per solid angle unit Ω (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 16) 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 17). For a red LED (660 nm) with I_e = 0.1 mW/sr, the luminous intensity is calculated as below:

$I_v = I_e*K_m*V(\lambda)$ = 0.1 mW/sr*683 lm/W*0.061 = 4.2 mcd.

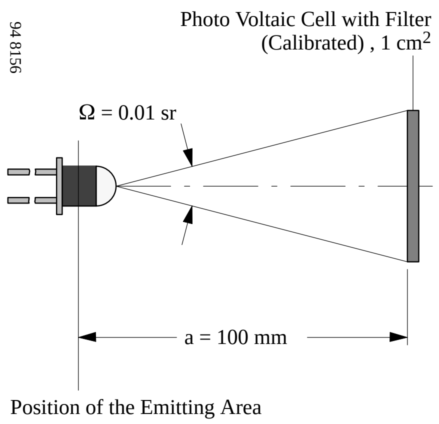


Figure 16. Radiant intensity measuring configuration

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 18).

A detector-filter combination, in which the red slope of the spectral sensitivity curve is matched precisely to the standarized curve of the human eye’s sensitivity, is therefore used for LEDs from green to red (figure 19). If blue LEDs are to be measured, a more expensive, high precision detector head which matches the total eye respose 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 ±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.

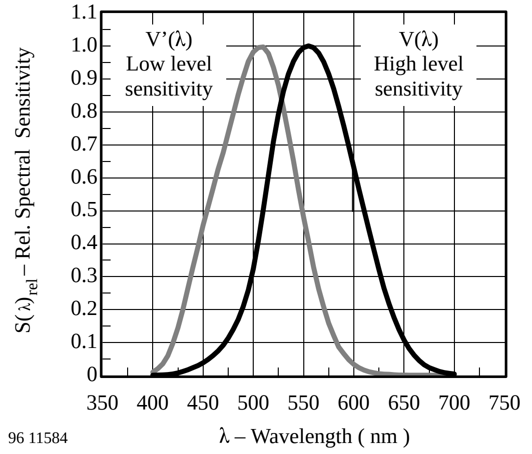


Figure 17. Relative spectral sensitivity of human eye

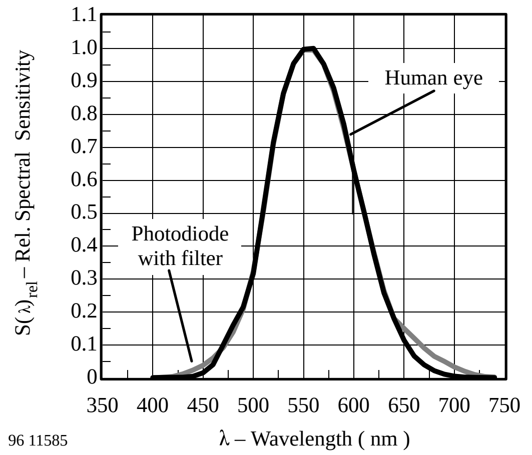


Figure 18. Correction filter

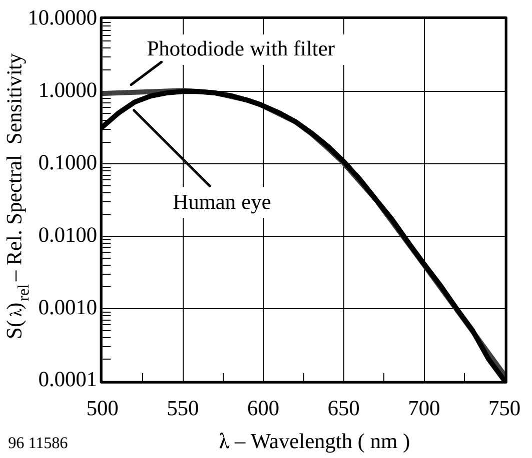


Figure 19. "Red photopic"

Measuring Configuration

The measuring configuration is a light-proof box, lined on the inside with black material (figure 20), 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°) 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 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.

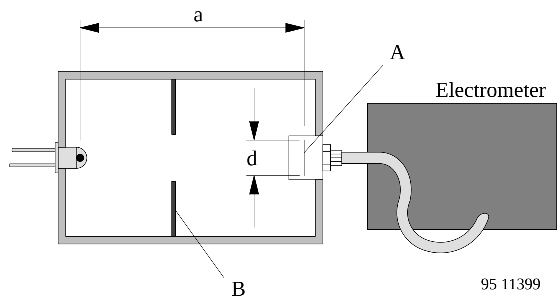


Figure 20. Luminous intensity measurement

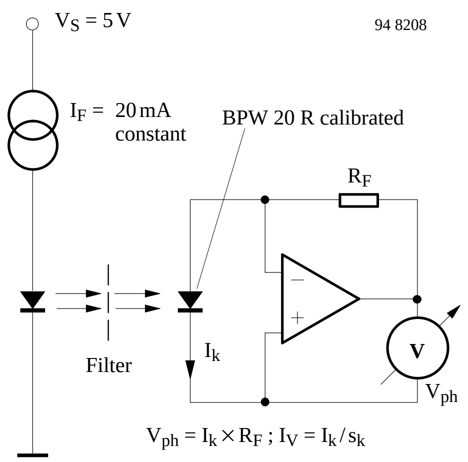


Figure 21. Test circuit with FET operational amplifier

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 21). Another method which has proved useful is to connect a measuring resistor of approximately 100 kΩ 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 22).

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):

$I_v = \Phi_v/\Omega = \Phi_v/0.01sr$.

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): $I_v = E_v * a^2 = E_v * 0.01\ m^2$.

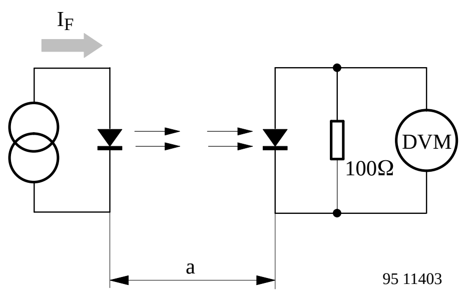


Figure 22. Configuration with a sensitive digital voltmeter

Measuring Angle

With a small measuring angle such as 0.01 sr, even LEDs with a very low radiant angle (± φ < 10°) 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 to be 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°). The electrical signal at the detector is then 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 (< ±5°), 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 (<< 0.01 sr = 6.5° plane angle). The reproducibility of these readings is improved with an increasing measuring angle.

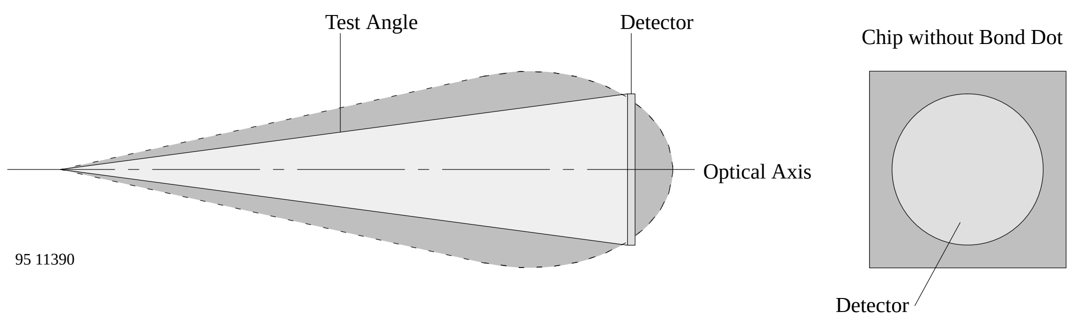


Figure 23. Simplified radiation characteristic

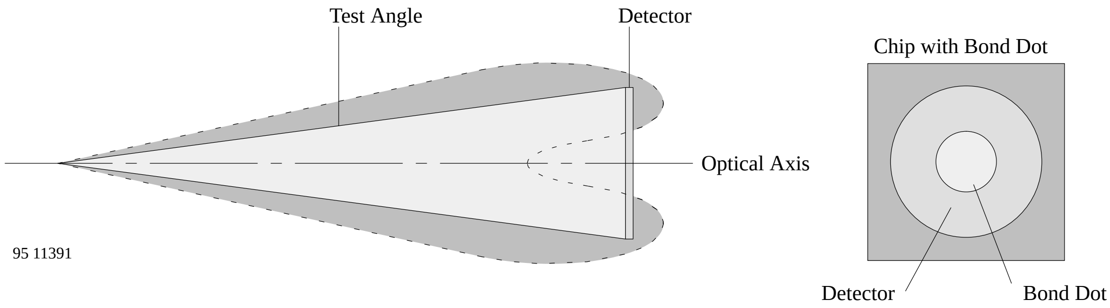


Figure 24. Radiation characteristic with bond dot

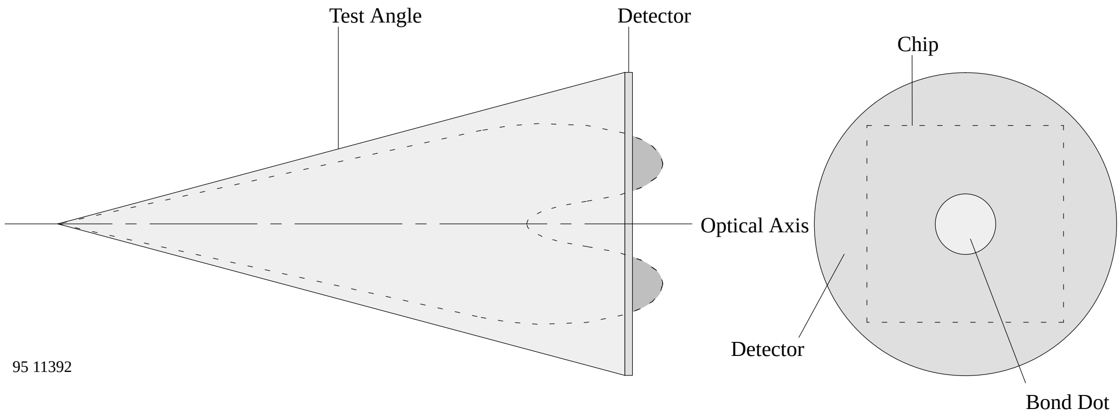


Figure 25. Large test angle

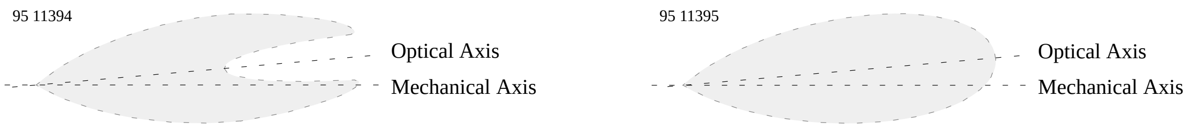


Figure 26. Deviation between optical and mechanical axis

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 devitation of the chip on the lead frame (< 100 µm) and of the frame in the plastic case (< 100 µm) 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.

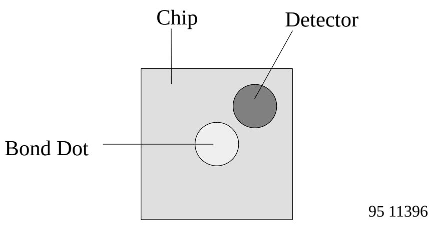


Figure 27. Small detector area

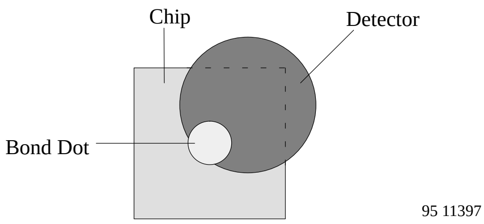


Figure 28. Middle detector area

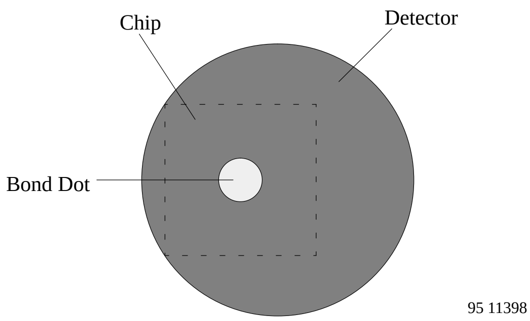


Figure 29. Large detector area

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 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. 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 measure 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 38). 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.

