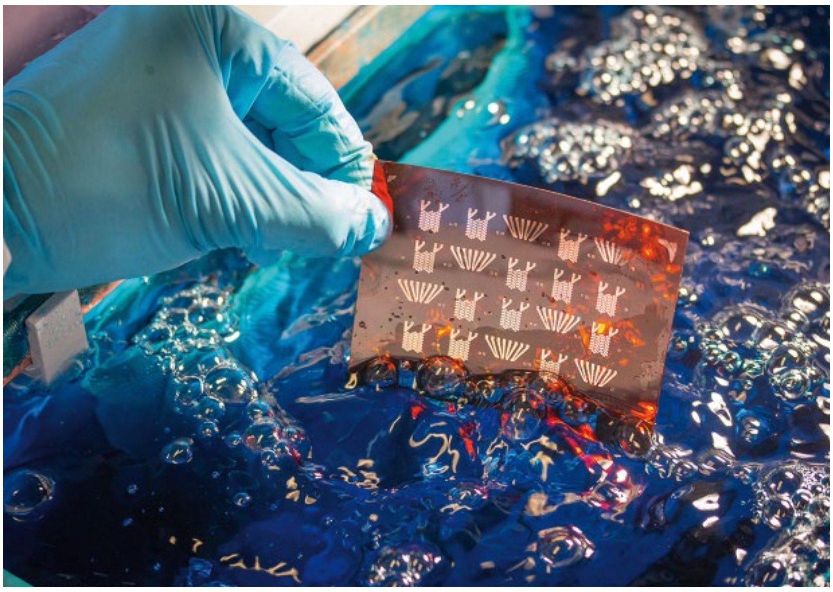
Sensors for Terahertz Spectroscopy and Quantum Cascade Lasers

Novel thermopile sensors detect laser power in the low µW-range

Susanne Dröscher and Manfred Gonnert

High-precision laser power measurement plays a crucial role in many laser applications, be it in the lab or in industrial settings. Only if the power of a laser can be measured precisely, the laser can be used correctly. The precise measurement of infrared lasers, for example quantum cascade lasers, and terahertz radiation used to be challenging because of a lack of adequate measurement tools. A novel measurement solution developed by Thorlabs GmbH now closes this gap. In collaboration with greenTEG AG, an ETH Zurich spin-off, Thorlabs developed a measurement head, which detects the power in the low µW-range independently of the wavelength of the laser. A low rise time of less than a second guarantees fast measurement results.



Electrochemical deposition allows greenTEG to produce sensor modules with a thickness of less than a millimeter, a key criteria for Thorlabs.

Since 1989 Thorlabs develops and manufactures components for lasers and optical systems. Since the appearance of the first QC-Lasers, the company with its headquarters in New Jersey, was challenged to exactly measure QCL. To precisely measure the diverging beam of QCLs, a sensor needs to be highly sensitive in the infrared range, since the lasing threshold can be as low as few µW. Furthermore, the sensor module needs to be as thin as possible in order to reduce mounting depth to a minimum. When Thorlabs decided to develop a new tool for low laser power measurements, the company found Swiss based greenTEG AG, which was founded in 2009 by researchers of ETH Zurich. greenTEG AG produces thermopile sensors with a novel process based on electrochemical deposition. The result are sensor modules with a thickness of less than a millimeter and therefore clear advantages with regards to rise time and sensitivity when compared to common thermopile modules.

Possibilities with the usual measurement methods

Besides thermopile sensors, photodiodes are mostly used to measure laser power. How do these two sensor types compare? The advantage of photodiodes comes with a high resolution and a fast rise time of far less than a second. When measuring low powers, photodiodes are often used. Like photovoltaic cells, photodiodes absorb light in the material and transform it into an electrical current proportional to the beam power. Depending on the composite of the material used in the photodiodes, each wavelength results in a different signal. Often only a narrow bandwidth even results in a signal, therefore further narrowing the application of a specific photodiode to a highly specific measurement task. Besides the widely available Si, Ge and InGaAs are also used as photodetectors. The absorption characteristics of those two materials extend into the NIR spectrum, up to 1800 nm. When electrically biased appropriately, InGaAs can even absorb at higher wavelengths. With HgCdTe (MCT) and In(As)Sb sensors, the available range is further expanded into the infrared, reaching beyond 5500 nm. GaP on the other hand allows radiation detection in the ultraviolet range down to 200 nm. Accordingly, the available photodiode sensors cover a total range of UV, VIS, and NIR.

