AVT-371 Research Workshop on

"Materials and technologies for electro-optical camouflage"

BiTs: Bispectral camouflage system based on switchable phase change materials (sPCM) and thermochromic coatings

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Fraunhofer ICT

Outline

1. **Introduction Phase Change Materials (PCM) in Concealment applications**
   - Phase Change Materials
   - Encapsulation methods
   - Experimental investigation of first laboratory samples

2. **Switchable Phase Change Materials (sPCM)**
   - Thermophysical properties and working principle
   - Simulation

3. **The BiTs-project**
   - sPCM: selection, modification, thermophysical properties
   - Thermochromic coatings
   - Construction and testing of laboratory samples

Introduction Phase Change Materials (PCM)

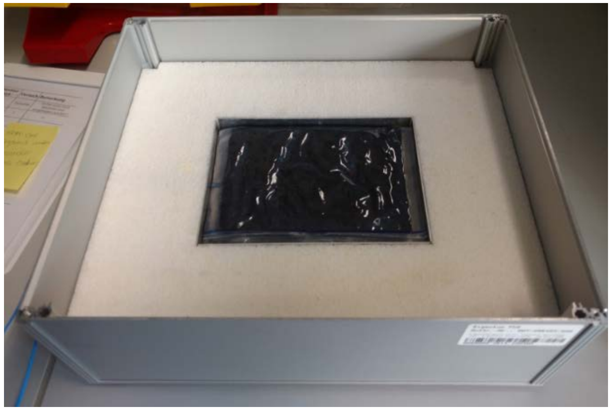
- Heat and cold storage in solid/liquid phase change
- Kerosenes, esters, sugar alcohols, fatty acids and salt hydrates
- Phase change temperature of T: -50 ° C
- to about 100 ° C
- Storage capacity: 155 kJ/kg to 300 kJ/kg
- Cycle stability >>1000 (organic materials)
- Volume change during phase change: up to 15%
- Thermal conductivity about 0.2 to 0.8 W/(m K)
- Viscosity: low viscosity 1 to 80 mPa s
- Density:
  - ~0.9 kg/L (organic PCM)
  - ~1.3 kg/L (salt hydrates)

Melting ice

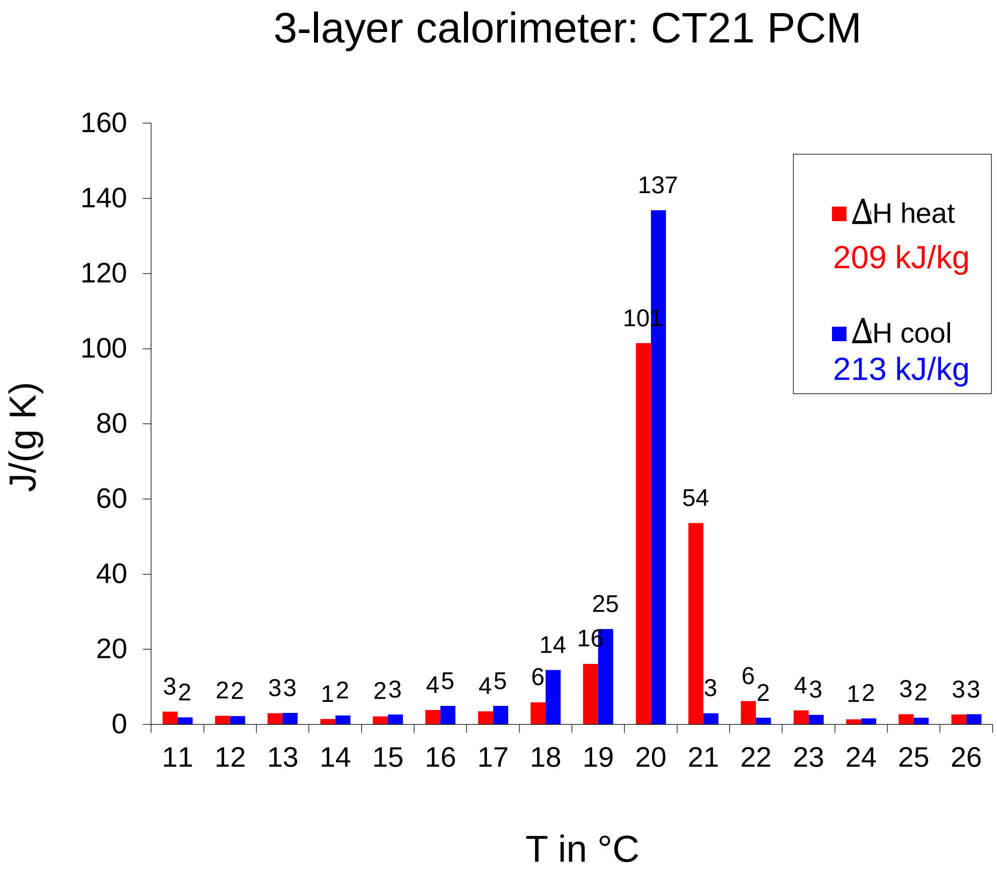
Melting organic PCM

Thermophysical Properties of PCM

3-layer calorimeter



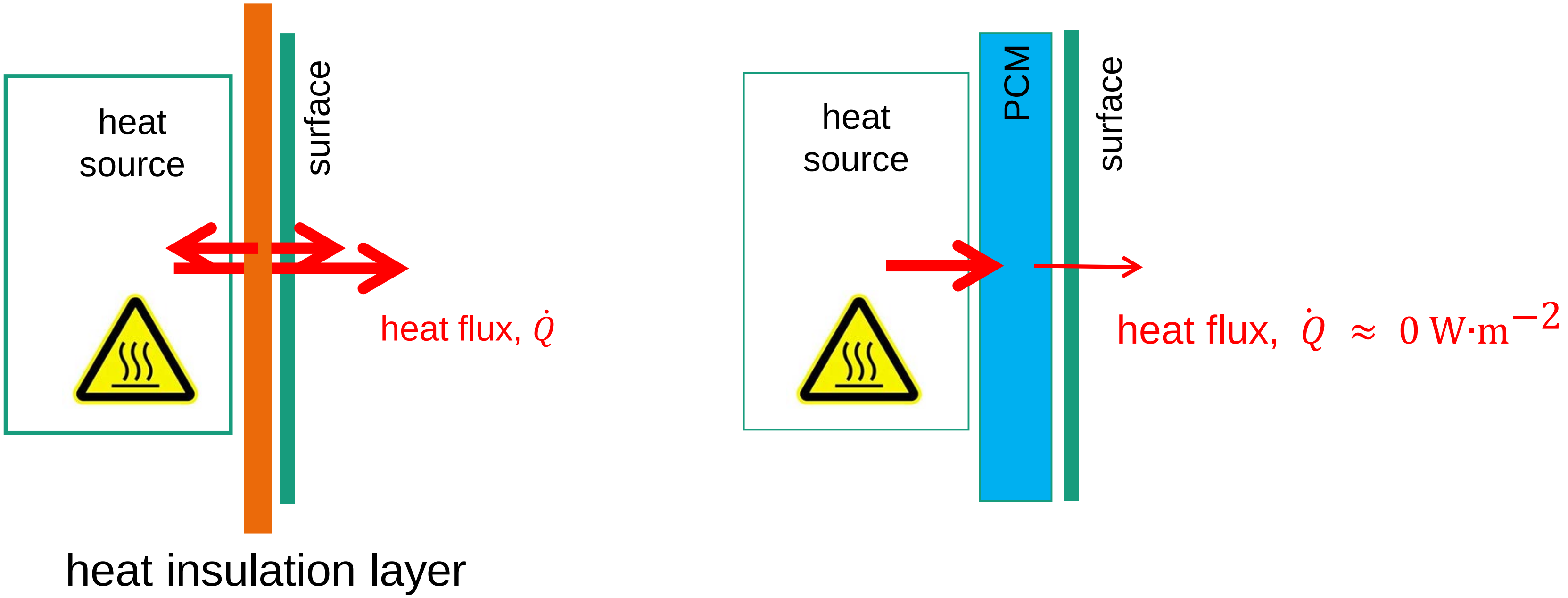
T-history calorimeter



Working principle PCM camouflage

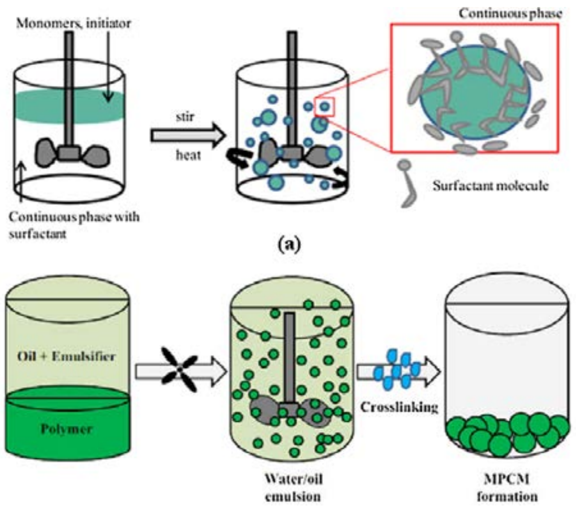
- **Classic concealment Systems:**
  - heat insulation layer -> heat accumulation

- **reduction of IR signatur by heat storage**

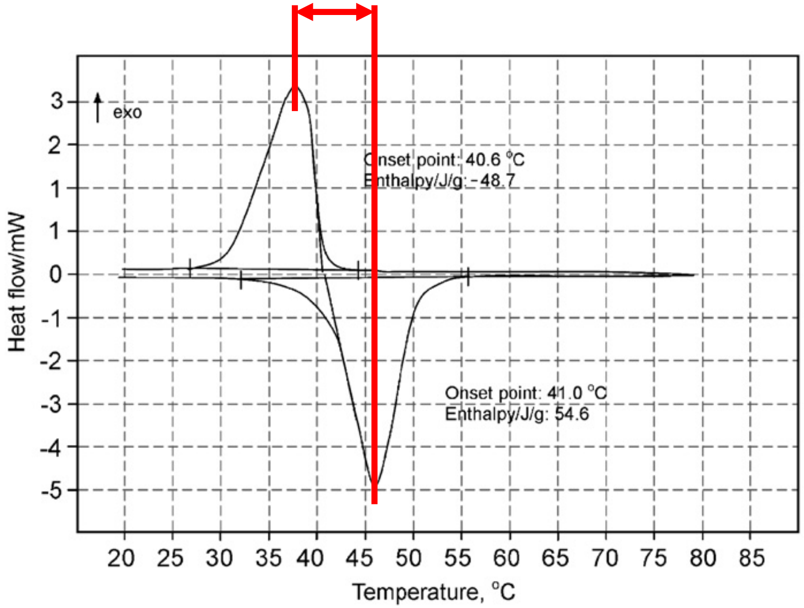


PCM micro-encapsulation

- In general only organic PCM can be microencapsulated → flammable
- High thermal hysteresis due to microencapsulation
- Lower phase transition enthalpy
- Advantage: High leckage safety



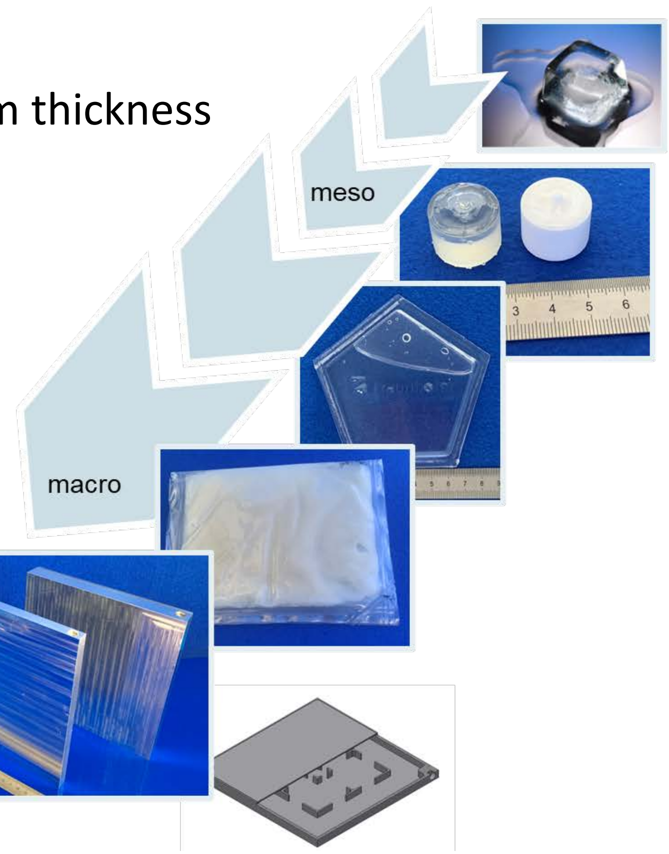
Huang, Xiang; Zhu, Chuqiao; Lin, Yaxue; Fang, Guiyin (2019): Thermal properties and applications of microencapsulated PCM for thermal energy storage: A review. In: Applied Thermal Engineering 147, S. 841–855. DOI: 10.1016/j.applthermaleng.2018.11.007.