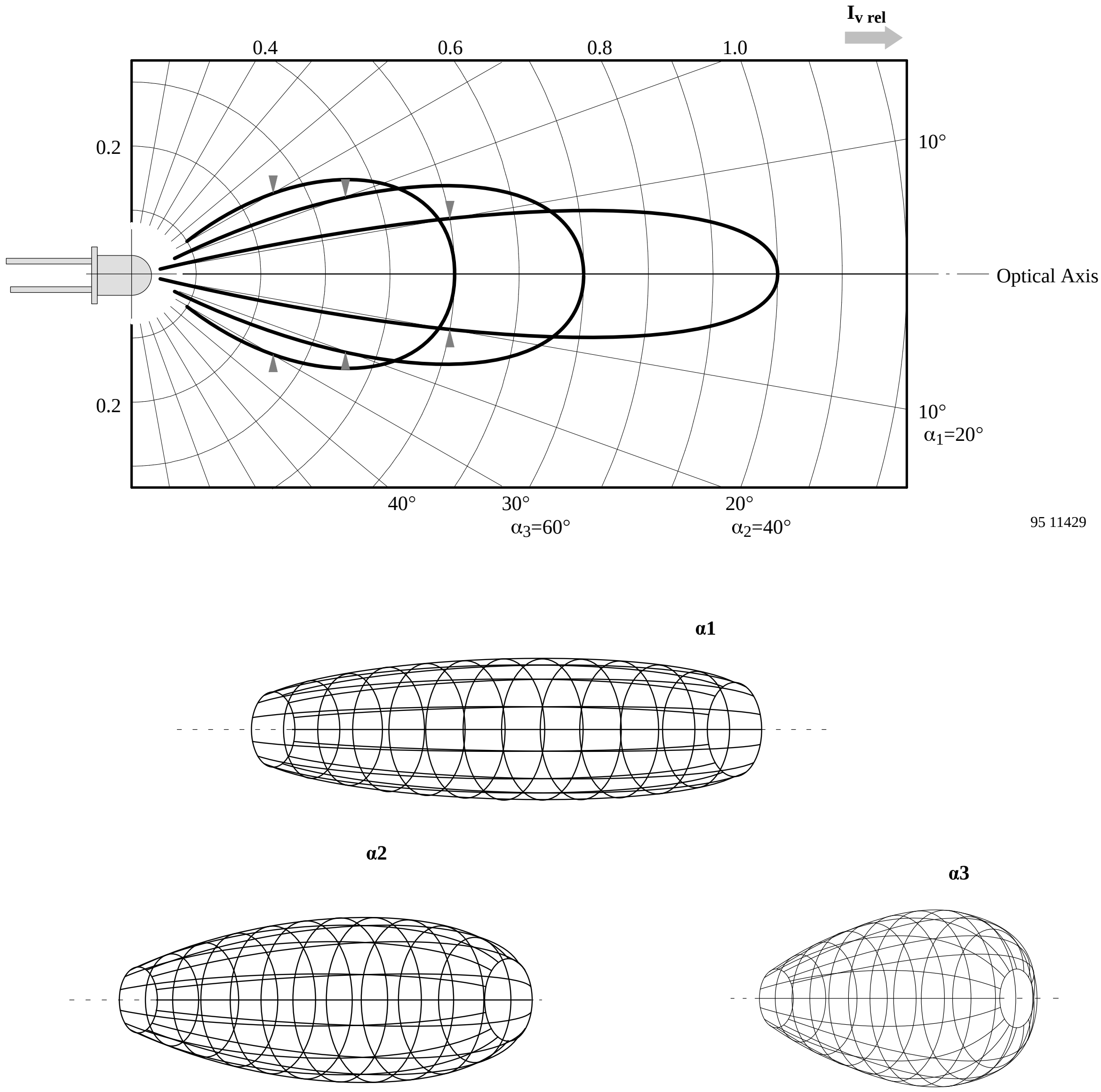


Figure 30. Radiation angles with corresponding angles of half intensity

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 rotatory mounting with angle scale is installed. After measurement of the axial luminous intensity I_V (angle setting 0°), 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 31. 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.

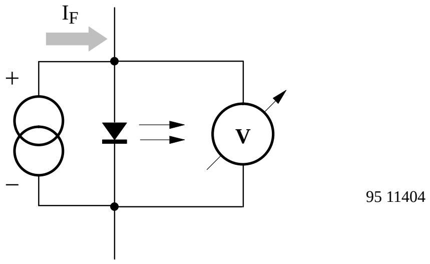


Figure 31. Forward voltage measuring

Breakdown Voltage

For most LEDs, $V_{(BR)}$ is specified at 10 μA 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 reading with a 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 λ_P:
the maximum point of the spectral curve

b) Main wavelength λ_S:
the main point of the spectral curve (identical with λ_P in the case of a symmetrical spectral curve)

c) Dominant wavelength λ_d:
The dominant wavelength λ_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 32).

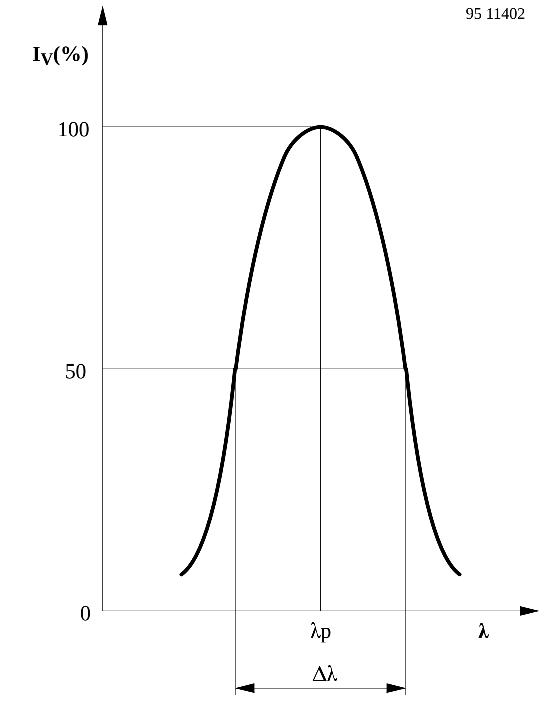


Figure 32. Spectral bandwidth

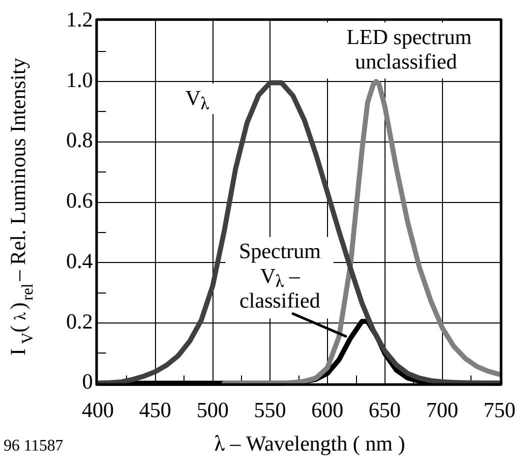


Figure 33. LED spectral curve weighted by V(λ)

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-filter combination, 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-filter combination are 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(λ) 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 ±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, the emission spectrum of LEDs is shifted in the longwave direction.

A shift of approximately +0.1 to 0.3 nm per degree is normally expected.

Component Construction

LEDs

The basis for an LED is a lead frame with treated surface. The chips are mounted in a reflecting tray in order to increase the light output.

The contacts are made on the cathode side by means of conductive adhesive and on the anode side via a gold wire to the lead frame. The plastic case encloses the chip area of the lead frame and determines the radiation characteristics as an optical system.

The special plastic material provides the component with high resistance against moisture and mechanical effects.

Displays

The LED chips are mounted with conductive adhesive on a lead frame. This frame is cast into the display housing which, with its highly reflective light channels, simultaneously provides the external and the segment configuration.

This construction provides the display with special characteristics: wide operating temperature range, protection against environmental effects; uniform, bright segment illumination; resistance to shock and vibration.

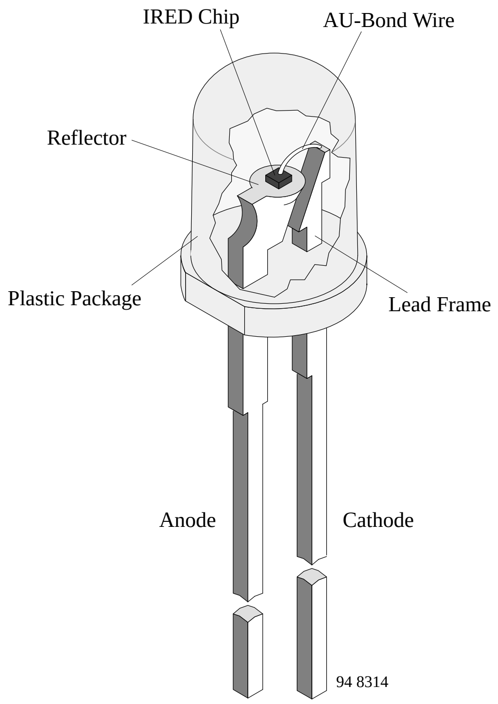


Figure 34. Standard LED design

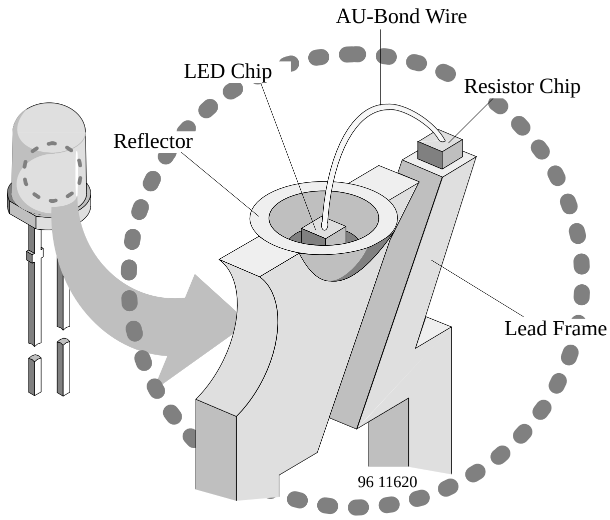


Figure 35. Resistor LED design

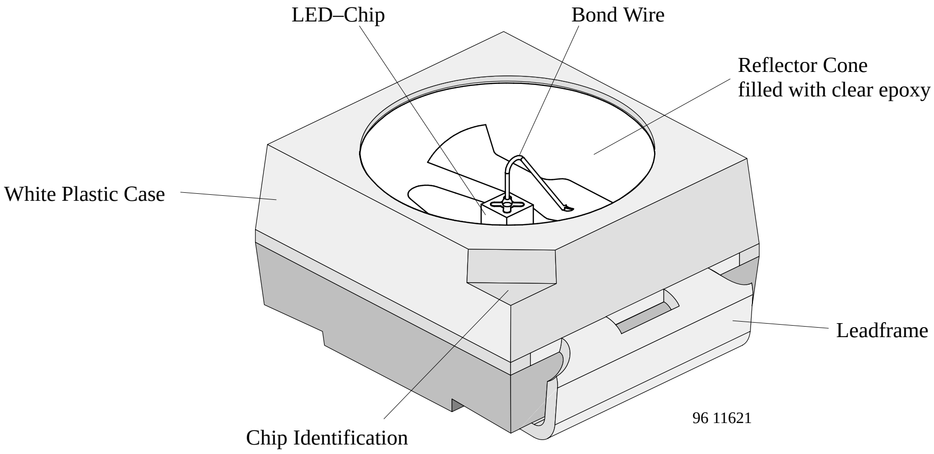


Figure 36. Typical SMD design

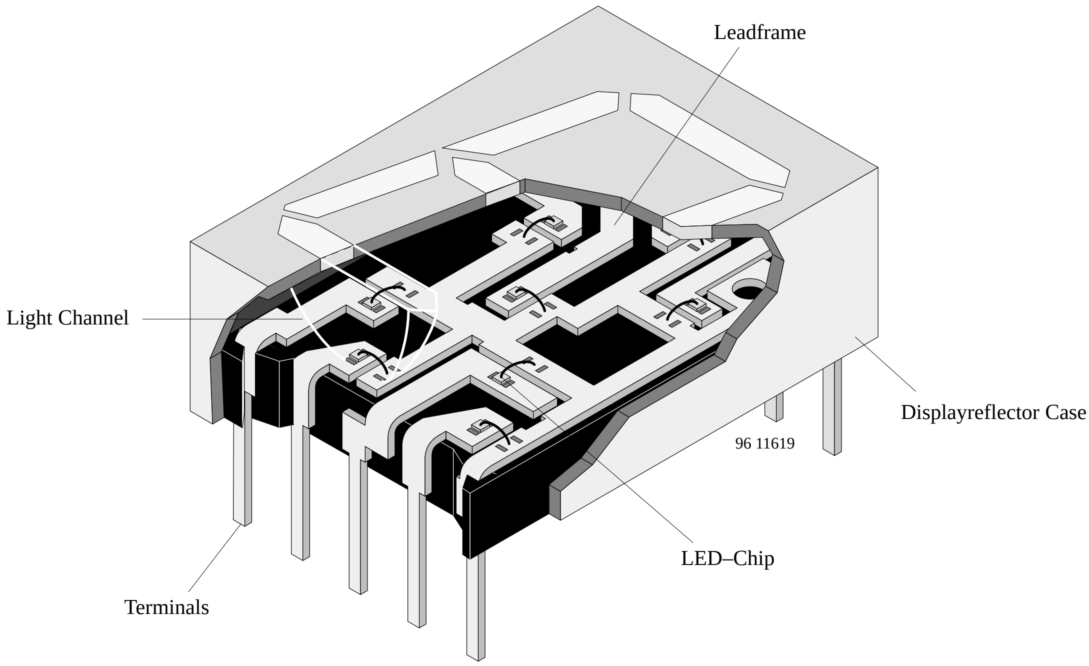


Figure 37. Typical display design

Classification of Components

Light Intensity Classification

LEDs and Displays (see tables below) are classified into light intensity groups. The light intensity ratio within a group does not exceed 2:1.