Characteristics of thermopile sensors

The working principle of thermopile sensors is fundamentally different from that of photodiodes. In a black absorption layer on the sensor surface, the incident radiation is transformed into

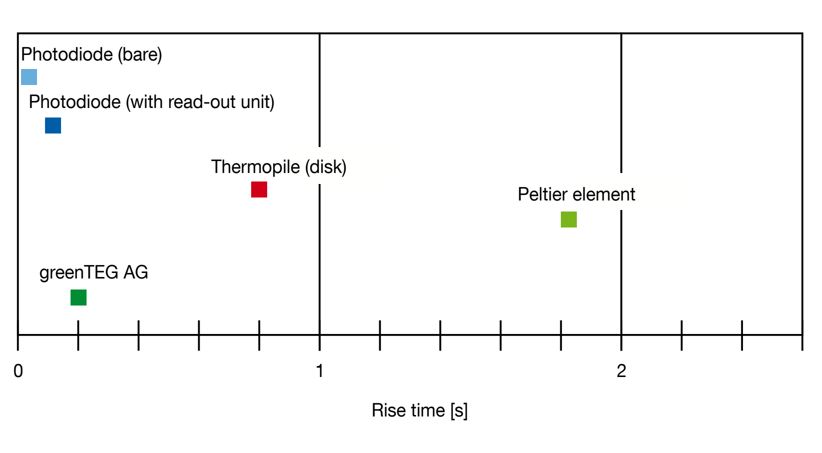


Fig. 1 Comparison of minimum rise time achieved for different types of power detectors.

heat energy. This heat is then flowing through the module causing a temperature difference across it. A series connection of thermocouples inside the sensor is arranged in such a way that the junctions are located alternating on the hot and the cold side. Due to the thermoelectric Seebeck effect, an electric voltage builds up proportional to the incoming radiation power. Thermopile sensors are therefore sensitive to radiation of all wavelengths, as long as the absorptive coating is efficient. Broad band absorbers are typically used and hence the spectrum from DUV to MIR lies within the detection range.

Three different types of thermopile detectors are commonly used, which vary in the arrangement of the thermopiles. Disk modules feature a circular absorption area in the center. The thermopiles are arranged in a ray-like manner, pointing outward towards an aluminum ring acting as a heat sink. Alternatively, axially arranged thermocouples are also used, resulting in a more compact design, since there is no passive area of the sensor. One example for such sensors are Peltier elements, where the cuboid shaped thermoelectric material is placed in between two thin alumina (Al_2O_3) plates. Another variation of the axial design is the design developed and commercialized by greenTEG AG. This technology allows for thermocouples with considerably smaller diameter (> 1 order of magnitude). The sensors are embedded between two aluminum foils, making the module thinner and more mechanically robust.

Monitoring laser power at highest speeds

Besides spectral characteristics, the response time of a sensor is an important parameter for an application. For example, to increase throughput in a production facility, the power measurement needs to take as little time as possible. Due to their working principles, the two detector types discussed above have different signal response time. In Fig. 1, the time it takes to reach 95 % of the signal amplitude (rise time) is shown for the different detectors. The minimum achievable time for each type is taken into account here.

Photodiodes are very fast and react within down to 1 ns to incoming radiation. When read out with commercially available power meters, the speed is lowered due to the electronics and results in a rise time of typically 0.2 s. Therefore, photodetectors are suitable for fast measurements and a good choice, if both the wavelength range and the power range (see Fig. 2, below) are appropriate.

Thermopile sensors are slower in their signal response. Since the sensors are based on thermal transport, the rise time is related to the thermal mass that needs to be heated. Therefore, larger or thicker thermopiles feature longer response times than thinner or smaller ones. Peltier elements respond to incoming radiation with a minimum rise time of 1.8 s due to their large thermal mass. Disks feature minimum response times of 1 s. greenTEG's electrochemically deposited thermopiles are considerably thinner and are able to achieve response times below 0.8 s.

