UK META MATERIALS NETWORK

University of Southampton

Metamaterials for Spacecraft Thermal Management

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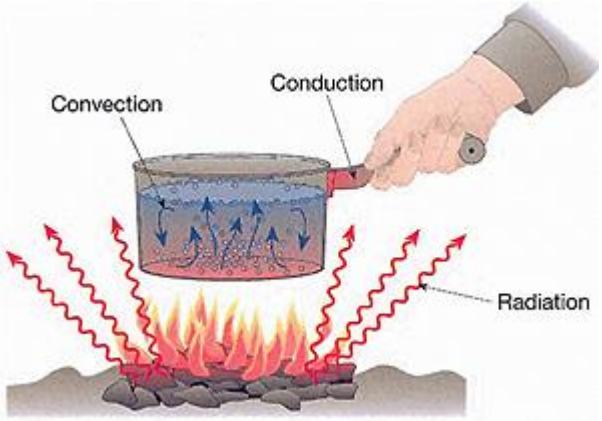
Thermal Management for Spacecraft

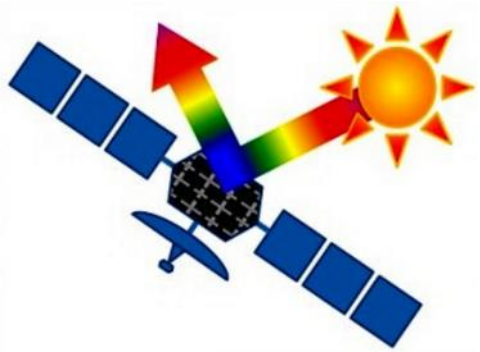
www.metamaterials.network

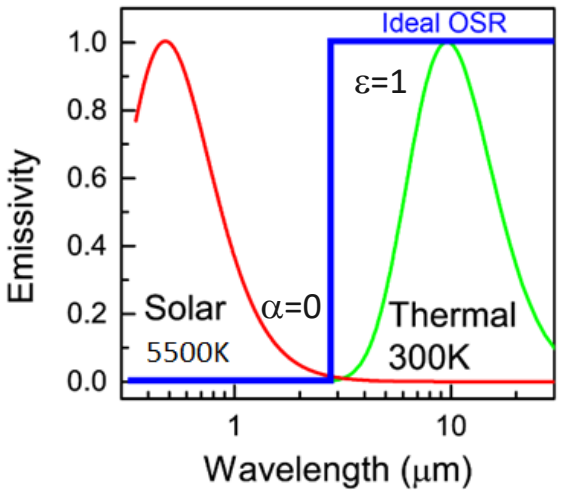
Heat transfer



Radiation Cooling

Optical Solar Reflector





Requirements for OSRs:

- Solar absorption:
  $\alpha < 0.2$ (EOL)
- Infrared emissivity
  $\varepsilon > 0.7$ (EOL)

Figure source: Northwestern University
Thales Alenia Space

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Metamaterials for OSR

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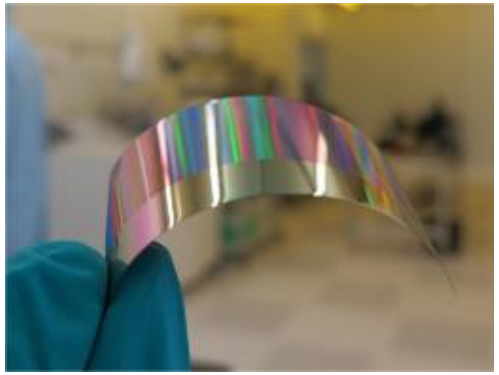
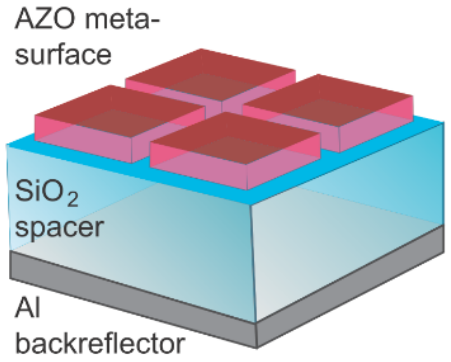
Glass tile OSR
Source: Excelitas