For LEDs

A code is marked on each packing

Group	Light intensity		Standard test conditions I_F = 10 mA
	Min.	Max.	
F	0.1	0.2	Exception: TLL. series I_F = 2 mA, TLDR–, TLH.58– and blue – series I_F = 20 mA
G	0.16	0.32	
H	0.25	0.5	
I	0.4	0.8	
K	0.63	1.25	
L	1.0	2.0	
M	1.6	3.2	
N	2.5	5.0	
P	4.0	8.0	
Q	6.3	12.5	
R	10	20	
S	16	32	
T	25	50	
U	40	80	
V	66	132	
W	100	200	
X	130	260	
Y	180	360	
Z	240	480	
AA	320	640	
BB	430	860	
CC	575	1150	
DD	750	1500	
EE	1000	2000	
FF	1350	2700	
GG	1800	3600	
HH	2400	4800	
II	3200	6400	
KK	4300	8600	

In accordance with selection, delivery is carried out in separate packing units. This permits construction of arrangements of several components to form displays of the same luminous intensity (see figure 38).

TLHG 5401 N 4

Type — Light intensity group — Color group

Figure 38. Example for labelling of components and packing materials

For 7-Segment-Displays

A code is marked on each package.
Standard test conditions I_F = 10 mA, exception TDSL – series I_F = 2 mA.

Group	Light intensity in µcd at 10 mA	
	Min.	Max.
C	70	140
D	110	220
E	180	360
F	280	560
G	450	900
H	700	1400
I	1100	2200
K	1800	3600
L	2800	5600
M	4500	9000

Color Classification

Group	Yellow		Green	
	Dom. wavelength (nm)			
	Min.	Max.	Min.	Max.
0				
1	581	584		
2	583	586		
3	585	588		
4	587	590	564	567
5	589	592	566	569
6	591	594	568	571
7			570	573
8			572	575

Group	Softorange		Pure green	
	Dom. wavelength (nm)			
	Min.	Max.	Min.	Max.
0			555	559
1	598	601	558	561
2	600	603	560	563
3	602	605	562	565
4	604	607		
5	606	609		
6	608	611		

The use of components of the same groups results in uniform color output.

Tape and Reel Standards

TEMIC offers T-1 (3 mm) and T-1$^{3}/_{4}$ (5 mm) LEDs packaged on tape. The following specification is based on IEC publication 286, taking into account the industrial requirements for automatic insertion.

Absolute maximum ratings, mechanical dimensions, optical and electrical characteristics for taped devices are identical to the basic catalog types and can be found in the specifications for untaped devices.

Note that the lead wires of taped components may be shorted or bent in accordance with the IEC standard.

Packing

The tapes of components are available on reels or in fan-fold boxes. Each reel and box is marked with labels which contain the following information:

– Tfk

– Type

– Group

– Tape code (see figure 39)

– Production code

– Quantity

Code for taped IREDs

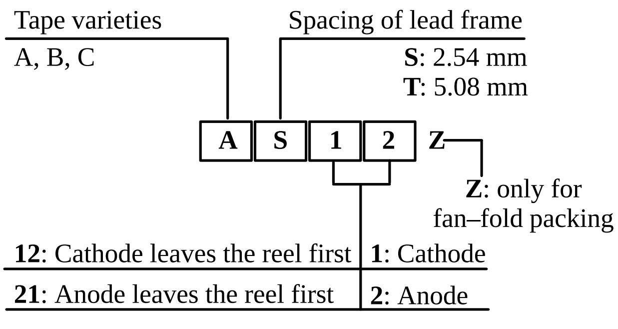


Figure 39. Taping code

Number of Components

Quantity per reel:	3 mm: 2000 pcs 5 mm: 1000 pcs
Quantity per fan-fold box:	3 mm: 2000 pcs 5 mm: 1000 pcs

This results in the increments for the ordering quantities:

3 mm: Increments of 2000 pcs
5 mm: Increments of 1000 pcs

Missing Components

Up to 3 consecutive components may be missing if the gap is followed by at least 6 components. A maximum of 0.5% of the components per reel quantity may be missing. At least 5 empty positions are present at the start and the end of the tape for tape insertion.

Tensile strength of the tape: ≧ 15 N

Pulling force in the plane of the tape, at right angles to the reel: ≧ 5 N

Note:
Shipment in fan-fold packages is standard for radial taped devices.
Shipments in reel packing are only possible, if the customer guarantees the removal of empty reels.
According to what is stated in a German packaging decree (Verpackungsverordnung) we are not able to accept the return of reels.

Order Designation

The type designation of the device is extended by the code shown above.

Example: TLHR4400AS12 (reel packing) or
TLHR4400AS12Z (fan-fold packing)

Reel Package, Dimensions in mm

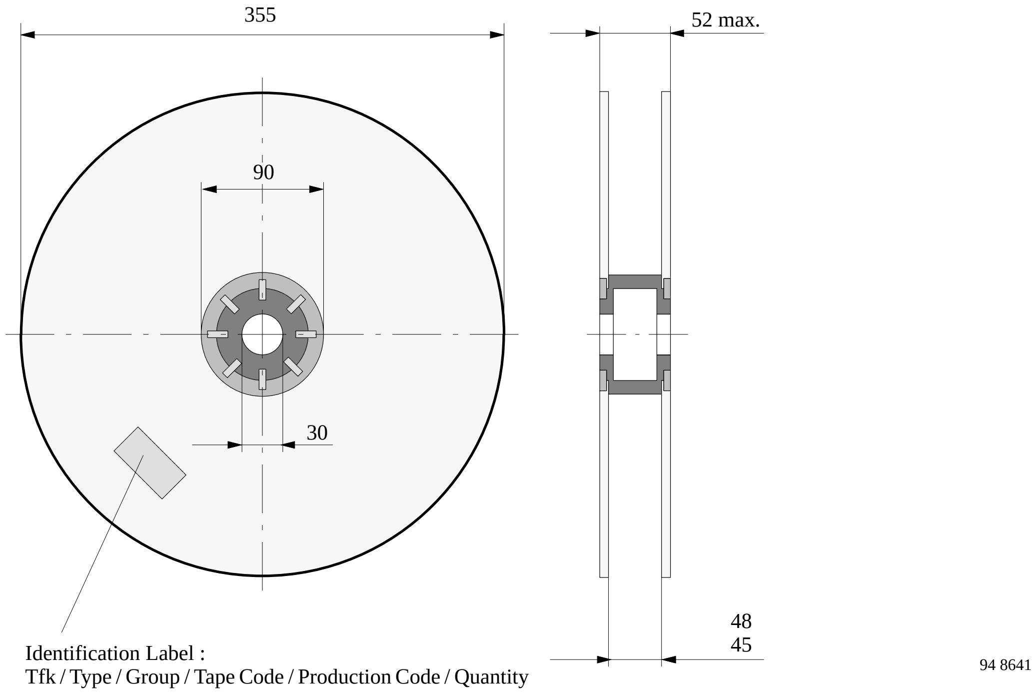


Figure 40. Reel dimensions

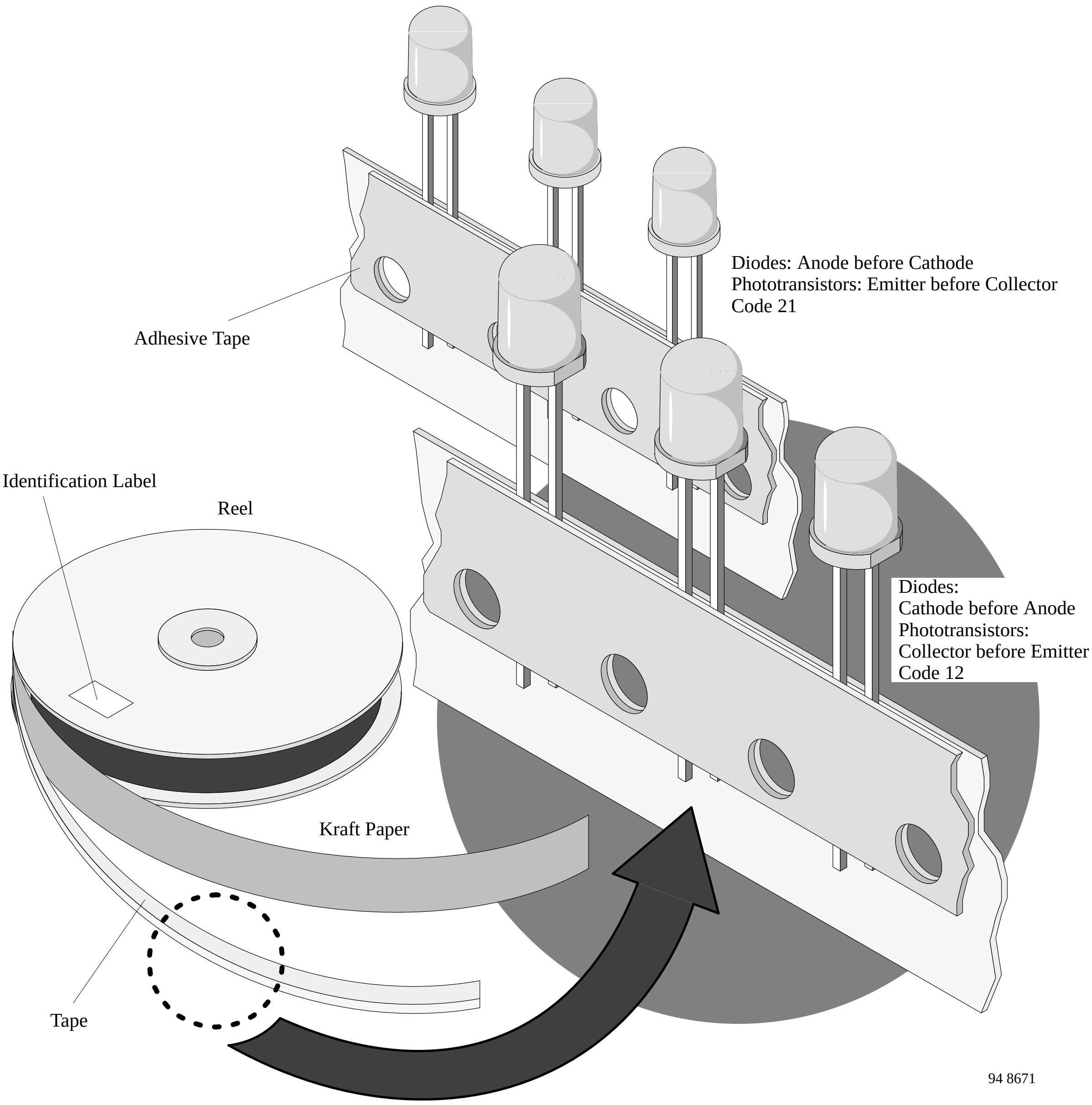


Figure 41. Winded devices

Tape Dimensions for ∅ 3 mm Standard Packages

Available Package Variations: 1 2, 1 2Z, 2 1

Table 5. Tape variations (3 mm standard)

