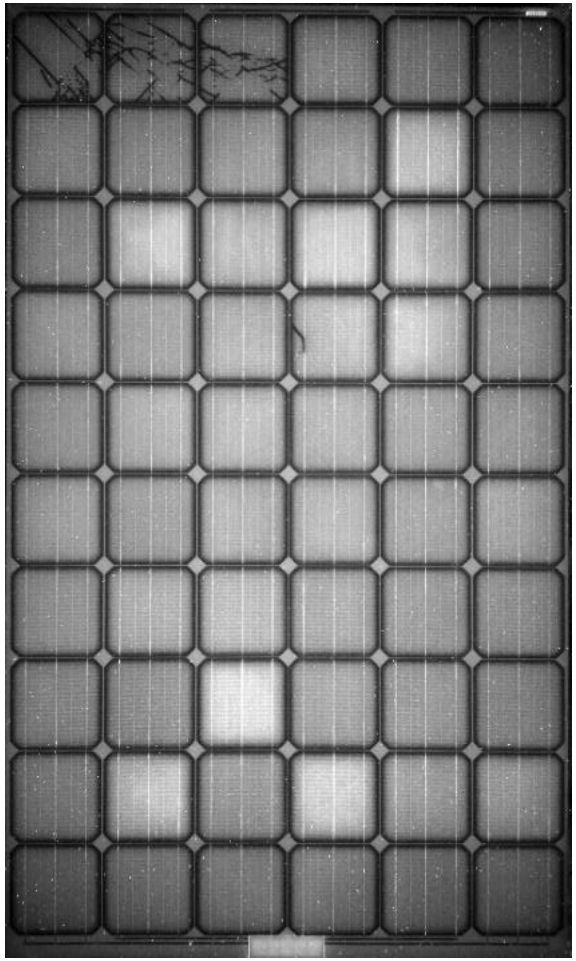

Temperature effects of formation and measurement of UV fluorescence

M. Siebert, A. Morlier, M. Köntges

Institute for Solar Energy Research Hamelin
ISFH

Leibniz Universität Hannover

Outline

- Effect of module temperature on fluorophores formation

- Effect of module / UV LED / camera temperature during fluorescence measurement

Outline

