Technologies for monitoring Laser Power

Pros and cons of available detector technologies

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The importance of absorptivity

Using laser light as a tool in industry or medicine requires the laser radiation to be absorbed and transformed into other forms of energy inside the specimen (for CW and long pulse lasers, it is converted into heat energy). The ability to absorb light greatly depends on the wavelength of the incident radiation and is different for each material. Due to these dependencies, the choice of laser wavelength is a critical factor for the conversion efficiency. As a second factor, the laser power needs to be considered since it determines the maximum absorption.

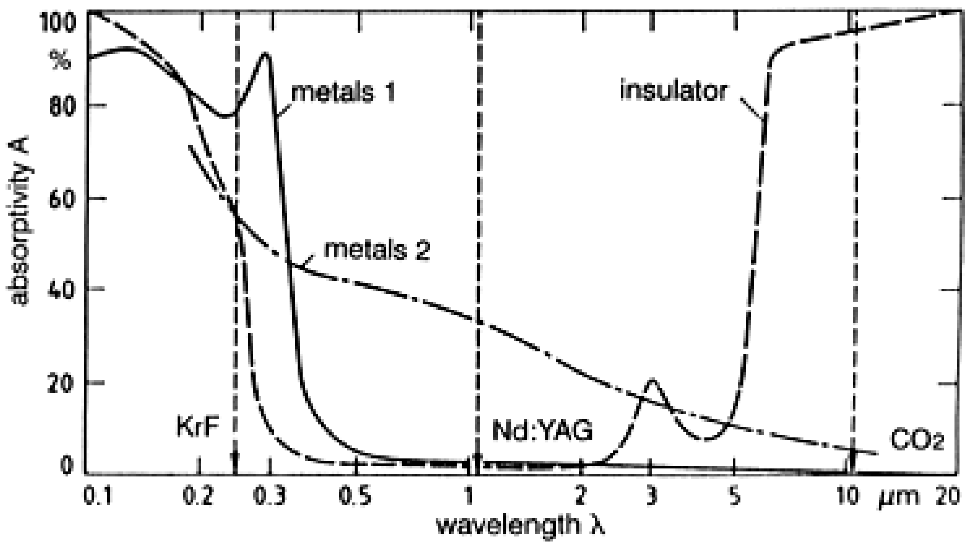

Figure 1: *Absorptivity as a function of wavelength for normal (perpendicular) laser beam incidence, smooth surfaces and room temperature. 'Metals 1' are those with full inner electron shells e.g. Au, Ag, Cu and 'metals 2' are transition metals e.g. Fe, Ni, Cr (Source: TWI-Global).*

Finding a trade-off between these two parameters has led to the employment of infrared lasers in industry. Mainly CO_2 (10.6 µm) and Nd:YAG (1064 nm) systems are employed for welding and cutting processes, although the absorption coefficient of most processed materials are comparably low in this wavelength range.

In medicine, an emission wavelength of 2.94 µm is desirable since it coincides with the maximum absorption of water, the main component of (human) tissue. More and more lasers enter the market at this wavelength, which are developed specifically to match the demands of medical applications.

In recent years, the ultraviolet spectrum has also gained popularity since lasers with emission wavelength below 400 nm get more powerful and reliable. Many materials (e.g. iron, copper, aluminum…) have a higher absorption coefficient for ultraviolet radiation, which makes the application of UV lasers a natural choice for the processing of these substances.

Narrow bandwidth and broad band detectors

For all laser sources, it is important to know the laser power of a system for process control and maintenance. In Fig. 2 below, the sensitivity ranges of currently used power sensors are displayed.

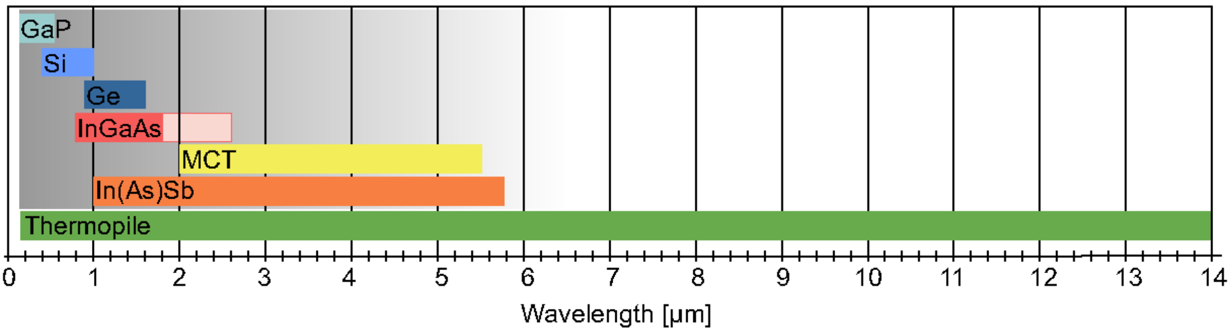

Figure 2: *Comparison of the wavelength ranges in which the different photodiode detectors and thermopiles are sensitive.*

