

Instruction Manual

for

**gSKIN[®] Heat Flux Sensors
for R&D Applications**



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Preface

gSKIN® Heat Flux Sensors are sensors of high quality. To take advantage of their outstanding performance, specific precautions must be taken during storage, assembly and packaging. Therefore, please read the following instructions carefully.

The exposure to volatile organic compounds requires special care. High concentration and long term exposure to specific chemicals must be avoided. Critical conditions are known to occur in manufacturing environment and/or during storage. Therefore, the handling and the choice of housing and packaging materials is crucial. Ambient conditions however, do not affect the performance of the gSKIN® sensors. Upon receiving gSKIN® Heat Flux Sensors check the packing list, verify that all the equipment is present and inspect for any signs of damage.

Applicability

This document is applicable to all gSKIN® Heat Flux Sensors for R&D applications supplied by greenTEG AG.

1. SHORT USER GUIDE

About the gSKIN® Heat Flux Sensors

The gSKIN® Heat Flux Sensors measure thermal power passing through the sensor surface. The high sensitivity of the modules coupled with its thin design and low thermal resistance ensure precise measurements with minimal influence on the thermal flow.

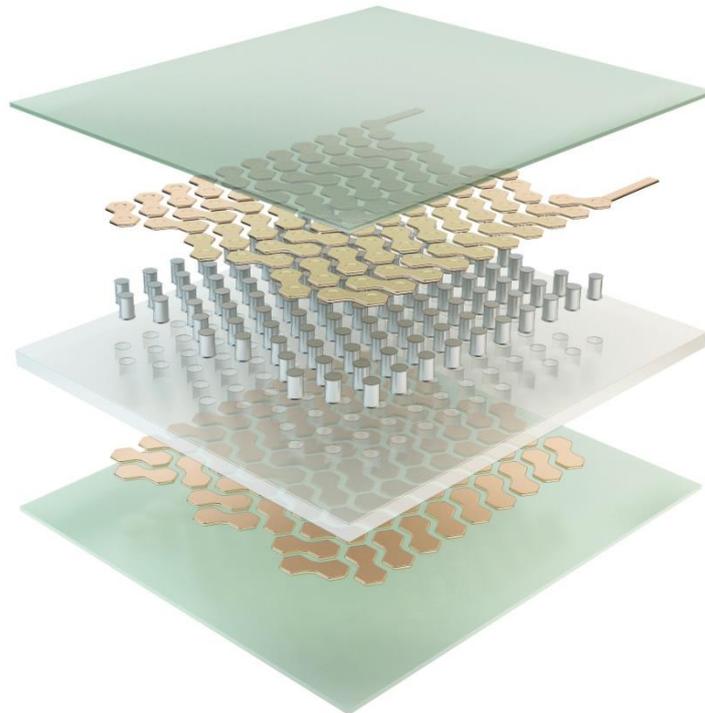


Figure 1: Picture showing the layers (Package, Contacts, Thermopiles, Substrate, Interconnects) of gSKIN® Heat Flux Sensor (thermopiles are highly integrated in the sensor substrate, which leads to high sensitivity sensor modules).

Measurement preparation

- Procure a mounting substance (i.e. tape, paste, or glue) to mount the sensor in your setup.
- Procure a read-out device (i.e. gSKIN® DLOG Data Logger, voltmeter, or 3rd party read-out device)

Mounting the sensor

Before mounting the sensor, the sensor must be tested as described in Section 3. Once the sensor's functionality has been verified, the mounting surface has to be prepared.

Ensure that the mounting surface is flat, dry, and free of dust and grease. Clean the sensor surface with ethanol or isopropanol. Do not use acids or bases for cleaning the sensor. Mount the sensor using a mounting substance. A detailed description of the sensor mounting is given in Section 4.