LED Series	
TLH. 4...	AS..; BT
TLL. 4...	AS..; BT
TLS. 21..	AS..
TLU. 24..	AS
TLUR.4...	AS..; BT
TLD. 4...	AS..; BT

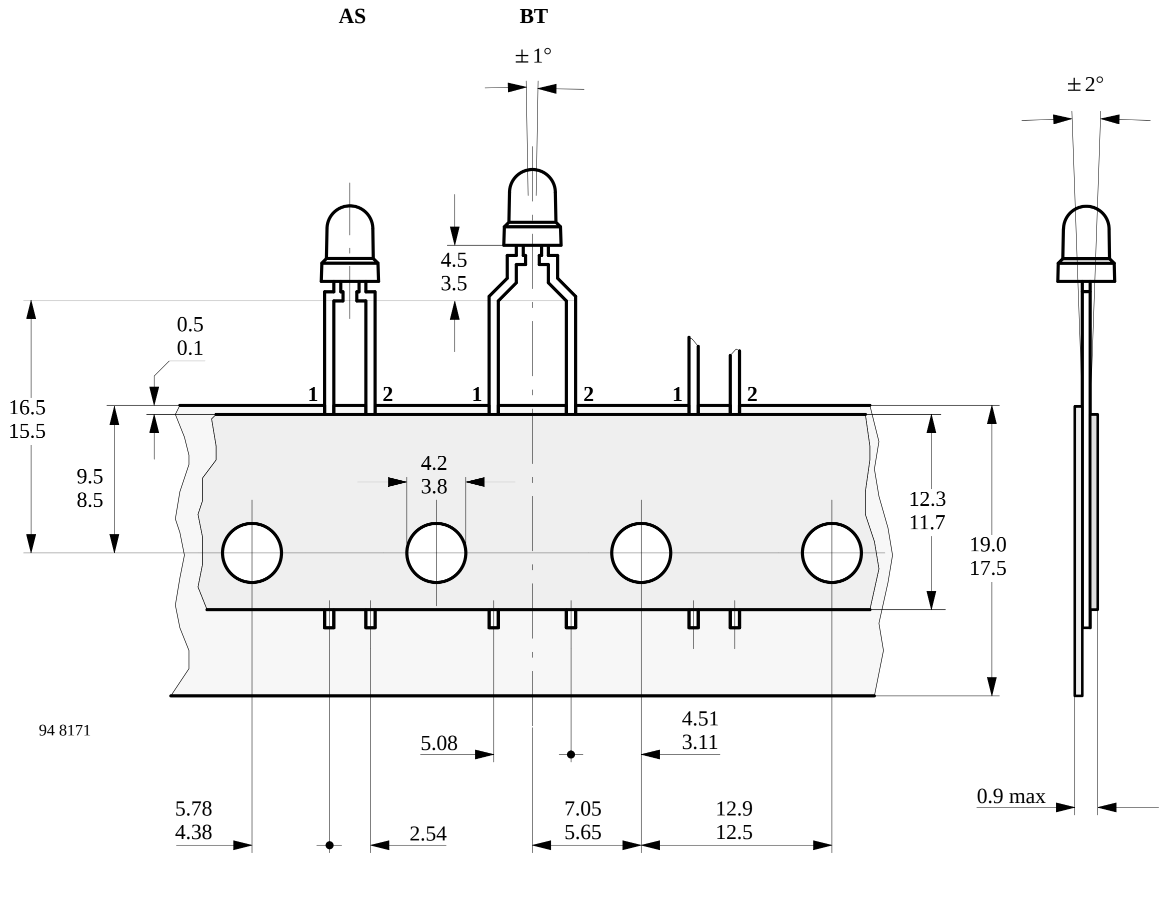


Figure 42. Tape dimensions ∅ 3mm devices

Tape Dimensions for ∅ 5 mm Standard Packages

Available Package Variations: 1 2, 1 2Z, 2 1

Table 6. Tape variations (5 mm standard)

LED Series	
TLH. 4...	AS..; BT
TLL. 4...	AS..; BT
TLS. 21..	AS..
TLU. 24..	AS
TLUR. 4...	AS..; BT
TLD. 4...	AS..; BT

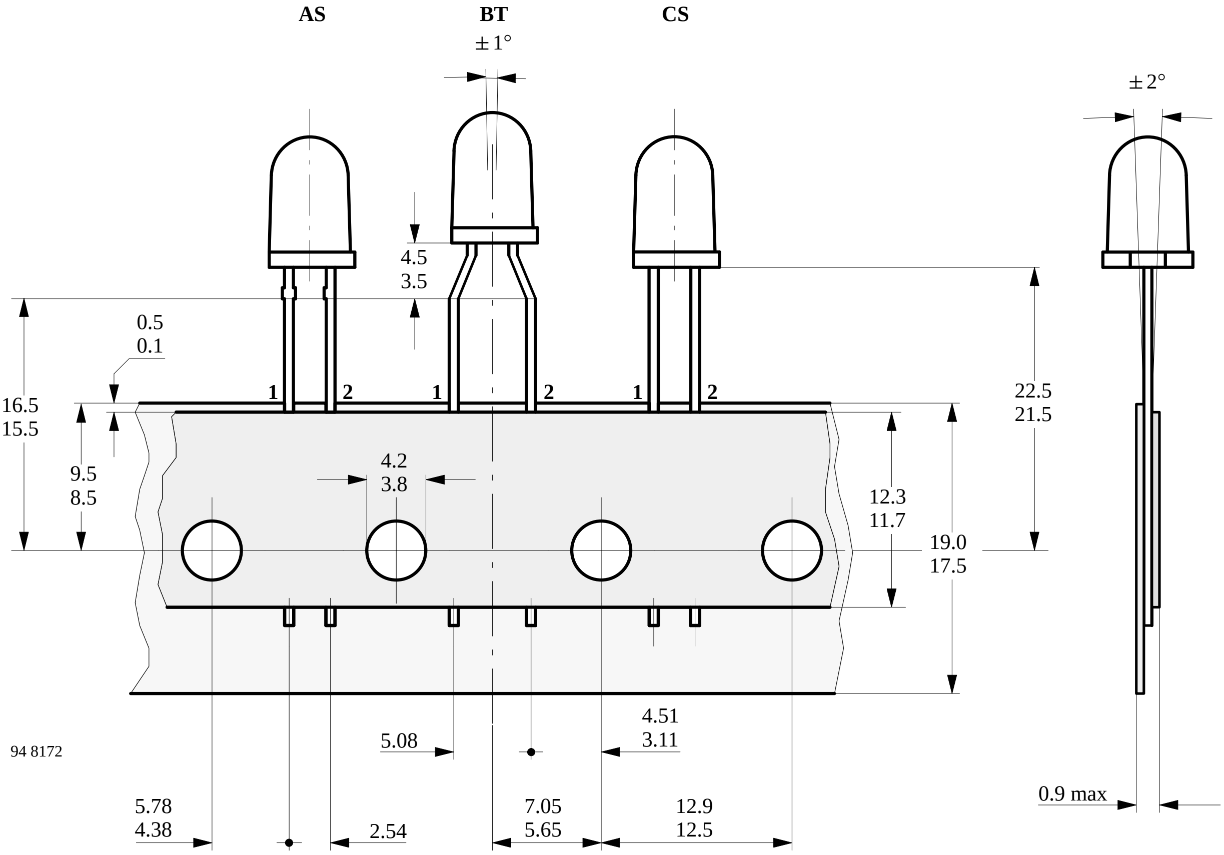


Figure 43. Tape dimensions ∅ 5 mm devices

Fan-Fold Packing

The tape is folded an a concertina arrangement and laid in the cardboard box.

If the components are required with the cathode before the anode (figure 44), the start of the tape should be taken from the side of the box marked "–". If the components are required with the anode before cathode (figure 45), the tape should be taken from the side of the box marked "+".

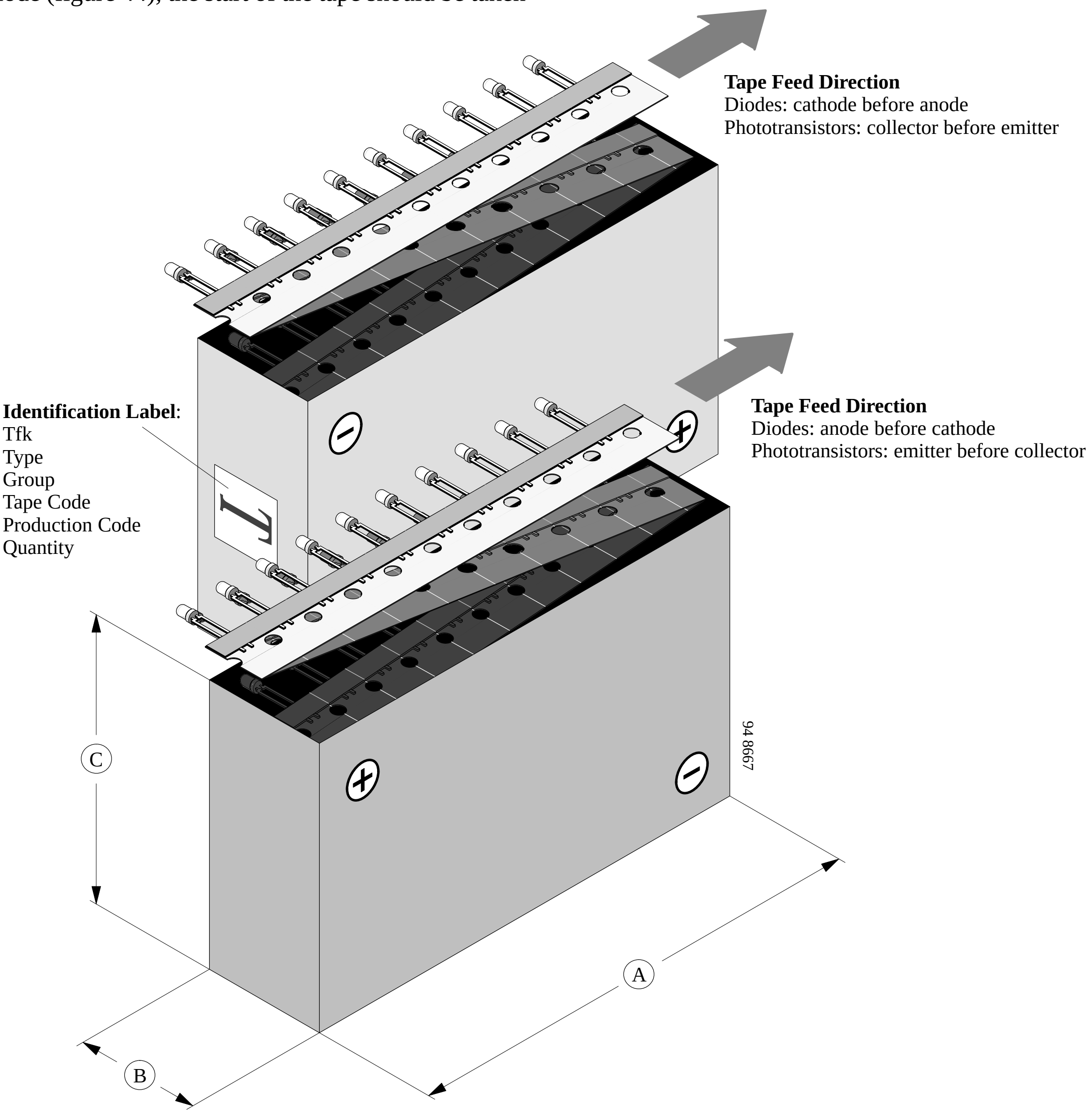


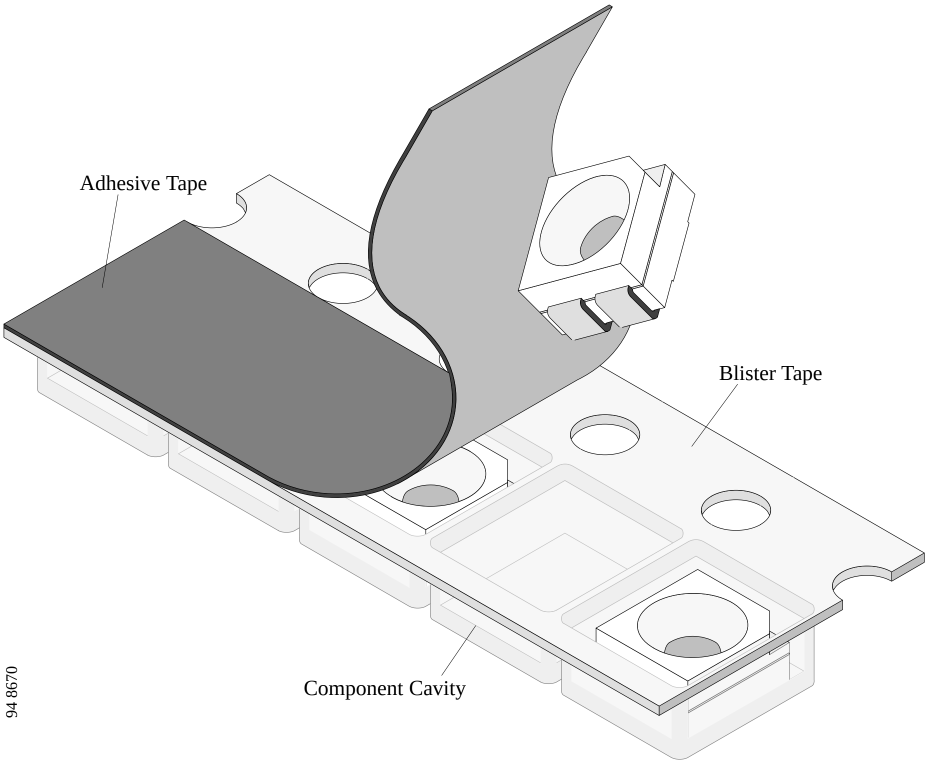
Figure 44. Tape direction

Table 7. Inner dimensions

A	B	C	Packages
340	46	125	∅5 mm
340	34	140	∅3 mm AS-Taping
340	41	140	∅3 mm other than AS-Taping

Taping of SMT Devices

TEMIC's LEDs in SMD packages are available in an anti-static 8 mm blister tape (in accordance with DIN IEC 40 (CO) 564) for automatic component insertion. The blister tape is a plastic strip with impressed component cavities, covered by a top tape.