The most common detectors for low powers are photodiodes (on grey background in the graph) due to their good power resolution and fast response time. Like in photovoltaic cells, light is absorbed in the material and converted into an electrical current proportional to the radiation power. Depending on the material composition, each wavelength results in a different signal and only a narrow bandwidth of wavelengths lead to an electric signal at all, as can be seen in the chart above. 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.

The working principle of thermopile sensors is fundamentally different from that of photodiodes. In an absorption layer on the sensor surface, the incident radiation is transformed into 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 on alternating hot and the cold sides. 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.

Commonly, three different types of thermopile detectors are 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. These allow for 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 (Al2O3) plates. Another variation of the axial design is the design developed at ETH Zurich, which is commercialized by greenTEG (referred to as ETH/greenTEG). This technology allows for thermocouples with considerably smaller diameter (>1 order of magnitude). The sensors are embedded between two aluminum foils, making the device thinner and more mechanically robust.

Monitoring laser power at high speed

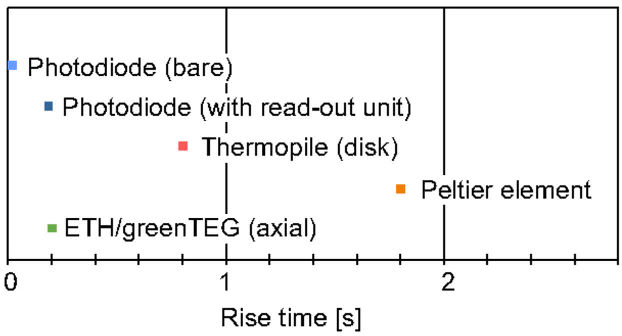

Figure 1: *Comparison of minimum rise time achieved for different types of power detectors.*

Besides spectral characteristics, the response time of a sensor is an important parameter for an application. For example, to achieve high 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. 3, 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 from 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 0.2 s. Therefore, photodetectors are suitable for fast measurements and a good choice, if both the wavelength range and the power range (see 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 1.8s due to their large thermal mass. Disks feature minimum response times of 1s. ETH/greenTEG thermopiles are considerably thinner and are able to achieve response times below 0.2s.

From ultralow powers to kilowatt radiation

When choosing a detector, the required power range is another crucial parameter. Both detector types cover a large dynamic range of powers, (see Fig. 4) and are therefore applied in different settings.

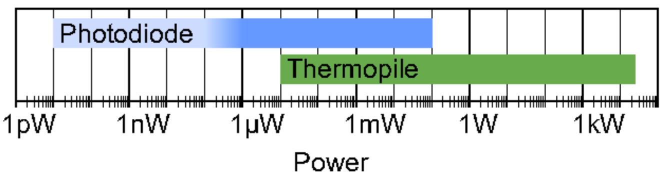

Figure 2: *Comparison of the power ranges in which photodiodes and thermopile detectors are deployable.*

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 distorted measurement results. Additionally, industrial applications use photodiodes typically from 500nW 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. ETH/greenTEG thermopiles are the best-in-class technology, featuring resolutions below 1 µW.

Not to be neglected: homogeneity, linearity, sensor signal across spectrum

The discussion above lists the crucial parameters for deciding which technology to apply. Still, there are more questions to consider when picking the right detector:

- Does my sensor signal needs to be homogeneous over the total detector surface making the signal robust to different beam sizes, beam positions and beam angles?
- Can I work with look-up tables with different responsiveness across the targeted power range or do I need a linear signal?
- Do I need a sensor working with different wavelengths?

The discussion of these additional parameters would go beyond the scope of this white paper. If you have any questions regarding those parameters, contact us at gSKIN@greenTEG.com.

Conclusion: The detector must suit the application

Thermopile sensors are the best choice for measuring average powers from 10 µW upwards. Especially outside the visible range, where photodiode technologies are expensive, thermopiles should be taken into account. Photodiodes, on the other hand, are the best choice when single pulses need to be analyzed or when power levels in the nW range should be resolved.

Document information

Pictures by greenTEG AG

Revision History

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