- Effect of module temperature on fluorophores formation

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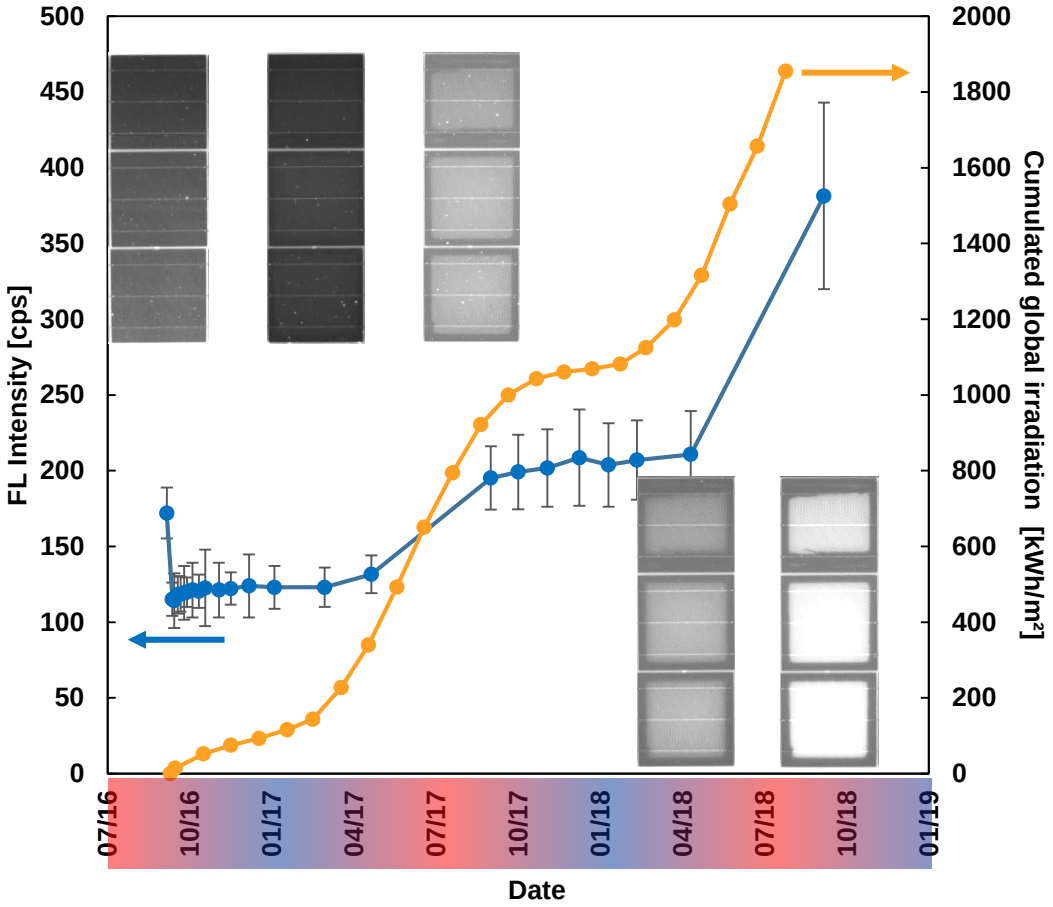
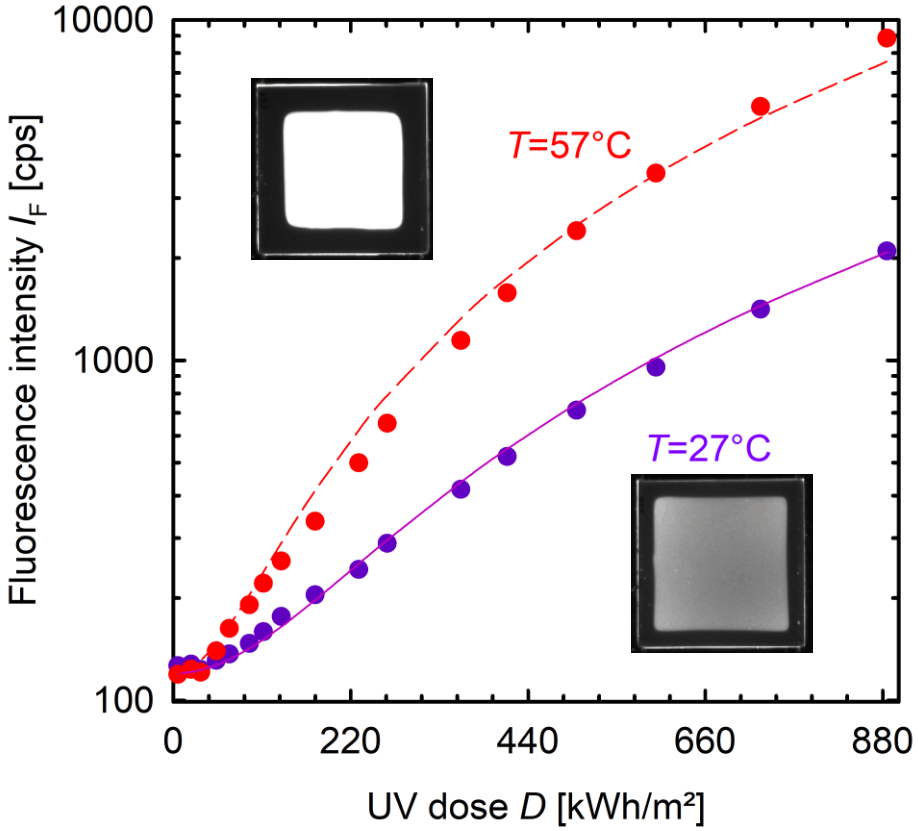
Formation of fluorophores



- Start of outdoor exposure in September 2016
- Initial fluorescence deleted in a few days
- No increase of FL in winter
- Strong increase of FL intensity in hot summer 2018
- Almost all formation of FL during summer