Cemil, Alkan; Sari, Ahmet; Karaipekli, Ali; Uzun, Orhan (2009): Preparation,characterization,andthermalpropertiesofmicroencapsulated phase changematerialforthermalenergystorage. In: Solar Energy Materials & SolarCells 93 (1), S. 143–147

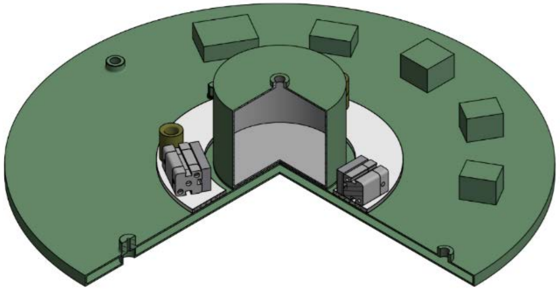
PCM meso- and macroencapsulation

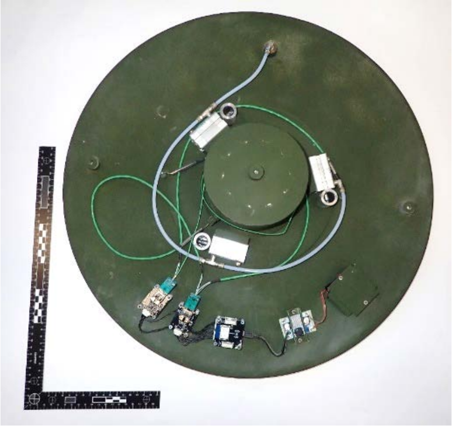
- **Meso- and macroencapsulation → higher volumetric heat storage density than microencapsulation, lower thermal hysteresis**
- **Foil bag**
  - ➢ HDPE, HDPE/PA, AL composite film... << 0.1mm thickness
- **Thermoforming**
  - ➢ HDPE, PET-G... up to 1mm film thickness
- **3D printing**
  - ➢ Stereolithography (SLA)
- **Shape stabilized metal encapsulation**
  - ➢ Made of aluminum

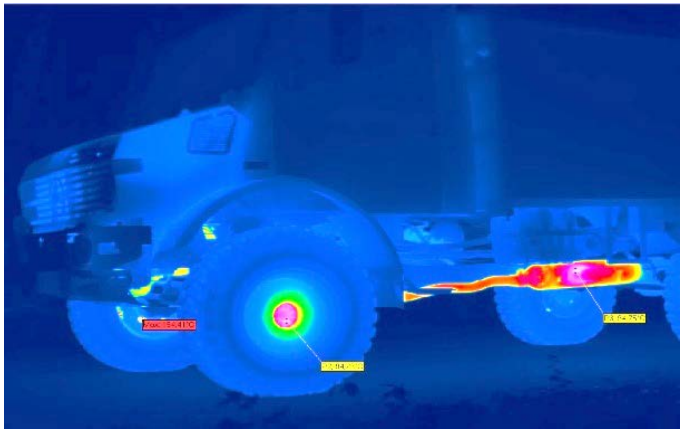


PCM in concealment applications

- **Time evolution of the wheel surface temperature**
  - ➢ Motion travel
  - ➢ Slope / gradient
  - ➢ Frequent heavy braking



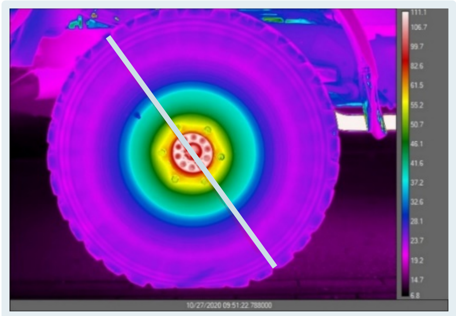




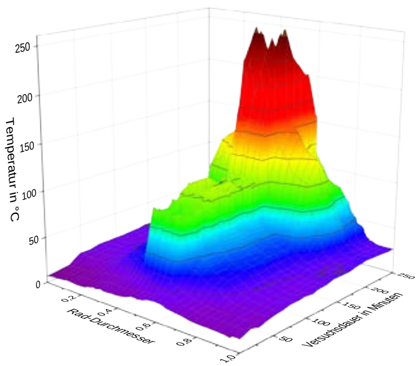
PCM in concealment applications

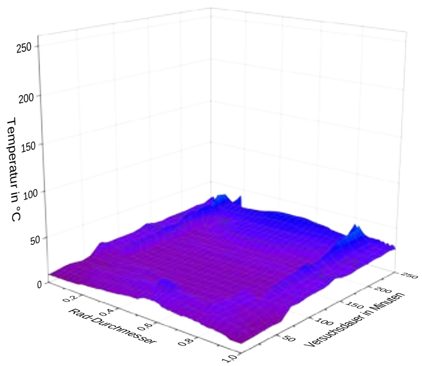
- **Time evolution of wheel surface temperature**
  - ➢ Motion travel
  - ➢ Slope / gradient
  - ➢ Frequent heavy braking

Without PCM

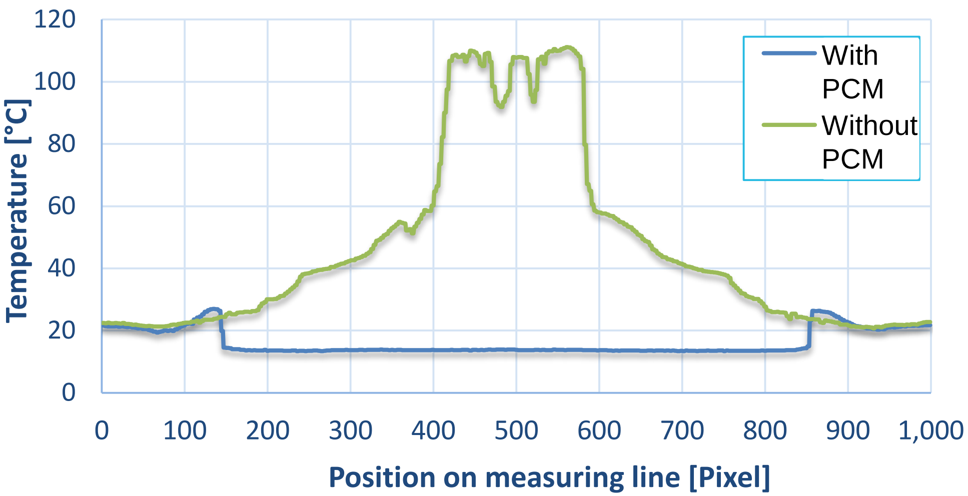


With PCM





Surface temperature (t = 96 min)



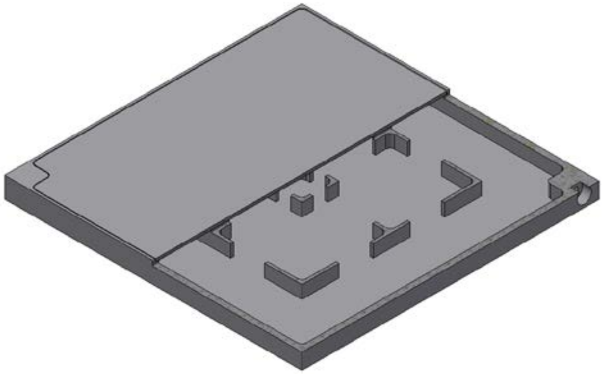
PCM laboratory demonstrators

- **Macroencapsulated PCM (Rubitherm company):**
  - **Rigid encapsulation made of HDPE (plastic)**
  - **Dimension (LxWxH): 170 x 85 x 25 mm**
  - **Filling weight per capsule approx. 285 g PCM**
  - **Air inclusions for mechanical stability**

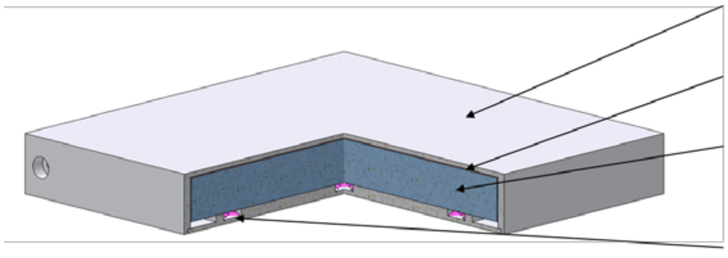
- **PCM bag (ICT):**
  - **Flexible encapsulation made of aluminum composite foil.**
  - **Dimension (LxWxH): 195 x 195 x 10 mm**
  - **Filling weight approx. 300 g PCM**
  - **Welded under vacuum (only minimal air inclusions)**

PCM laboratory demonstrators

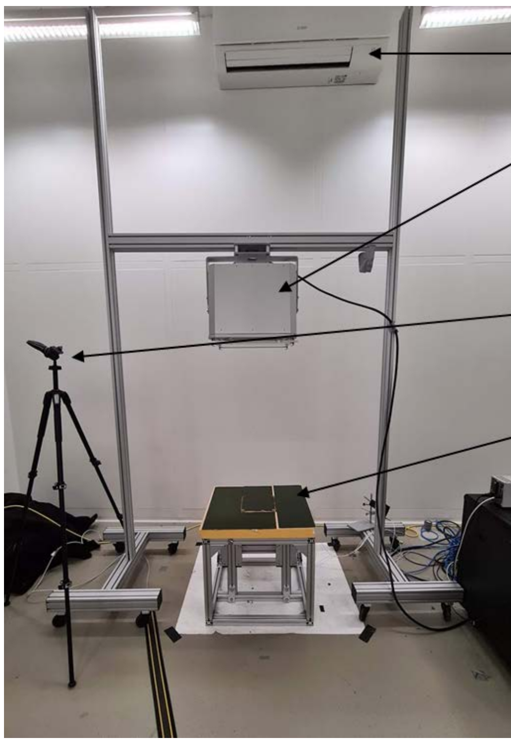
- **Metal Encapsulation MI (ICT):**
  - **Rigid aluminum encapsulation**
  - **Dimension (LxWxH): 200 x 200 x 14 mm**
  - **Filling weight per battery approx. 290 g PCM**
  - **bars absorb compressive forces, only small, filling-related air pockets**

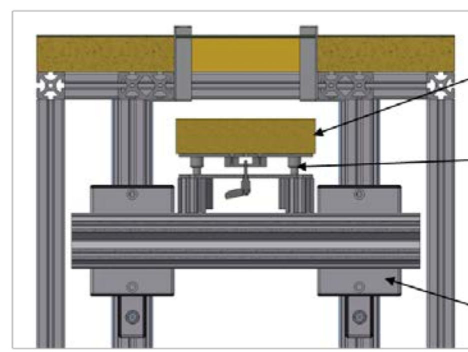


- **Metal Encapsulation MII (ICT):**
  - **Flexible encapsulation made of aluminum composite foil**
  - **Dimension (LxWxH): 200 x 200 x 27.6 mm**
  - **Filling weight approx. 330 g PCM**
  - **Porous aluminum absorbs compressive forces, only small, filling-related air pockets**
  - **Porous aluminum conducts heat into deeper PCM**
  - **Thermal bonding optimized by graphite foil and contact springs**

