Concentrated Solar Flux Measurement in a High Flux Solar Simulator Using an Optical Fiber Based Radiometer

Manuel JEREZ[1], **Alejandro CARBALLAR**[1], **Ricardo CONCEIÇÃO**[2], **José GONZÁLEZ-AGUILAR**[2]

1. Electronic Engineering Department, Universidad de Sevilla; C/ Camino de los Descubrimientos, s/n, 41092, Sevilla, Spain
2. High Temperature Processes Unit, IMDEA Energy, Av. Ramón de La Sagra, 3, 28935, Móstoles, Madrid, Spain

***Contact: Manuel JEREZ (mjerez@us.es)**

INTRODUCTION

Objective: Measurement of high radiation flux using a new radiometer configuration based on optical fiber and photodiode as the radiation sensor.

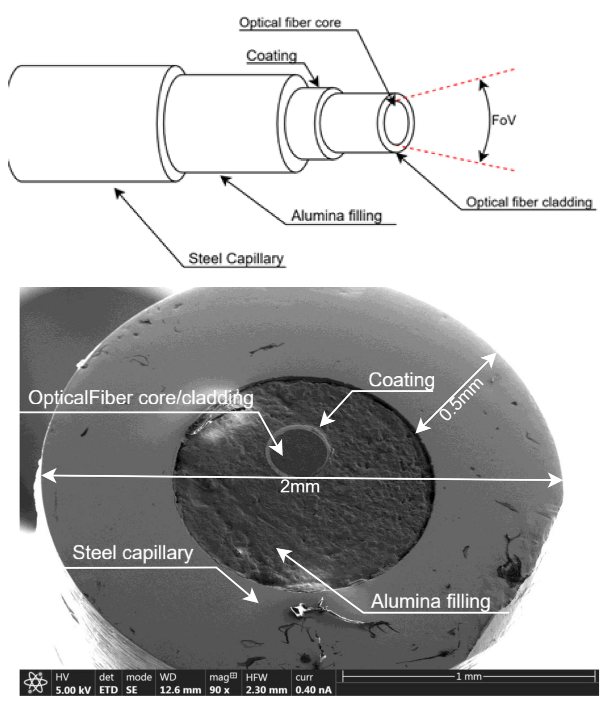
Concentrating Solar Thermal Energy (CSP/CST): Challenges

CST/CSP is a dispatchable technology for large-scale clean electricity generation harnessing heat generated through solar energy concentration. However, this technique faces significant challenges, notably the difficulty in conducting proper plant operation monitoring [1]. Conventional instruments for radiation measurements are not suitable to determine continuously the value and distribution of the received radiation in commercial solar tower technologies due to high temperatures (up to 1000 °C) at the solar receiver [2].

Why optical fibers?

The use of high-temperature optical fibers installed in the tower receiver as an element for solar radiation collection, emerges as a viable option to monitor incident concentrated sunlight. An analogous setup was already successfully tested as a radiometer [3]. This configuration offers multiple advantages, such as spatial efficiency and isolation of the measurement location from extreme temperatures. In this work, the proof of concept was tested at a high-flux solar simulator and results are presented.

HIGH TEMPERATURE OPTICAL FIBERS



Schematic and detail of optical fiber tips exposed to radiation

Optical fiber were designed and manufactured by Engionic (Berlin, Germany). Their design can be examined in adjacent figures. They rely on:

- High temperature coating around optical fiber, made of either polyamide or gold.
- Alumina filling to prevent heat conduction.
- Steel capillary ensuring structural integrity.
- 0.22 numerical aperture, resulting in FoV of 25°.

This design ensures:

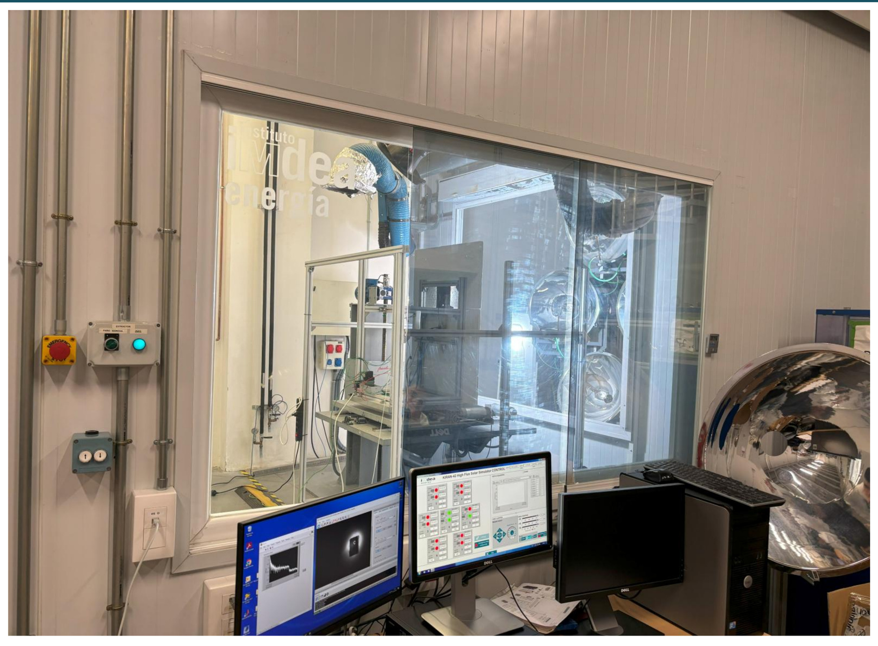
- Reduced size, maintaining minimal interference with CSP receiver.
- Stable performance up to 700 °C.
- Withstanding peak temperatures up to 1000 °C.