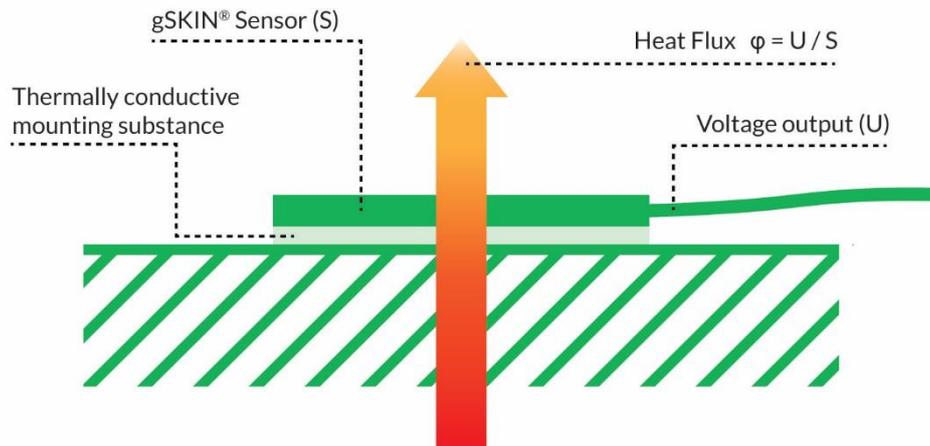


Figure 2: Schematic diagram of mounting and functionality of a gSKIN® Heat Flux Sensor.

How to calculate heat flux

The heat flux ϕ describes the transfer of thermal power per surface unit and is calculated using the following formula:

$$\phi = U / S \quad [\text{W}/\text{m}^2]$$

where U is the sensor output voltage, in μV
 S is the temperature-corrected sensitivity of the sensor, in $\mu\text{V}/(\text{W}/\text{m}^2)$

2. gSKIN® HEAT FLUX SENSOR INTRODUCTION

Positive side of the gSKIN® Sensor

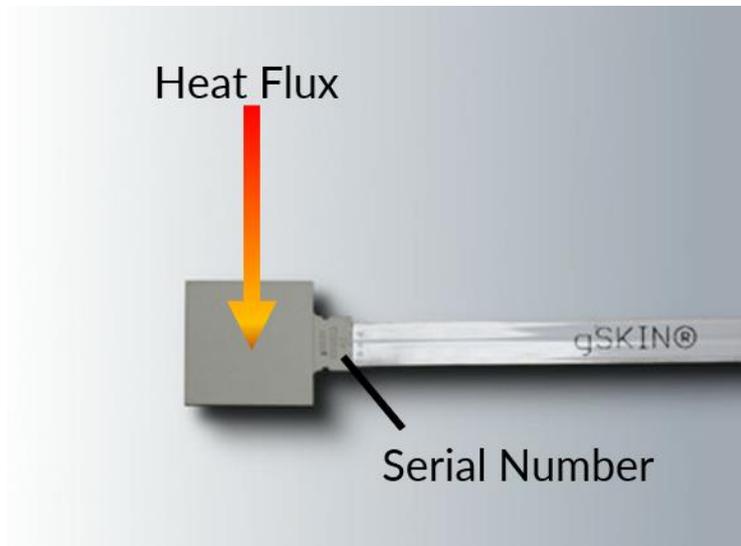


Figure 3: This placement shows the positive side of the sensor (i.e. assuming a heat flux from top (hot side) to bottom (cold side), this sensor will generate a positive voltage signal). Alternatively, the correct sensor orientation can be determined by placing the flex print in such a way, that the serial number is not visible.

Positive and negative side of the gSKIN® Heat Flux Sensor

Heat energy always flows from the hot side to the cold side of a system. The gSKIN® Heat Flux Sensor should be mounted with the positive side of the sensor in the direction of the expected positive heat flux. However, the gSKIN® Heat Flux Sensors can be used bi-directionally: If the direction of the heat flux is reversed, the sign of the sensor voltage output changes (i.e. from positive to negative or vice versa).

Note

It is very important, that applying any force to the flex print (i.e. tearing) **needs to be avoided**. This destroys the electrical connection to the sensor and therefore results in breaking the sensor.