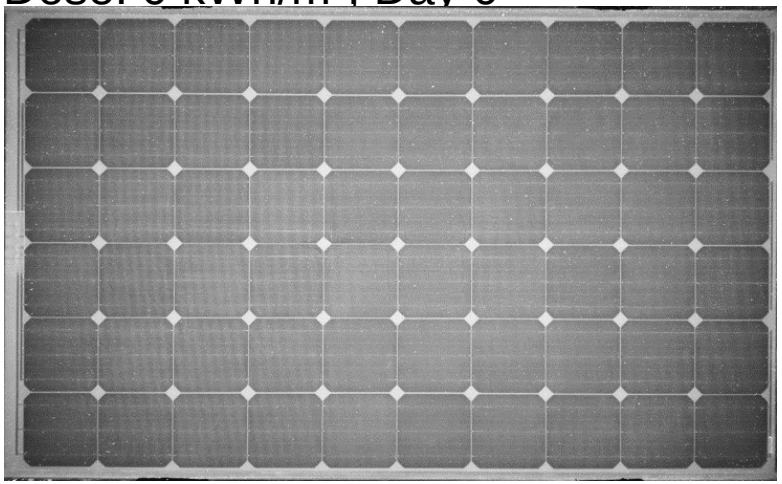
Formation of fluorophores



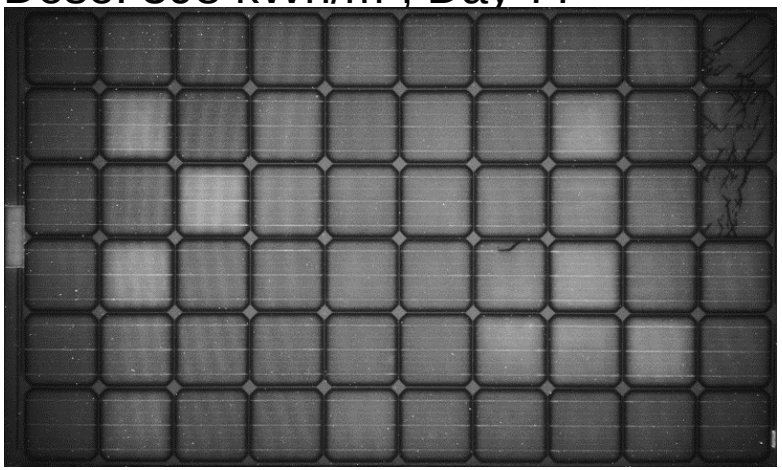
- Two equal glass/EVA/glass laminates in UV chamber
- Sample temperature T in UV chamber controlled at 27°C and 57°C
- Heat during irradiation accelerates formation of fluorophores

Fluorescence inhomogeneity

Dose: 0 kWh/m², Day 0



Dose: 398 kWh/m², Day 77



- Mono-Si module, never exposed to sunlight
- Initial: homogeneous fluorescence over the whole surface of the module[1,2]
- Outdoor exposure, short circuited

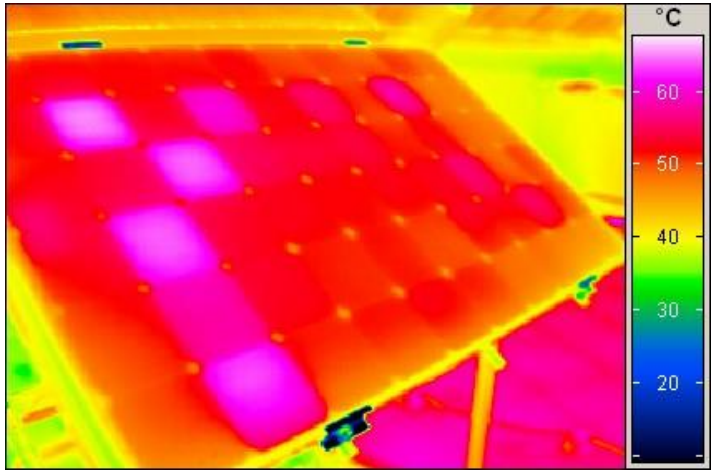
- After exposure: Some cells show a more intense fluorescence than average.

Why?

[1]A. Morlier, M. Köntges, S. Blankemeyer, I. Kunze, *Energy Procedia*, vol. 55, pp. 348-355, 2014.
[2]J. Schlothauer, M. Ralaiarisoa, A. Morlier, M. Köntges, B. Röder, *Journal of Polymer Research*, vol. 21, pp.457-463, 2014.

FL / Operating temperature

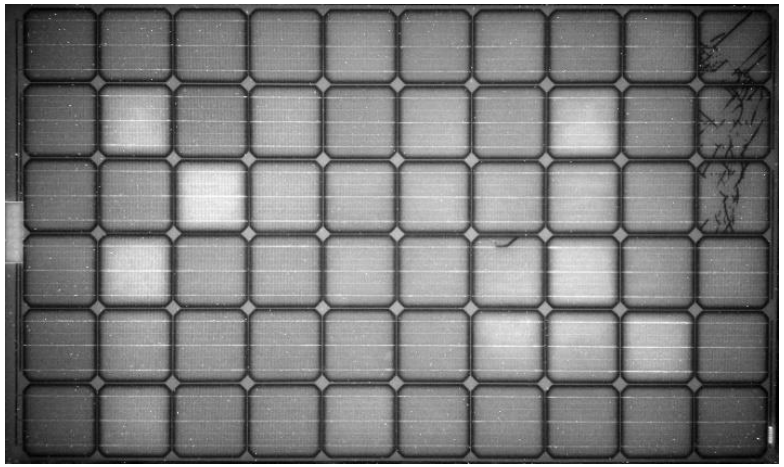
IR-image @ 28°C, ca. 780 W/m², short-circuited



