LED solder point temperature measurement with thermocouples

Application Note

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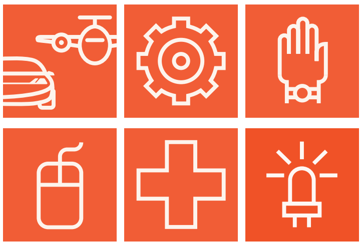

Valid for:
all LEDs

Abstract

To ensure a long lifetime for LEDs, the maximum junction temperature specified in the data sheet must not be exceeded. To calculate this temperature, it is important to know the solder joint temperature that can be measured. Temperature measurement generally can be divided into two main categories — contact thermometry and radiation thermometry. Contact thermometry consists of a thermocouple which always remains in contact with the device under test, while radiation thermometry measures the radiation of the device under test without contact, by means of an infrared sensor.

This application note provides information on the measuring methods, the thermocouples used and their installation. It also points out systematic errors and how to avoid them.

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1 Basics

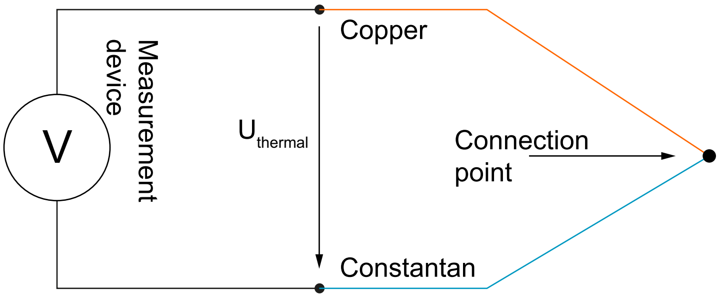
As the LED junction temperature cannot be measured directly it is necessary to take measurements at another defined point. An appropriate location is the solder point, since the thermal resistance $R_{th,JS}$ between the solder point and the junction is fixed by the package design and can be obtained from the corresponding data sheet. For a particular solder point temperature T_S, the junction temperature T_J can be calculated. The calculation of the LED junction temperature for a given solder point temperature and the measurement point are described in the application notes “Thermal management of light sources based on SMT LEDs” and “Thermal measurement point of LEDs”.

1.1 Functionality of a thermocouple

Thermocouples are the most commonly used temperature sensors. The accurate temperature measurements can be made with a typical low-level voltmeter.

A thermocouple consists of two different metal wires (for example, copper and constantan) which are welded together at one end, and then separated from each other with insulated leads. The influence of heat at the welding point creates a DC voltage (thermoelectric voltage) between the two metals (Figure 1). This voltage can be measured and provides information about the prevailing temperature. The voltage generated by the thermocouple is largely proportional to the difference between the measured temperature and the reference temperature.

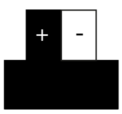
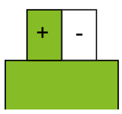
Figure 1: Principle test arrangement for the temperature range of - 200 °C to + 600 °C



1.2 Thermocouple selection

Various thermocouples are available which are differentiated according to type and construction. Table 1 gives an overview of the two most used thermocouples according to DIN EN 60584. The insulation for the negative lead is white for all thermocouples. The positive lead is colored like described. But note, certain manufacturers may use a different color coding or adhere to country-specific standards. Besides this color coding, the thermocouple types are divided into three tolerance classes. These classes define the permissible tolerances and limit deviations.

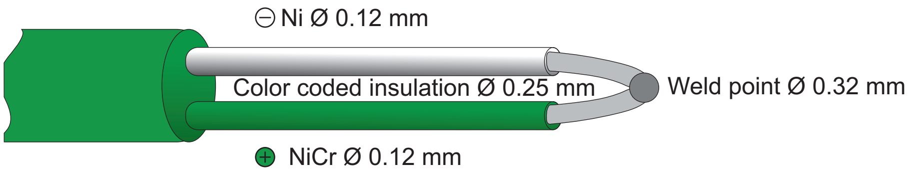
Table 1: Color coding according to IEC 304 and tolerance classes according to DIN EN 60584