3. FUNCTIONALITY TEST

All gSKIN® Heat Flux Sensors adhere to high manufacturing standards. Before shipping, the performance of each gSKIN® Heat Flux Sensor is individually checked. However, external factors (e.g. transportation, prior use), may affect the functionality of the sensor module. **Before permanent installation**, the sensor functionality must be tested. This section describes the necessary steps to perform the functionality test.

3.1. Checking electrical resistance of the sensor

Electrical resistance testing is done using a standard multimeter via a two probe resistance measurement. The resistance measurement must be done without any applied temperature gradient (e.g. with the sensor hanging in air holding it at the cables).

The resistance for each sensor will be in the range specified in its respective datasheet. These values include the resistance of cables. Resistance below 0.5 ohm indicates a short circuit, while a resistance higher than the value stated in the datasheet indicates physical wearout of the sensor and/or its cables. In both cases, the sensor is not functional and must be replaced.

3.2. Checking sensor behavior with a temperature difference

Connect the sensor to a voltmeter (resolution preferably in the 0.1mV range). Place the sensor on a metallic surface at room temperature. When touching the sensor with a warm finger on the upper surface, you should get a signal in the mV range.

A sensor signal below 0.1 mV indicates a short circuit. Check whether the resistance of the sensor is > 0.5 ohm as described in Section 3.1.

If the signal randomly fluctuates between a positive and negative signal, or the voltages are in the ± 1 V range, you may have an open circuit. Check the connection of your electrical probes.

If the signal shows one of the three described features above, the sensor is not functional and has to be replaced. In this case, please contact the vendor.



4. INSTALLATION OF A gSKIN® HEAT FLUX SENSOR

This section describes two general mounting options of the gSKIN® Heat Flux Sensors. The various application notes available on greenTEG's webpage, describe additional task-specific mounting options. All application notes are available at www.greenTEG.com.

4.1. Mounting substance

In order to obtain meaningful measurement data, the gSKIN® Heat Flux Sensor has to be mounted with adequate mounting substances. Adequate mounting substances feature high thermal conductivity and low thickness. Three types of mounting substance are suitable: adhesive tape, thermally conductive paste, and thermally conductive glue.

The mounting substance should be chosen based on the measurement setup. greenTEG offers each of these mounting substances through its webshop www.shop.greenTEG.com.

Adhesive tape

Adhesive tape should be used for simple tasks, where quick setup is crucial and the thermal coupling is of secondary importance.

Clean the surface to be measured and apply the tape to the backside of the sensor. Mount the sensor onto the surface by applying gentle pressure to establish adhesion. You can add thermal paste (see next section) for improving thermal coupling to the surface.

Thermally conductive paste

Thermally conductive paste is recommended in applications where pressure is used to fix the gSKIN® Heat Flux Sensor in the measurement setup. It generates a very strong thermal coupling as the paste adapts to surface inhomogeneities.

Clean the surface to be measured and spread a thin layer of paste onto the backside of the sensor. Then press the sensor onto the surface. You may need to hold the sensor in place with tape across the electric cables.

Thermally conductive glue

Thermally conductive glue is suitable for applications where additional mechanical stability is required. Similar to the paste, it generates a strong thermal coupling and adapts to surface inhomogeneities.

Clean the surface to be measured and spread a thin layer of thermal glue onto the backside of the sensor. Then press the sensor onto the surface and follow the curing instructions of the glue.

Removal of the mounting substance

To remove the different mounting substances, refer to the respective manufacturer's instruction manual. If no instructions are available, contact the supplier. Isopropanol and ethanol can be used as cleaning agents whereas acids and bases must be avoided to avoid damage to the sensors. Rub the surface gently with a soaked tissue to remove residues of the mounting substance.

Note

To remove **thermally conductive tape** put isopropanol or alcohol on the sensor and wait 60 seconds and then slowly try to remove the sensor (at no point tear at the contacts).

In case you use **thermally conductive glue** the sensor cannot be removed anymore.