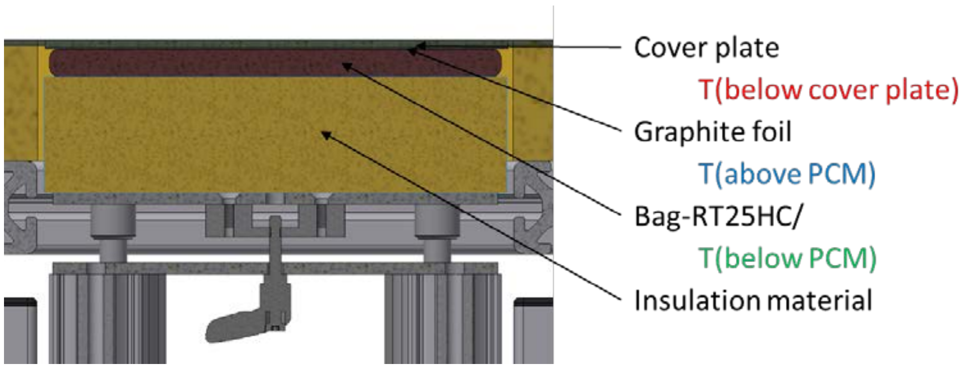


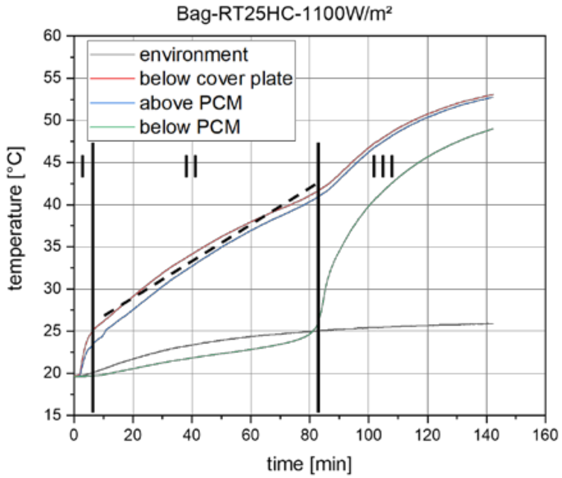
Investigation of laboratory samples

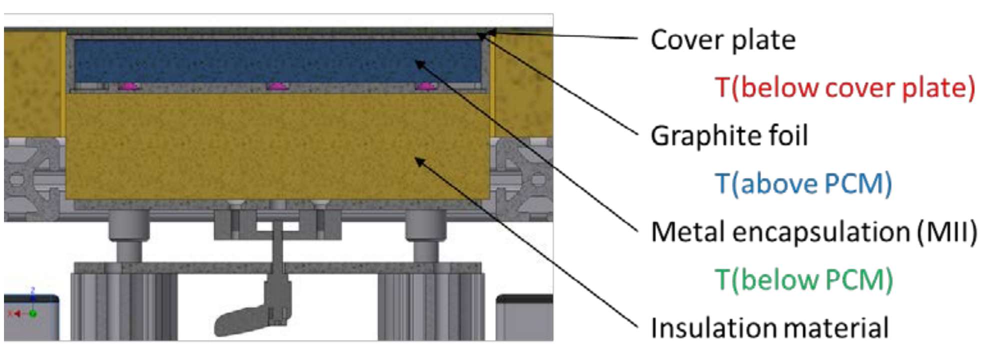


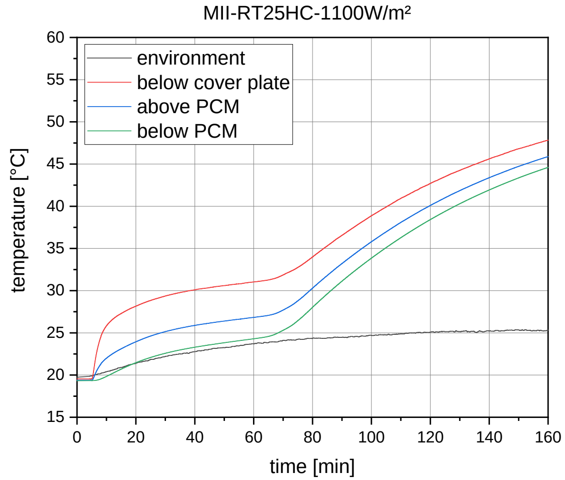


Laboratory samples experimental investigation



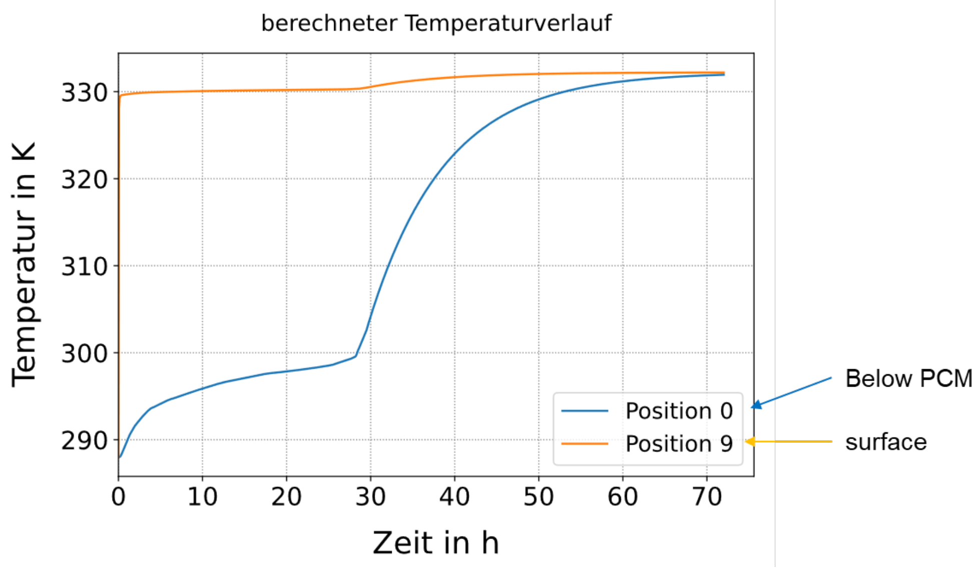


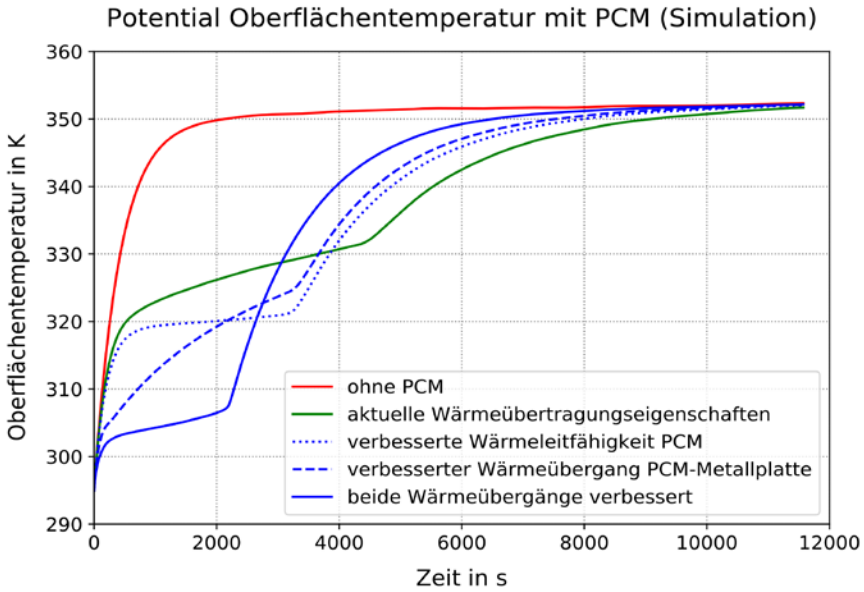




PCM 1D simulation code

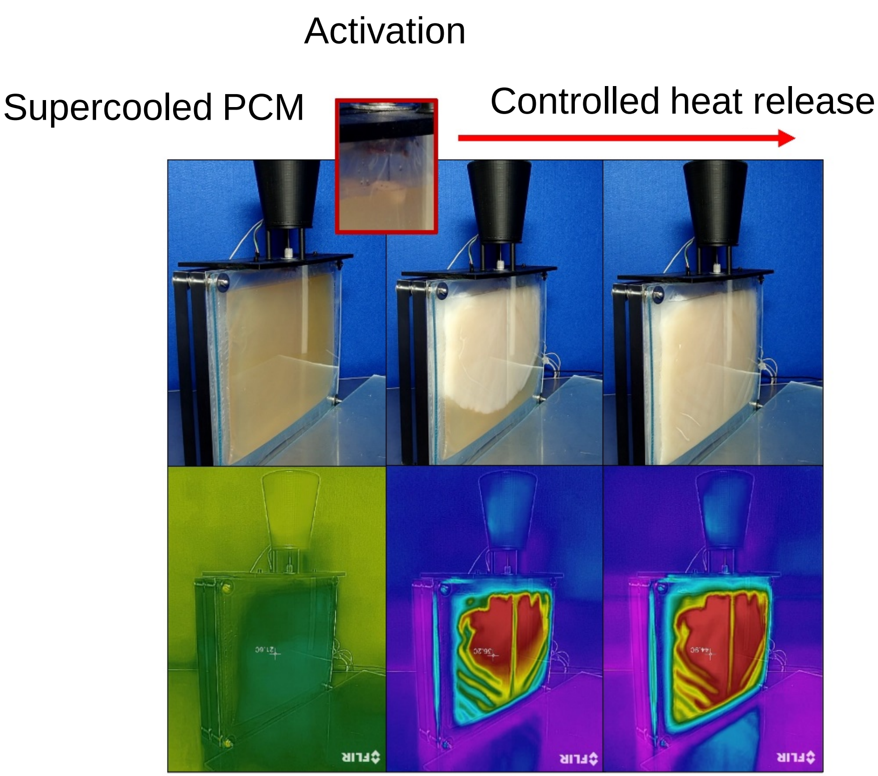
- Changes in thermophysical properties and thermal coupling can be simulated using ICT-PCM-simulation code

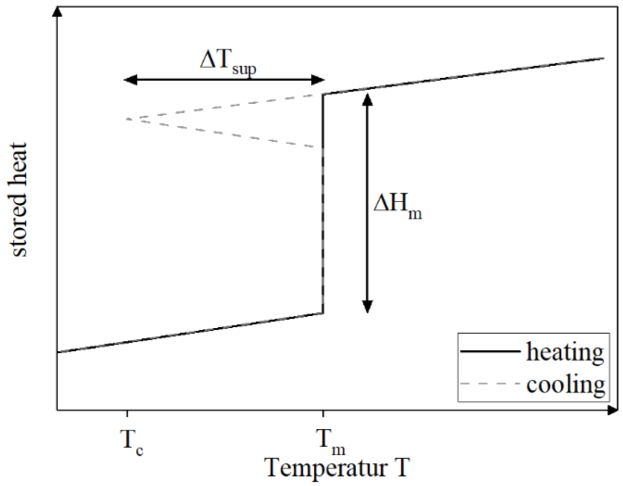


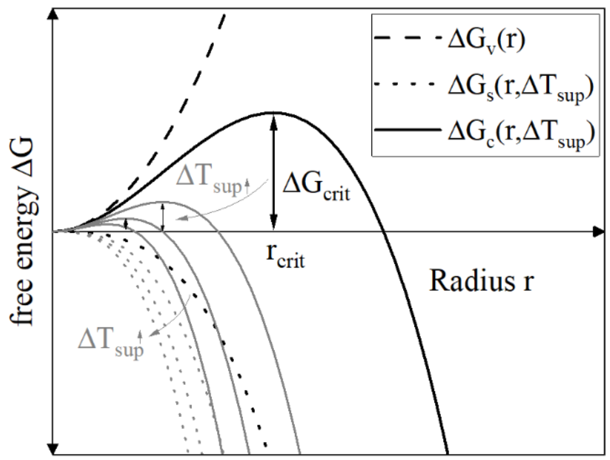


Switchable PCM (sPCM)

- **Switchable PCM = PCM with controlled supercooling**
- **sPCM are also included in 1D-simulation code**

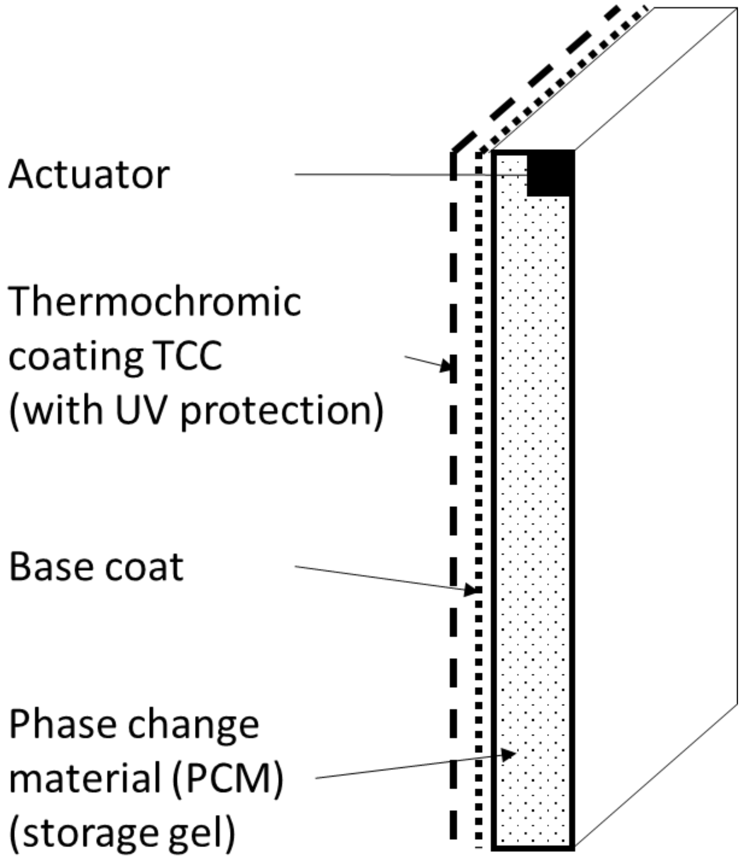






The BiTs project

- **Idea Combination of:**
  - sPCM: Thermal control
  - Thermochromic Coating: Change of color in visible range
- **Main goal:**
  - Proof of concept



