Using Semiconductor Photodiodes as Detector Element for Solar Radiation Measurements

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Introduction

Objective: Evaluate and compare the use of different photodetectors when measuring solar irradiance in a novel pyrheliometer configuration

¿What is solar irradiance?

Solar irradiance is defined as the radiant flux received by a surface per unit area. It is decomposed into two main components, Direct Normal Irradiance (DNI) when talking about the solar radiation coming directly from a small solid angle centered in the solar disk, and Diffuse Horizontal Irradiance (DHI), which refers to the radiation received from any path but the one directly from the sun. The sum of both components is known as Global Horizontal Irradiance (GHI) [1].

¿How is solar irradiance measured nowadays?

Following International Organization for Standardization (ISO) norms, the device used for measuring DNI is the pyrheliometer, while DHI and GHI are measured with a pyranometer [2]. In both cases, the solar radiation captured needs to be converted into an electrical signal to be processed digitally. Two options are available for this process: a thermopile in conjunction with a surface that absorbs light and converts it into heat, or a semiconductor photodiode, which transforms incident light into electric current [3].

System Description

The proposed optical fiber-based pyrheliometer and its calibration algorithm has already been presented in [4,5], where only results corresponding to a silicon photodiode were showcased. In this work, three photodetectors are compared, two Si-based photodetectors (volumetric THORLABS S140C and compact S150C) and volumetric InGaAs-based THORLABS S144C.

Mounting of the fibers onto the solar tracker and placed next to a commercial pyrheliometer

Device	Sensitivity	Response time
Silicon S140C	1nW	<1µs
Silicon S150C	10pW	<1µs
InGaAs S144C	1nW	<1µs

For the evaluation of the photodetectors, two optical fibers have been mounted next to a commercial KIPP & ZONEN CHP1 pyrheliometer and mounted on the KIPP & ZONEN SOLYS Gear Drive solar tracker to ensure consistent tracking of the sun throughout the day; while the other tips were connected to the different photodetectors, which were linked to the optical power monitor (OPM) THORLABS PM320E.

Application Requirements

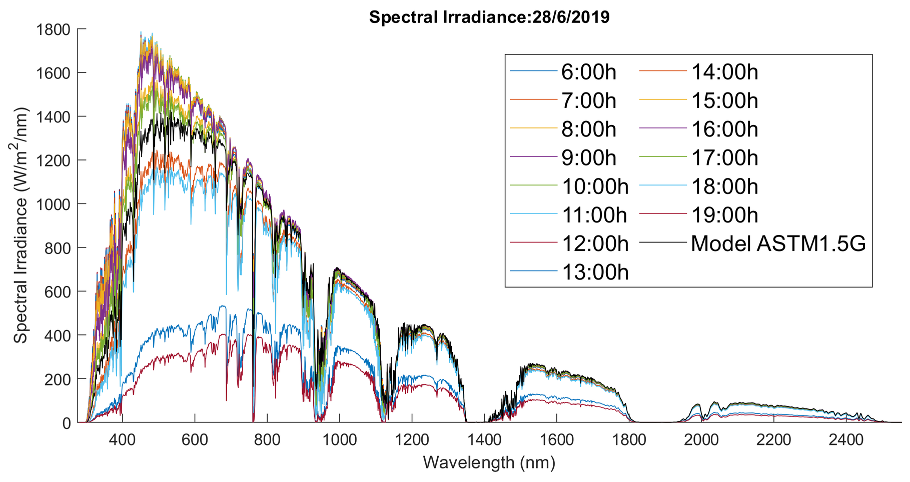
Key parameters

The photodetector is responsible for transforming captured radiation into electrical energy to generate an optical power measurement. While any photodetector could theoretically fulfil this function, certain specifications are essential:

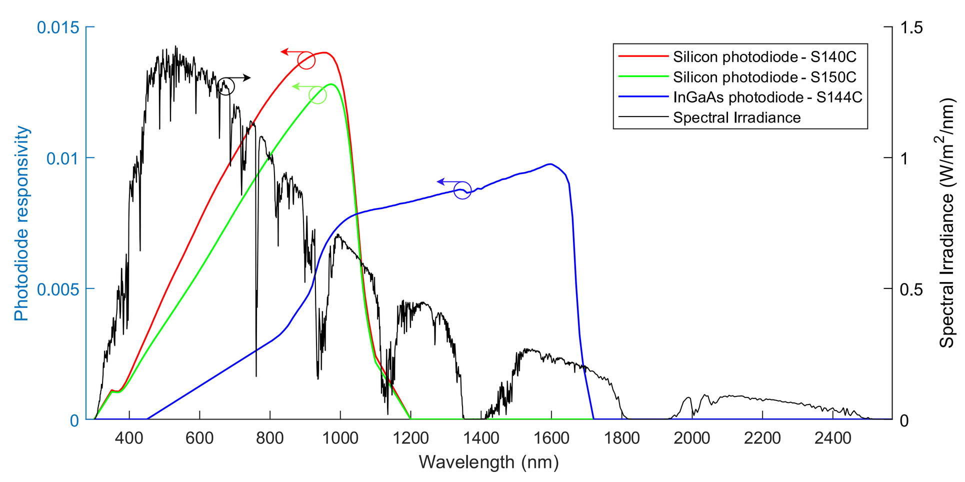
- Sensitivity: Ensure the smallest changes on irradiance are detected.
- Response time: Enable real-time detection.
- Spectral response: Cover most of the solar radiation spectrum, ranging between 300nm to 4000nm, as flat as possible to react equally to all radiation captured.

¿Why photodiodes?

Due to their superior sensitivity and faster response time, which are crucial for detecting small, rapid variations in irradiance. While thermopiles offer a flatter spectral response, their reliance on thermal processes leads to slower reaction times and insufficient sensitivity for this application, where changes in the order of microwatts must be detected reliably, making unsuitable for this application. The spectral disadvantages of photodiodes, whose response is irregular and limited, imposes the use of the calibration algorithm documented in [4,5].



Spectral irradiance evolution measured in Seville, Spain over 28th June 2019, compared against ASTM 1.5 G173-03 Reference Spectra.

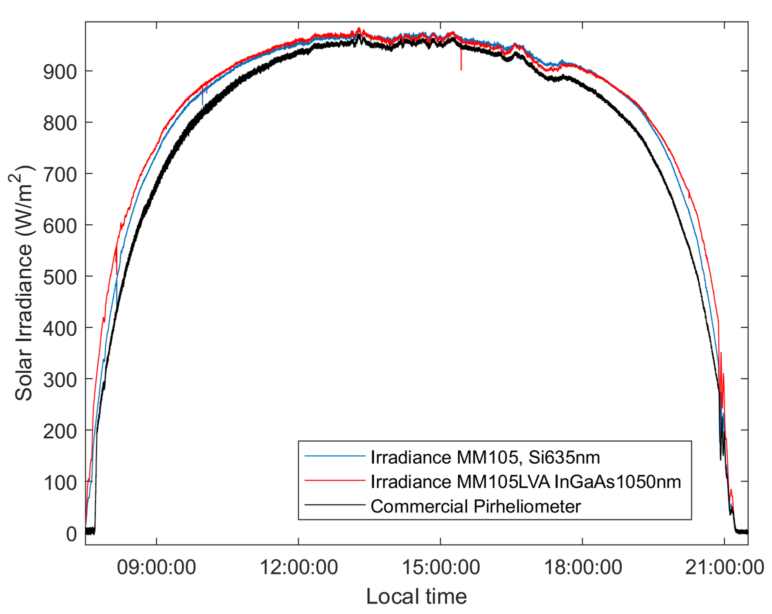


Spectral response of the semiconductor photodiodes [8] analyzed against the reference solar spectrum [7]. The spectral response of photodiode S150C has been scaled for the purpose of the illustration.