4.2. Mounting

The sensor responds to all three types of heat transfer: conduction, convection and radiation. gSKIN® Heat Flux Sensors are fully calibrated for measuring conductive heat flux. The conductive calibration ensures highly precise measurements for the following two measurement scenarios.

a) At the interface between a solid surface and gas

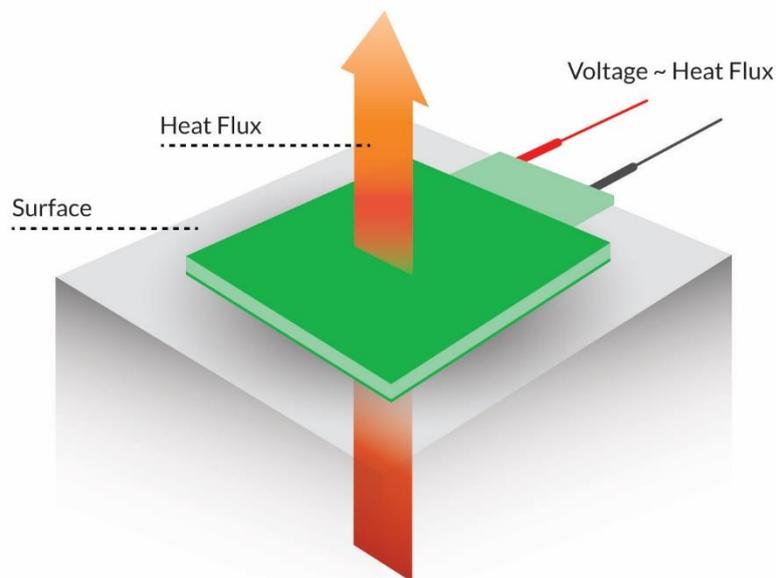


Figure 4: gSKIN® Heat Flux Sensor mounted on a solid surface

Mounting instructions:

1. Select a representative area of the surface you want to study.
2. Ensure that the area of interest is flat, dry, and free of dust and grease. Clean the sensor surface with ethanol or isopropanol. Do not use acids or bases for cleaning the sensor.
3. Apply the sensor using any of the above described mounting substances. When mounting the sensor, make sure no air is trapped between the surface and the sensor. Air gaps are thermally insulating and heavily distort the measurement results.
4. Mount the sensor with the positive side of the sensor in the direction of the expected positive heat flux (as described in Section 2)
 - o Do not apply more than 100 N per cm² of compressive force to the sensor at any time.
5. In order to ensure meaningful results, we recommend making the exposed sensor surface similar to the finish of the surface to be measured. For example, if the surface to be measured is covered with white paint, you will get maximum accuracy by painting the sensor surface with the same paint.

b) Between two solid materials

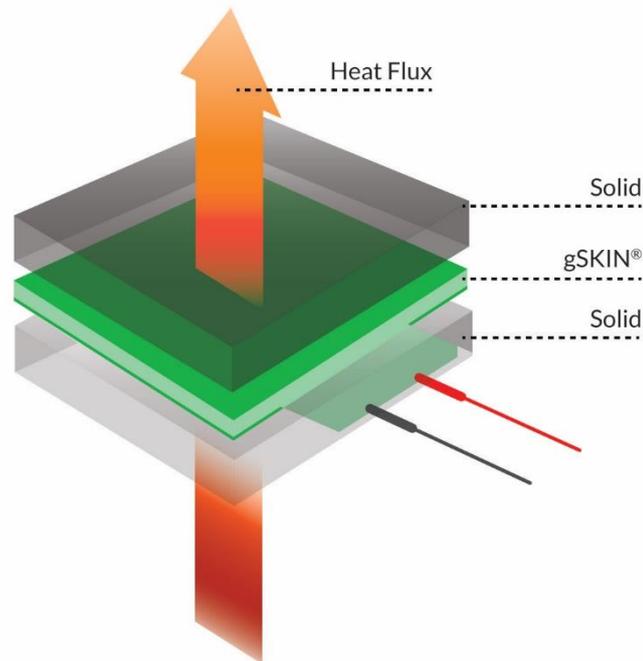


Figure 5: gSKIN® Heat Flux Sensor mounted between two solid materials

Mounting instructions:

1. Ensure that both solid bodies have a contact area at least as large as the gSKIN® Heat Flux Sensor.
2. Ensure that the two solid planes are perfectly parallel to each other and that the contact surfaces are flat, dry and free of dust and grease. Clean the sensor surface with ethanol or isopropanol. Do not use acids or bases for cleaning the sensor.
3. Mount the sensor with the positive side of the sensor in the direction of the expected positive heat flux.
4. Sandwich the sensor between the two contact areas using any of the above described mounting substances. It is highly recommended to use thermally conductive paste or glue to increase the quality of the thermal contacts between the surfaces and the sensor.
 - Do not use too much thermal paste or glue as it increases the risk of thermal short-cuts between the two contact surfaces. Furthermore, ensure that no air is trapped between the surface and the sensor. Air gaps are thermally insulating and heavily distort measurement results.
5. A clamping force of 10N - 100N per cm² is recommended in order to optimize the thermal contact. The maximal value of 100N per cm² should not be exceeded at any time.

4.3. Mounting material

| Materials | Preparation | Installation |
|---------------|---|--|
| Metal | <u>Smooth surface:</u> Degrease by Organic Solvent | Use adhesive tape Use thermally conductive glue Use thermally conductive paste |
| | <u>Rough surface:</u> Make the surface smooth | Use thermally conductive paste |
| Concrete | Make the surface smooth | Embed to the material Use thermally conductive glue Use thermally conductive paste |
| Glass, tiles | Degrease by organic solvent | Use adhesive tape |
| Wood | Place the sensor according to the direction of grain | Use thermally conductive glue Use thermally conductive paste |
| Glass wool | Make the surface as smooth as possible | Embed the material Use thermally conductive glue Use thermally conductive paste |
| Perlite board | Make the surface as smooth as possible | Use thermally conductive glue Use thermally conductive paste |



5. SENSOR READ-OUT

The gSKIN® Heat Flux Sensor's output is an analog voltage signal. Depending on the measurement task, the voltage signal can be in the μV to mV range.

To read-out the sensor signal, three options are available: the gSKIN® DLOG Data Logger, a voltmeter, or a 3rd party read-out device. The following section describes each option separately.

5.1. gSKIN® DLOG Data Logger

The gSKIN® DLOG Data Loggers are specifically developed for reliable and straightforward heat flux measurements in combination with the gSKIN® Heat Flux Sensors. The gSKIN® DLOG Data Loggers work as a complete solution with included software. The gSKIN® DLOGs can be set to measure either the analog voltage signal (in V) or heat flux signal (in W/m^2). Please follow the Instruction Manual, which is available for all gSKIN® DLOG Data Loggers.

Optionally, the gSKIN® DLOG Data Loggers can be equipped with 2 temperature sensors. Detailed information is available at greenTEG's webshop www.shop.greenTEG.com.

Applicability

The gSKIN® DLOG Data Loggers are compatible with all gSKIN® Heat Flux Sensor with a plug.

Readout Software

The gSKIN® DLOG Data Loggers are compatible with Heat Flux Sensor Software ([download link](#)).

5.2. Voltmeter as read-out device

Voltmeters are used for simple measurement tasks and/or for sensor functionality tests. In order to read the output voltage of the sensor with high accuracy, you need a voltmeter with high resolution. The resolution of the heat flux measurement is limited by the voltmeter resolution and noise. Table 1 demonstrates the relevance of voltmeter resolution.

| | Voltmeter resolution = 1mV | Voltmeter resolution = 1 μV |
|--|----------------------------|--|
| Heat flux resolution [W/m^2] | 143 | 0.14 |

Table 1: Heat flux resolution of a gSKIN®-XP 26 9C Heat Flux Sensor with a sensitivity of $7.00\mu\text{V}/(\text{W}/\text{m}^2)$.