Element type & color code	Material combination	Class 1	Class 2	Class 3
Type J 	Fe - CuNi	**Tolerance:** ± 1.5 °C **Temperature range:** -40 °C ... +750°C	**Tolerance:** ± 2,5 % °C **Temperature range:** -40°C ... +750°C	-
Type K 	NiCr - Ni	**Tolerance:** ± 1.5°C **Temperature range:** -40°C ... +1000°C	**Tolerance:** ± 2.5°C **Temperature range:** -40°C ... +1200°C	**Tolerance:** ± 2.5°C **Temperature range:** -200°C ... +40°C

Since these measurement procedures involve contact thermometry, a systematic error is introduced. When attaching a thermocouple, energy is dissipated. Therefore, it is important to know which level of accuracy is required.

Type K is most commonly used in industrial measurement technology. It can also be used in the low temperature range. In order to measure the LED solder point temperature T_S, a thermocouple of type K is recommended, since the thermal conductivity for this type is lowest and therefore less energy is dissipated than with other types. To minimize the occurrence of systematic errors, the dimensions of the thermocouple should be as small as possible.

Figure 2: Thermocouple of type K



2 Mounting the thermocouple

Several mounting methods are possible, two methods are presented below.

2.1 Solder method

Soldering guarantees that the thermocouple maintains good thermal contact with the device under test, and permits exact temperature measurement. In addition, the mounting point can be exactly determined. This good thermal coupling allows quickly varying temperatures to be accurately measured. However, this method has essentially two significant disadvantages:

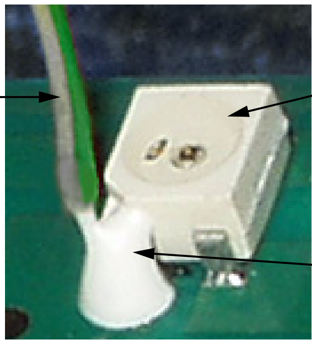
- An electrical connection is present between the thermocouple and device under test (no voltage isolation).
- In addition, EMI disturbances can arise, which influence the measurement sequence (for example, a cell phone the measurement site).

2.2 Adhesive method

Using an adhesive is an alternative to soldering. The primary advantage of an adhesive is the voltage isolation between the thermocouple and the device under test. Furthermore, the thermal resistance between the measurement object and the sensor is increased. This means, however, that less energy is dissipated from the thermocouple which inevitably causes the measurement to become sluggish and less precise. Consideration should be given regarding the adhesive type and the secondary influences which arise at the mounting location.

A thermal adhesive is recommended. These thermal adhesives are electrically nonconductive and have a thermal conductivity in the range of 7.5 W/mK. The adhesive is easy to administer and handle. Figure 3 shows a thermocouple fixed with the thermal adhesive method.