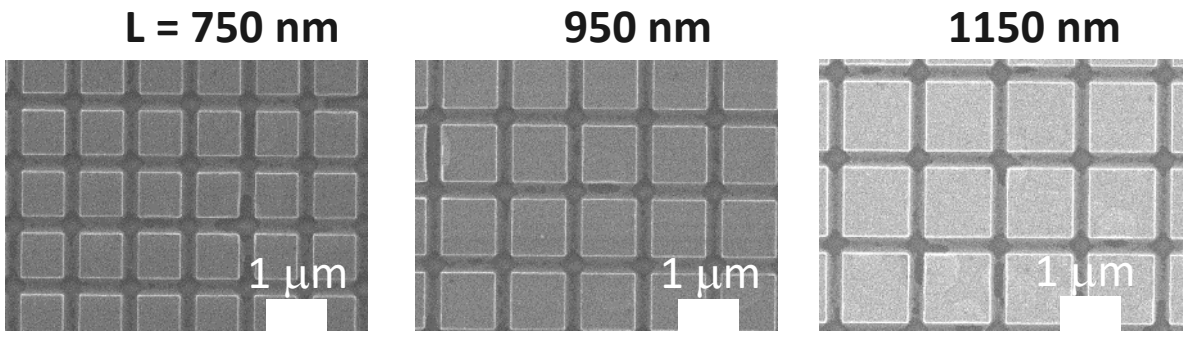


Meta-OSR
Soton, CREO, NILT

	Quartz	Meta-OSR (25 μm foils)
Weight / launch cost	😐 500 g/m^2 10,000 €/m^2	☺☺ <100 g/m^2 2,000 €/m^2
Durability in space	☺☺	☺☺
Freedom in substrate / coverage	☹ Mechanical constraints	☺☺
Assembly, integration & testing (AIT)	☹ Labour intensive	☺
Overall cost (procurement, AIT & launch)	☹ >24,000 €/m^2	☺ <8000 €/m^2

AZO Metasurface-OSR





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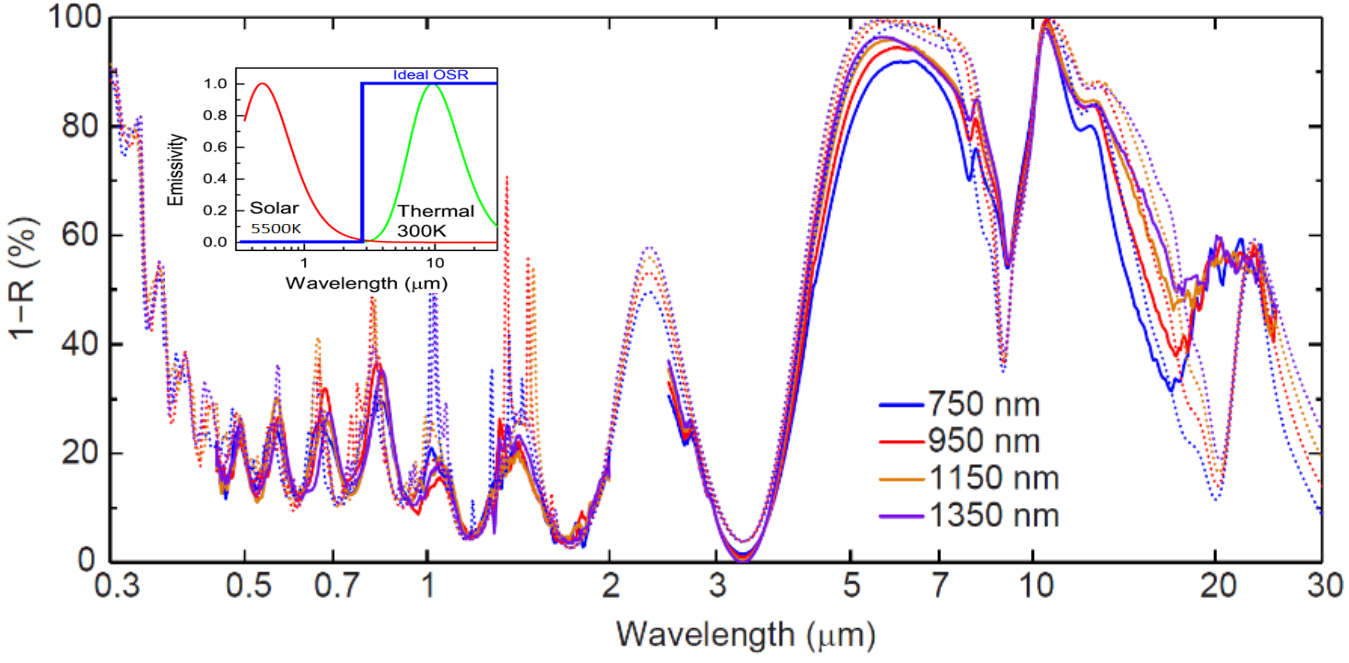
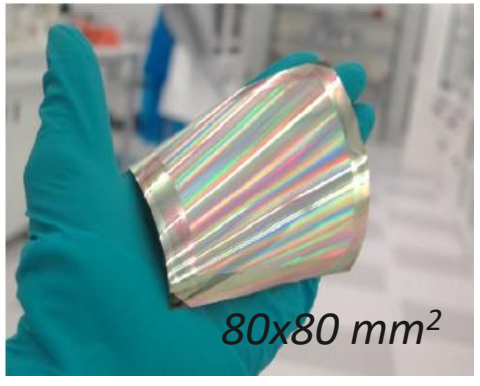
Solid: experiments Dash: simulations