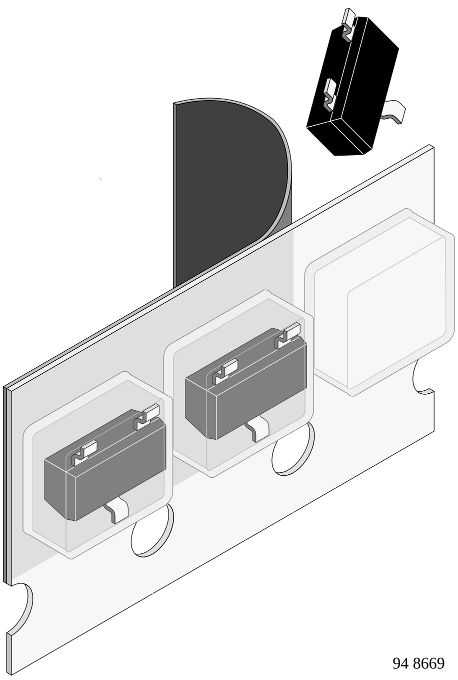


Figure 45. Blister tape

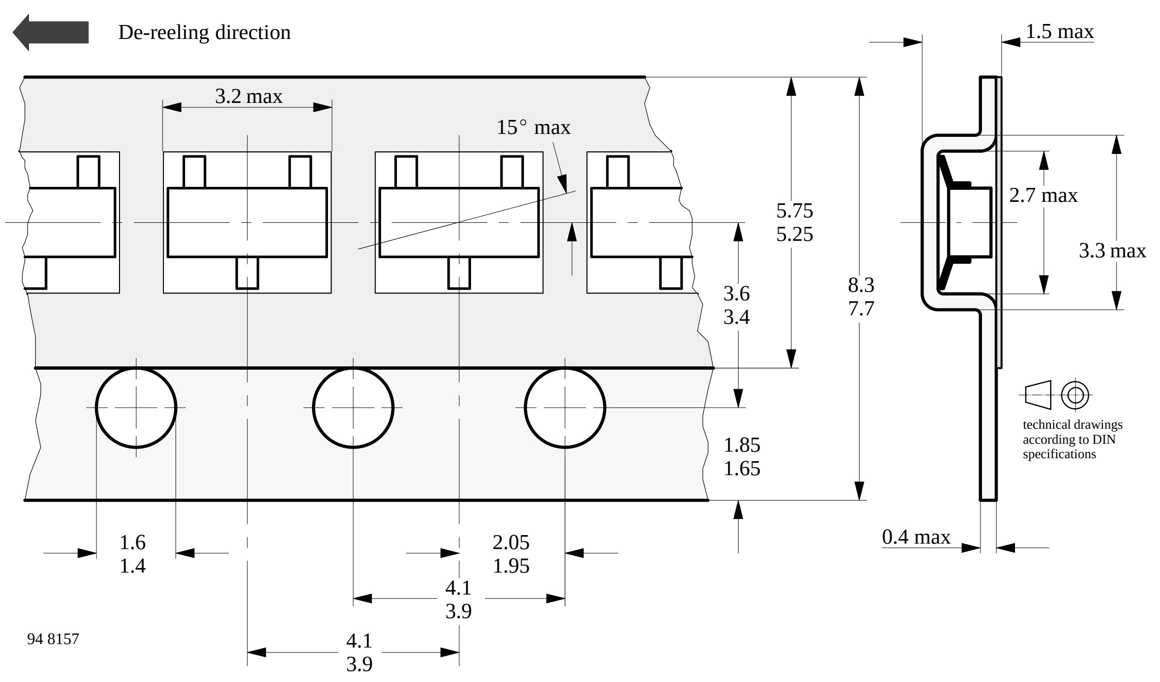


Figure 46. Tape dimensions in mm for SOT23. The mounting side of the components is oriented to the bottom side in the tape.

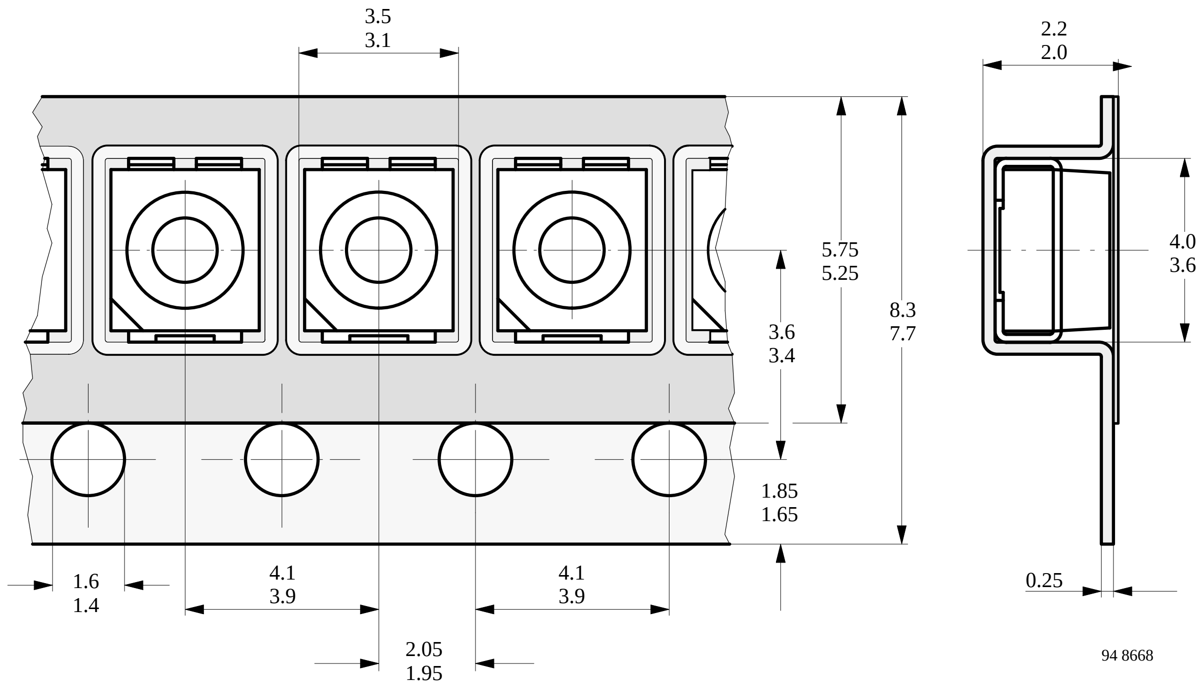


Figure 47. Tape dimensions in mm for PLCC2

Number of Components

Quantity per reel in SOT23 package: 3000 pcs
PLCC2 (Tantal B) package: 1500 pcs (minimum quantities for order)

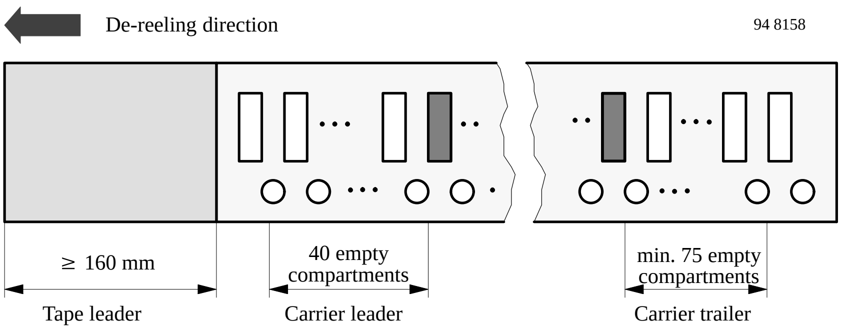


Figure 48. Beginning and end of reel

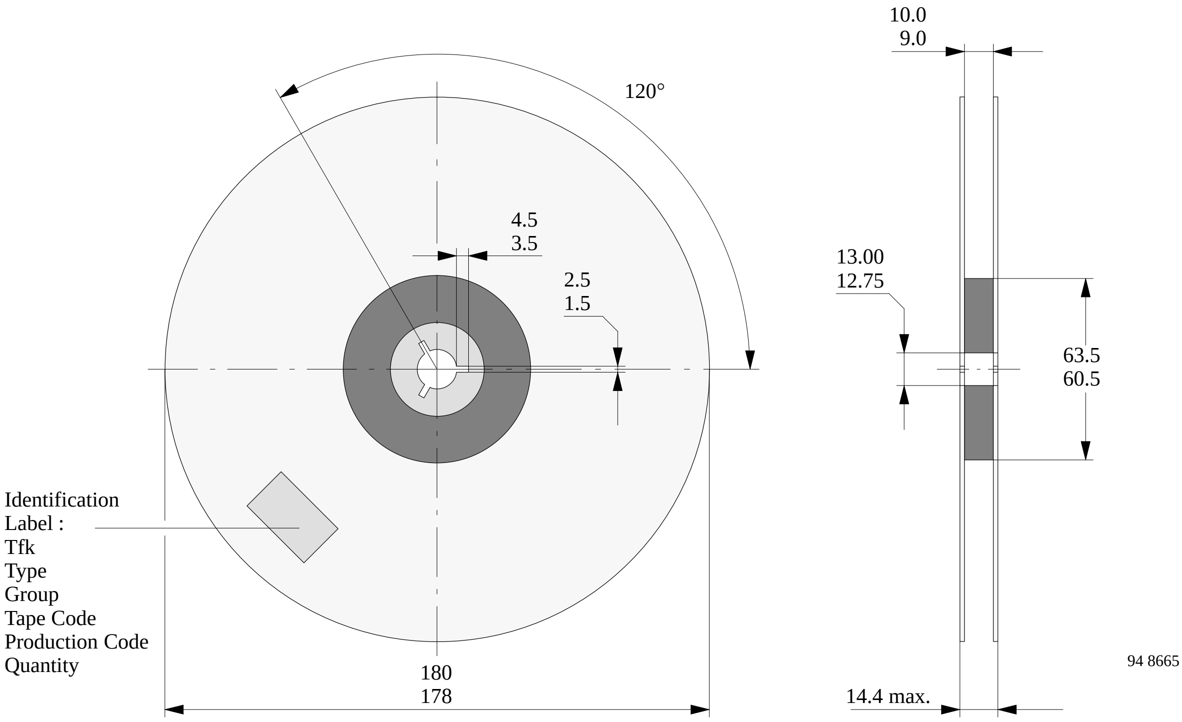


Figure 49. Reel dimensions

Missing Devices

A maximum of 0.5% of the total number of components per reel may be missing, exclusively missing components at the beginning and at the end of the reel. A maximum of three consecutive components may be missing, provided this gap is followed by six consecutive components.

The tape leader is at least 160 mm and is followed by a carrier tape leader with at least 40 empty compartments. The tape leader may include the carrier tape as long as the cover tape is not connected to the carrier tape.

The last component is followed by a carrier tape trailer with at least 75 empty compartments and sealed with cover tape.

Top Tape Removal Force

The removal force lies between 0.1 N and 1.0 N at a removal speed of 5 mm/s.

In order to prevent components from popping out of the blisters, the cover tape must be pulled off at an angle of 180°C with regard to the feed direction.

Ordering Designation

The type designation of devices in SOT23 package is extended by the code GS08.

Example: TEMD2100GS08

Assembly Instructions

General

Optoelectronic semiconductor devices can be mounted in any position. Connection wires may be bent, provided the bend is not less than 1.5 mm from the bottom of the case. During bending, no forces must be transmitted from the pins to the case (e.g., by spreading the pins).

If the device is to be mounted near heat generating components, consideration must be given to the resultant increase in ambient temperature.

Soldering Instructions

Protection against overheating is essential when a device is being soldered. Therefore, it is recommended that the connection wires are left as long as possible. The time during which the specified maximum permissible device junction temperature is exceeded at the soldering process should be as short as possible (one minute maximum). In the case of plastic encapsulated devices, the maximum permissible soldering temperature is governed by the maximum permissible heat that may be applied to the encapsulant rather than by the maximum permissible junction temperature.

The maximum soldering iron (or solder bath) temperatures are given in table 8. During soldering, no forces must be transmitted from the pins to the case (e.g., by spreading the pins).

Table 8. Maximum soldering temperatures

	Iron Soldering			Wave or Reflow Soldering		
	Iron Temperature	Distance of the soldering position from the lower edge of the case	Maximum allowable soldering time	Soldering Temperature see temperature/ time profiles	Distance of the soldering position from the lower edge of the case	Maximum allowable soldering time
PLCC2 Package	260°C	–	3s	230°C 260°C	–	10s 5s
Devices in plastic case ≥3 mm	≦260°C ≦300°C	≧2.0 mm ≧5.0 mm	5s 3s	235°C 260°C	≧2.0 mm ≧2.0 mm	8s 5s
Devices in plastic case <3 mm	≦300°C	≧5.0 mm	3s	260°C	≧2.0 mm	3s

Soldering Methods

There are several methods to solder devices on to the substrate. The following list of methods is not complete as a complete list.

(a) Soldering in the vapor phase

Soldering in saturated vapor is also known as condensation soldering. This soldering process is used as a batch system (dual vapor system) or as a continuous single vapor system. Both systems may also include preheating of the assemblies to prevent high-temperature shock and other undesired effects.

(b) Infrared soldering

When carrying out an infrared (IR) reflow soldering, the heating is contact-free and the energy for heating the assembly is derived from direct infrared radiation and from convection.