Cell temperature backsheet

55	55	53	54	56	56	56	57	59	59
58	73	61	67	60	63	60	68	58	57
57	59	65	58	58	60	59	61	56	57
58	70	58	59	59	63	64	67	59	59
57	64	58	56	57	56	60	63	66	60
54	65	58	58	59	59	59	60	57	55

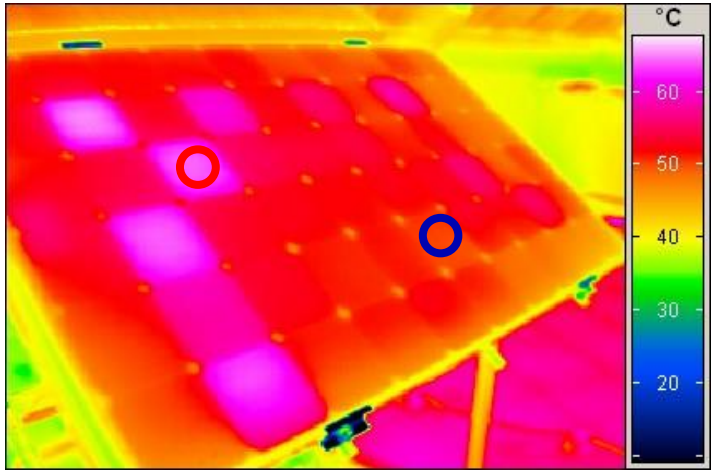
Fluorescence measured in the lab



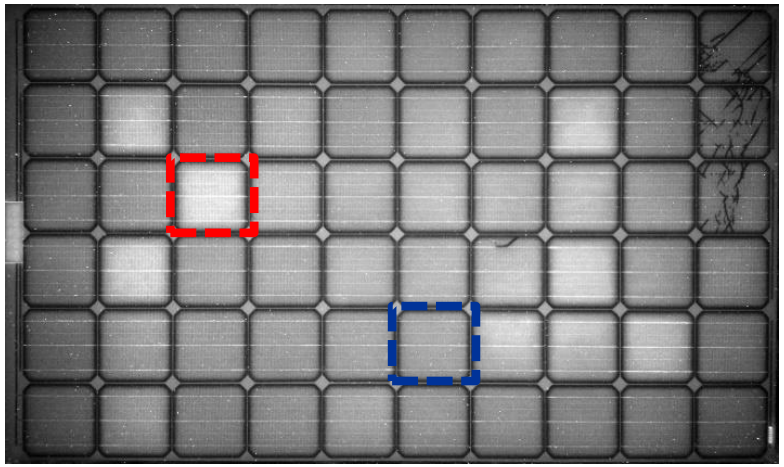
- 10°C operating temperature difference @ 780 W/m² easily observable with FL

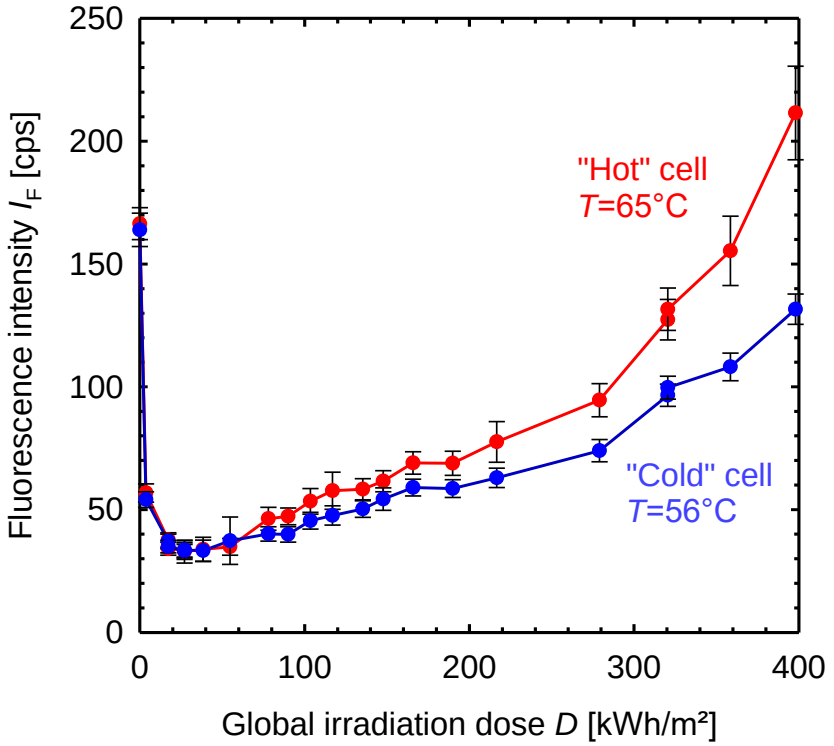
FL / Operating temperature

IR-image @ 28°C, ca. 780 W/m²



Fluorescence measured in the lab





- After 3 weeks outdoor in summer, the operating temperature difference is detectable with UV FL