Results

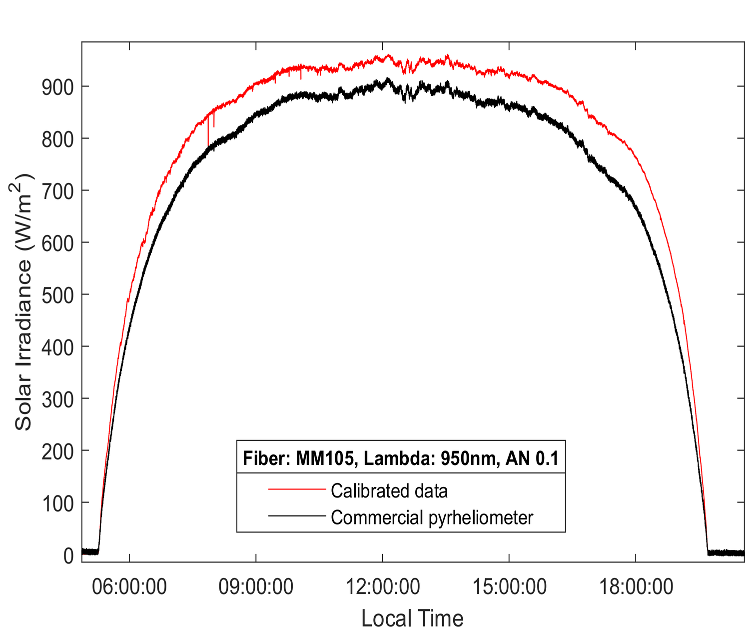
First results presented are for measurements during the same day with two different photodiodes (silicon S140C and InGaAs S144C) using fiber THORLABS FG105LVA, with 105µm core diameter and 0.22AN, compared against a commercial pyrheliometer, it is clear that the behavior of both photodiodes is similar during the central hours of the day, where the irradiance values after being processed are similar to those from the commercial device, proving great sensitivity and similar response times to the pyrheliometer, keeping relative errors below 5% from 10:30h to 19:00h.

If the analysis is focused on the divergencies seen on the comparison, they happen mainly at dawn and dusk, where the spectral irradiance suffers most variations against the model used in the calibration algorithm. If examined with further detail, the values from the InGaAs photodiode are higher than the silicon photodiode also at these times, while this did not happen at central hours of day. As shown in previous section, the responsivity of the InGaAs photodetector covers higher wavelengths in the spectrum, having more influence of these components at sunrise and sunset.



DNI measurement using as optical collector an optical fiber with 105µm core-diameter and silicon S140C and InGaAs S144C photodiodes, compared against commercial pyrheliometer.

Lastly, figure on right side demonstrates that the performance of the S150C photodiode is analogous to previous photodiodes. However, the divergence between the curve generated by this device and the commercial pyrheliometer is more pronounced, although the relative error consistently remains below 10%, which could be due to fiber misalignment, manufacturing tolerance or a divergence between theoretical and real photodiode response curves. This phenomenon is consistently observed across all measurements conducted with this fiber and detector, so it could potentially be mitigated by refining the calibration algorithm. This could be done in several ways, but current work focuses on changing the spectra used as a reference for the calibration factor computing depending on different conditions, such as time of day and season of the year. Besides, the use of a photodiode that is less sensitive to changes in spectrum could be beneficial, reducing the influence of these changes. In this sense, the InGaAs photodiode S144C has a flatter response, and covers a side of the spectrum with less changes along the day, potentially being the best option.



DNI measurement using as optical collector an optical fiber with 105µm core-diameter and silicon S150C photodiode, compared against commercial pyrheliometer.

Conclusions

In this work, various photodetectors were analyzed as solar radiation detectors in a new optical fiber-based pyrheliometer configuration. The study encompassed two stages: an initial phase examining the specifications of different employed devices and assessing their suitability for the intended application, followed by a second phase where the photodetectors were tested in a novel radiometer setup previously demonstrated. **Among the options considered, semiconductor photodiodes exhibited superior performance leveraging their sensitivity and response time capabilities while overcoming spectral response curve limitations through the calibration algorithm employed; compared to the thermopile, which was considered an invalid option for this application due to its low sensitivity and response time.** Among the evaluated photodiodes, the two volumetric models demonstrated the most promising performance, generating results comparable to those of a conventional pyrheliometer. Although both behave similarly, the silicon photodiode gave more accurate results, whereas the InGaAs photodiode behaved worse at the start and end of the day.

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