Measurement of Concentrated Solar Flux in Solar Simulator Using Optical Fiber-Based Radiometer

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Introduction

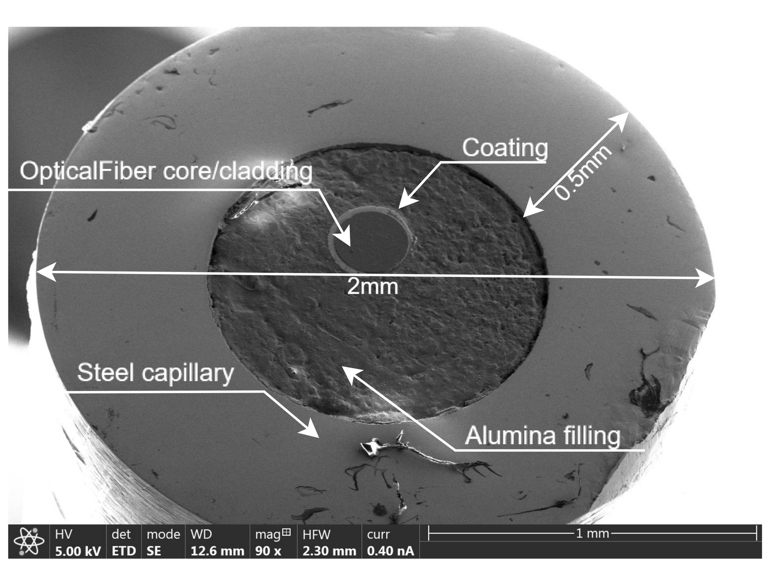
Why measuring concentrated solar flux?

- **Performance optimization:** Measuring concentrated solar flux ensures accurate alignment of heliostats and receivers, maximizing efficiency and energy output.
- **Thermal safety:** Flux mapping prevents overheating and material damage in receivers, protecting equipment and extending its lifetime.
- **Operational control:** Real-time monitoring of flux distribution enables adaptive control of heliostat fields and supports safe, reliable plant operation.

Why optical fibers?

- **Spatial efficiency and resolution:** Minimization of the area occupied at the receiver, allowing for multiple measurement points and high spatial resolution.
- **Fast response:** Dynamics are not dependent on thermal dynamics, but light propagation.
- **Measurement decoupling:** Eliminates the necessity for active cooling, reducing operational complexity.

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 figure. They rely on:

- **High temperature coating** around optical fiber, made of either polyimide 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:

- Stable performance up to 700 °C.
- Withstanding peak temperatures up to 1000 °C.

Methodology

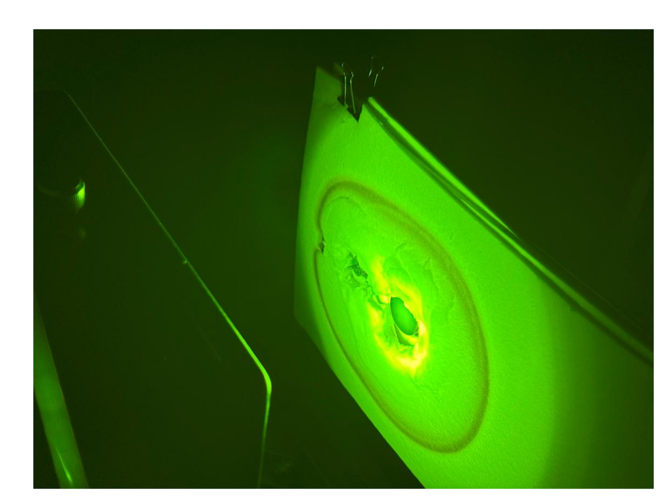
High flux solar simulator specifications

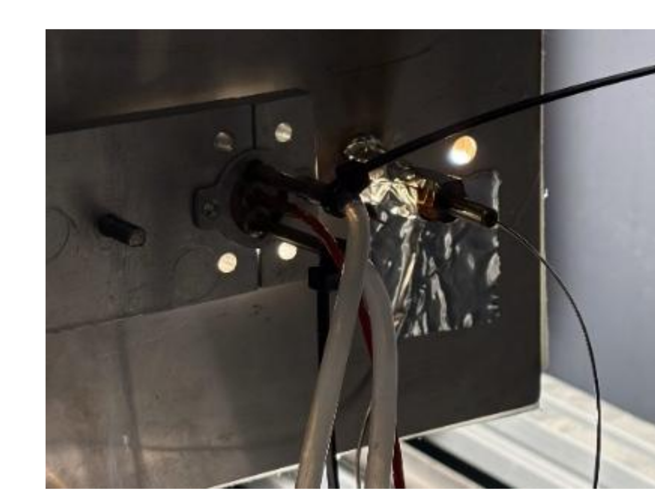
- **Xenon lamp** housed in enclosure.
- **Ellipsoidal mirror** focusing light outside enclosure.
- **Adjustable** power levels.
- Flux at focal point between **180 kW/m² to 1.1 MW/m².**
- **3 axis positioning table.**

CENER's high-flux solar simulator

Experimental assembly

- **Stainless steel plate** was mounted on the positioning table.
- Fiber was exposed to radiation through a connector to align the tip of the optical fiber cable.
- **Gardon radiometer** was positioned next to the fiber tip to provide benchmarking measurements.
- Steel plate was covered with **ceramic wool** to minimize thermal influence
- A **thermocouple** was attached on the rear side for temperature monitoring.





