



Full Performance Check of DIY Passive Radiative Cooler with INVENIO

Application Note M184

Passive radiative cooling (PRC) is a zero-energy, zero-carbon method that allows terrestrial objects to lose heat to the cold of outer space. By utilizing long wavelength infrared (LWIR) transmission windows in the atmosphere (around 8 to 13 μm – so-called atmospheric window), this technique cools objects under the open sky. It has gained prominence as an alternative or complement to active cooling methods for various applications, including cooling buildings, dew harvesting, and thermoelectric power generation. Diverse materials and designs, from photonic architectures to scalable polymer films, have been developed specifically for efficient radiative cooling^[1-13].

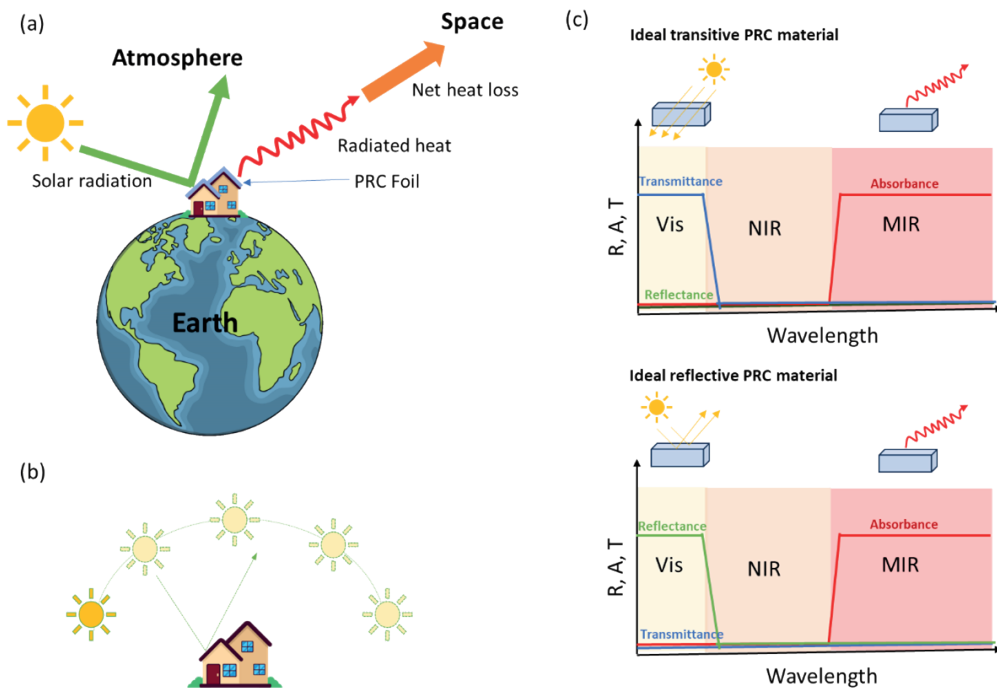


Fig. 1 The general principle of PCR (a), Sun movement concerning the material orientation (b), and spectral characteristics of ideal PRC materials.

How does it work?

PRC employs two primary mechanisms: transmissive and reflective cooling. In the transmissive mechanism, materials possess high transmittance (T) in the solar spectrum, allowing them to transmit sunlight without significant absorption, thereby preventing excessive surface heating. Conversely, reflective cooling relies on materials with high reflectance (R) in the Vis spectrum to minimize the absorption of solar radiation and subsequent heating. In the MIR thermal and atmospheric transmission window, both types of materials must possess high absorbance (A), which via 2nd Kirchoff's law of radiation translates to high thermal emissivity (ϵ).

$$A + T + R = 1 \rightarrow \text{if } T = 0, A = \epsilon \rightarrow \epsilon = 1 - R$$

Spectral characteristics are pivotal for both mechanisms. Materials selected for passive cooling typically exhibit **high transmittance/reflectance in the Vis/NIR range**, ensuring efficient transmission of solar radiation while possessing **high emittance in the thermal infrared range** (low wavelength infrared – LWIR) to facilitate the emission of heat generated by the system.

The angular dependence is critical due to the movement of the sun. Varying incident angles of sunlight necessitate materials that maintain optimal performance across changing solar conditions. Understanding and optimizing angular dependencies ensure efficient sunlight rejection and redirection, enhancing the effectiveness of PRC mechanisms in diverse environments and applications.