→ **UV FL shows a history of the cell operating temperature**

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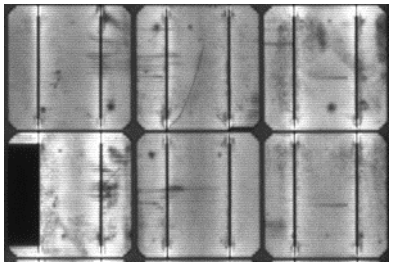
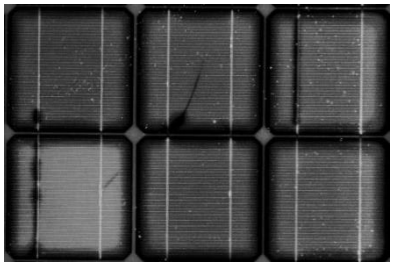
Application: cell cracks & hotspots

Electroluminescence

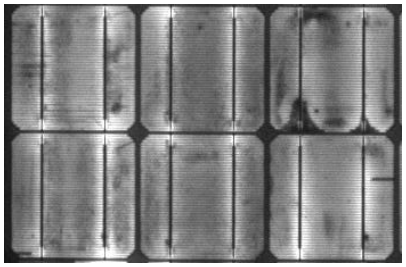


Fluorescence

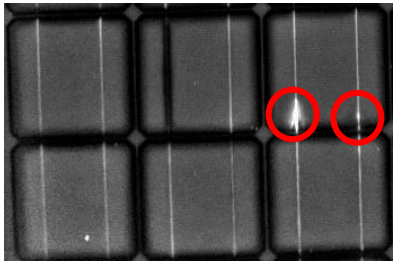


- Critical cell crack leads to higher cell operating temperature. Cell shows higher fluorescence intensity

Electroluminescence



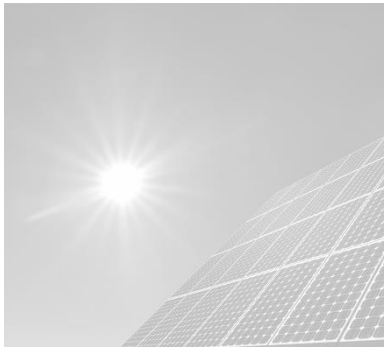
Fluorescence



- Electroluminescence shows 2 electrical path damages, corresponding hotspots are revealed by intense fluorescence