EXPERIMENTAL SETUP

To test the feasibility of the proposed device, the KIRAN-42 high-flux solar simulator (HFSS), located at IMDEA Energy, Móstoles, Spain, was utilized. The HFSS has the following specifications:

- 7Xe arc lamps.
- Peak flux up to 3.6MW/m^2 at focal point.
- Remote control from adjacent room.
- XYZ positioning table for radiation exposure placing.

Among the 7 lamps, only two were used, providing 300 kW/m^2 and 400 kW/m^2 at focal point with the use of one or two lamps, respectively.



Overview of KIRAN-42 HFSS facilities at IMDEA Energy

The fibers were exposed to radiation using an Inconel plate with two MK-125-A sealed connectors. The plate was covered with an alumina plate, only exposing to radiation a small section of the Inconel containing fiber terminals.

The fibers were connected to silicon photodiode THORLABS S140C and to an optical power meter, generating a power trace to be processed [3].

Irradiance was also measured by a Gardon sensor, from Vatell Corporation. The sensor, coated with Pyromark 1200, can measure peak fluxes up to 1.6 MW/m^2 with a sensitivity of 0.062 mV/W/cm^2 and an accuracy of ±3%.

Detail of optical fibers assembly in experimental setup

RESULTS

Two optical fibers were used during the testing campaign:

- 200/220Au: 200 µm core diameter, 220 µm cladding diameter, gold coating.
- 200/220PI: 200 µm core diameter, 220 µm cladding diameter, polyamide coating.

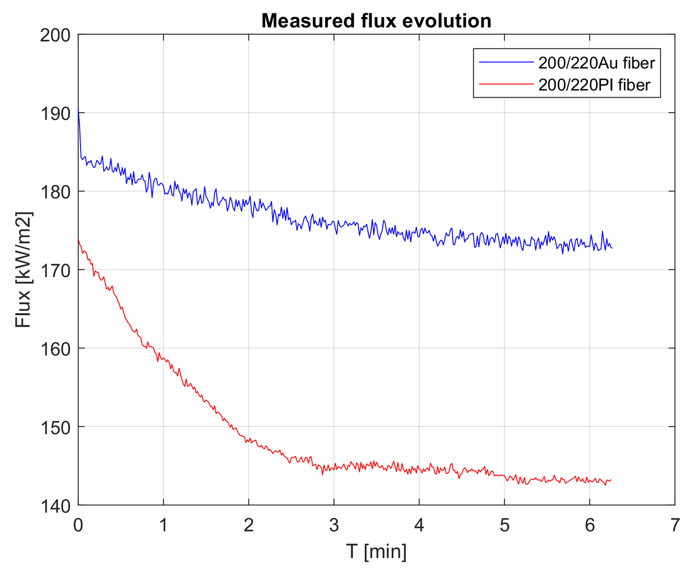
The results demonstrate the viability of using optical fibers for concentrated solar flux measurements, although some challenges still need to be addressed. Regarding static measurements, peak values measured are summarized in the table below.

Peak Flux measured	*One lamp turned on*	*Two lamps turned on*
Gardon radiometer	*310 kW/m^2*	*400 kW/m^2*
200/220Au	*194 kW/m^2*	*206 kW/m^2*
200/220PI	*173 kW/m^2*	*202 kW/m^2*

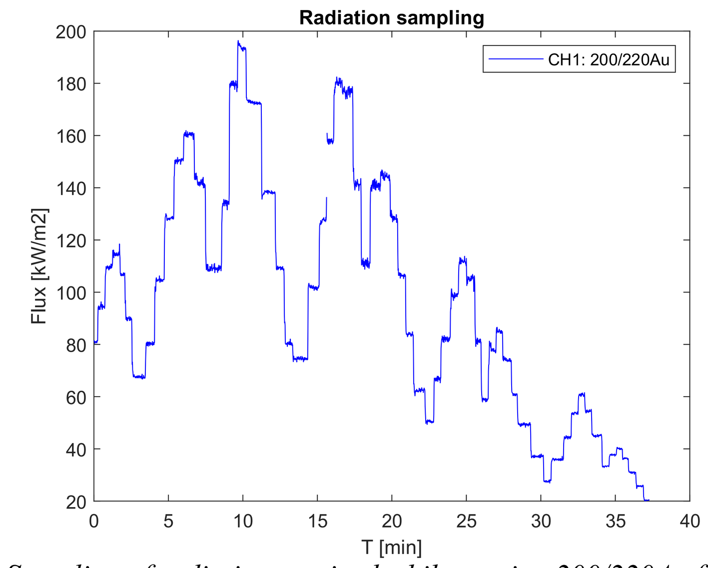
Why lower values?