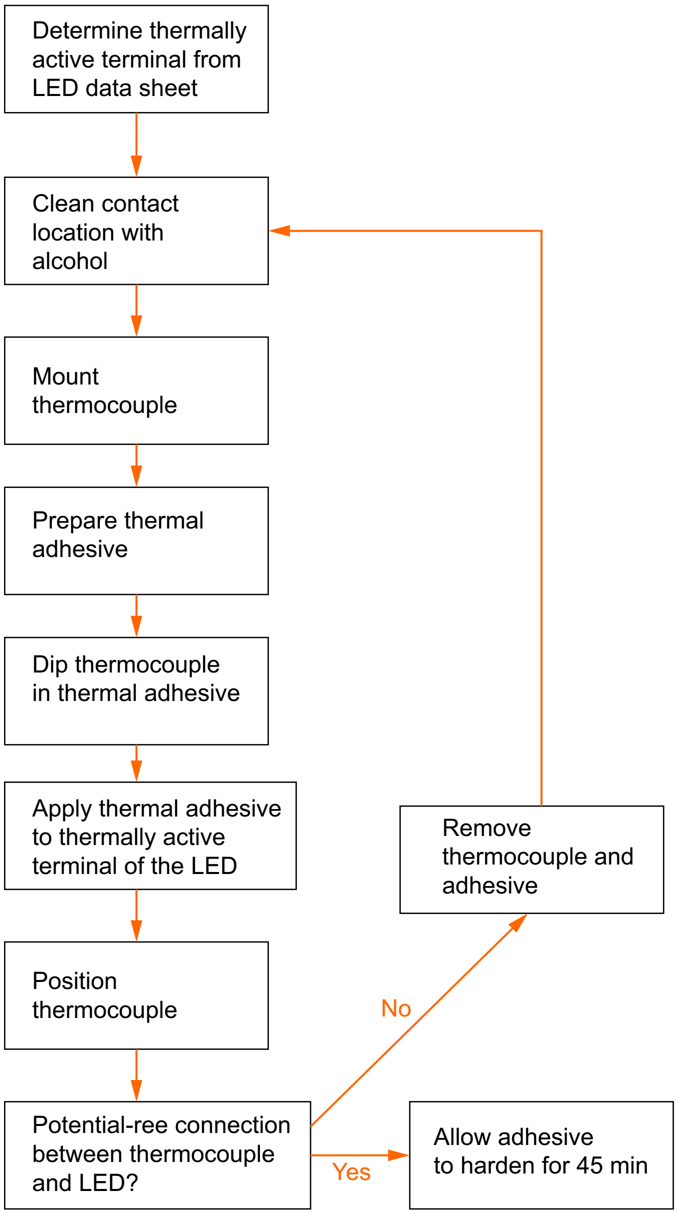
Figure 3: Thermocouple attached to a Power TOPLED™



To fix the thermocouple, mix components A and B in a ratio of 1:1 on a glass surface. Apply the adhesive to the measurement site, and attach the thermocouple to the prepared location and then secure the component firmly in place. This can be accomplished with a rubber band or hot glue.

Make sure that there is not too much pressure on the thermocouple and that no undesired metal contact is present between the thermocouple and the LED. To be sure, the circuitry should be checked with an ohmmeter. In case of electrical contact, the procedure must be redone. After about 40 minutes, the adhesive is suitable for measurement purposes. A soldering iron can be used to remove the thermocouple, since most adhesives become fluid at this temperature. Figure 4 gives a overview of the process for mounting the thermocouple to an LED.

Figure 4: Process overview: Mounting the thermocouple to an LED



3 Accuracy of the temperature measurement

To investigate the question of how accurate the measurement with a thermocouple is, a comparative test was carried out. The error estimation is expressly for thermocouples of type “K” with the specific construction shown in Figure 2. The error estimation is based on a series of experimental comparison measurements. Comparison measurements are carried out with an infrared camera and thermocouple showed no significant error for the thermocouples used.

The comparison measurements clarify that the error term arising from the energy transfer to the thermocouple is less than the tolerance bandwidth of the infrared camera (±2°C) and the thermocouple (± 2.2 °C). The setup and implementation of the error estimation is shown in chapter 6.1 "Comparison measurements".

4 Additional important information

4.1 Adhesives

In principle, one must ensure that the adhesive possesses a high thermal conductivity. Most thermal adhesives have a thermal conductivity of > 7.5 W/mK, which is quite sufficient for this purpose.

Caution is advised when using cyanoacrylate-base adhesives (instant adhesive): the thermal transmission is not particularly good and the adhesive is relatively brittle and unstable. Furthermore, an exothermic reaction occurs during hardening which causes a noticeable increase in temperature during the first ten minutes.

Polymer adhesives offer an alternative method of bonding. However, they are not all-purpose adhesives, and a UV lamp is additionally required. Furthermore, removal of the thermocouple is extremely difficult. Epoxy adhesives have a relatively long hardening time (ca. 5 h), which requires that the thermocouple be fixed securely in place, and are therefore less appropriate in practice. Removal of the thermocouple is relatively difficult, since this adhesive has a high mechanical cohesiveness.

In general, the bonding surface should be as small as possible, exhibit no electrical contact, and allow for removal of the thermocouple.