K. Sun et al., ACS Photonics 5, 495 (2018)

- AZO metasurface for higher IR emissivity
- Low emissivity cladding for lower solar absorption
- AZO meta-OSR on polyimide (80 × 80 cm²)
- a = 0.16 and ε = 0.79

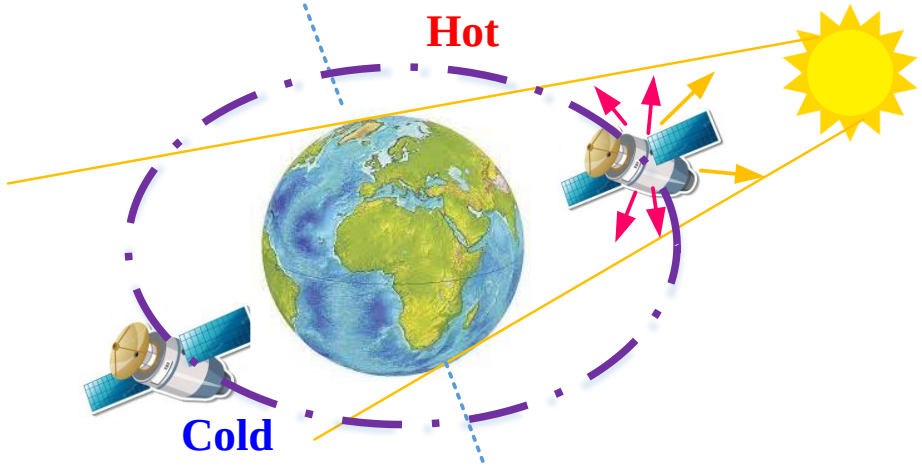
AZO meta-OSR on polyimide (Kapton)

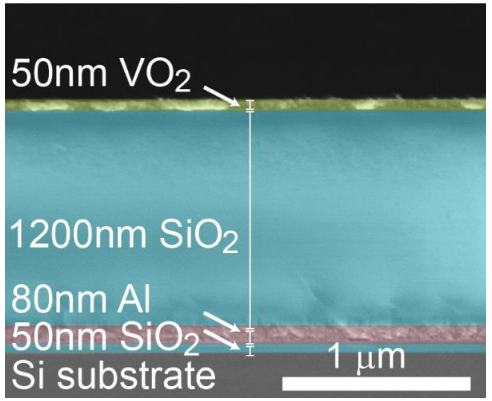


NIL TECHNOLOGY

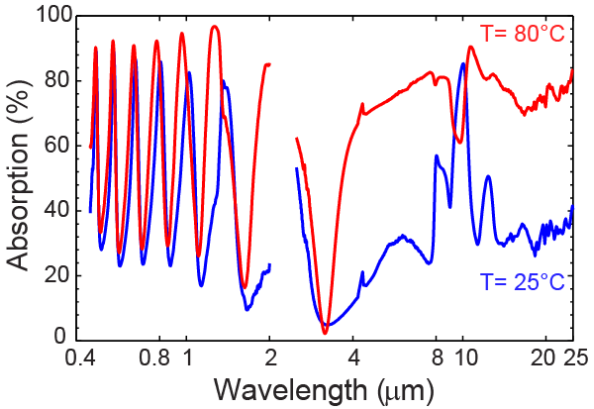
CREO
Centro Ricerche Elettro-Ottiche

Smart Thermal Management





Absorption (1-R) for thin film device



- **High IR emissivity contrast (Δε ~ 0.45)**
- **High solar absorption (a = 0.57)**
- **Higher processing temperature for polyimide foil**
- **Transition temperature 70ºC**