The voltmeter resolution is the most critical feature when choosing the optimal device. Due to the low electrical resistance of the sensor, there are no special requirements regarding the input resistance of the voltmeter.

The gSKIN® Heat Flux Sensors can be used bi-directionally: If the direction of the heat flux is reversed, the sign of the sensor voltage output changes (i.e. from positive to negative). Since the sensitivity of the sensor does not depend on the direction of the heat flux, the measurement of the reversed heat flux has the same accuracy. However, on some voltmeters the measurement of negative voltages may not be possible or may be less accurate than the measurement of positive voltages. Further information about the positive and negative side of the sensors can be found in Section 2.

Applicability

Voltmeters are compatible with all gSKIN® Heat Flux Sensor without a plug.

5.3. 3rd party read-out device

A data logger is highly recommended for the measurement of time-dependent variations of the sensor signal. For the choice of a suitable device, the same considerations as for the voltmeter apply.

Applicability

3rd party read-out devices are compatible with all gSKIN® Heat Flux Sensor without a plug.

5.4 Surface-temperature measurement read-out^a

The surface temperature is measured with a NTP thermistor^b and can be read out with an ohm-meter which has at least a range between 0.5 and 200kOhm. Simply connect the green and black colored wire to the ohm-meter and read out the resistance. With the lookup table^c the resistance can be transformed into the corresponding temperature.

| Temperature (°C) | Resistance (kOhm) |
|------------------|-------------------|
| -10 | 42.889 |
| -5 | 34.196 |
| 0 | 27.445 |
| 5 | 22.165 |
| 10 | 18.010 |
| 15 | 14.720 |
| 20 | 12.099 |
| 25 | 10.000 |
| 30 | 8.309 |
| 35 | 6.939 |
| 40 | 5.824 |

Figure 6: Small section of the look-up table. The entire table can be found online^c

This lookup table can be approximated very well $\pm 0,2^{\circ}\text{C}$ in different temperature ranges using the following equations (Steinhart Hart equations):

- 10 - 50°C: $T[^{\circ}\text{C}] = \frac{3354}{\ln(R) + 8.952} - 273.15$ where R is the measured resistance in kOhms.
- below 10°C: $T[^{\circ}\text{C}] = \frac{3171}{\ln(R) + 8.296} - 273.15$ where R is the measured resistance in kOhms.
- 50°C - 80°C: $T[^{\circ}\text{C}] = \frac{3466}{\ln(R) + 9.300} - 273.15$ where R is the measured resistance in kOhms.

^a Only for XO-66 7C-Temp

^b Sensor: <https://www.murata.com/en-us/products/productdetail?partno=NCP15XH103D03RC>

^c <https://www.murata.com/en-us/products/productdata/8796842262558/NTHCG271.txt?1437970080000>



6. DATA ANALYSIS

This section contains the basic analysis methods needed to interpret data from the gSKIN® Heat Flux Sensors. All data necessary for these can be found in the following documents:

1. Calibration certificate
 - This certificate is delivered with every Heat Flux Sensor for R&D Applications. It contains the sensor specific sensitivity at calibration temperature (S_0) and the correction factor (S_c).
2. Datasheet
 - The datasheet provides an overview for all technical parameters of gSKIN® Heat Flux Sensor. It also states the sensor area, which is necessary for calculating thermal power.

6.1. Temperature corrected sensitivity

The sensitivity of the gSKIN® Heat Flux Sensors depends on the temperature at which they are used. This can be neglected in case your measurement takes place at room temperature and uncertainties of +/-5% are accepted. Use the following instructions to achieve highest precision, especially when operating at high temperature (>30°C) and low temperature (<10°C).