4.2 Power supplies for device under test

A stable power supply must exclusively be used for the device under test (e.g.: circuit board with LEDs) which is electrically isolated from the supply voltage (e.g.: a conventional power supply with a transformer). It should be noted that many switching power supplies do not have an isolating transformer, which can lead to unwanted voltage swings during the measurement process (Figure 5). These voltage swings can also be observed from an attached thermocouple which is electrically isolated from the device under test (Figure 5 and 6).

Faulty electrical isolation of the power supply for the device under test can be amplified to become an error and lead to feedback in the measurement equipment.

Figure 5: Switching power supply without electrical isolation from power line

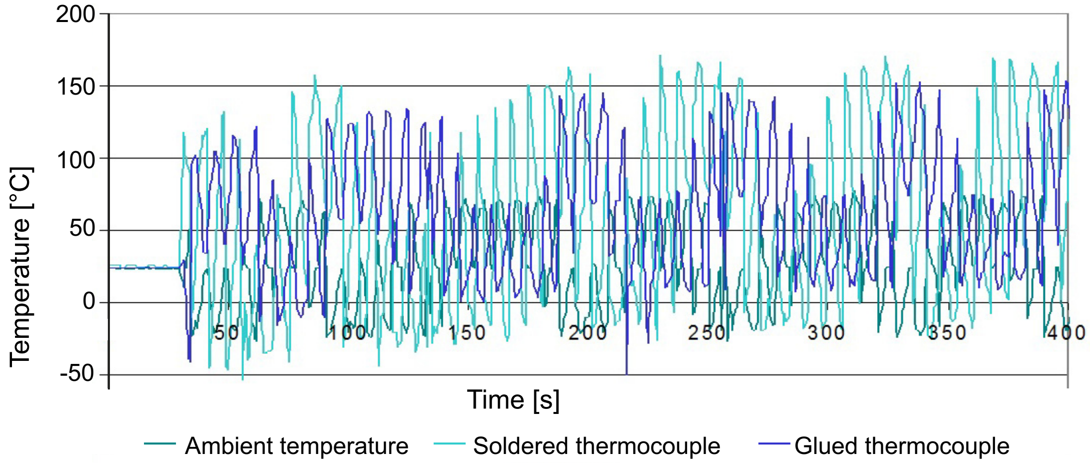
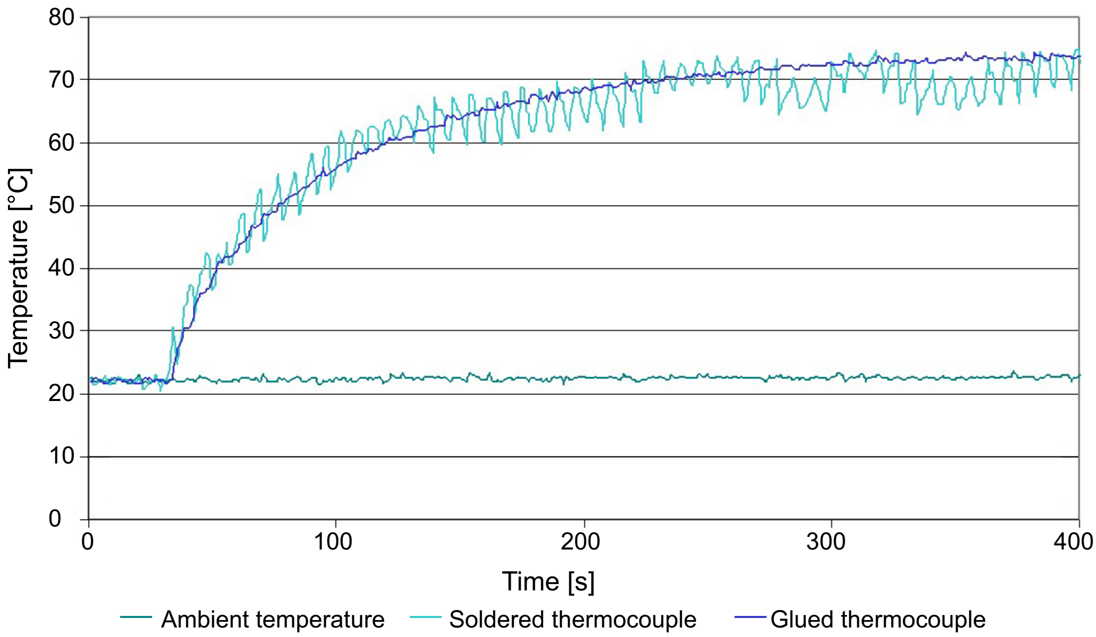
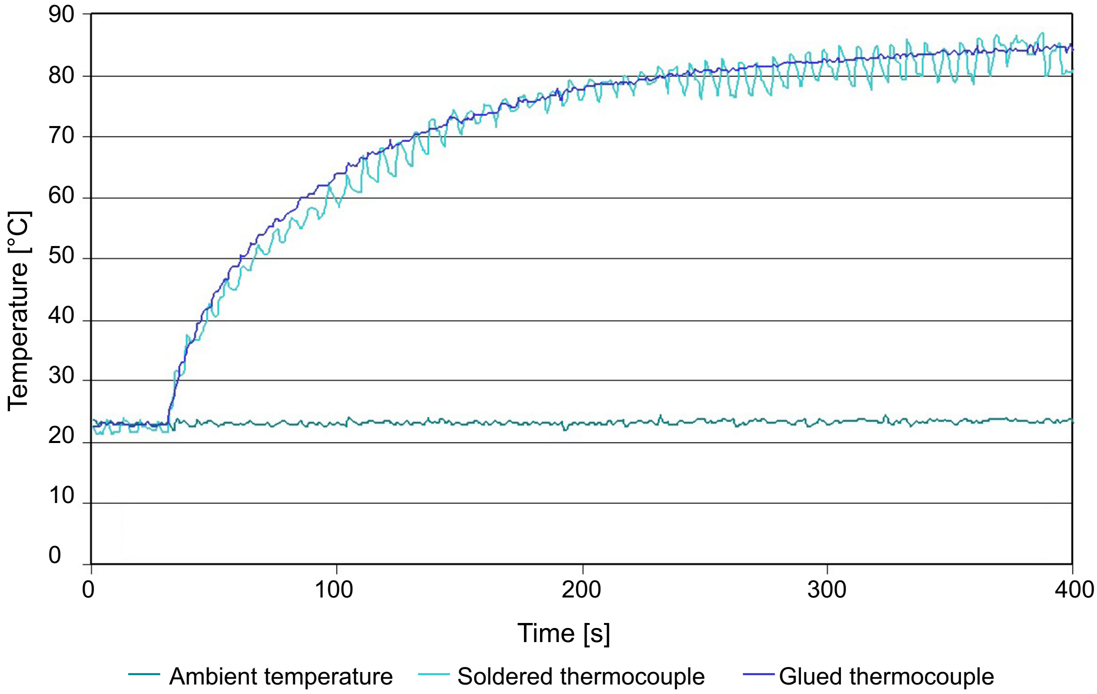