Sun *et al.*, ACS Photonics 5, 2280 (2018)

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Metamaterial-based Smart OSR

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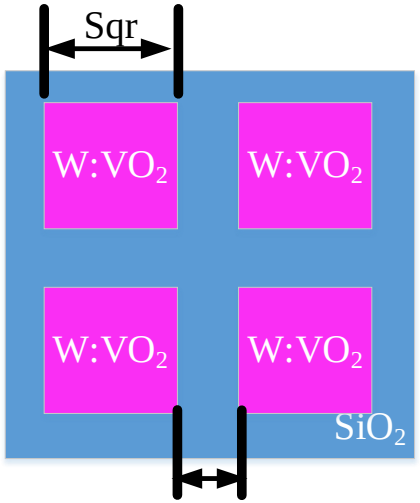

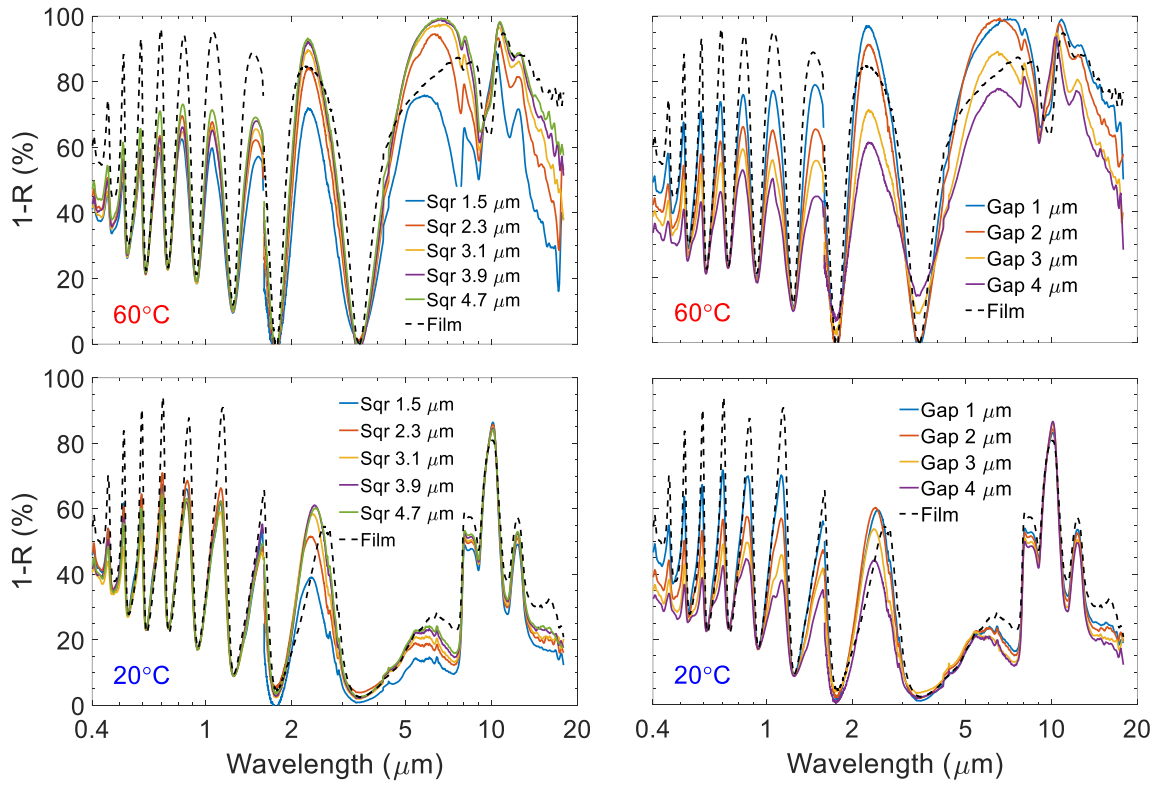

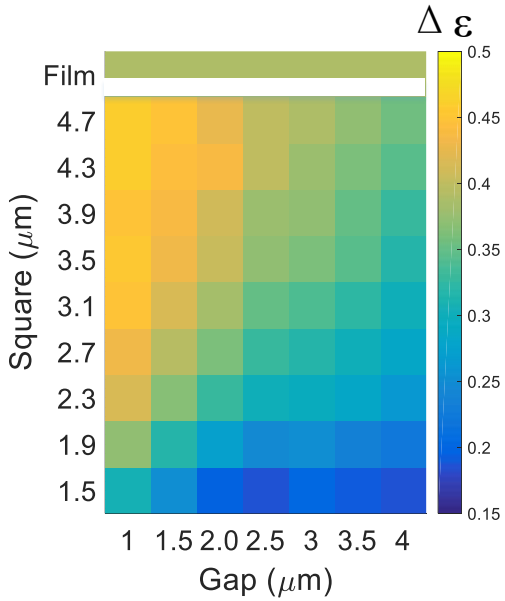

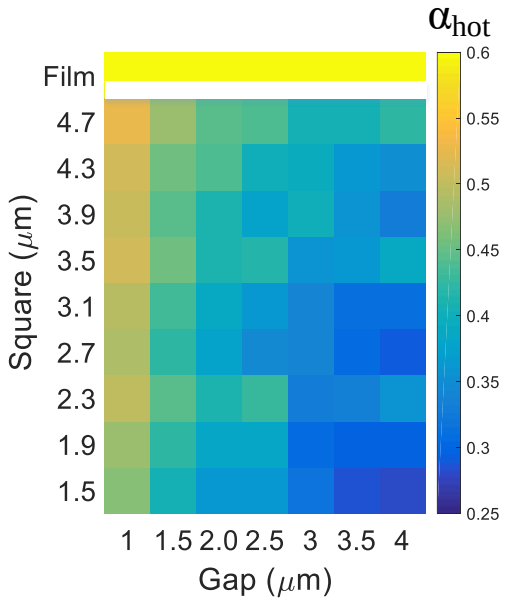

- High IR emissivity contrast (Δε ~ 0.45)