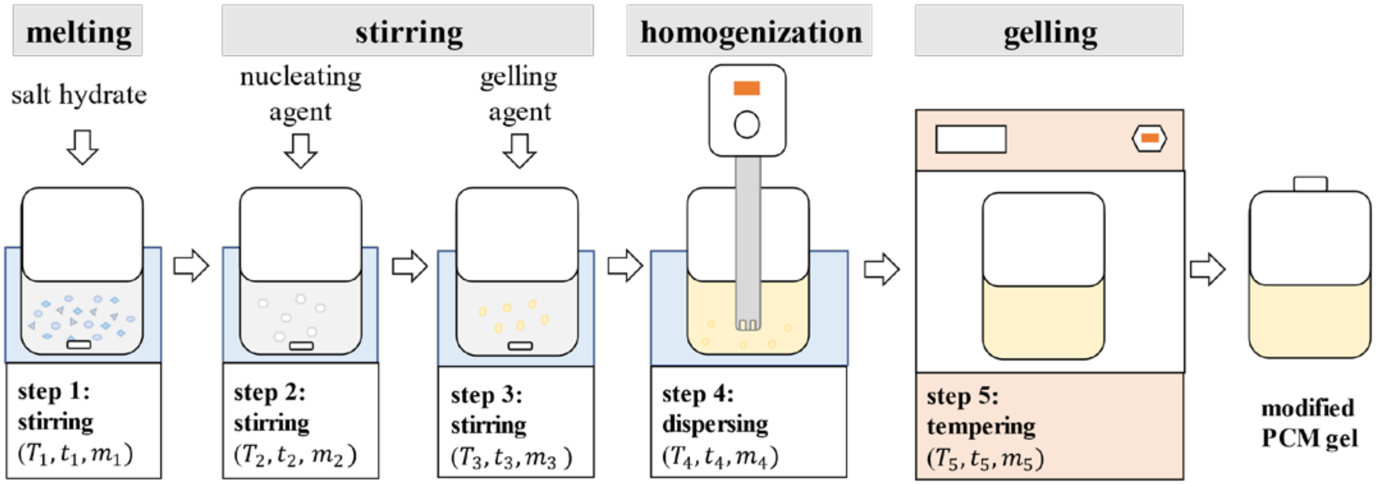
sPCM- selection

- **Salt hydrates are used because of their supercooling behaviour**
  - Sodium acetate
  - Calcium chloride
- **Salt hydrates are inflammable**

	Sodium acetate trihydrate (SAT)	**calcium chloride hexahydrate (CCH)**
Chemical formula	$NaCH_3COO*3H_2O$	$CaCl_2*6H_2O$
Phase change temperature [°C]	58	29
Phase change enthalpy [kJ/kg]	230	190
Degree of supercooling (stable) [K]	>50	>20
Thermal conductivity [W/(m·K)]	0.7 (solid) -	1.01 (solid) 0.54 (liquid)

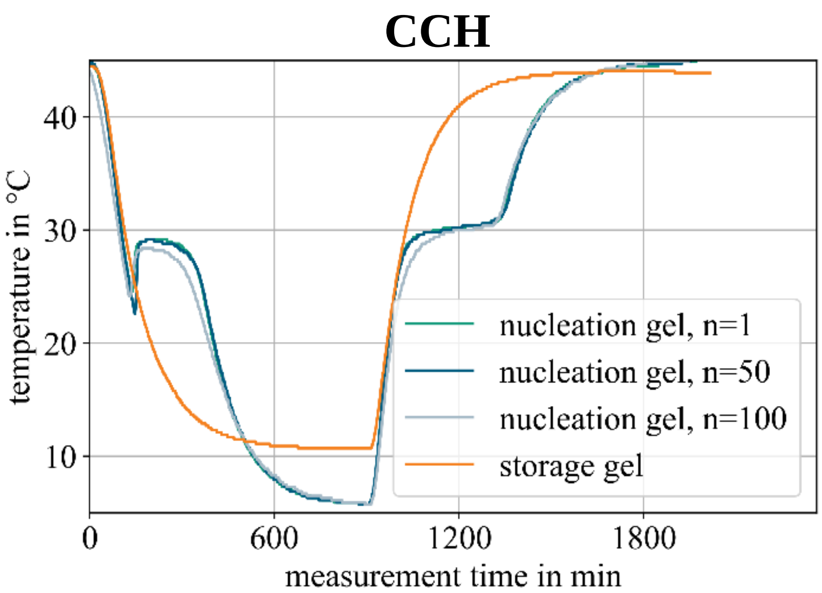
sPCM- modification

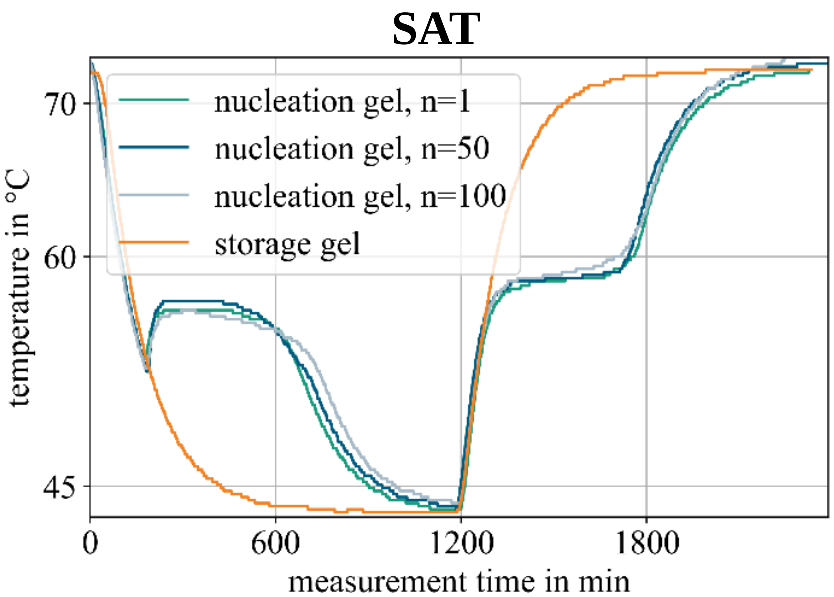
- **Salt hydrates tend to phase segregation**
- **sPCM are gelated to improve cycle stability**



sPCM- thermophysical properties

- **Two types of PCM are needed for BiTs:**
  - Nucleation gel to produce seed crystals (no supercooling)
  - Supercoolable storage gel that is activated using seed crystals
- **Nucleation gel is created using special additives that prevent supercooling**
- **Thermophysical properties are measured using three layer calorimeter and T-history calorimeter**

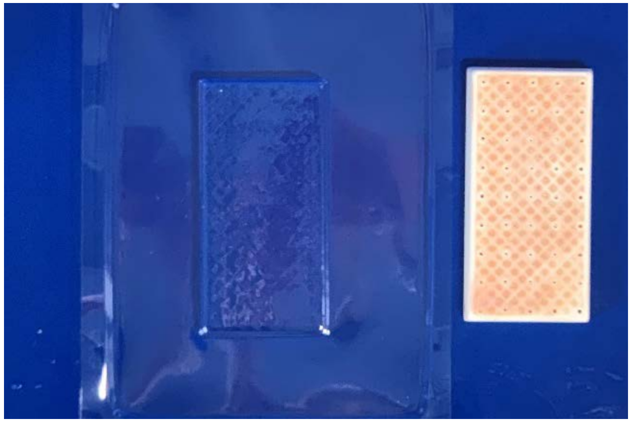




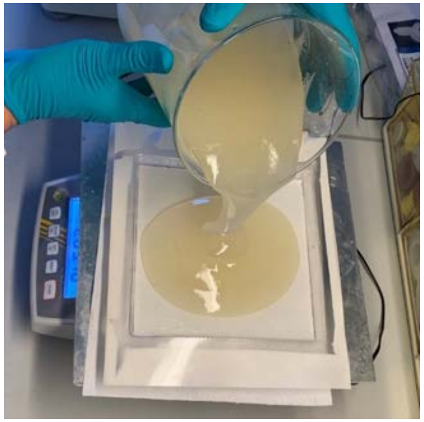
sPCM- encapsulation

1. Macroencapsulation is made of thermoformed plastic sheets
2. Macrocapsules are filled with liquid PCM and sealed thermally
3. The activation mechanism is glued to the macroencapsulation

1.



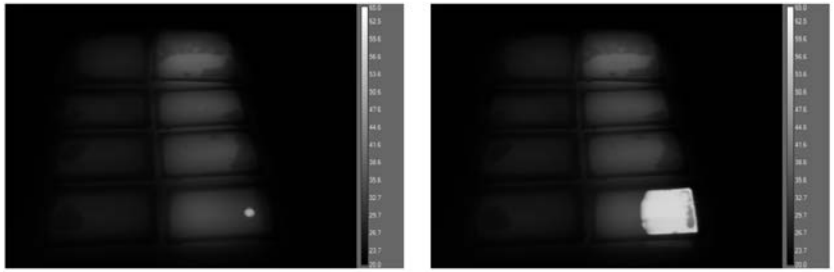
2.



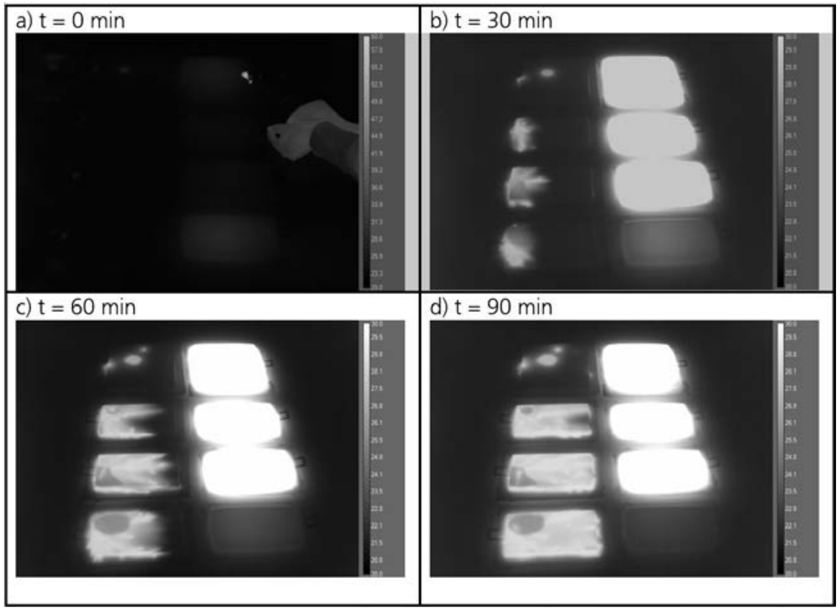
3.