Company

Thorlabs, Inc.
Dachau / Munich, Germany

Thorlabs, a vertically integrated photonics products manufacturer, was founded in 1989 to serve the laser and electro-optics research market. As new innovations came to market, Thorlabs extended its core competencies. The organization's highly integrated and diverse manufacturing assets include semiconductor fabrication of Fabry-Perot, DFB, and MEMS-VCSEL lasers, fiber draw towers, MBE/ MOCVD crystal growth, advanced thin film deposition capabilities, and optomechanical and optoelectronic shops.

www.thorlabs.com

Company

greenTEG AG
Zurich, Switzerland

greenTEG develops, manufactures, and markets thermal sensor solutions. The company was founded five years ago as an ETH Zurich spin-off and has since built up an international customer base as well as a global distributor network. greenTEG's thermal sensors are integrated into diverse applications by customers active in markets such as Laser, Building Technologies, Medtech, Automotive, Process Industry and R&D.

www.greenTEG.com

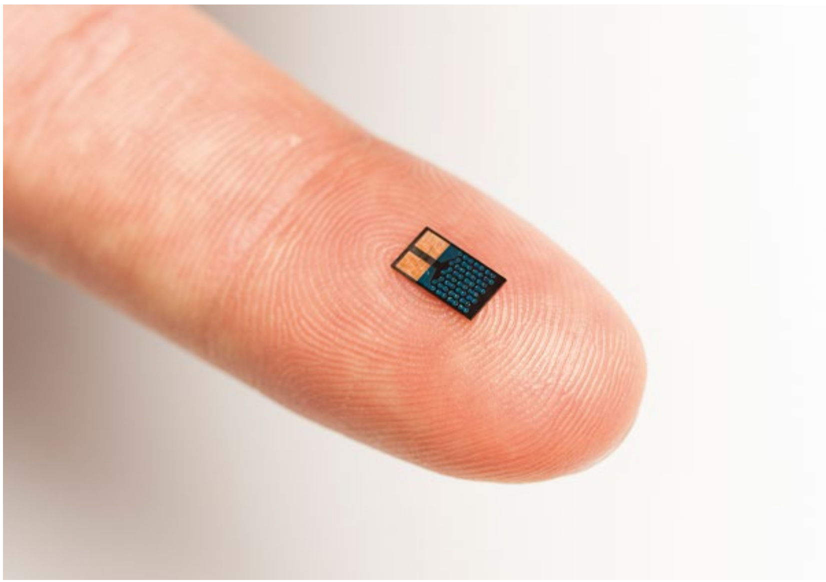
Power ranges for photodiodes and thermopile sensors

A further important parameter when choosing a detector is the power range in which it should be able to measure. Photodiodes and thermopile sensors both cover a large dynamic range of powers (1 pW – 1 kW). Photodiodes are sensitive for powers down to 10 pW. Incoming radiation in excess of 100 mW leads to a saturation of the electrical signal, setting the limit for the maximum power. The power saturation is critical when monitoring e. g. ultrafast pulse lasers. Although the average power might be rather low (and within the power range of the detector), the power of the short pulses greatly exceeds the upper power limit of the detector leading to saturation of the signal and hence to distorted measurement results. Additionally, industrial applications use photodiodes typically from 500 nW upwards (when detecting stray light or fractions of the beam), giving a very small dynamic range and complicating its integration into the system. For such applications, a thermopile detector is preferable, since it has a broad dynamic range and integrates the signal of the individual pulses, therefore monitoring the average power.

Thermopile sensors are used to monitor laser beams of up to 25 kW. The upper limit for those detectors is mainly attributed to the ability of cooling the sensor efficiently. In recent years, the minimum detectable power has been shifted more and more into the range of photodiodes and has reached 10 µW. greenTEG thermopiles feature resolutions of 1 µW.

High-precision laser power measurements in a broad wave spectrum

The thinness of greenTEG's thermopile sensors resulting in a fast reaction time and their mechanical robustness convinced Thorlabs to integrate them into the "S401C High Sensitivity Thermal Power Sensor". "The reaction time of less than a second, the high sensitivity and the low thickness of the sensor where the main reasons for our decision to integrate the sensor technology developed by greenTEG into our measurement head", stresses Manfred Gonnert, product developer at the German subsidiary Thorlabs GmbH in Dachau (Munich, Germany). A further advantage of the cooperation was the fact that greenTEG is still a relatively young company withshort development cycles. As a result, the S401C could be launched in less than nine months. The measurement head has a rise time of less than a second, a resolution of 1 µW and covers a power range of 10 µW to 3 W and a spectral range from deep ultra-violet to medium infra-red. With these characteristics, the detector is especially suited for the measurement of quantum cascade lasers (QCL) and in terahertz spectroscopy.