- Improved solar absorption (a ~ 0.4)
- Transition temperature near room temperature
- Trade-off between solar absorption and IR emissivity contrast

Smart Meta-OSR for Thermal Management

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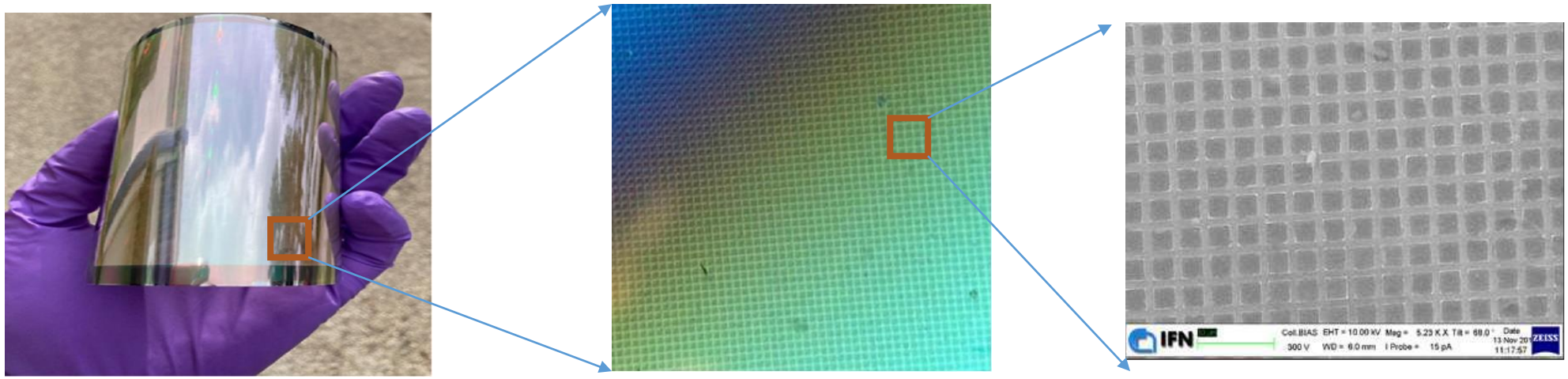
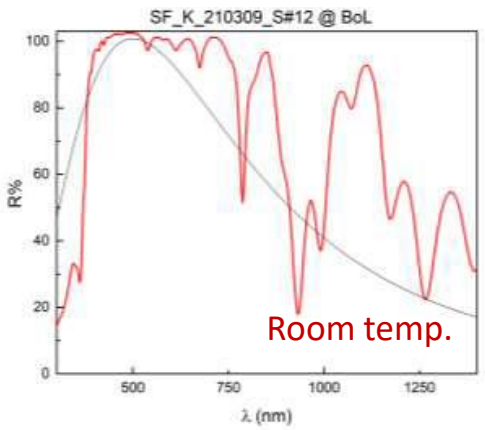
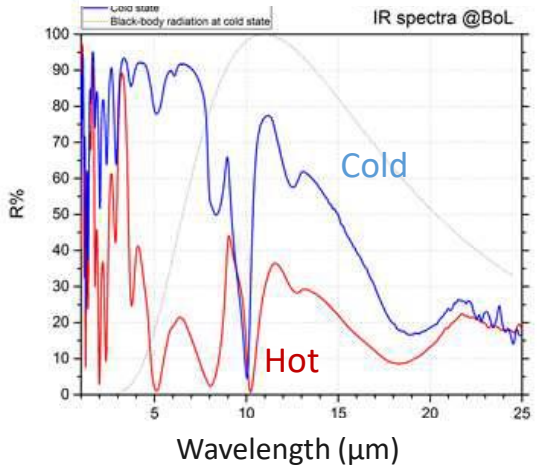
10 cm × 10 cm