Figure 6: Conventional power supply with electrical isolation from power line



In order to achieve a higher level of certainly and precision, it often makes sense to use a lead battery (Figure 7) for the device under test.

Figure 7: Lead battery (lowest noise)



For thermocouples which are soldered in place, it is especially important to pay attention to which type of measurement instrument will be used and what type of power supply it has. Since the majority of thermocouples exhibit a thermocouple voltage of around 5 mV at 100 °C, the low voltage levels are susceptible to EMI. With battery powered measurement instruments, electrical isolation of the device under test is less important, since no connection to the power line is present and therefore no feedback can arise.

4.3 Measuring equipment

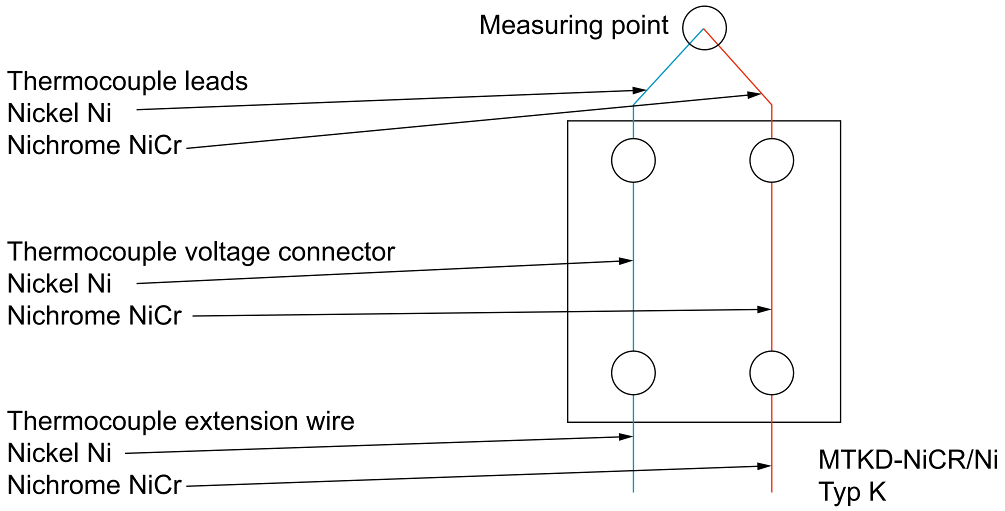
When selecting a measuring device, it is important to know whether only one discrete value or several discrete values will be measured over time. For measuring a single value, a small handheld battery driven temperature measuring device with two connections for external thermocouples is recommended. The second connection is important for measuring the ambient temperature. For recording several discrete values over time, a more elaborate instrument is required. At best, a multichannel instrument with computer interface should be used, since the data is easier to manage, and is compatible with standard software (spreadsheet calculations).

4.4 Extending thermocouple leads

When thermocouple leads are extended, it has the effect of creating additional thermocouples at the connection points which under certain circumstances can significantly influence the outcome of the measurement.

In case an extension is inevitable, the use of special clamps is highly recommended which serve to compensate for the errors which arise. In contrast to typically available serial connectors, thermocouple voltage connectors should be used, since their special construction expressly provides for pair wise connections. The contact bars consist of various metals and are individually matched to the material in the thermocouple. This permits the combination of metals in the temperature measuring element to be extended without interruption.

Figure 8: Principle arrangement of thermal clamps



4.5 Error sources and how to avoid them

When determining the solder joint temperature using a thermocouple, there are various possible error sources that must be avoided. Some of these are listed below:

- Thermocouple polarity

  Reversing the polarity of the thermocouple results in incorrect measurement data.

- Thermocouple type

  The type of the thermocouple used must be set in the measurement instrument.

- Extension of thermocouple leads

  Appropriate thermocouple voltage connectors must be used, corresponding to the type of thermocouple.

- Mounting the thermocouple

  Use an exact dosage of adhesive, limited to a small bonding area.

- Correct solder joint location

  The correct measurement location is the solder point for the LED. However, it should be noted which terminal (anode or cathode) of the LED is thermally active. For further information please refer to the application note "The thermal measurement point of LEDs".

- Correct measurement setup
  - Calibrate the measurement equipment
  - Create the appropriate test environment
  - Use or modify the original housing
  - Avoid forced convection, if not desired
  - Avoid direct sunlight
  - No metal objects should be used as a platform, mounting assembly, etc
  - No contact should occur outside of the weld point of the thermocouple
- EMI

  Cell phones, powerful transmitters and phase control devices can have a negative effect on the measurement sequence.
- External power supply

  Devices with external power supplies, PC interfaces and the device under test should be electrically isolated from the power line. Warning: many switching power supplies have no electrical isolation.
- Voltage isolation

  Strong fluctuations of the measurement data can occur when the thermocouple is soldered in place. This effect rarely occurs for thermocouples which are mounted with adhesives. If this does occur, the mounting procedure should be repeated.