An uncoated greenTEG sensor module. The compactness of the sensor allows for easy integration into diverse applications.

Applications in QCL and terahertz spectroscopy: extending measurement limits

Amongst other applications, the S401C is used for measuring quantum cascade lasers (QCLs). Alpes Lasers S. A., a company specializing in the production of QCL laser sources, calibrates and characterizes laser with power measurements. So far, reliable measurement results were difficult to achieve when measuring lasers with a low laser treshold, because of the lack of detectors for emissions in the infrared-range. With the S401C developers at Alpes Lasers S. A. can now measure laser power even at thresholds of a few µW with high precision. "Some of our lasers have a lasing threshold of less than 100 µW. The S401C allows us to measure in the µW-range and to calibrate these lasers reliably," says Yves Bidaux, developer at Alpes Lasers S. A.

Quantum cascade lasers consist of a layered semiconductor structure, which forms so called quantum wells for the charge carriers (electrons) present in the material. Making use of quantum effects, light is emitted. Its wavelength depends on the voltage bias, applied to the layer structure. By changing this voltage during lasing, the wavelength can even be tuned over a considerable range. Hence, such lasers are beneficial for spectroscopy applications like gas sensing. Further, the typical emission in the near infrared (3 – 5 um) is interesting for optical communication.

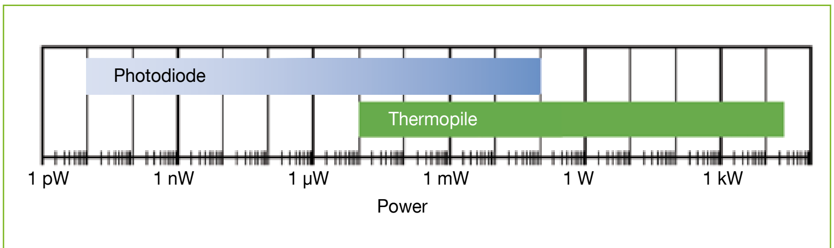


Fig. 2 Comparison of the power ranges in which photodiodes and thermopile detectors are deployable.

At ETH Zurich's Quantum Optoelectronics group, researchers also had good experiences with the S401C. The center under the lead of Prof. Jérôme Faist belongs to the leading research groups in developing long wave lasers. Currently, the group is working on IR-laser for terahertz spectroscopy. Terahertz waves are electro-magnetic waves in the frequency range of 100 GHz and 3 THz. Many molecules show characteristic signatures in the absorption spectrum and for THz waves many materials, which are impenetrable for visible light and infrared light, are transparent. These interactions between the electromagnetic waves and materials opens new application possibilities in many areas of measurement techniques. For the study of solids, liquids, and gases as well as the destruction free material testing and quality control terahertz spectroscopy opens new dimensions.

Also in communications technology THz waves help to even further increase the performance of existing systems. The development of user friendly THz sources is currently the aim of many research groups. To characterize these laser sources appropriate measurement tools are necessary. However, such tools were not available until recently. With Thorlabs S401C measurements are now also possible in this range (for example at 3.5 THz and power of less than 8 mW). "So far there was rarely any commercially available power measurement tool for THz-radiation. The new Thorlabs head is therefore really precious: it even measures ultra-long waves with a high sensitivity and low powers with high precision" says Dr. Giacomo Scalari, Senior Research Scientist at Prof. Faist's group.

Fruitful and continuing cooperation

The cooperation between Thorlabs and greenTEG brought an innovative product to the market, which allows to make predictions in a so far difficult to measure wave range. With the measurement tool PM160T and S470C Thorlabs already launched further tools with greenTEG's sensor technology – other developments are in planning.

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Susanne Dröscher started at greenTEG's R&D department three years ago. She specializes in laser applications of greenTEG's laser power sensors and supports customers in finding the best solution for their measurement needs. Susanne received her PhD from ETH Zurich in 2012.

Manfred Gonnert took the product and project lead for the Thorlabs optical power meter line ten years ago. He joined the company in 1991 after his degree in communication engineering at the University of Applied Sciences in Munich. He works at the German Thorlabs location, the engineering and manufacturing department for optical power meters and other electronics oriented test and measurement equipment.

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