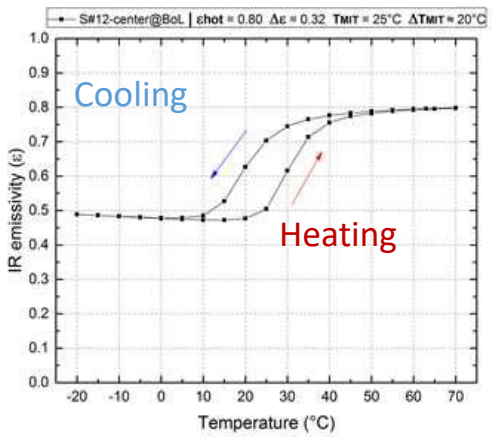
Solar absorption region



IR emission region



Emissivity (ε)



Performance	
α_{Hot}	0.24
ε_{Hot}	0.77
$\Delta\varepsilon$	0.32
T_{MIT}	27°C

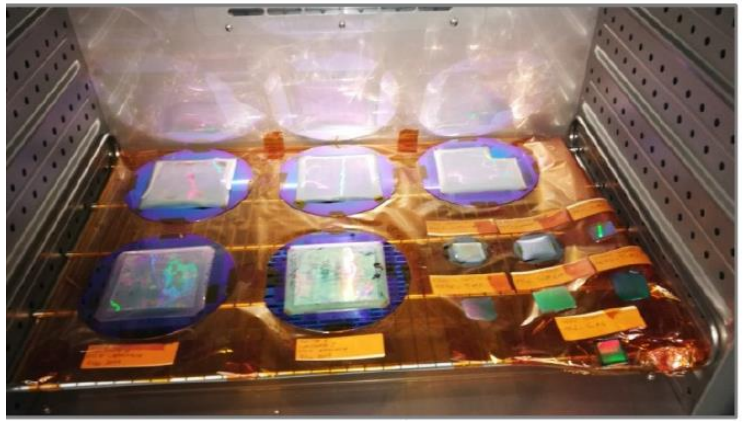
Verification tests for Space Application

Thermal ageing

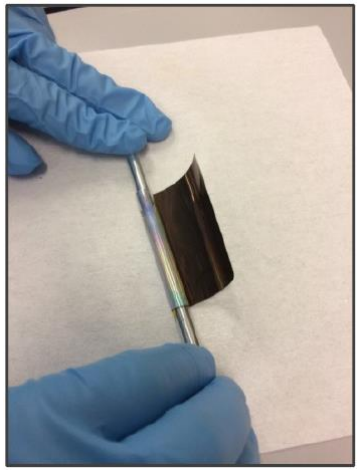
Thermal Ageing
Duration: 336h (14 days)
Extreme T: T = 90 -5/+0 °C
Thermal Gradient: 2±1 °C/min