How to characterize PRC materials?

Several parameters can be used to fully characterize PRC materials:

- Long-wavelength infrared (LWIR, 8 – 13 μm) emittance near-normal angle of incidence ($\theta = 10^\circ - 15^\circ$) - $\epsilon^{\text{LWIR}}(\text{NNIA})$, defined as an average value of ϵ in LWIR range.
- Hemispherical long wavelength infrared (8 – 13 μm) emittance - $\epsilon^{\text{LWIR}}(\text{HS})$ is defined as an average value ϵ in the LWIR range.
- Near-normal incidence angle emittance selectivity: $S^{\text{NNA}} = \epsilon^{\text{LWIR}}(\text{NNIA})/\epsilon^{\text{BB}}(\text{NNIA})$, where $\epsilon^{\text{BB}}(\text{NNIA})$ is an average broad-band (0.4-20 μm) emittance near-normal angle of incidence.
- Hemispherical emittance selectivity: $S^{\text{HS}} = \epsilon^{\text{LWIR}}(\text{HS})/\epsilon^{\text{BB}}(\text{HS})$, where $\epsilon^{\text{BB}}(\text{HS})$ is an average broad-band (0.4-20 μm) hemispherical emittance.
- Angular long-wavelength infrared (8 – 13 μm) emittance ($\theta = 13^\circ - 83^\circ$) - $\epsilon^{\text{LWIR}}(\theta)$, defined as an average value of ϵ in LWIR range over all the incidence angles.
- Angular emittance selectivity: $S^\theta = \epsilon^{\text{LWIR}}(\theta)/\epsilon^{\text{BB}}(\theta)$, where $\epsilon^{\text{BB}}(\theta)$ is an average broad-band (0.4-20 μm) hemispherical emittance over all incidence angles.

Both, specular reflection at near-normal angle of incident as well as angular dependent measurements can be performed using Bruker's motorized **Variable Angle Reflectance Accessory A513/Q-A**. With its Python script control, it provides a powerful and fully automated tool to study the angular dependence of PRC materials reflectance. Hemispherical reflectance can be measured with **Integrating Spheres: A562-G/Q (gold) and A562-P/Q (PTFE)**. The emittance can be simply extracted from Kirchoff's law.

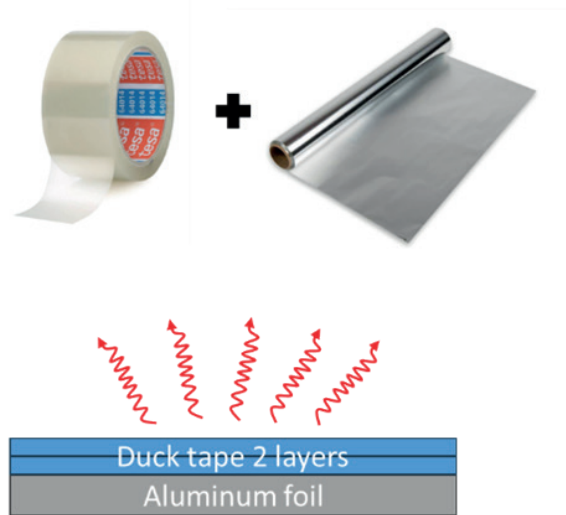
INVENIO X spectrometer enables broad-range measurements without the need for manual exchange of optical components. In combination with the above-mentioned accessories, it provides a complete and powerful setup for PRC materials characterization.

The magic of the "Scotch tape" DIY reflective PRC material

Recently, there has been significant interest in low-cost radiative coolers, offering the potential to significantly broaden the application of radiative cooling^[14]. Huang, Mandal, and Raman designed the minimum-cost do-it-yourself PRC material made of two layers of Scotch tape on aluminum foil^[15]. Typical Scotch tape comprises an acrylic adhesive on a polypropylene film. Both acrylic and polypropylene have chemical bonds that absorb and hence radiate heat in the

LWIR wavelengths. An absence of highly emissive chemical bonds in the non-LWIR thermal wavelengths makes sufficiently thin films of both materials selectively LWIR emissive. This simple design has been found to have comparable efficiency with many other more expensive and sophisticated materials.