Functional testing of macroencapsulated sPCM

Spontaneous crystallization

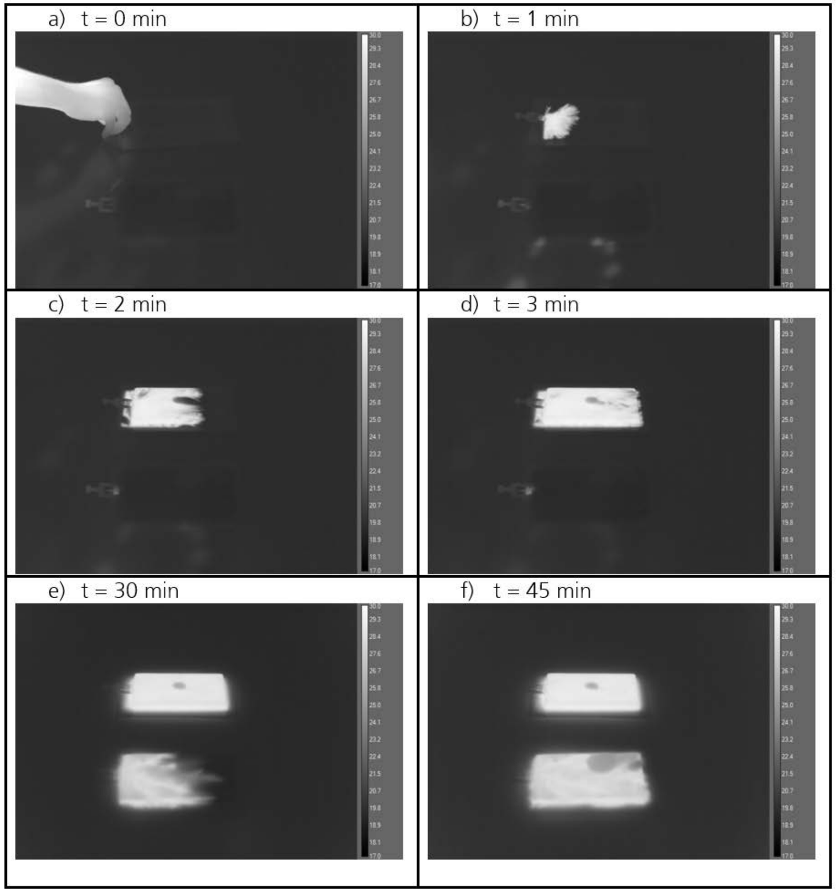


Controlled activation



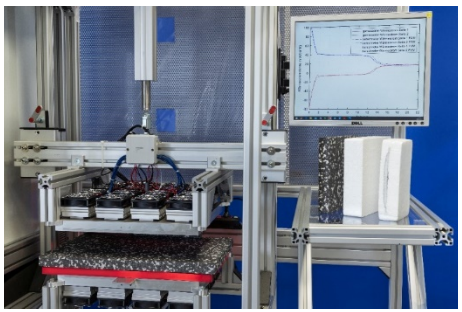
Functional testing of macroencapsulated sPCM

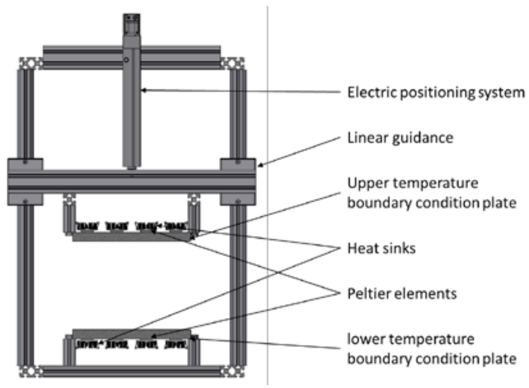
Influence of the proportion of gelling agents

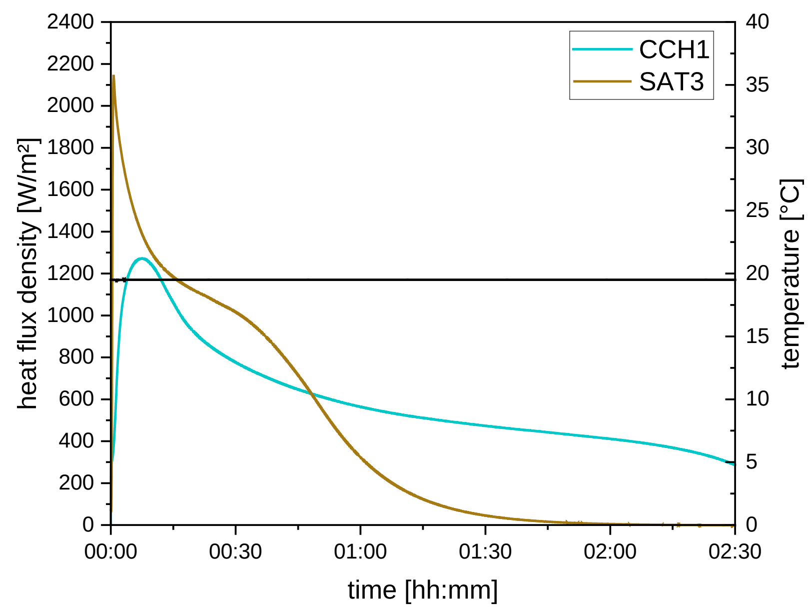


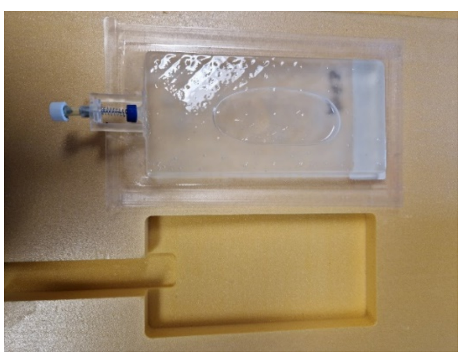
Functional testing of macroencapsulated sPCM

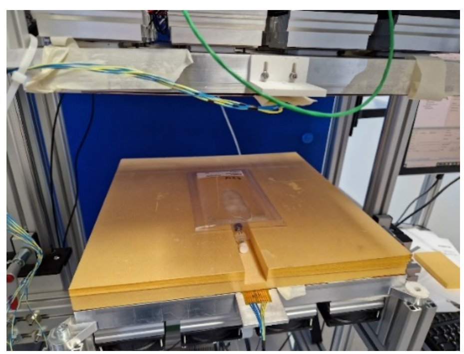
- **Experimental investigation in heat flux test bench**











Thermochromic coatings - overview

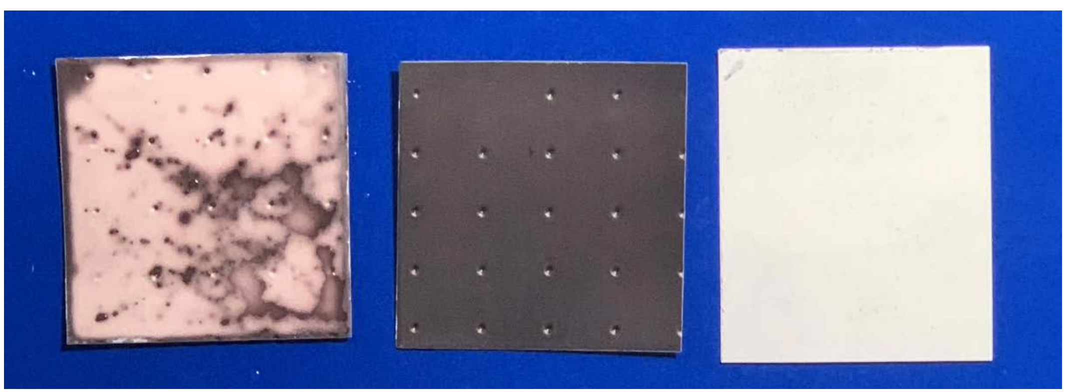
- **Thermochromic colors with negative thermochromic effect = become transparent if color change temperature (CCT) is exceeded**

Name	Manufacturer	Type	Color		Color change temperature
Black Thermochromic 28	Dipon	Powder/Pigments	black		28 °C
Deep Blue Thermochromic 28	Dipon	Powder/Pigments	navy blue		28 °C
Purple Thermochromic 28	Dipon	Powder/Pigments	purple		28 °C
Cadet Blue Thermochromic 28	Dipon	Powder/Pigments	blue/turquoise		28 °C
Sea Green Thermochromic 28	Dipon	Powder/Pigments	dark green		28 °C
Canary Yellow Thermochromic 28	Dipon	Powder/Pigments	yellow		28 °C
Medium Orchid Thermochromic 28	Dipon	Powder/Pigments	lighter purple		28 °C
Pineapple Salmon Thermochromic	Dipon	Powder/Pigments	orange		28 °C
Coral Red Thermochromic 28	Dipon	Powder/Pigments	red		28 °C
Kandydip © Deep Blue 28 °C	Dipon	Spray can/spray foil	dark blue		28 °C
Kandydip © Black 28 °C	**Dipon**	**Spray can/spray foil**	**black**		**28 °C**
Kandydip © Purple 28 °C	Dipon	Spray can/spray foil	purple		28 °C
Thermochromic varnish	**Stardust Colors**	**Water-based acrylic varnish**	**black**		**10-15°C, 26-31 °C, 40-45 °C, 57-62 °C**
Thermochromic varnish	Stardust Colors	Water-based acrylic varnish	blue		10-15°C, 26-31 °C
Thermochromic varnish	Stardust Colors	Water-based acrylic varnish	red		10-15°C, 26-31 °C

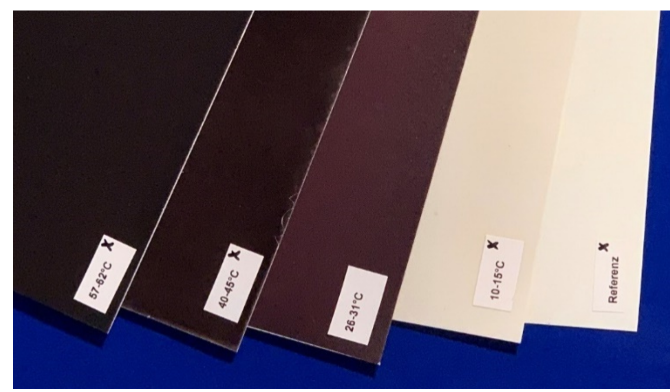
Thermochromic coatings - selection

No.	short name	manufacturer	color change temperature (CCT) [°C]	color
1	K28	Dipon	28	black
2	SC10_15	Stardust Colors	10-15	black
3	SC26_31	Stardust Colors	26-31	black
4	SC40_45	Stardust Colors	40-45	black
5	SC57_62	Stardust Colors	57-62	black

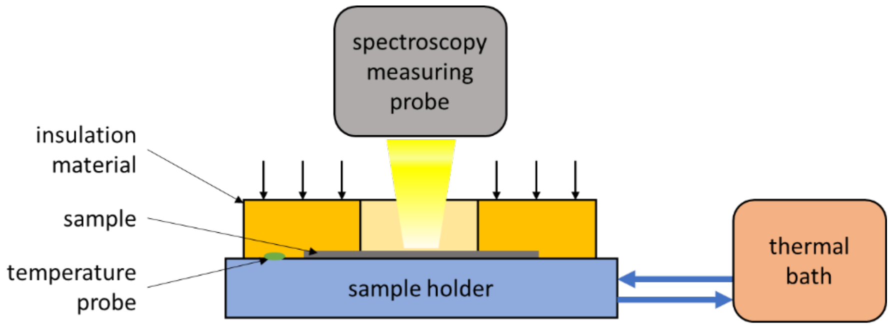
K28

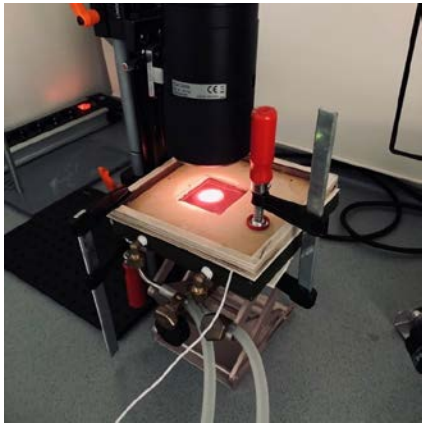


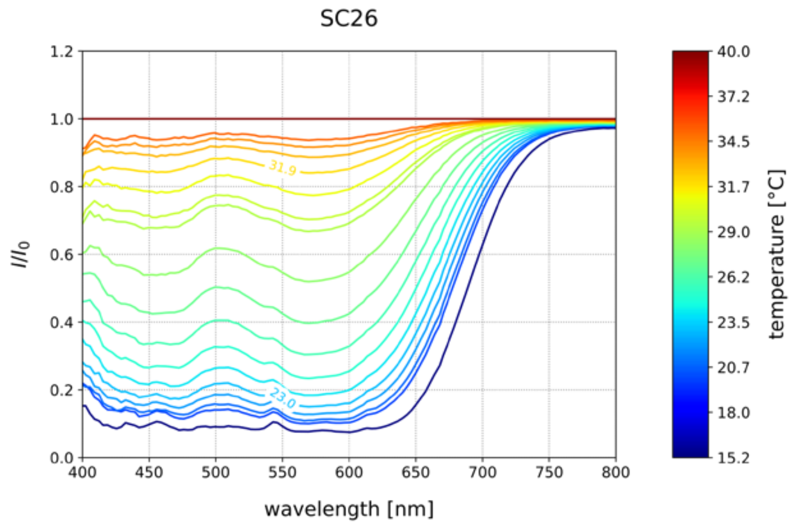
SC57, SC40, SC26, SC10, Ref

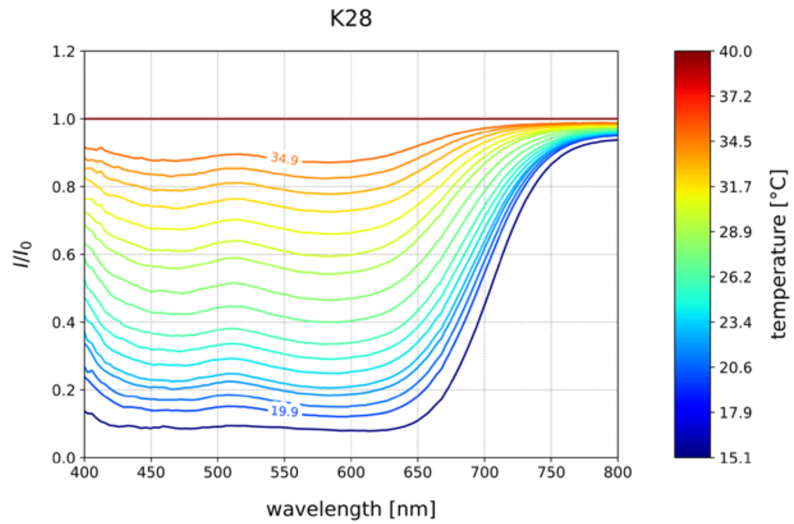


Thermochromic coatings – testing (CCT)