Front (left) and rear (right) of the steel plate used as mounting for the optical fiber, radiometer and thermocouple

Results

The optical fiber utilized for the testing campaign specifications were 200 µm core diameter, 220 µm cladding diameter and polyimide coating.

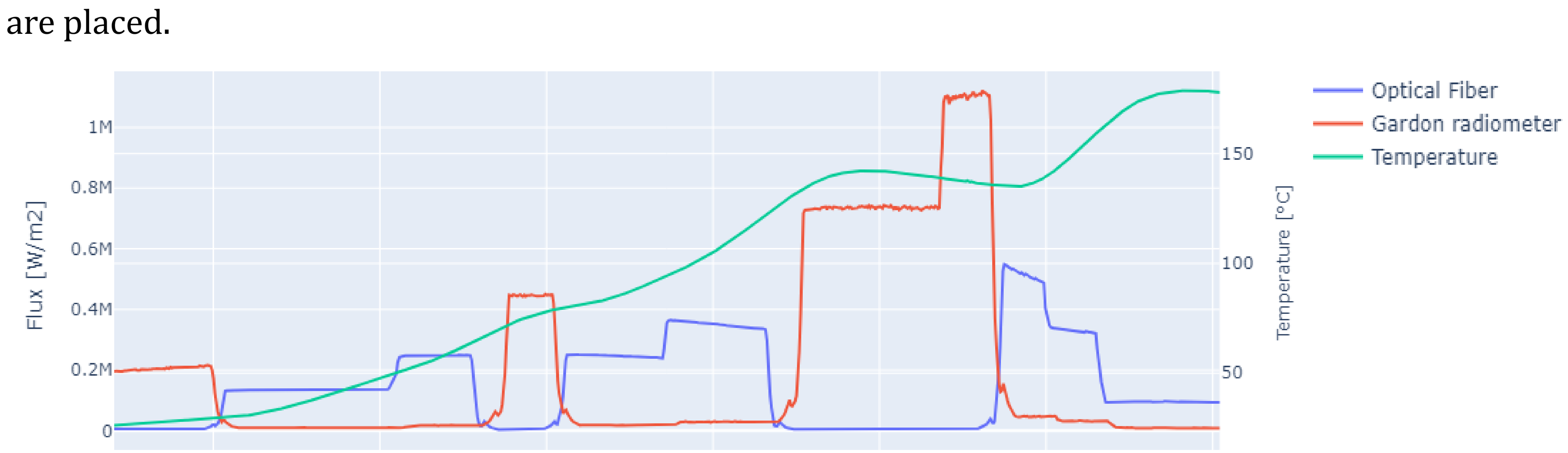
Geometrical considerations

- Lamp emission has a half-aperture angle of 19.3º, ideally distributed uniformly.
- The optical fiber has 12.7º half-angle field of view, theoretically allowing **coupling up to 65.8% of the emitted light**.
- No light is received directly from central angles, as it is where electrical connections are placed.

Gardon measurement	*Fiber measurement*	*Temperature*	*Relation*
445 kW/m2	*252 kW/m²*	*80 ºC*	*56.6%*
450 kW/m2	*229 kW/m²*	*137 ºC*	*50.8%*
450 kW/m2	*178 kW/m²*	*208 ºC*	*39.5%*
737 kW/m2	*365 kW/m²*	*94 ºC*	*49.5%*
737 kW/m2	*320 kW/m²*	*160 ºC*	*43.41%*
1100 kW/m2	*548 kW/m²*	*135 ºC*	*49.8%*
1100 kW/m2	*427 kW/m²*	*150 ºC*	*38.8%*

Observations

- The maximum flux measured by the fiber was around 550 kW/m² when lamp was delivering 1100 kW/m² at focal point.
- The percentage of light coupled is lower than theoretical maximum. This is due to the attenuation of light incident with directions different than perpendicular to the optical fiber surface.
- There is a big dependance of the measurement with temperature, reducing light measured when temperature increases.
- Temperatures were measured at the rear of the steel plate, which means that the optical fiber tip itself was subjected to much higher temperatures, up to 1000ºC.
- Other phenomena, such as potential damage on the fiber tip could have influence in the values measured.



Concentrated flux and temperature measurement while increasing progressively lamp power

Concentrated flux and temperature evolution while using active cooling

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 500 kW/m², 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 is 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

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