Thermal vacuum cycling

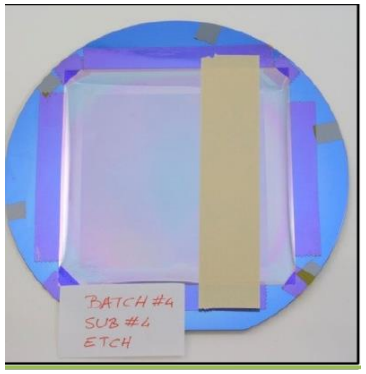
Thermal cycling



Bending tests



Adhesion (tape) tests



- *We demonstrated **10 cm X 10 cm** VO_2 based smart-optical solar reflectors on **Kapton** with an **emissivity tunability $\Delta\varepsilon > 0.30$, solar absorption $\alpha \sim 0.24$** and **transition around the room temperature**.*
- *We have plans to do space test of our OSRs in the frame of the PLATiNO program funded by the ASI (small satellites in LEO orbit for agricultural applications).*

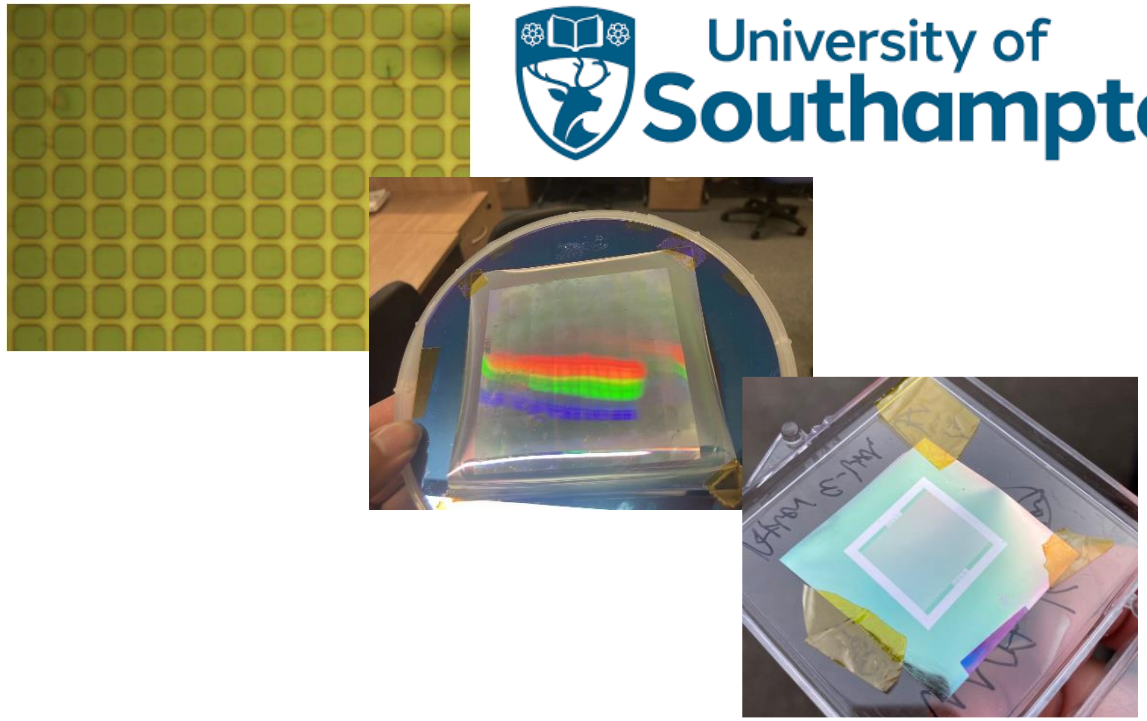
Meta-OSR for Space Thermal management

- A novel **metasurface-based OSR foil** as the spacecraft radiative cooling solution **lower weight** and **higher mechanical robustness**.
- A novel 'smart' **VO_2** metasurface solution with temperature controlled **tunable IR emissivity**.
- A novel **W-doped VO_2** on **polyimide** substrate with transition temperature near 30-70°C.
- Smart **W:VO_2 meta-OSRs** on flexible substrate with **α=0.24**, **Δε=0.32** and **T_c around 30°C**

Dr Kai Sun

Prof. C.H. de Groot

Prof. Otto. L. Muskens



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Sun et al., ACS Photonics 2018, 5, 495

Sun et al., ACS Photonics 2018, 5, 2280

Sun et al., Nanophotonics 2022, 11, 4101

Sun et al., Adv. Opt. Mat. 2022, 10, 2200452

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