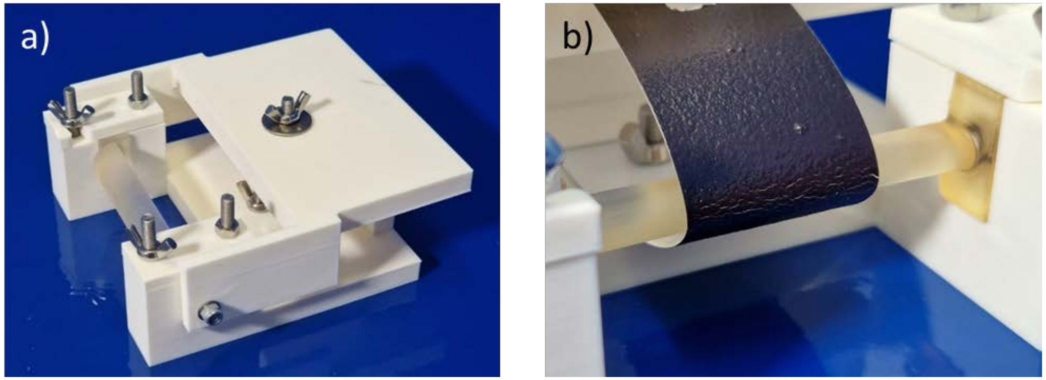


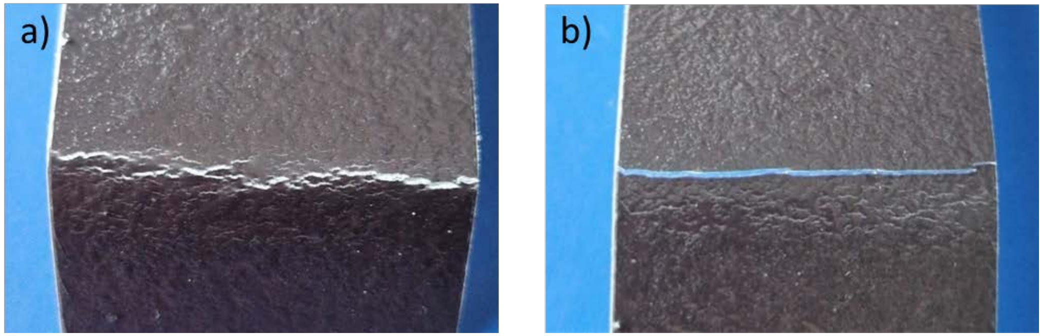




Thermochromic coatings – testing (bending)

- **Bending test according to** DIN EN ISO 1519
- **All thermochromic coatings withstand small deformations**

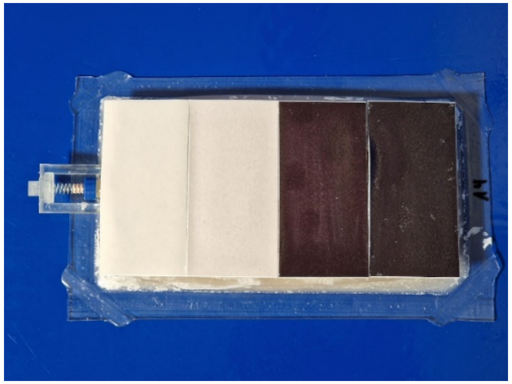




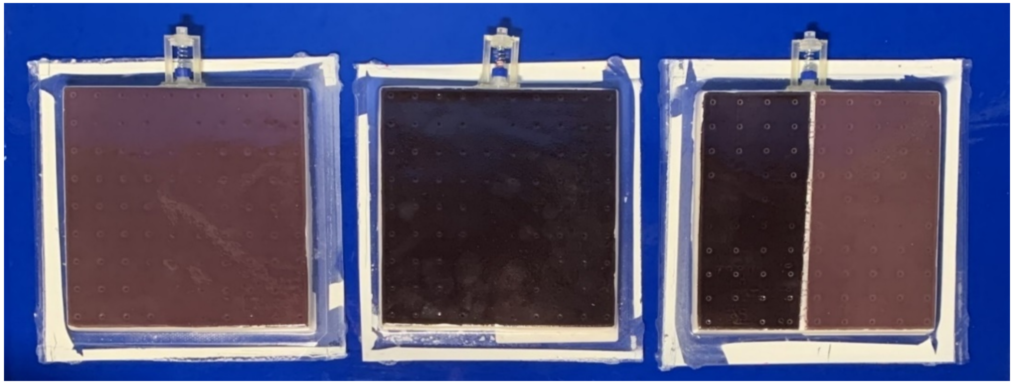
BiTs- final laboratory samples

- **More than 20 labroratory samples were produced**
- **Different combinations of PCM and thermochromic coatings were realized**

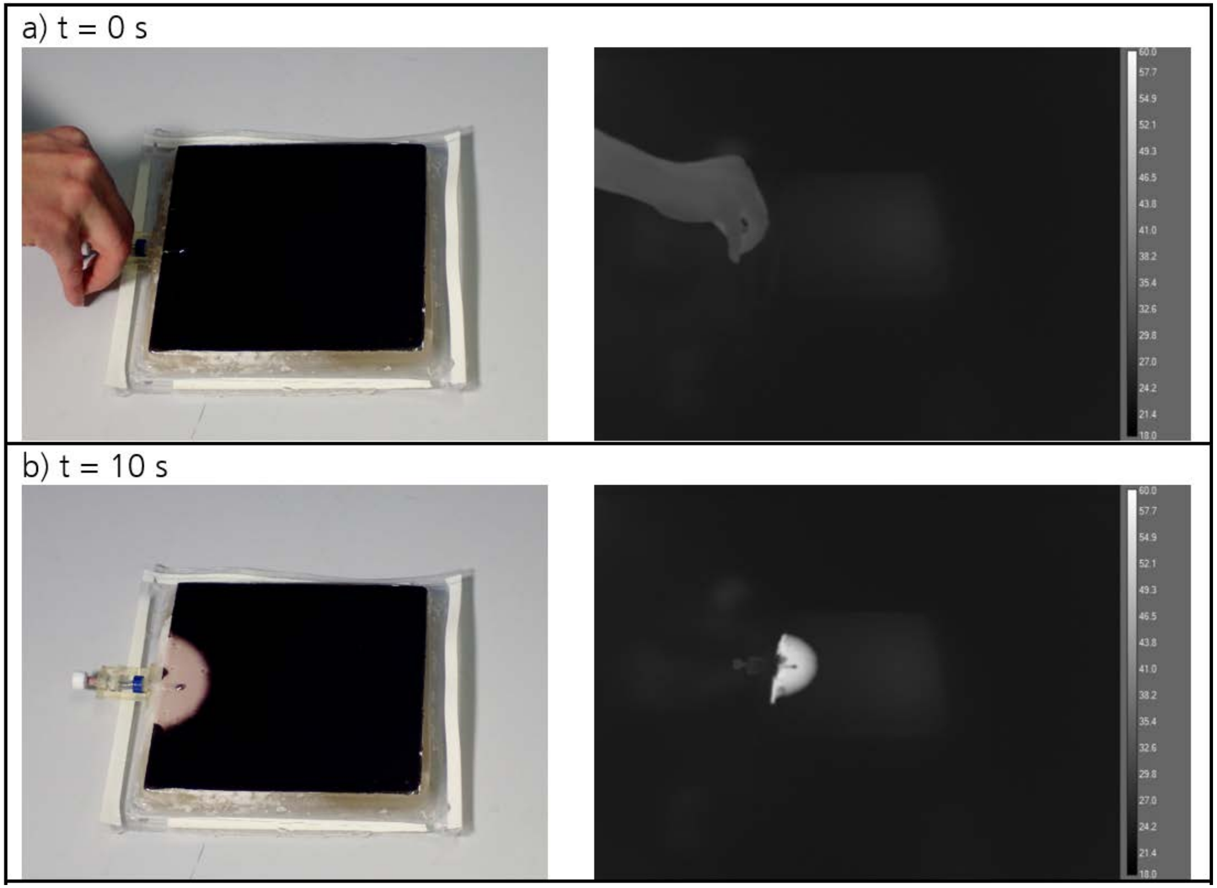
B_SAT_SC10_26_40_57



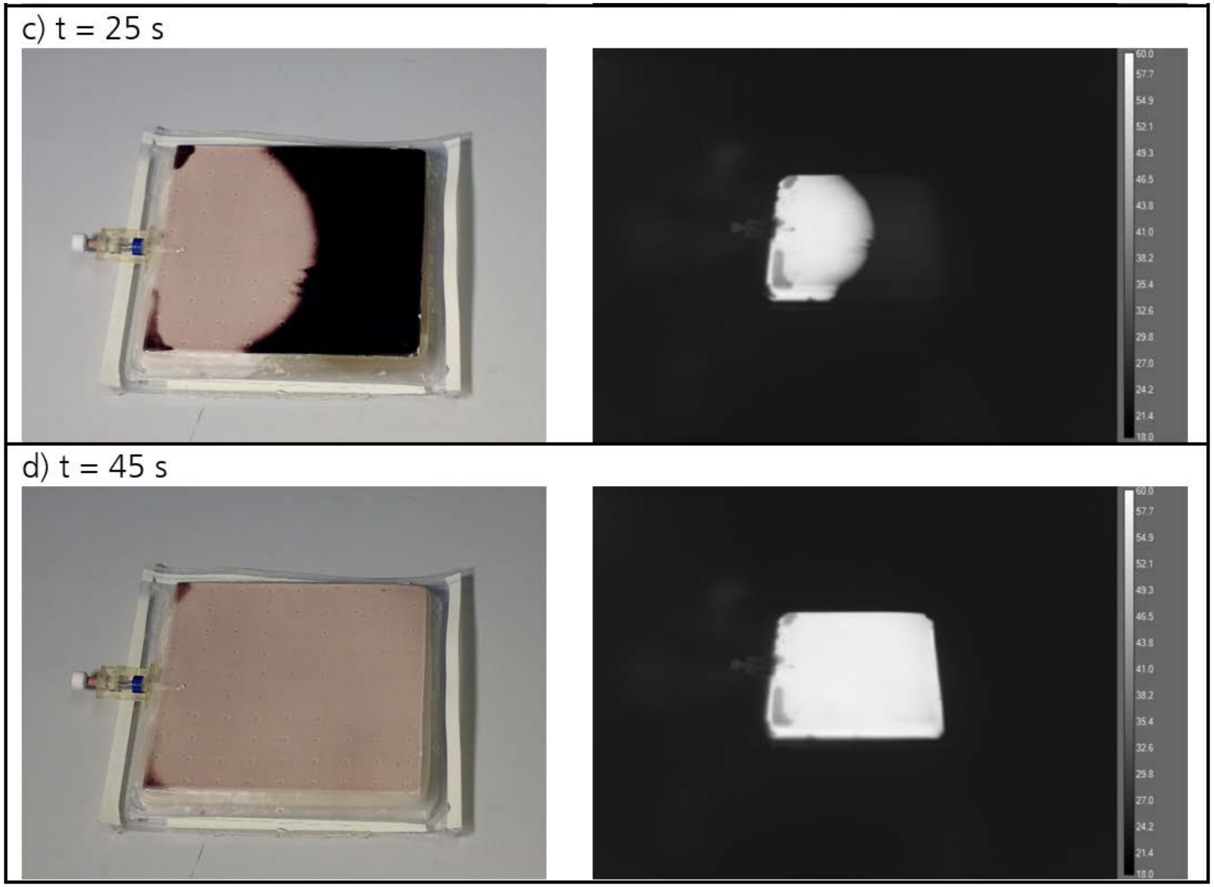
A_SAT_SC26, A_SAT_SC_26_40 and A_SAT_SC40