The heating rate in an IR furnace depends on the absorption coefficients of the material surfaces and on the ratio of the component’s mass to an As irradiated surface.

The temperature of parts in an IR furnace with a mixture of radiation and convection can not be determined in advance. Temperature measurement may be performed by measuring the temperature of a certain component while it is being transported through the furnace.

There is no 3 mm / 5 mm LED classification for this process.

Influencing parameters on the internal temperature of the component are as follows:

– Time and power
– Mass of the component
– Size of the component
– Size of the printed circuit board
– Absorption coefficient of the surfaces
– Packing density
– Wavelength spectrum of the radiation source
– Ratio of radiated and convected energy

Temperature/time profiles of the entire process and the influencing parameters are given in figure 50.

(c) Wave soldering

In wave soldering, one or more continuously replenished waves of molten solder are generated while the substrates to be soldered are moved in one direction across the wave's crest.

Temperature/ time profiles of the entire process are given in figure 51.

(d) Iron soldering

This process can not be carried out in a controlled situation. It should therefore not be used in applications where reliability is important.. There is no SMD classification for this process.

(e) Laser soldering

This is an excess heating soldering method. The energy absorbed may heat the device to a much higher temperature than desired. There is no SMD classification for this process at the moment.

(f) Resistance soldering

This is a soldering method which uses temperature-controlled tools (thermodes) for making solder joints. There is no SMD classification for this process at the moment.

Temperature-Time-Profiles

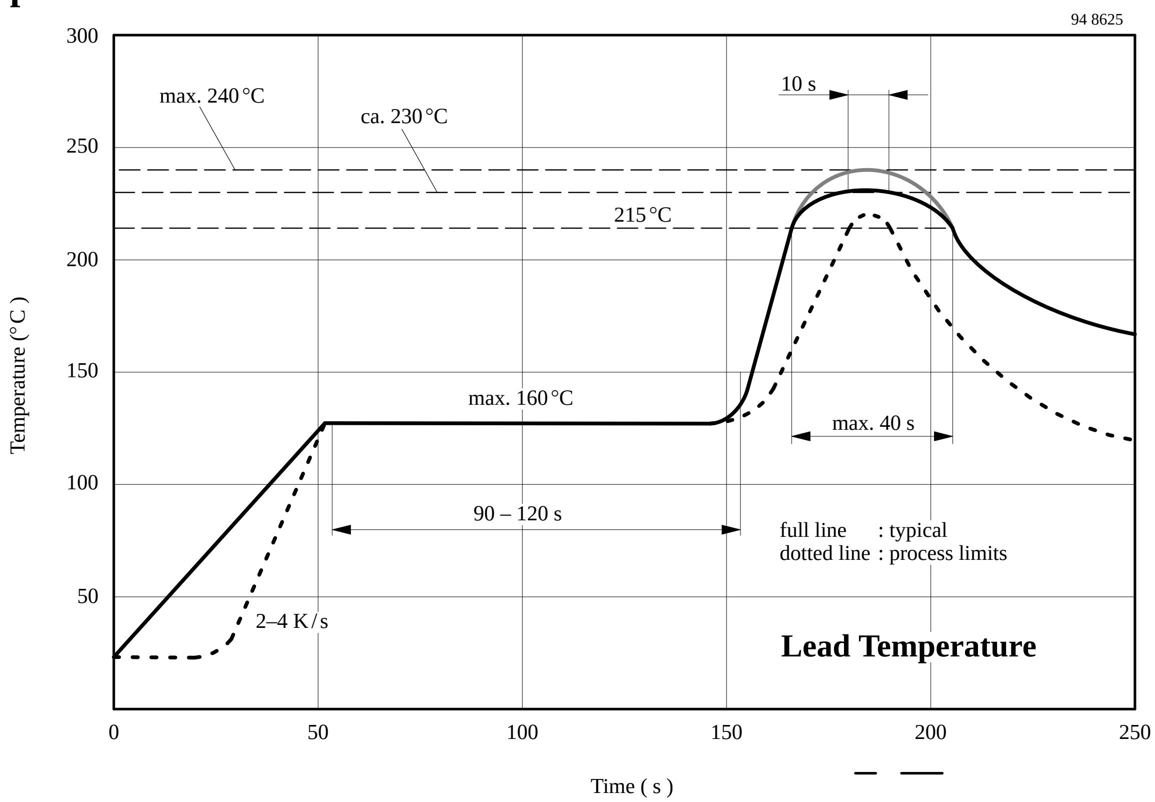


Figure 50. Infrared reflow soldering of optodevices (PLCC2 package)

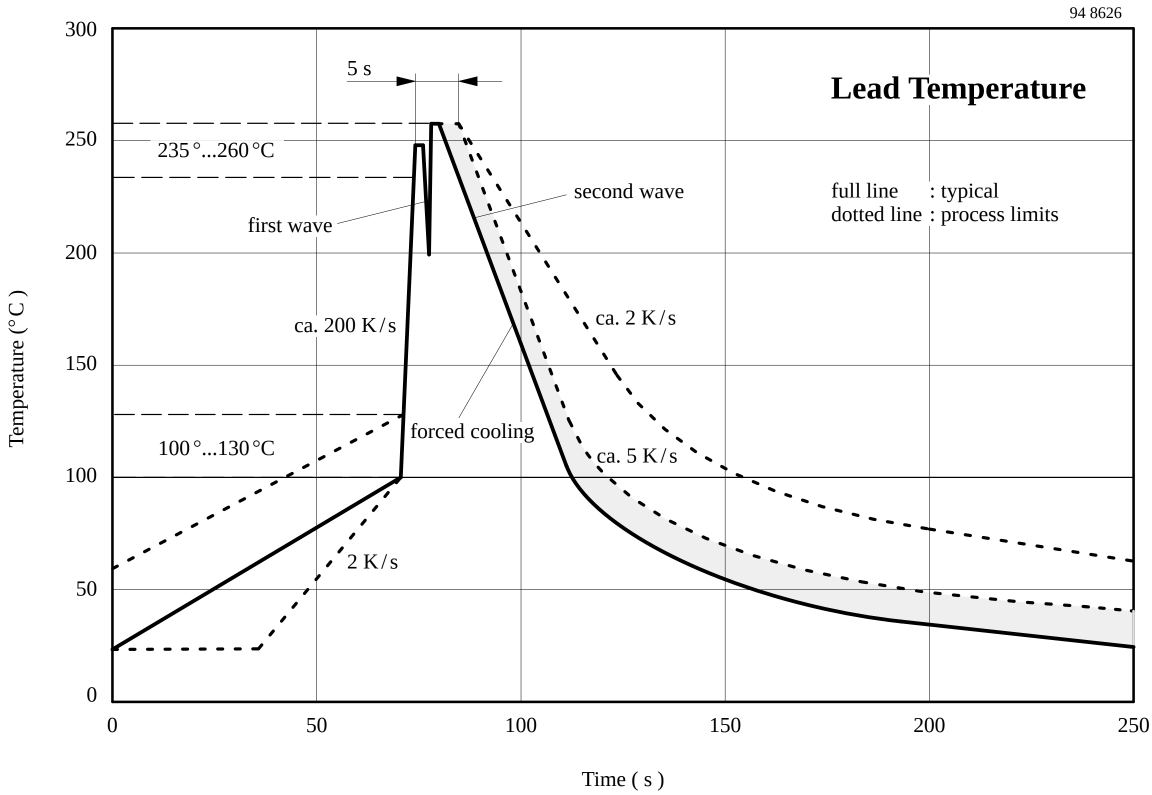


Figure 51. Wave soldering of double wave optodevices

Heat Removal

To keep the thermal equilibrium, the heat generated in the semiconductor junction(s) must be removed and the junction returned to ambient temperature.

In the case of low-power devices, the natural heat conductive path between the case and the surrounding air is usually adequate for this purpose. The heat generated in the junction is conveyed to the case or the header by conduction rather than convection. An indicator of the effectiveness of heat conduction is the measurement of inner thermal resistance or thermal resistance junction case, R_{thJC}, the value of which is governed by the construction of the device.

Any heat transfer from the case to the surrounding air involves radiation convection and conduction. The effectiveness of transfer is expressed in terms of an R_{thCA} value, i.e., the external or case ambient thermal resistance. The total thermal resistance, junction ambient is:

$R_{thJA} = R_{thJC} + R_{thCA}$

The total maximum power dissipation, $P_{tot\,max}$, of a semiconductor device can be expressed as follows:

$$P_{tot\,max} = \frac{T_{jmax} - T_{amb}}{R_{thJA}} = \frac{T_{jmax} - T_{amb}}{R_{thJC} + R_{thCA}}$$

where:

T_{jmax}	the maximum allowable junction temperature
T_{amb}	the highest ambient temperature likely to be reached under the most unfavorable conditions
R_{thJC}	the thermal resistance, junction case
R_{thJA}	the thermal resistance, junction ambient, is specified for the components. The following diagram shows how the different installation conditions affect the thermal resistance
R_{thCA}	the thermal resistance, case ambient. R_{thCA} depends on cooling conditions. If a heat dissipator or sink is used, R_{thCA} depends on the thermal contact between case and heat sink, heat propagation conditions in the sink and the rate at which heat is transferred to the surrounding air.

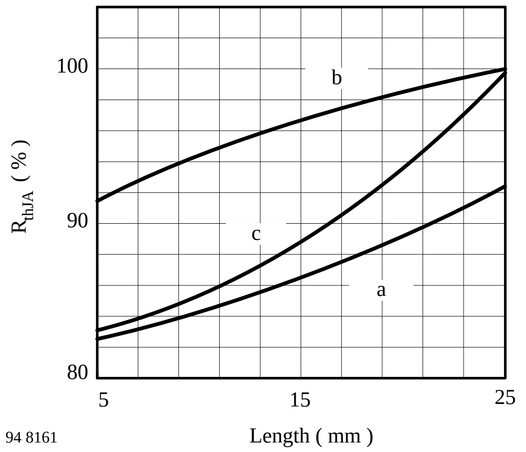


Figure 52. Thermal resistance junction / ambient vs. lead length

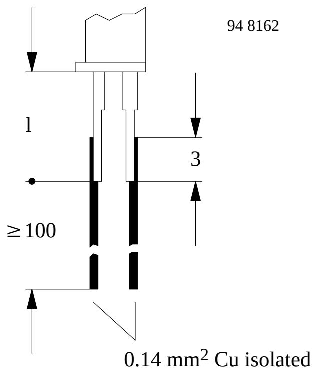


Figure 53. In the case of wire contacts (curve b, figure 52)

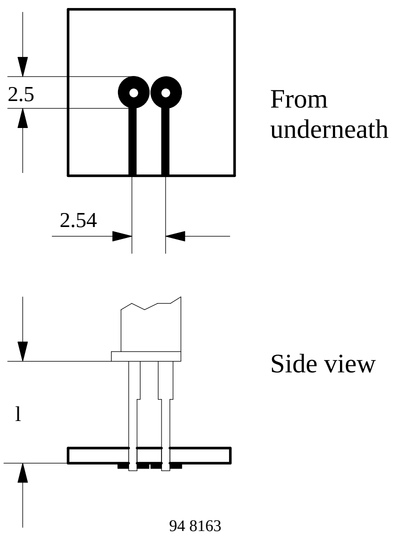


Figure 54. In the case of assembly on PC board, no heatsink (curve c, figure 52)

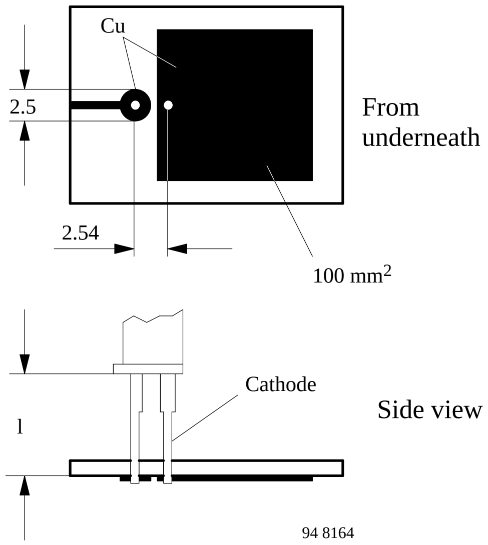


Figure 55. In the case of assembly on PC board with heatsink (curve a, figure 52)

Cleaning

Soldered assemblies can be cleaned with the following solvents:

1. A mixture of 1, 1.2-trichlorotrifluoroethane, 70 ± 5% by weight and 2-propanol (isopropyl alcohol), 30 ± 5% by weight. Customary grades (industrial use) shall be used.
   Warning: The component 1, 1.2-trichlorofluoroethane is hazardous to the environment. Therefore, this solvent should only be used if the solvents mentioned in 2 or 3 can not be applied.
2. 2-propanol (isopropyl alcohol). Customary grades (industrial use) should be used.
3. Demineralized or distilled water having a resistivity of not less than 500 mΩ corresponding to a conductivity of 2 mS/m.