Fig. 2
Schematic drawing of DIY Tesa tape/Al reflective passive radiative cooler.



Experimental results

The aluminum-coated glass was covered with 2 layers of standard Scotch tape from Tesa. The whole spectral characteristics were performed on INVENIO X spectrometer equipment with the following optical components:

For more information, please contact our specialist via Bruker website.

Sources	MIR, NIR
Beamsplitters	KBr (T303/IX), VIS-Quartz (T502/IX)
Detectors	DLaTGS (D301/M), InGaAs (D429/M), Si-diode (D510/M), enlarged element detectors : DLaTGS (D301250B), InGaAs (#1008160) and Si-diode (#1008159)
Accessories	A513/Q-A, A562-G/Q, and A562-P/Q

Hemispherical reflectance measurement

To fully cover the range from 0.4 to 20 μm 3 steps are required.

- Step 1: MIR measurement with a golden integrating sphere and DLaTGS detector
- Step 2: NIR measurement with a golden integrating sphere and InGaAs detector
- Step 3: Vis measurement with a PTFE integrating sphere and Si detector

Measurements with integrating spheres are straightforward and can be easily performed following the A562 Product note M53-07/08 and User manual. All necessary manipulations can be performed using OPUS (Merge Spectral Ranges, $1/\text{cm} \leftrightarrow \mu\text{m}$, nm, and Spectrum Calculator). The resulting spectrum obtained for our DIY passive radiative cooler is presented in Figure 3.

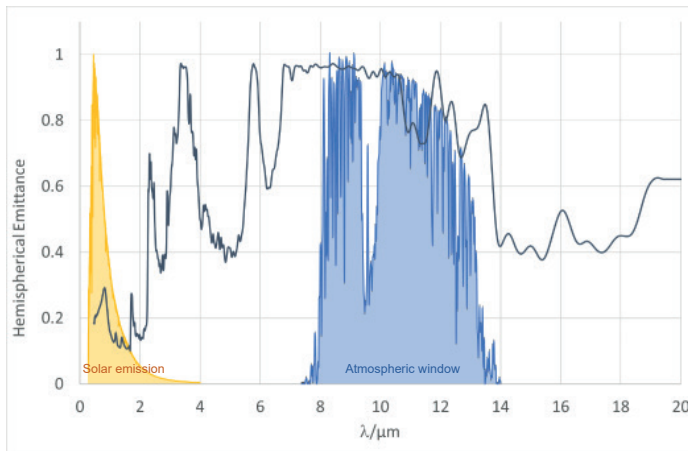


Fig. 3
Hemispherical emittance
(=1 - reflectance) of Tesa
tape/Al DIY PRC.

The $\epsilon^{\text{LWIR}}(\text{HS})$ was calculated to be 0.85 and hemispherical emittance selectivity $S^{\text{HS}} = 1.36$. These values are comparable to 0.83 and 1.32 obtained by Huang, Mandal, and Raman in their experiment^[15].

Directional reflectance measurement

The variable A513/Q-A accessory is completely automated and can be controlled by the included Python script. It enables not only measuring the whole set of angles from the preprogrammed list but also multiple experiments. For more information, please refer to the A513/Q-A Product note M19-01/11 and User manual.

The accessory was placed inside the sample compartment of the INVENIO X spectrometer. The uncoated Al mirror was used as a reference. As the first step, the set of three XPM files has to be created and saved. Ready XPM files set can be provided by Bruker.

In the second step inside the Python script, the angle list can be created. In this experiment, we automatically created the list of angles from 13 to 83° with a 5° increment. In the tab Measure, multiple XPMs files can be selected. After selecting all necessary paths and names background measurement can be started. It is followed by replacing the mirror with the sample and Sample measurement. From the obtained result files the analysis can be performed using the same workflow as in the case of hemispherical measurements.

In Figure 4 the emittance spectrum at near-normal angle of incidence (in our case 13°) is presented. The long wavelength emittance $\epsilon^{\text{LWIR}}(\text{NNIA})$ was estimated to be 0.84. The $\epsilon^{\text{LWIR}}(\text{NNIA})$ is very similar to that obtained for the Scotch tape (0.83). However, our Tesa tape sample seems to show higher selectivity $S^{\text{NNIA}} = 1.52$ versus 1.28 obtained for the Scotch tape.