BiTs- testing of laboratory A_SAT_SC_40



BiTs- testing of laboratory A_SAT3_SC_40



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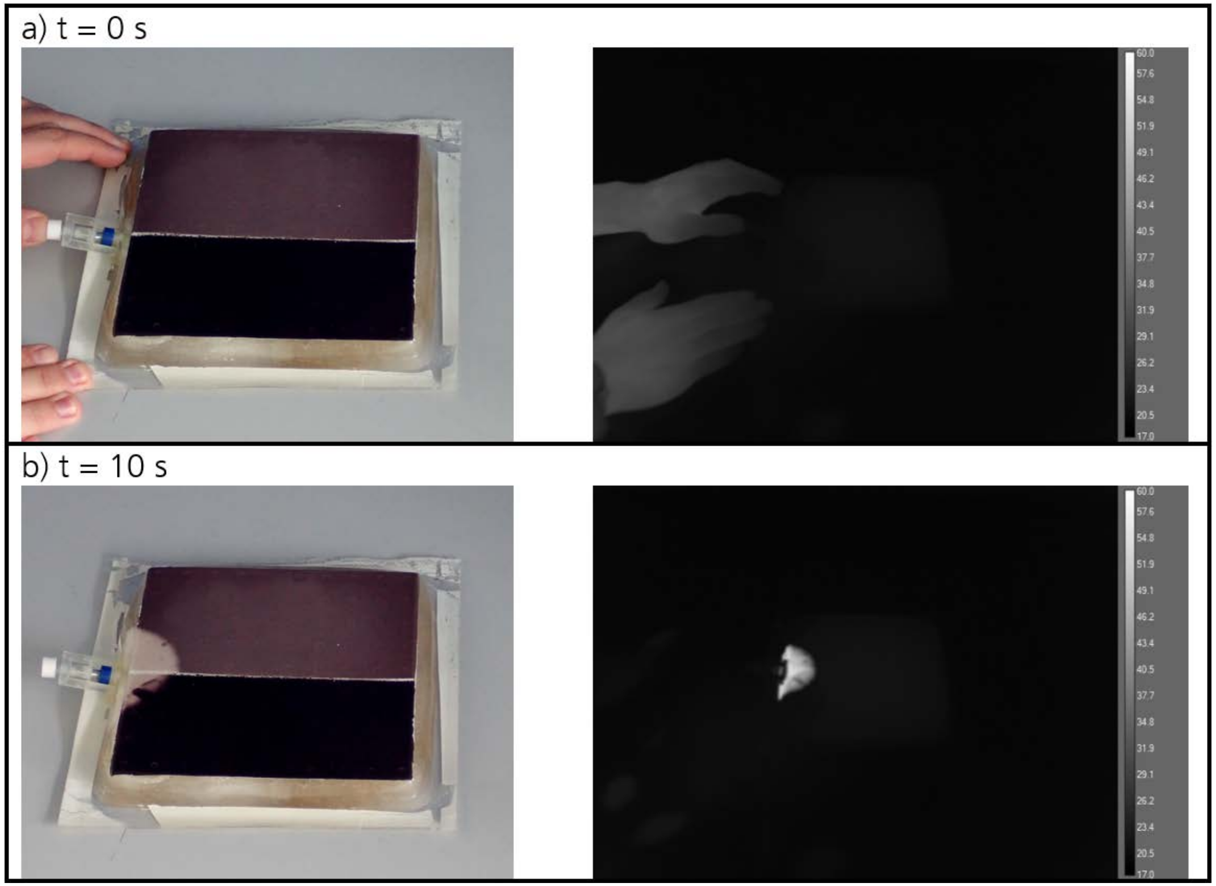

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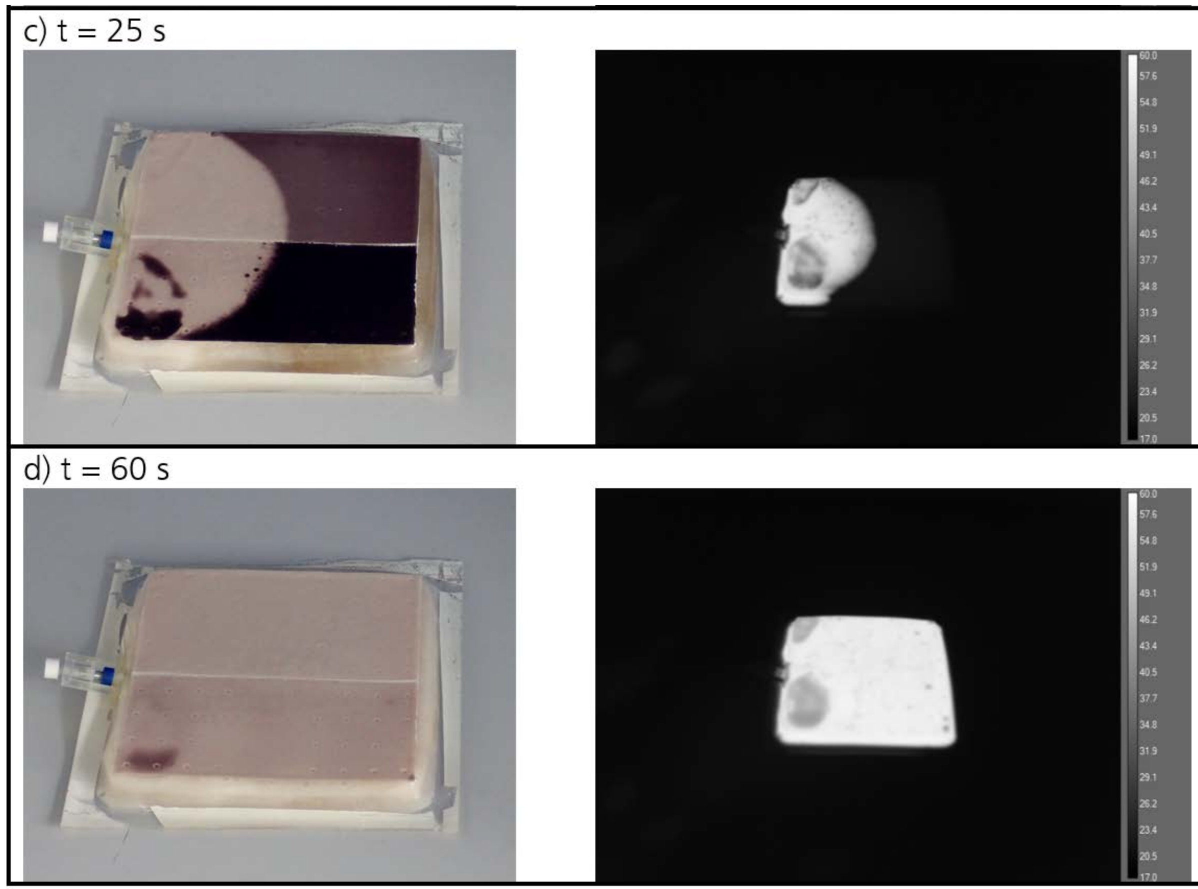

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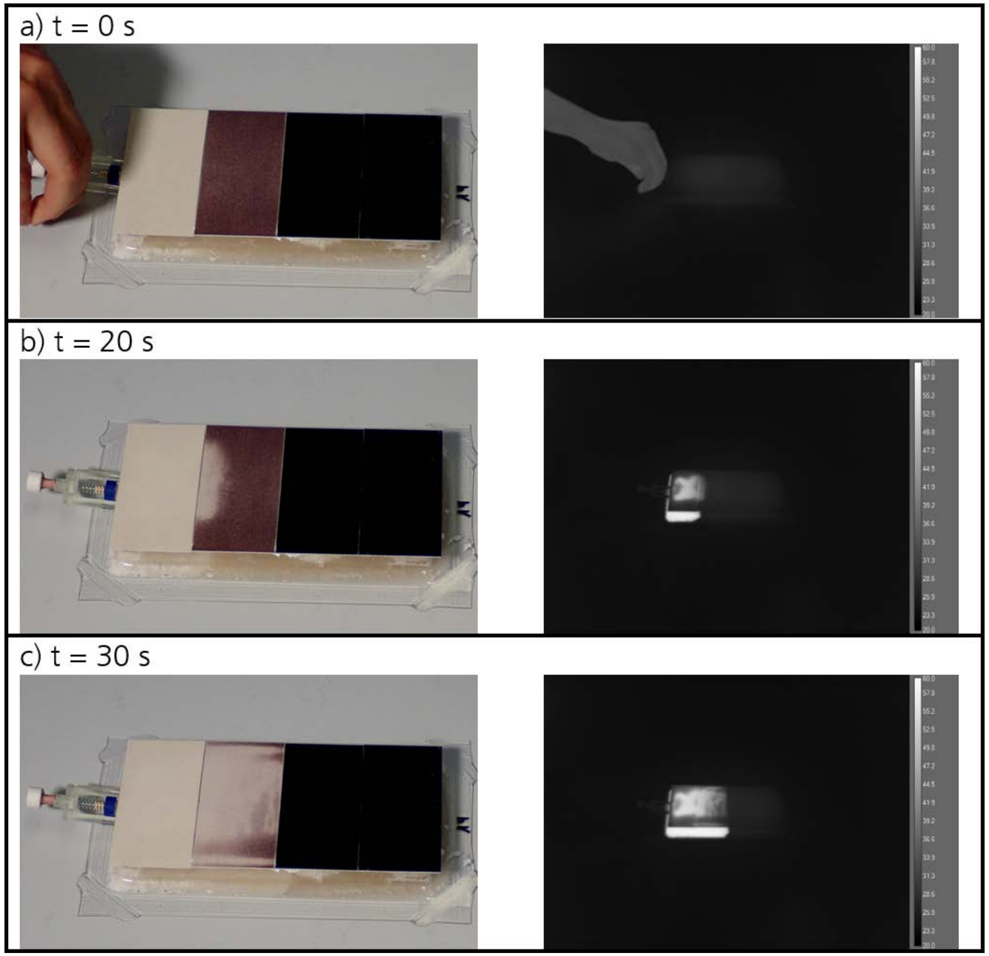

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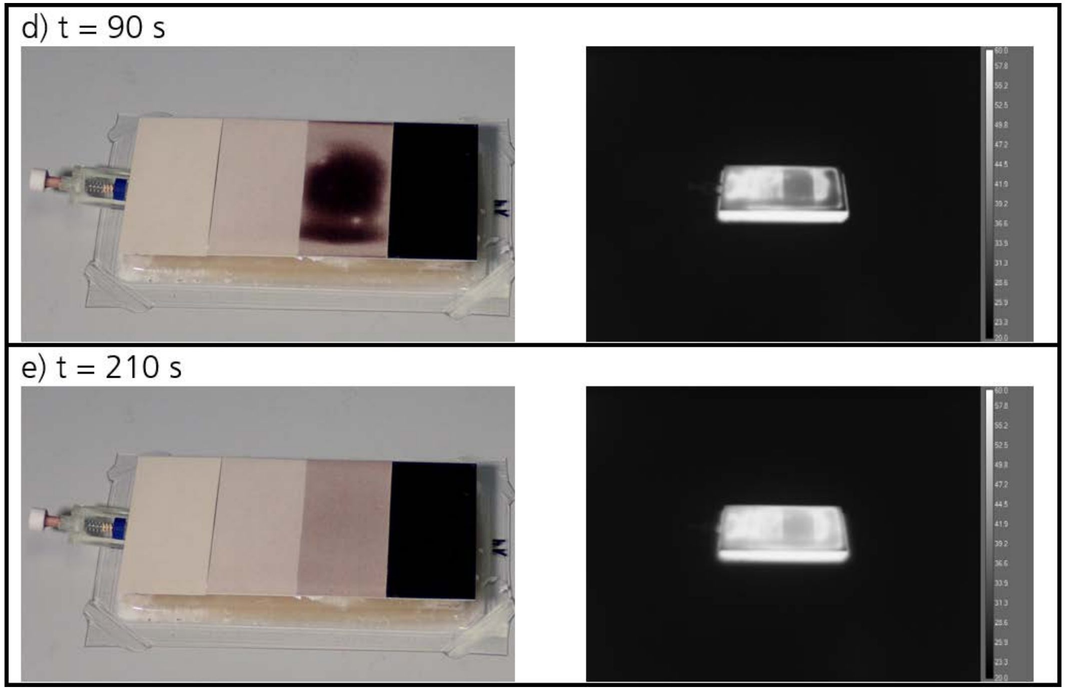