The temperature-corrected sensitivity of the sensor is calculated using the following formula:

$$S = S_0 + (T_s - T_0) * S_c \quad [\mu V / (W/m^2)]$$

where S_0 is the sensitivity at calibration temperature, in $\mu V / (W/m^2)$
 S_c is the linear correction factor, in $(\mu V / (W/m^2)) / ^\circ C$
 T_0 is the calibration temperature, in $^\circ C$
 T_s is the mean sensor temperature level, in $^\circ C$

Values S_0 , S_c , and T_0 are sensor specific calibration values and are provided together with each gSKIN® Heat Flux Sensor purchase in the calibration certificate.

If T_s is not measured, it can be approximated by the following formula:

$$T_s = (T_h + T_c) / 2 \quad [^\circ C]$$

where T_h and T_c are the respective temperatures of the hot and the cold reservoir of the system, in $^\circ C$.

If the sensor is mounted onto a hot surface exposed to air (i.e. gas), T_s is better approximated by

$$T_s = T_h \quad [^\circ C]$$

Example for calculating a temperature corrected sensitivity

The sensor is mounted on a warm surface and is exposed to air. The surface has a temperature of 40°C, which is a good approximation for T_s (see last section). Furthermore the following specifications are given by the calibration certificate:

$$S_0 = 9.41 \mu\text{V}/(\text{W}/\text{m}^2)$$

$$S_c = 0.0049 (\mu\text{V}/(\text{W}/\text{m}^2))/^\circ\text{C}$$

$$T_0 = 22.5^\circ\text{C}$$

The temperature corrected sensitivity is calculated as follows:

$$\begin{aligned} S &= S_0 + (T_s - T_0) * S_c &= 9.41 \mu\text{V}/(\text{W}/\text{m}^2) + (40^\circ\text{C} - 22.5^\circ\text{C}) * 0.0049 (\mu\text{V}/(\text{W}/\text{m}^2))/^\circ\text{C} \\ & &= 9.41 \mu\text{V}/(\text{W}/\text{m}^2) + 0.0858 \mu\text{V}/(\text{W}/\text{m}^2) \\ & &= 9.4958 \mu\text{V}/(\text{W}/\text{m}^2) \end{aligned}$$

The higher temperature induced a change in sensitivity of 0.9%.

6.2. Heat flux measurement

The heat flux ϕ describes the transfer of thermal power per surface unit and is calculated using the following formula:

$$\phi = U / S \quad [\text{W}/\text{m}^2]$$

where U is the sensor output voltage, in μV

S is the temperature-corrected sensitivity of the sensor, in $\mu\text{V}/(\text{W}/\text{m}^2)$

Example for a heat flux measurement

Measured voltage $U = 320 \mu\text{V}$

Temperature-corrected sensitivity $S = 10.02 \mu\text{V}/(\text{W}/\text{m}^2)$

Calculated heat flux $\phi = 320 \mu\text{V} / 10.02 \mu\text{V}/(\text{W}/\text{m}^2) = 31.94 \text{ W}/\text{m}^2$

6.3. Thermal power measurement

The thermal power Φ describes the amount of heat energy that passes through the sensor area per second. The unit of thermal power is W and is calculated using the following formula:

$$\Phi = A * U / S = A * \phi \quad [\text{W}]$$

where A is the sensor area, in m^2

U is the sensor output voltage, in μV

S is the temperature-corrected sensitivity of the sensor, in $\mu\text{V}/(\text{W}/\text{m}^2)$

Example for a thermal power measurement

Measured voltage $U = 320 \mu\text{V}$

Temperature-corrected sensitivity $S = 10.02 \mu\text{V}/(\text{W}/\text{m}^2)$



Sensor area (data sheet)
Calculated thermal power

$$A = 10\text{mm} * 10\text{mm}$$
$$\Phi = 320\mu\text{V} * 10\text{mm} * 10\text{mm} / 10.02\mu\text{V}/(\text{W}/\text{m}^2) = 3.19\text{mW}$$

7. MAINTENANCE OF THE SENSOR

7.1. Removing a sensor from a measurement setup

If the gSKIN® Heat Flux Sensor has been mounted using thermally conductive tape or paste, it can be easily removed without destroying the sensor. greenTEG's thermally conductive tape and thermally conductive paste can be removed following the instructions mentioned in Section 4.1.