The differences between both measurements are explained by various factors:

- Numerical Aperture: Although 0.22NA allows coupling from central lamp; light from second lamp is not; which explains almost no difference between both measurements.
- Attenuation: Although coupled, all rays reaching fiber surface with different than normal incidence are attenuated.
- Light spectrum: Lamp manufacturer does not provide the lamp spectral behavior, needed to perform calibration and estimate flux [3]. Although an approximation was done, it is not guaranteed that some error was introduced.
- Other phenomena, such as the extreme temperatures, or damage, could have influence on peak values measured.



Concentrated flux measurement with two fibers over 6 minutes

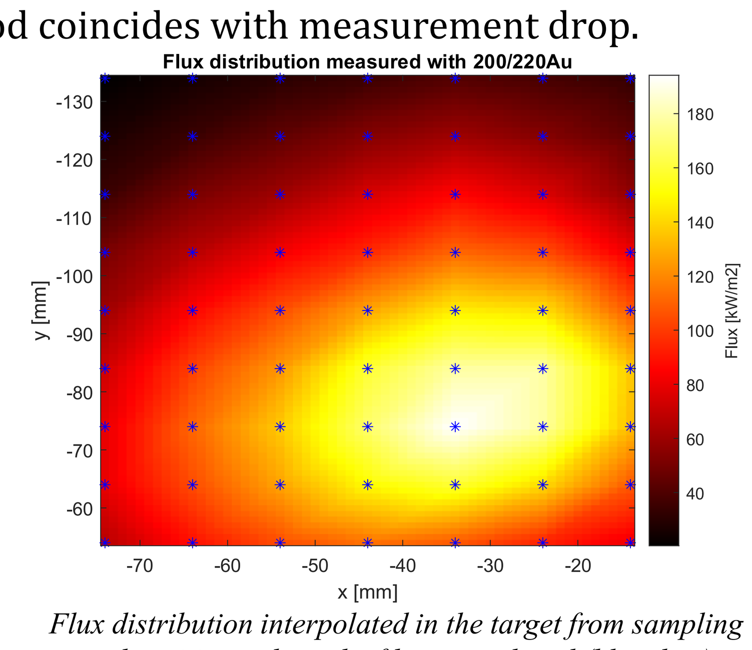


Sampling of radiation received while moving 200/220Au fiber around focal area

Dynamic Behavior

From the moment of the first exposure to light and the previously mentioned peak value, a drop occurs:

- Both fibers show a decline in measurement until a stabilization point is reached. The decline is less pronounced in gold-coated fiber, that also reaches a higher stabilization point.
- This phenomenon is evident in the first image shown on the left, where exposure is minutes long; but also seen on second image.
- The phenomenon is attributed to temperature effects: When placed on focal point, fiber starts heating up. The heating period coincides with measurement drop.



Flux distribution interpolated in the target from sampling and positions where the fiber was placed (blue dots)

CONCLUSIONS

The results presented demonstrate the feasibility of measuring high radiation fluxes using an optical fiber as a radiation collection element in concentrating solar systems, measuring values surpassing 200 kW/m^2 in an environment of around 500 °C, although some challenges still need to be addressed. The measurements obtained fall short of those provided by the Gardon radiometer used as reference. This discrepancy may be due to multiple factors, notably the temperature dependence of the measurement and material degradation due to extreme operating conditions, as well as the limited numerical aperture of the fiber. Future work should focus on developing mechanisms to protect fiber tips from extreme environment and enhancing the field of view, with solutions that might include, but are not limited to, the use of diffusers and lenses, as well as reducing the measurements' temperature dependence.

ACKNOWLEDGEMENTS

This work has been developed within the framework of the research projects of the Ministerio de Ciencia e Innovación, CHLOE with reference PID2021-125786OB-C22, and CATION with reference TED2021-132190B-C22; as well as the ASTERIx-CAESar project, which has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement Nº 101122231.

REFERENCES

[1] K. P. Sibin et al., "Multiscale textured solar absorber coatings for next-generation concentrating solar power", Renewable and Sustainable Energy Reviews 207 (2025), 114959.
[2] N. Jelley et al., "Concentrated solar power: Recent developments and future challenges", Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 229(2015).
[3] A. Carballar et al., "Measuring DNI With a New Radiometer Based on an Optical Fiber and Photodiode", Sensors 2024, 3674.
[4] R. Paschotta, "Numerical Aperture", RP Photonics Encyclopedia, 2004.