5 Summary

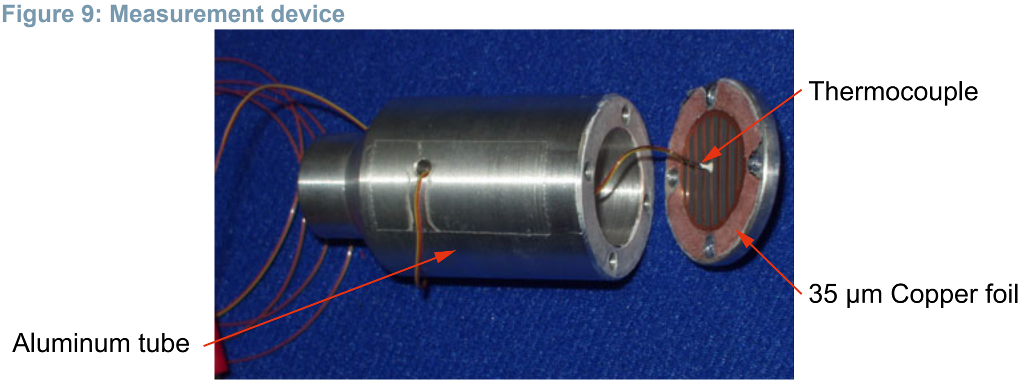
Temperature measurement by means of thermocouples is a multilaterally applicable method. In many cases, it is not possible to use infrared cameras, pyrometers and other temperature sensors for temperature measurement. Thermocouples prove to be well suited for these applications. By comparison measurements and other measurement techniques, an error estimate can be made. The analysis of these measurement procedures shows that one can achieve satisfactory results regarding the physical principles with relatively inexpensive equipment. Bonding the thermocouple with a thermal adhesive has proven to be a reliable mounting method.

6 Appendix

6.1 Comparison measurements

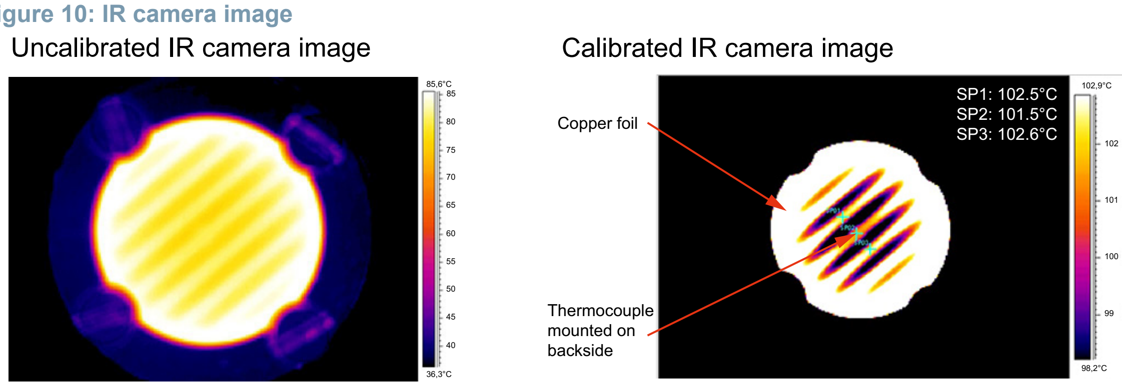
In this test setup, it was compared how far the measurements with the thermocouple correspond to a measurement with an infrared measuring device. The specially built measurement device pictured in Figure 9 serves only for comparison measurements, permitting simultaneous measurements by infrared camera and thermocouple.

Figure 9: Measurement device



The measurement device is heated at the narrow end. The tick-walled aluminum cylinder serves to homogeneously distribute the heat to the contact surface. A specially etched copper foil (thickness 35 µm) with thermally conductive paste, a fastening ring and four screws are mounted on the contact surface. A black foil with $\varepsilon = 0.94$ is used as the emission converter for the camera. The thickness of the copper foil corresponds to the thickness of a solder pad which is normally used with LEDs. This permits the effect of the thermocouple to be visualized with the aid of an infrared camera. Figure 10 shows two different IR camera images. An uncalibrated IR camera image and a calibrated image.