7.2. Cleaning the sensor

Cleaning is only necessary before mounting the sensor. Clean the sensor surface with ethanol or isopropanol. Once the sensor is mounted, no further cleaning is necessary.

7.3. Storage

Store unused gSKIN® Heat Flux Sensors at ambient temperature in a clean and dry place. No further care is required.

8. ADDITIONAL CONSIDERATIONS

8.1. Electromagnetic interference

Due to the low electrical resistance of the sensor and the aluminum coating, the output signal is resistant to electromagnetic interference. In most cases, no countermeasures are necessary. If electromagnetic interference is a problem within an application, typical countermeasures (e.g. shielded cables, grounding) have to be taken.

8.2. Trouble shooting electrical problems

In case of electrical problems, check all connections and cables. Check for loose connections and/or short circuits in the leads. In some cases, corroded cables are the issue. If the problem cannot be located in the leads/cables, the sensor may be broken and has to be replaced.

8.3. Application in temperatures outside of the calibration temperature range

The calibration temperature range of the gSKIN® Heat Flux Sensors is stated in the respective data sheets. Within this temperature range, greenTEG guarantees a relative error of +/-3%. Outside of this range, the relative error may exceed this value.

8.4. Influences of radiative heat flux

Electromagnetic radiation from deep ultraviolet wavelengths (DUV) to mid infrared(MIR) may interfere with your measurement (e.g. when measuring windows).To achieve highest precision make sure to block off this radiation.

8.5. Use in fluids

Use in fluids is not recommended. However, the sensor may be exposed to moisture or clean neutral water at temperatures less than 50° C (323.15 K) for a short time by properly insulating all electrical parts. This may be done by sealing with lacquer, silicone rubber or similar materials. In these environments, it is recommended to mount the sensor with thermally conductive glue. However, long term exposure to wet ambient conditions is not recommended as this may corrode the metallic leads. In any case, do not expose the sensor to strong acids or bases.

8.6. General problems

For additional problems and considerations that are not listed in this instruction manual please refer to the FAQ Heat Flux Measurements ([download link](#)).



9. LIST OF SYMBOLS

| Name | Symbol | Unit |
|---|----------------|--|
| Heat Flux Density | φ | W/m ² |
| Thermal power | Φ | W |
| Sensor output voltage (measured) | U | V |
| Temperature corrected sensitivity | S | $\mu\text{V}/(\text{W}/\text{m}^2)$ |
| Sensitivity at calibration temperature | S ₀ | $\mu\text{V}/(\text{W}/\text{m}^2)$ |
| Correction factor | S _c | $(\mu\text{V}/(\text{W}/\text{m}^2))/^\circ\text{C}$ |
| Thermal resistivity | k | Km/W |
| Absolute thermal resistance | K | K/W |
| Heat transfer coefficient | H | W/(m ² K) |
| Thermal conductivity, Heat conductivity | λ | W/(mK) |
| Electrical resistance | R | Ohm |
| Temperature of the hot side | T _h | °C |
| Temperature of the cold side | T _c | °C |
| Calibration temperature | T ₀ | °C |
| Sensor temperature | T | °C |
| Sensor area | A | m ² |
| Sensor thickness | d | μm |

Disclaimer

The above restrictions, recommendations, materials, etc. do not cover all possible cases and items. This document is not to be considered to be complete and it is subject to change without prior notice.

Revision History

| Date | Revision | Changes |
|--------------------|-------------------|------------------------------------|
| 11. November 2013 | 0.1 (preliminary) | Initial revision |
| 23. September 2014 | 1.0 | Updated figures, minor corrections |
| 20. January 2015 | 1.5 | Updated product portfolio |
| 1. April 2015 | 1.7 | Minor revisions |
| 30. October 2015 | 1.8 | Minor revisions |
| 12. February 2018 | 2 | Information on XO-Temp added |
| 23. March 2022 | 2.1 | Updated sensor polarity convention |