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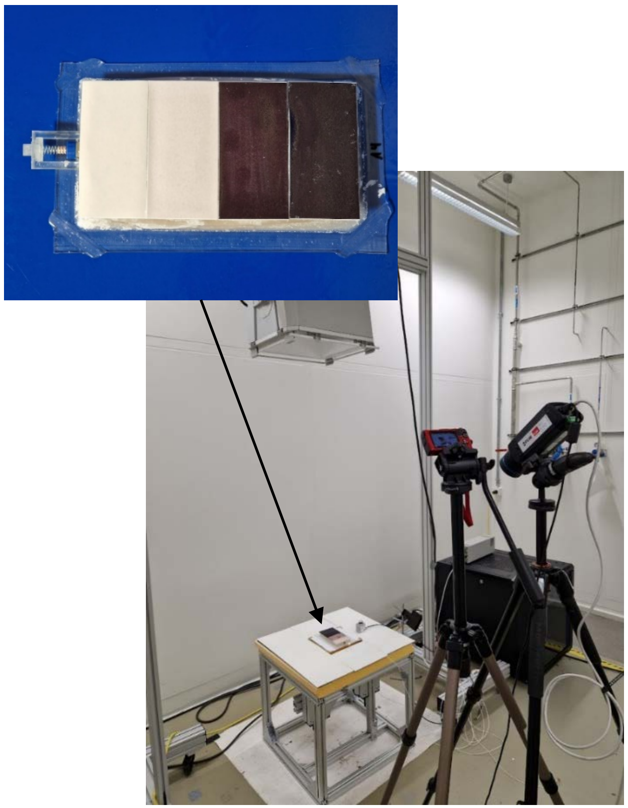
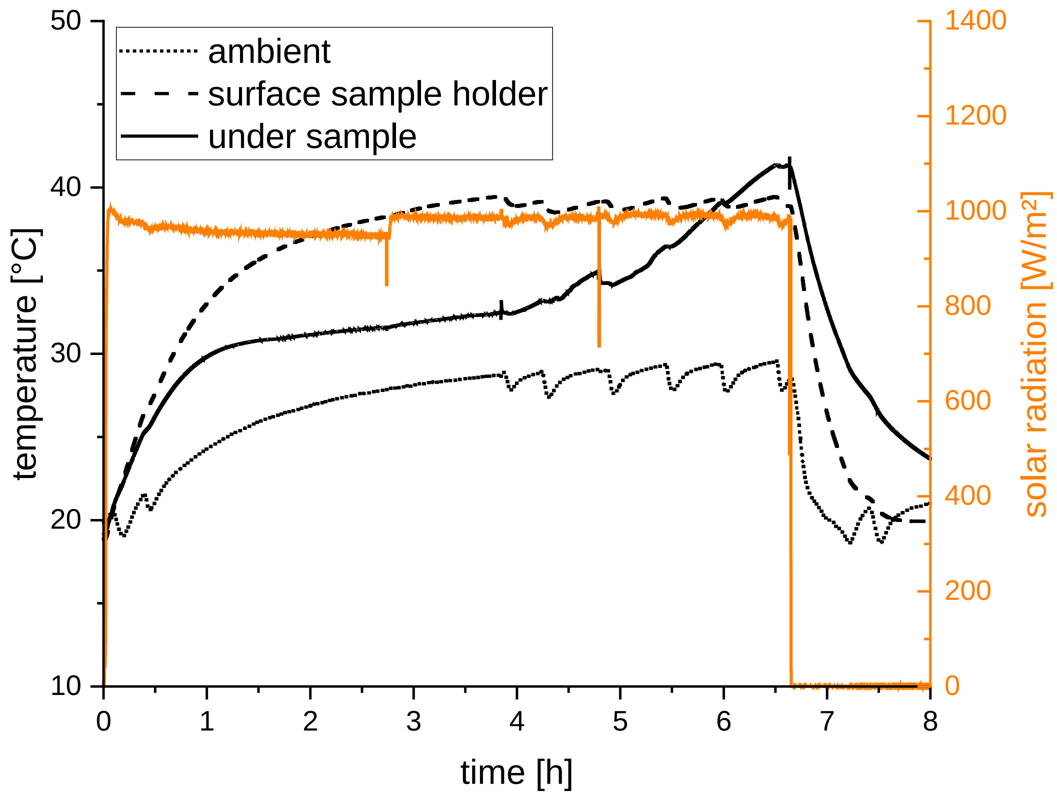
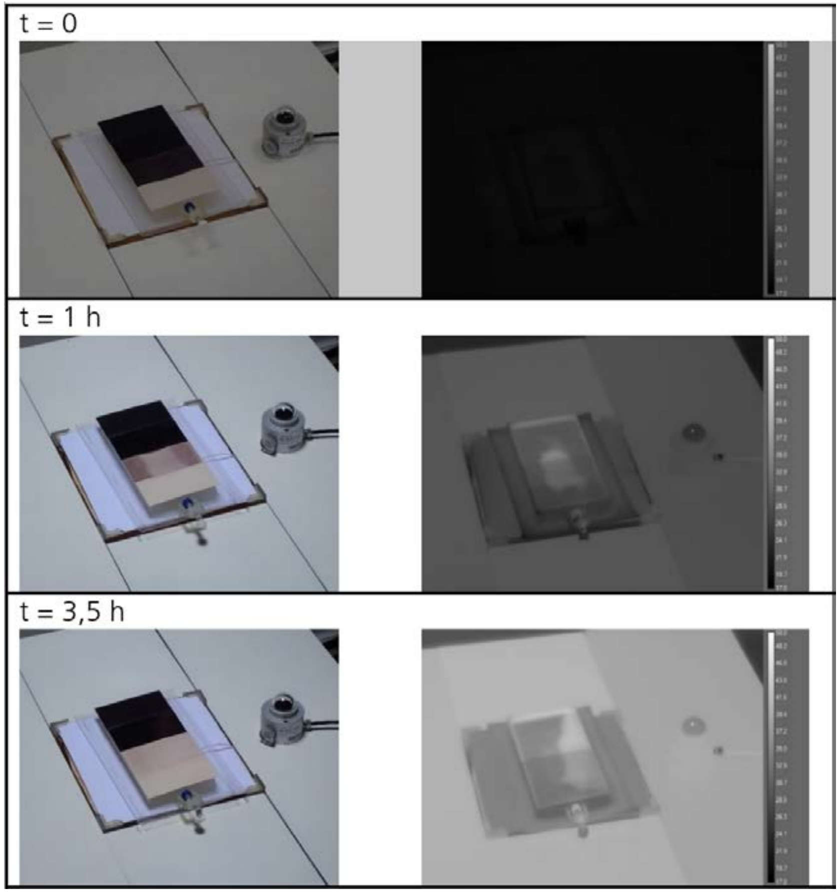
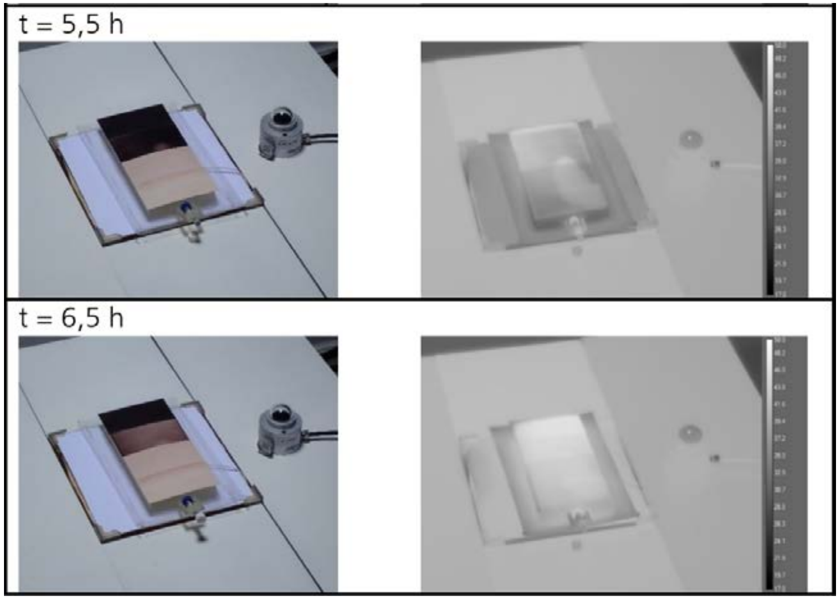


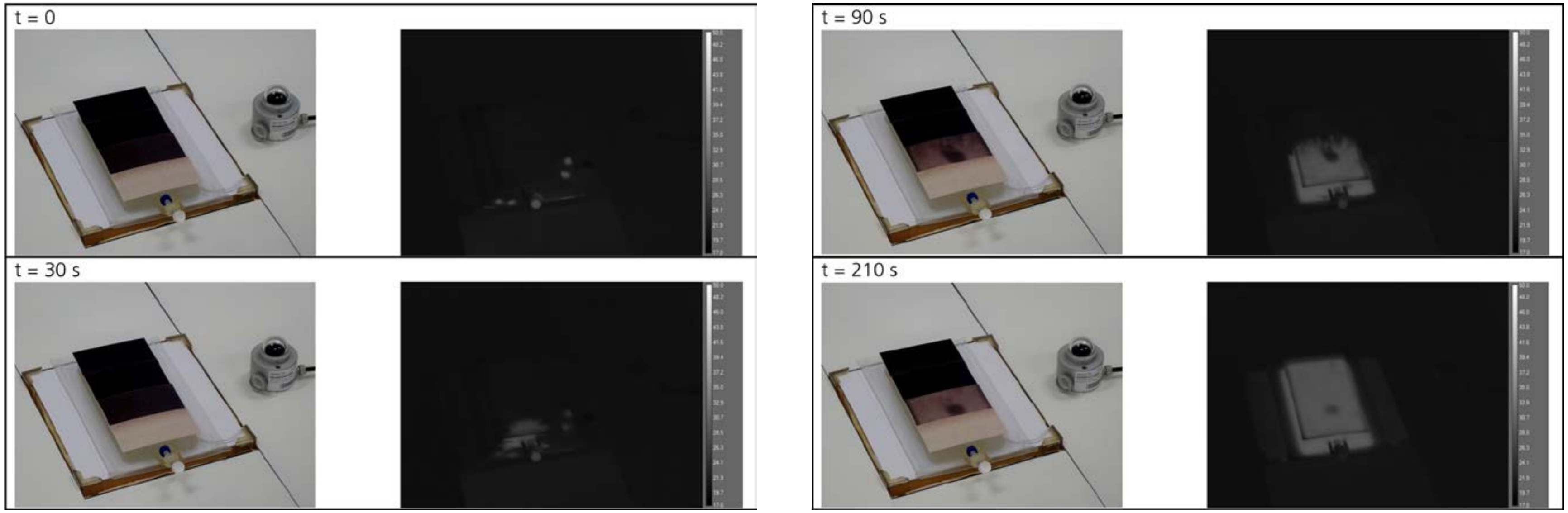


BiTs- B_CCH_SC_10_26_40_57: melting





BiTs- B_CCH1_SC_10_26_40_57: crystallization



Summary and conclusions

- **The functioning of conventional PCM in camouflage applications is demonstrated**
- **Switchable PCMs (sPCM) are introduced**
- **Salt hydrates can be used as non-flammable sPCM**
- **For sufficient long-term stability, PCMs based on salt hydrates are gelated**
- **The thermal performance of PCM camouflage systems depends on the exact material composition of the PCM and the encapsulation used**
- **The general functionality for a bispectral camouflage system based on sPCM and thermochromic coatings is demonstrated**