More detailed information on the directional reflectivity can be obtained from angle-dependent measurements. The results are presented in Figure 5. The $\epsilon^{\text{LWIR}}(\theta)$ and S^θ were estimated to be 0.78 and 1.49, respectively. However, we can see that DIY PRC's properties weaken with angles of incidence closer to the horizontal. This result is also consistent with the reported properties of aluminized Scotch tape designs^[15].

Fig. 4

The near-normal angle of incidence emittance (=1 - reflectance) of Scotch tape/Al DIY PRC.

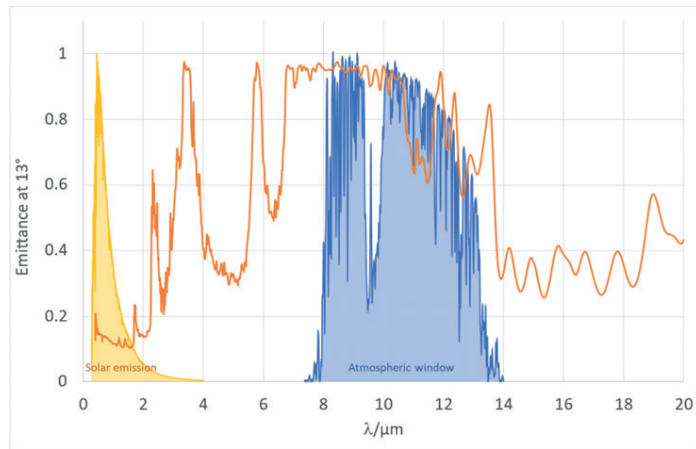
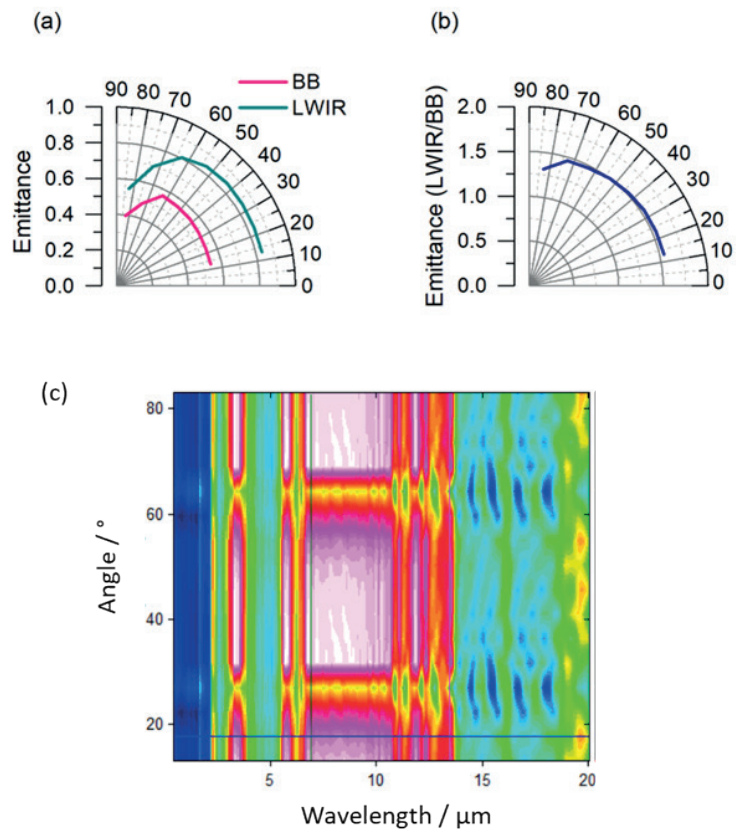


Fig. 5

Angular emittance (broadband and long wavelength) (a), selectivity (b), and emittance (13° - 83°) of DIY Tesa tape/Al PRC.



Summary

Bruker offers a comprehensive suite of tools for characterizing passive radiative cooling (PRC) materials. These tools simplify material analysis and full performance assessment, using just one spectrometer. Our simple experiment confirms that low-cost, straightforwardly designed PRCs hold promise for sustainable energy-saving construction. Bruker's technology contributes to a greener, more efficient future.

References

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