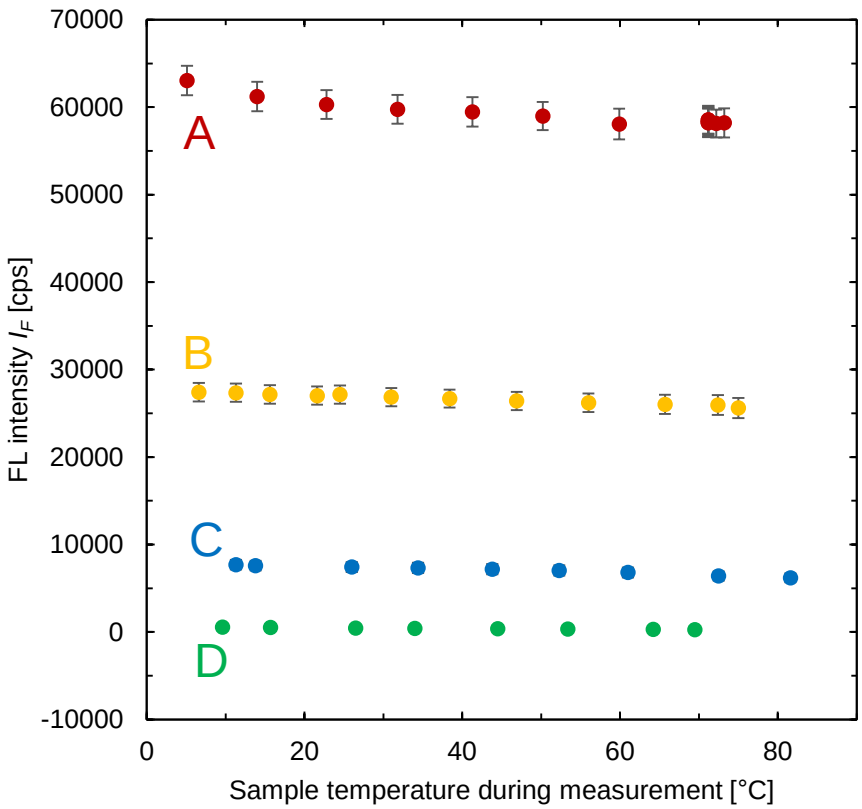
Outline

- Effect of module temperature on fluorophores formation



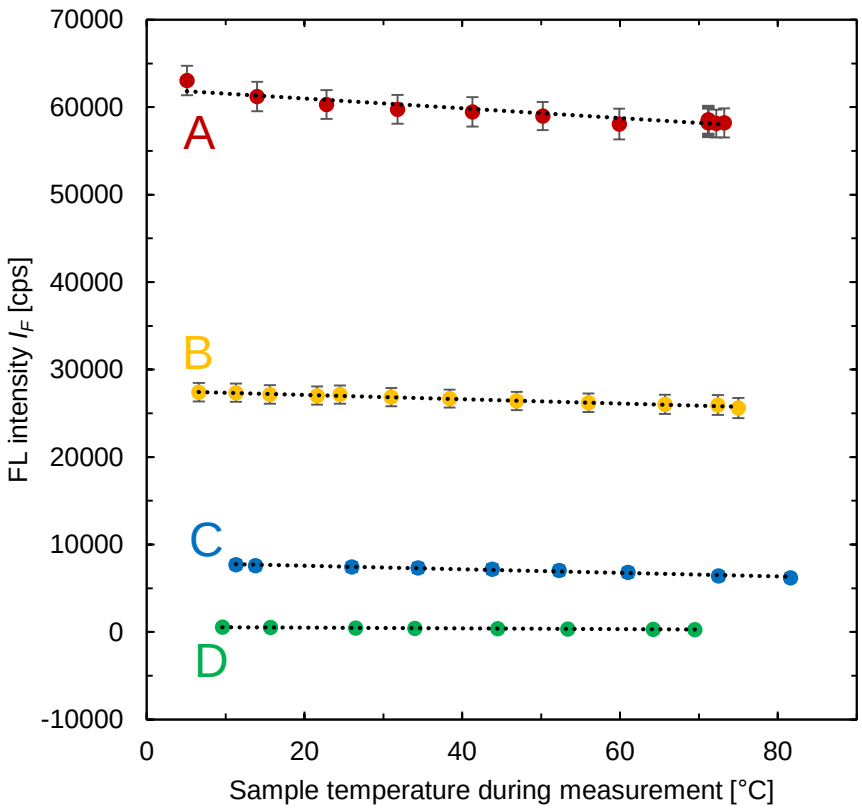
- Effect of module / UV LED / camera temperature during fluorescence measurement

Temp. effect on FL measurement



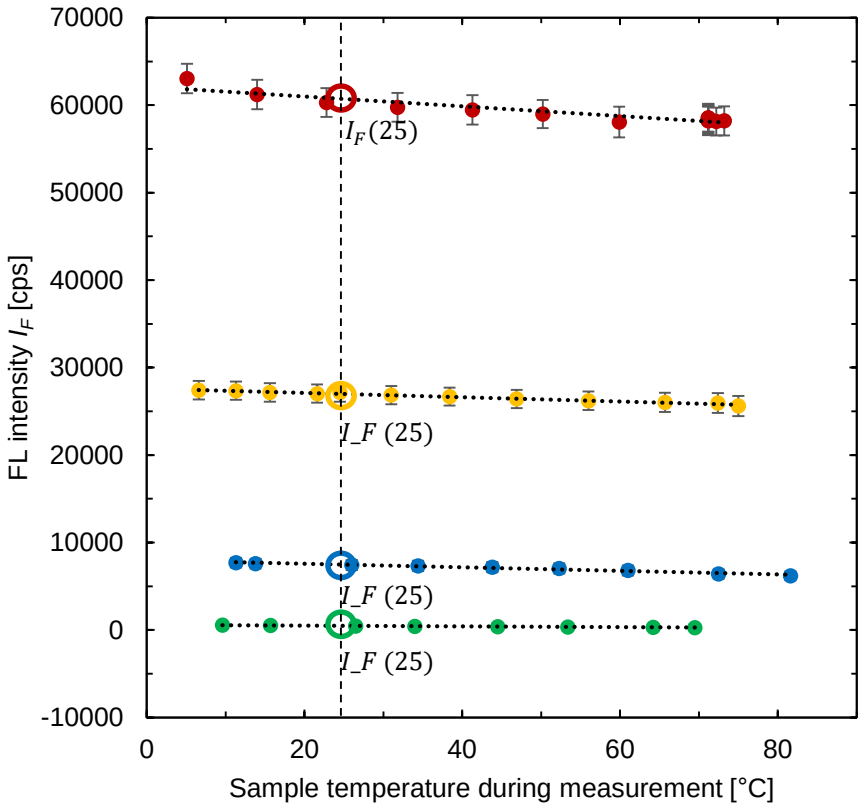
- EVA samples with different FL measured at different sample temperatures
- Fluorescence intensity I_F decreases with increasing sample temperature