Caution: The use of tetrachlor, acetone, trichloroetylene or similar is **NOT ALLOWED!**

Warning

Exceeding any one of the ratings (soldering, cleaning or short time exceeding the railings) could result in irreversible changes in the ratings.

Quality Information

TEMIC Continuous Improvement Activities

- TEMIC conducts quality training for ALL personnel including production, development, marketing and sales departments.
- Zero defect mindset
- Permanent Quality Improvement Process
- Total Quality Management (TQM)
- TEMIC's Quality Policy is established by the Management Board.
- Quality System certified per ISO 9001 on July 12, 1993 (Commercial Quality System).
- Quality System formerly approved per AQAP-1 (Military Quality System).

TEMIC Tools for Continuous Improvement

- TEMIC qualifies materials, processes and process changes.
- TEMIC uses Process FMEA (Failure Mode and Effects Analysis) for all processes. Process and machine capability as well as Gage R&R (Repeatability & Reproducibility) are proven.
- TEMIC's internal qualifications correspond to IEC 68–2 and MIL STD 883.
- TEMIC periodically requalifies device types (Short Term Monitoring, Long Term Monitoring).
- TEMIC uses SPC for significant production parameters. SPC is performed by trained operators.
- TEMIC offers Burn-In of selected device types.
- TEMIC's 100% testing of finished products.
- TEMIC's lot release is carried out via sampling. Sampling acceptance criterion is always c = 0.

TEMIC's Quality Policy

Our goal is to achieve total customer satisfaction

through everything we do.

Therefore, the quality of our products and services

is our number one priority.

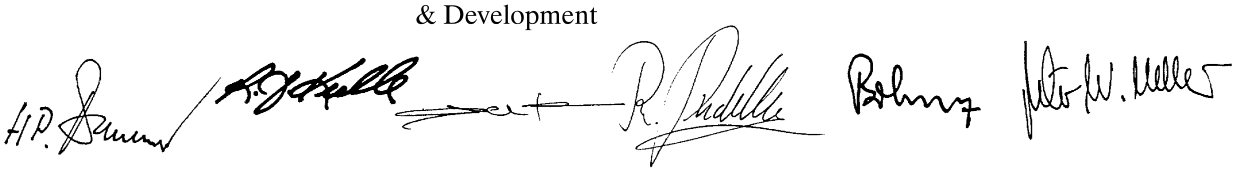
Quality comes first!

All of us at TEMIC are part of the process of

continuous improvement.

Board of Management, TEMIC Semiconductors:

H.P. Eberhardt Chairman	R.J. Kulle Operations	M. Desbard Quality/ Research & Development	R. Pudelko Design/ Tools	G. Bolenz Controller	P.W. Weber Marketing



General Quality Flow Chart Diagram

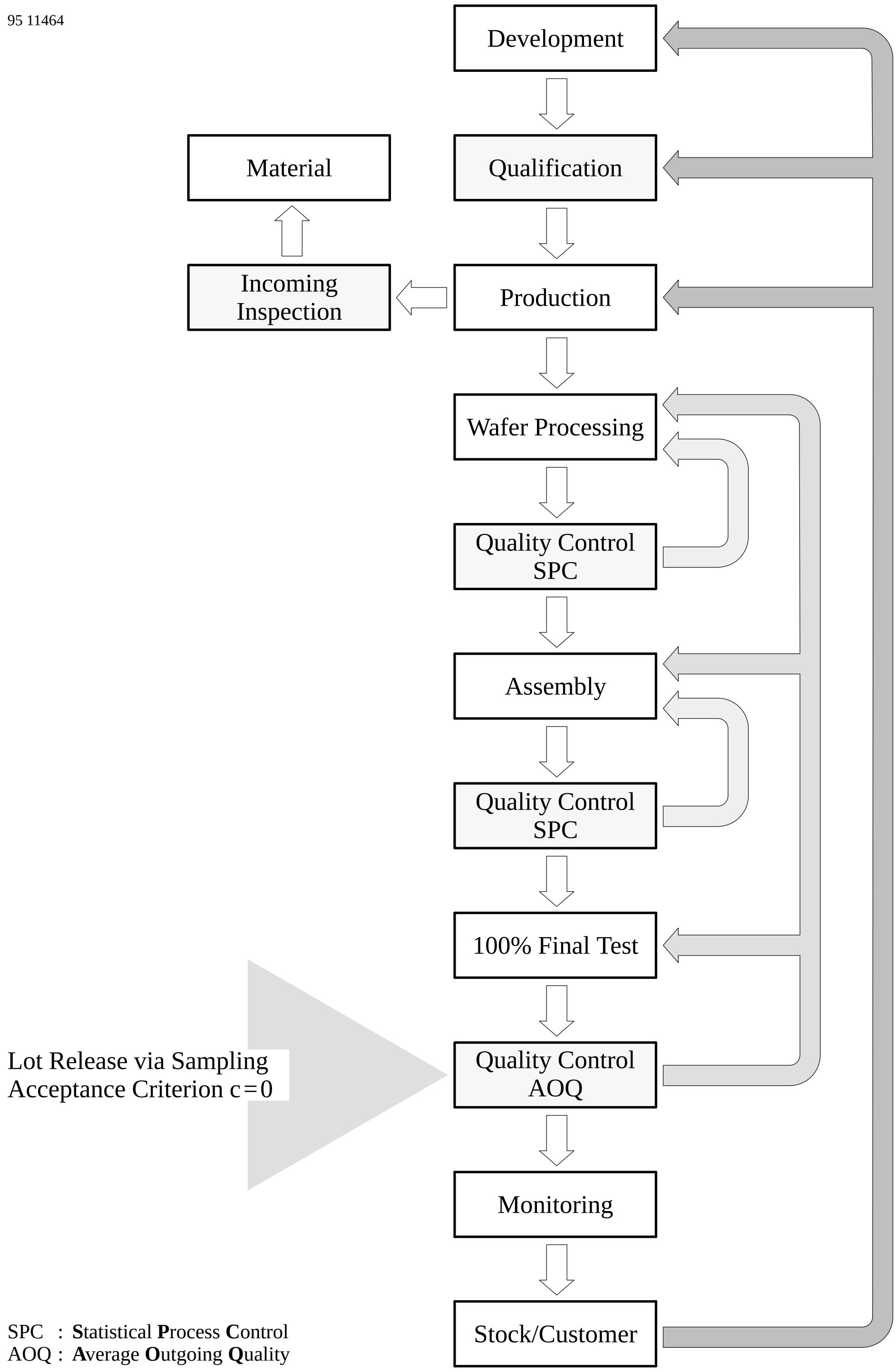
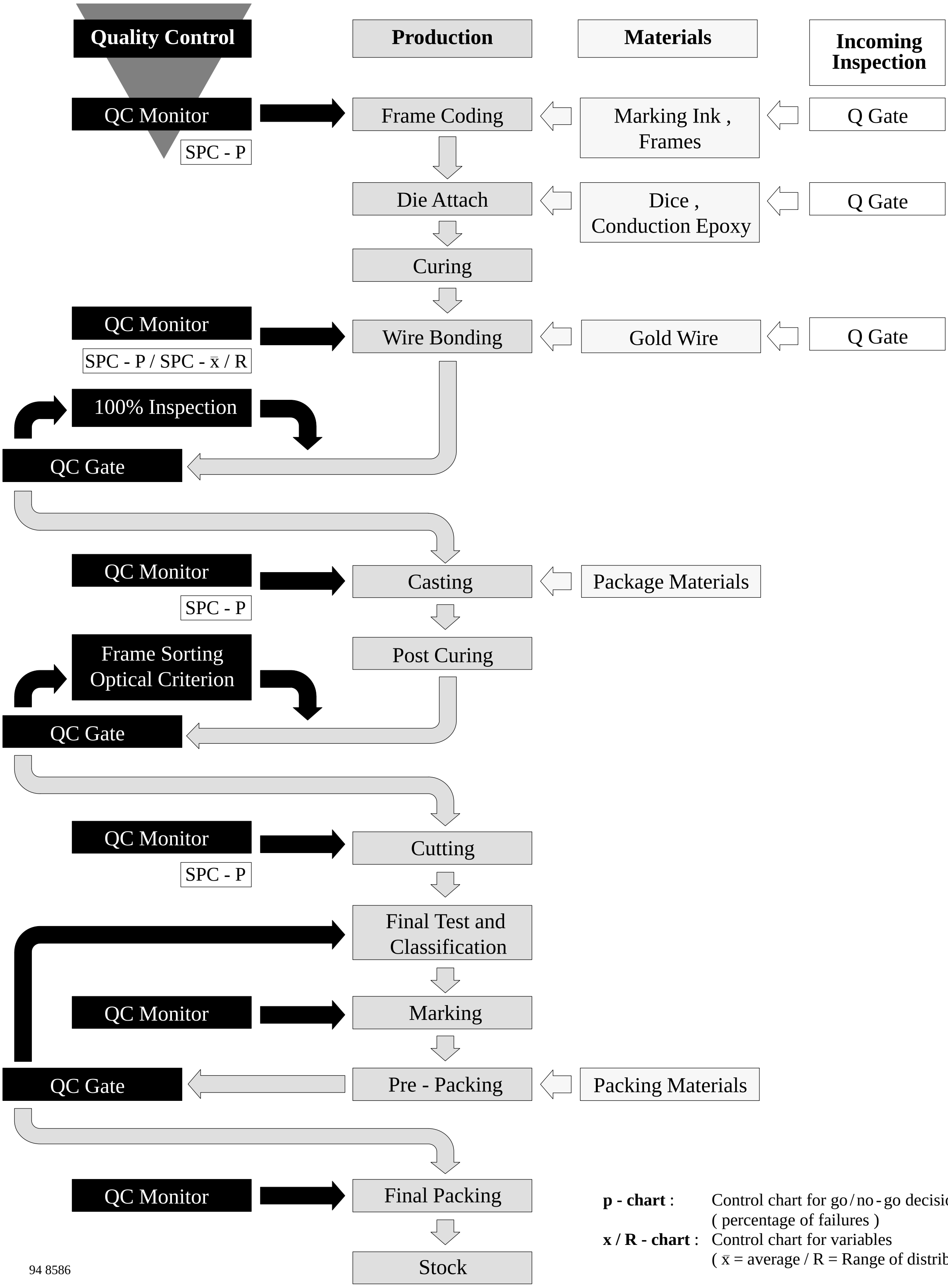


Figure 56.

Production Flow Chart Diagram



p - chart : Control chart for go / no - go decisions (percentage of failures)

x / R - chart : Control chart for variables ($\bar{x}$ = average / R = Range of distribution)

Figure 57.

Qualification and Release

New wafer processes, packages and device types are qualified according to the internal TEMIC Semiconductors specification QSA 3000.

QSA 3000 consists of five parts (see figure 58).

Wafer process release: The wafer process release is the fundamental release/qualification for the different technologies used by TEMIC Semiconductors. Leading device types are defined for different technologies. Three wafer lots of these types are subjected to an extensive qualification procedure and are used to represent this technology. A positive result will release the technology.

Package release: The package release is the fundamental release/ qualification for the different packages used. Package groups are defined (see figure 58).

Critical packages are selected: two assembly lots are subjected to the qualification procedure representing that package group. A positive result will release all similar packages.

Device type release: The device type released is the release of individual designs.

Monitoring: Monitoring serves both as the continuous monitoring of the production and as a source of data for calculation of early failures (early failure rate: EFR).

Product or process changes are released via ECN (**E**ngineering **C**hange **N**ote). This includes proving process capability and meeting the quality requirements.

Test procedures utilized are IEC 68–2–... and MIL–STD–883 D respectively.

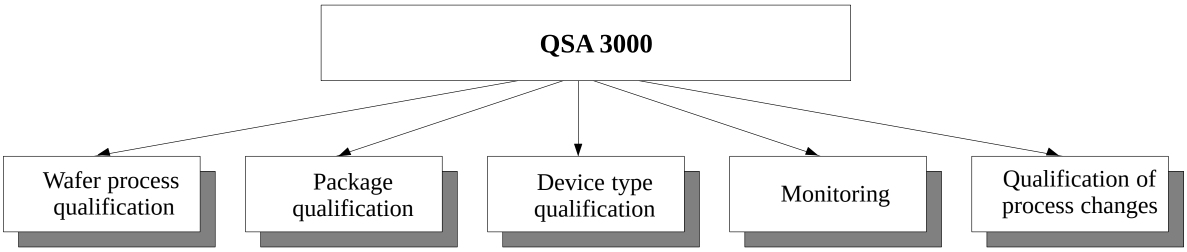


Figure 58. Structure of QSA 3000

Statistical Methods for Prevention

To manufacture high-quality products, it is not sufficient controlling the product at the end of the production process.

Quality has to be ‘designed-in’ during process- and product development. In addition to that, the ‘designing-in’ must also be ensured during production flow. Both will be achieved by means of appropriate measurements and tools.