Figure 10: IR camera image



At the uncalibrated IR image, the stripes of the 35 µm thick and 1 mm wide copper foil can be recognized. The brighter area (white) shows the temperature distribution of the copper foil the noticeable dark part (yellow stripes) indicate the symmetrical etched area on the foil. The yellow stripes results from missing any thermal conductive material. No objective conclusion can be reached from this image, however, it only serves to provide a better idea.

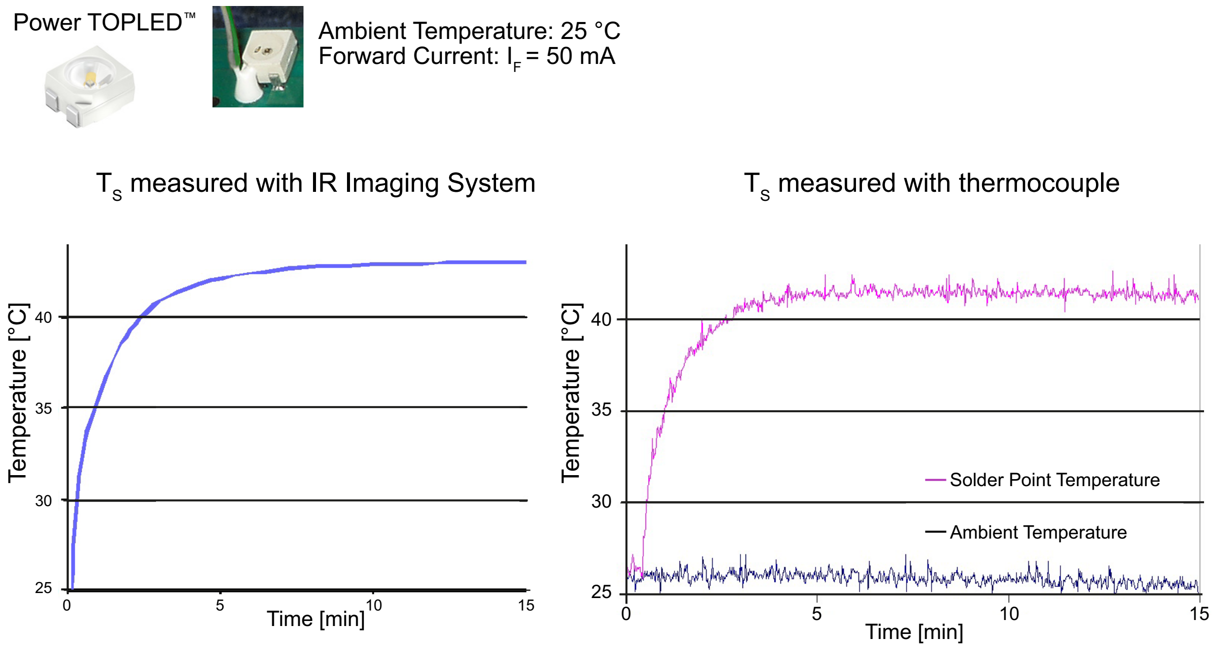
In contrast, in the calibrated IR camera image, it is clear that the temperature at the thermocouple is lower that of the two neighboring symmetrical strips. Specifically, the temperature deviation (error) in this image amounts to 1.0 °C for a device temperature of around 100 °C and an ambient temperature of 27 °C.

Please note, that the error increases with increasing temperature and decreases with decreasing temperature. In the operating temperature range of an LED (- 40 °C... + 100 °C) the error remains nearly linear.

Conclusion: Since the error originating from the thermocouple of 1 °C lies within the tolerance range of the IR camera and the range specified for the thermocouple itself, no further correction is necessary for the thermocouple with the dimensions and data shown in Figure 2.

To verify this, a comparative measurement was set up on a Power TOPLED™ (Figure 11) to measure the solder point temperature. The temperature was measured once with a thermocouple and once with an IR camera.

Figure 11: Verification Power TOPLED™



The verification shows very little deviation of the solder point temperature when measured with the thermocouple and infrared camera. No correction factor needs to be calculated, however since the error for the comparison measurement clearly lies within the deviation range of the instruments.

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