Temp. effect on FL measurement



- EVA samples with different FL measured at different sample temperatures
- Fluorescence intensity I_F decreases with increasing sample temperature
- Linear dependence of I_F on sample temperature

Temp. effect on FL measurement



- Definition of a relative fluorescence temperature coefficient δ_{25}

$$\delta_{25} = \frac{dI_F(T)}{dT} * \frac{100}{I_F(25)}$$

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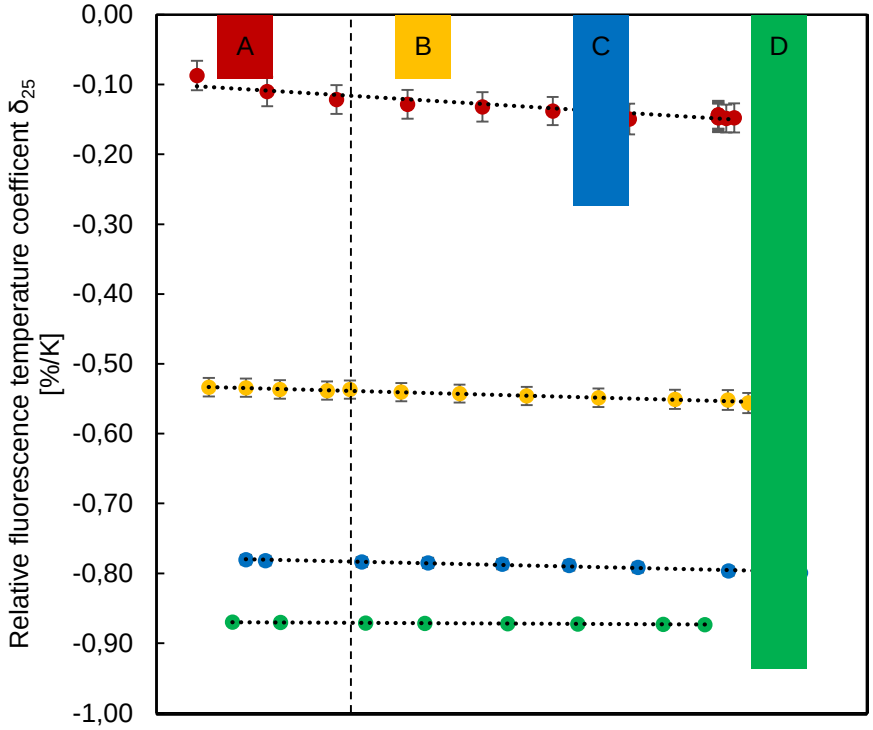
Temp. effect on FL measurement



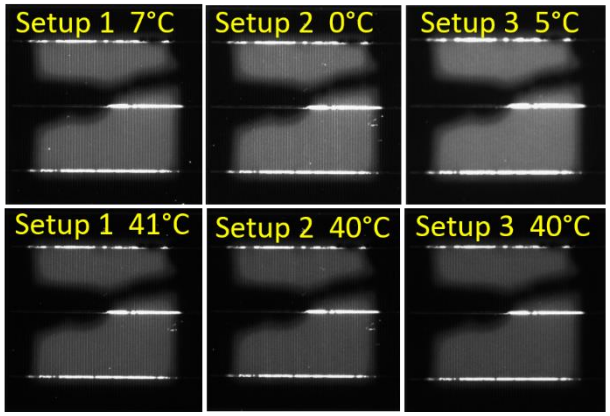
- Definition of a relative fluorescence temperature coefficient δ_{25}

$$\delta_{25} = \frac{dI_F(T)}{dT} * \frac{100}{I_F(25)}$$

- More influence of temperature on low FL intensity samples

Temp. effect on FL measurement

	Setup 1	Setup 2	Setup 3
	PV module		
Module	Climatic chamber -20°C - 80°C	Climatic chamber 0°C - 46°C	Climatic chamber 5°C - 45°C
UV LED	Lab ambience ca. 20°C	Temp. as Module	Temp. as Module
Camera	Lab ambience ca. 20°C	Isolated (5°C - 16°C)	Temp. as Module