- Statistical Process Control (SPC)
- R&R– (Repeatability and Reproducibility) tests
- Up– Time Control (UTC)
- Failure Mode and Effect Analysis (FMEA)
- Design Of Experiments (DOE)
- Quality Function Deployment (QFD)

TEMIC Semiconductors has been using SPC as a tool in production since 1990/91.

By using SPC, deviations from the process control goals are quickly established. This allows control of the processes before the process parameters run out of specified limits. To assure control of the processes, each process step is observed and supervised by trained personnel. Results are documented.

Process capabilities are measured and expressed by the process capability index (C_{pk}).

Validation of the process capability is required for new processes before they are released for production.

Before using new equipment and new gauges in production, machine capability (C_{mk} = machine capability index) or R&R (Repeatability & Reproducibility) is used to validate the equipment’s fitness for use.

Up–Time is recorded by an Up–Time Control (UTC) system. This data determines the intervals for preventive maintenance, which is the basis for the maintenance plan.

A process–FMEA is performed for all processes (FMEA = Failure Mode and Effect Analysis). In addition, a design– or product– FMEA is used for critical products or to meet agreed customer requirements.

Design of Experiments (DOE) is a tool for the statistical design of experiments and is used for optimization of processes. Systems (processes, products and procedures) are analyzed and optimized by using designed experiments.

A significant advantage compared to conventional methods is the efficient perfomance of experiments with minimum effort by determining the most important inputs for optimizing the system.

As a part of the continuous improvement process, all TEMIC Semiconductors’ employees are trained in using new statistical methods and procedures.

Reliability

The requirements concerning quality and reliability of products are always increasing. It is not sufficient to only deliver fault–free parts. In addition, it must be ensured that the delivered goods serve their purpose safely and failure free, i.e., reliably. From the delivery of the device and up to its use in a final product, there are some occasions where the device or the final product may fail despite testing and outgoing inspection.

In principle, this sequence is valid for all components of a product.

For these reasons, the negative consequences of a failure, which become more serious and expensive the later they occur, are obvious. The manufacturer is therefore interested in supplying products with the lowest possible

- AOQ (Average Outgoing Quality) value
- EFR (Early Failure Rate) value
- LFR (Long-term Failure Rate) value

Average Outgoing Quality (AOQ)

All outgoing products are sampled after 100% testing. This is known as “Average Outgoing Quality” (AOQ). The results of this inspection are recorded in ppm (parts per million) using the method defined in JEDEC 16.

Early Failure Rate (EFR)

EFR is an estimate (in ppm) of the number of early failures related to the number of devices used. Early failures are normally those which occur within the first 300 to 1000 hours. Essentially, this period of time covers the guarantee period of the finished unit. Low EFR values are therefore very important to the device user. The early life failure rate is heavily influenced by complexity. Consequently, ‘designing-in’ of better quality during the development and design phase, as well as optimized process control during manufacturing, significantly reduces the EFR value. Normally, the early failure rate should not be significantly higher than the random failure rate. EFR is given in ppm (parts per million).

Long-Term Failure Rate (LFR)

LFR shows the failure rate during the operational period of the devices. This period is of particular interest to the manufacturer of the final product. Based on the LFR value, estimations concerning long-term failure rate, reliability and a device's or module's usage life may be derived. The usage life time is normally the period of constant failure rate. All failures occuring during this period are random.

Within this period the failure rate is:

$$\lambda = \frac{\text{Sum of failures}}{\sum (\text{Quantity} \times \text{Time to failure})} \; \frac{1}{\text{hours}}$$

The measure of λ is FIT (Failures In Time = number of failures in 10^9 device hours).

Example

A sample of 500 semiconductor devices is tested in a operating life test (dynamic electric operation). The devices operate for a period of 10,000 hours.

Failures: 1 failure after 1000 h
1 failure after 2000 h

The failure rate may be calculated from this sample by

$$\lambda = \frac{2}{1 \times 1000 + 1 \times 2000 + 498 \times 10000} \; \frac{1}{h}$$

$$\lambda = \frac{2}{4983000} \; \frac{1}{h} = 4.01 \times 10^{-7} \frac{1}{h}$$

This is a λ-value of 400 FIT, or this sample has a failure rate of 0.04% / 1000 h on average.

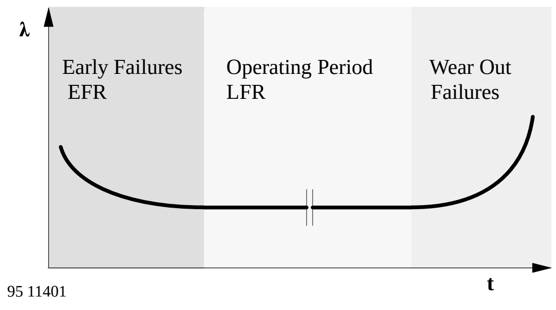


Figure 59. Bath tub curve

Confidence Level

The failure rate λ calculated from the sample is an estimate of the unknown failure rate of the lot.

The interval of the failure rate (confidence interval) may be calculated, depending on the confidence level and sample size.

The following is valid:

- The larger the sample size, the narrower the confidence interval.
- The lower the confidence level of the statement, the narrower the confidence interval.

The confidence level applicable to the failure rate of the whole lot when using the estimated value of λ is derived from the $\varkappa^2$-distribution. In practice, only the upper limit of the confidence interval (the maximum average failure rate) is used.

Therefore:

$$\lambda_{max} = \frac{\varkappa^2/2 \; (r; P_A)}{n \times t} \text{ in } \frac{1}{h}$$

$$LFR = \frac{\varkappa^2/2 \; (r; P_A)}{n \times t} \times 1 \times 10^9 \text{ in [FIT]}$$

r: Number of failures

P_A: Confidence level

n: Sample size

t: Time in hours

$n \times t$: Device hours

The $\varkappa^2/2$ for λ are taken from table 9.

For the above example from table 9:
$\varkappa^2/2$ (r=2; P_A=60%) = 3.08
$n \times t$ = 4983000 h

$$\lambda_{max} = \frac{3.08}{4983000} = 6.18 \times 10^{-7} \frac{1}{h}$$

This means that the failure rate of the lot does not exceed 0.0618% / 1000 h (618 FIT) with a probability of 60%.

If a confidence level of 90% is chosen from the table 9:
$\varkappa^2/2$ (r=2; P_A=90%) = 5.3

$$\lambda_{max} = \frac{5.3}{4983000} = 1.06 \times 10^{-6} \frac{1}{h}$$

This means that the failure rate of the lot does not exceed 0.106% / 1000 h (1060 FIT) with a probability of 90%.

Operating Life Tests

Number of devices tested:	n = 50
Number of failures (positive qualification):	c = 0
Test time:	t = 2000 hours
Confidence level:	P_A = 60%

$\varkappa^2/2$ (0; 60%) 0.93

$$\lambda_{max} = \frac{0.93}{50 \times 2000} = 9.3 \times 10^{-6} \frac{1}{h}$$

This means, that the failure rate of the lot does not exceed 0.93% / 1000 h (9300 FIT) with a probability of 60%.

This example demonstrates that it is only possible to verify LFR values of 9300 FIT with a confidence level of 60% in a normal qualification tests (50 devices, 2000 h).

To obtain LFR values which meet today's requirements (< 50 FIT), the following conditions have to be fulfilled:

- Very long test periods
- Large quantities of devices
- Accelerated testing (e.g., higher temperature)

Table 9.

Number of Failures	Confidence Level			
	50%	**60%**	**90%**	**95%**
0	0.60	0.93	2.31	2.96
1	1.68	2.00	3.89	4.67
2	2.67	3.08	5.30	6.21
3	3.67	4.17	6.70	7.69
4	4.67	5.24	8.00	9.09
5	5.67	6.25	9.25	10.42
6	6.67	7.27	10.55	11.76
7	7.67	8.33	11.75	13.16
8	8.67	9.35	13.00	14.30
9	9.67	10.42	14.20	15.63
10	10.67	11.42	15.40	16.95

Mean Time to Failure (MTTF)

For systems which can not be repaired and whose devices must be changed, e.g., semiconductors, the following is valid:

$$MTTF = \frac{1}{\lambda}$$

MTTF is the average fault-free operating period per a monitored (time) unit.

Accelerating Stress Tests

Innovation cycles in the field of semiconductors are becoming shorter and shorter. This means that products must be brought to the market quicker. At the same time, expectations concerning the quality and reliability of the products have become higher.

Manufacturers of semiconductors must therefore assure long operating periods with high reliability but in a short time. Sample stress testing is the most commonly used way of assuring this.

The rule of Arrhenius describes this temperature-dependent change of the failure rate.

$$\lambda(T_2) = \lambda(T_1) \times e^{\left[\frac{E_A}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$$

Boltzmann's constant
$k = 8.63 \times 10^{-5}$ eV/K

Activation energy
E_A in eV

Junction temperature real operation
T_1 in Kelvin

Junction temperature stress test
T_2 in Kelvin

Failure rate real operation
$\lambda\,(T_1)$

Failure rate stress test
$\lambda\,(T_2)$

The acceleration factor is described by the exponential function as being:

$$AF = \frac{\lambda(T_2)}{\lambda(T_1)} = e^{\left[\frac{E_A}{k} \times \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]}$$

Example

The following conditions apply to an operating life stress test:

Environmental temperature during stress test
$T_A = 125°C$

Power dissipation of the device
$P_V = 250$ mW

Thermal resistance junction/environment
$R_{thJA} = 100$ K/W

The system temperature/junction temperature results from:

$T_J = T_A + R_{thJA} \times P_V$

$T_J = 125°C + 100\ K/W \times 250\ mW$

$T_J = 150°C$

Operation in the field at an ambient temperature of 100°C and at an average power dissipation of 100 mW is utilized. This results in a junction temperature in operation of $T_J = 110°C$. The activation energy used for bipolar technologies is $E_A = 0.7$ eV.

The resulting acceleration factor is:

$$AF = \frac{\lambda(423K)}{\lambda(383K)} = e^{\left[\frac{E_A}{k} \times \left(\frac{1}{383K} - \frac{1}{423K}\right)\right]}$$

$AF \approx 7.4$

This signifies that, regarding this example, the failure rate is lower by a factor of 7.4 compared to the stress test.

Other accelerating stress tests may be:

- Humidity (except displays type TDS.)
  T_A = 85°C
  RH = 85%

- Temperature cycling
  Temperature interval as specified

The tests are carried out according to the requirements of appropriate IEC–standards (see also chapter 'Qualification and Release').

Activation Energy

There are some conditions which need to be fulfilled in order to use Arrhenius' method:

- The validity of Arrhenius' rule has to be verified.

- 'Failure-specific' activation energies must be determined.

These conditions may be verified by a series of tests. Today, this procedure is generally accepted and used as a basis for estimating operating life. The values of activation energies can be determined by experiments for different failure mechanisms.

Values often used for different device groups are:

Opto components	0.7 eV
Bipolar ICs	0.7 eV
MOS ICs	0.6 eV
Transistors	0.7 eV
Diodes	0.7 eV

By using this method, it is possible to provide long–term predictions for the actual operation of semiconductors even with relatively short test periods.

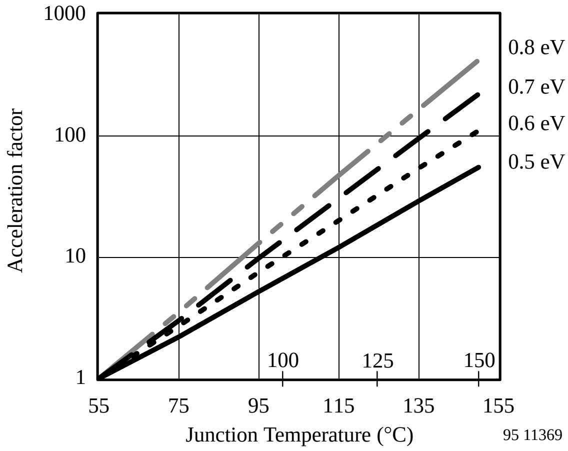


Figure 60. Acceleration factor for different activation energies normalized to T_j = 55°C

Safety

Reliability and Safety

All semiconductor devices have the potential of failing or degrading in ways that could impair the proper operation of safety systems. Well-known circuit techniques are available to protect against and minimize the effects of such occurrences. Examples of these techniques include redundant design, self-checking systems and other fail-safe techniques. Fault analysis of systems relating to safety is recommended. Environmental factors should be analyzed in all circuit designs, particularly in safety-related applications.

If the system analysis indicates the need for the highest degree of reliability in the component used, it is recommended that TEMIC be contacted for a customized reliability program.

Toxicity

Although gallium arsenide and gallium aluminium arsenide are both arsenic compounds, under normal use conditions they should be considered relatively benign. Both materials are listed by the 1980 NIOH 'Toxicology of Materials' with LD_{50} values (Lethal Dosis, probability 50%) comparable to common table salt.

Accidental electrical or mechanical damage to the devices should not affect the toxic hazard, so the units can be applied, handled, etc. as any other semiconductor device. Although the chips are small, chemically stable and protected by the device package, conditions that could break these crystalline compounds down into elements or other compounds should be avoided.