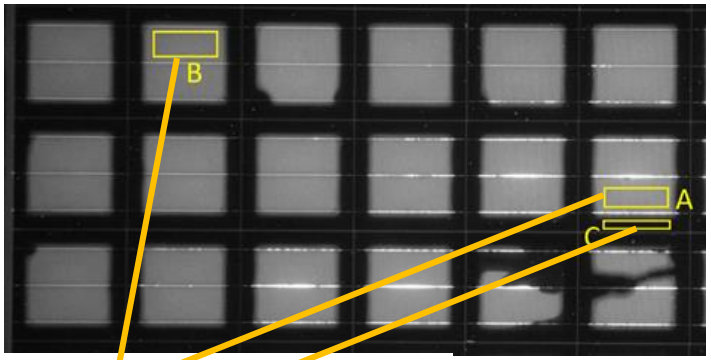


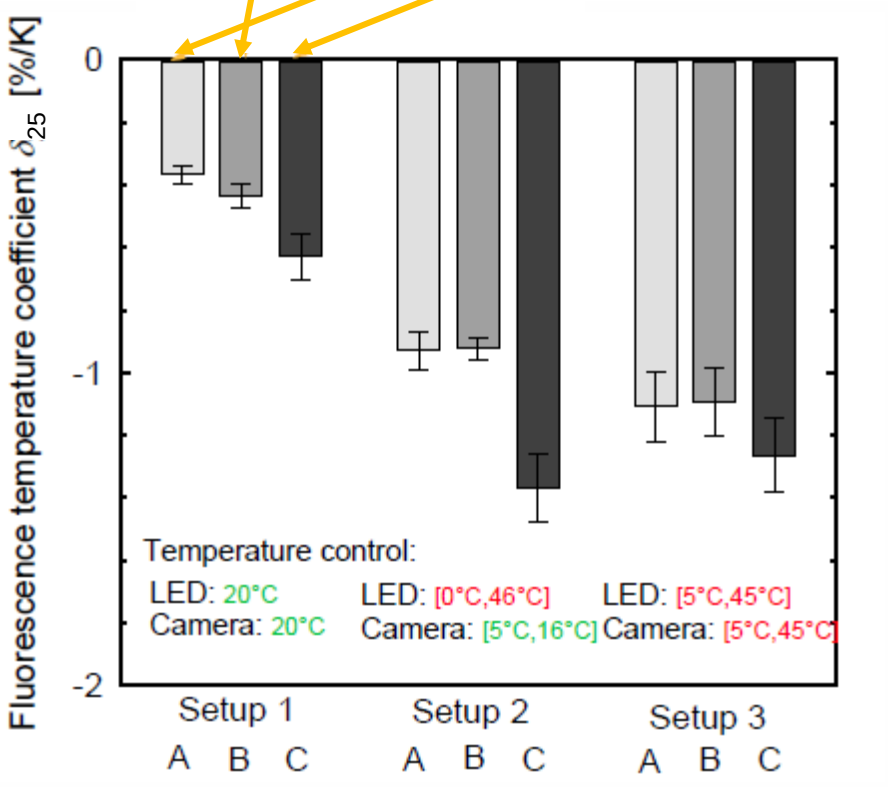
3 setups:

- Module under thermal cycle
- Module and UV-LED unter thermal cycle
- Module, UV-LED and camera under thermal cycle

- Measured I_F decreases with increasing module temperature in every setup

Temp. effect on FL measurement





- 3 modules zones with different I_F
- Determination of δ_{25} of each zone under each setup
- UV-LED and camera temperature stabilization allow for significantly lower δ_{25}
- UV-LED efficiency is temperature sensitive: high impact on δ_{25}
- Camera temperature control has a slight effect
- **UV-LED temperature is the key element to control in the field**
- **Module temperature should be controlled in the lab**

Conclusion

- Almost all formation of fluorophores in PV modules during summer
- UV FL can detect warmer cells or hot spots
- UV FL shows history of cell operating temperature

- FL intensity decreases when sample temperature increases
- The fluorescence temperature coefficient δ_{25} is higher on low fluorescence intensity
- Temperature of module and UV-LED should be controlled for quantitative measurements

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