COMSOL simulation for daytime radiative cooling

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Abstract: The increase in cooling demand of diurnal human activities using mechanical systems to dissipate heat to the surroundings consumes large amounts of energy with excess heat production and CO_2 emissions. The passive cooling process of the earth by infrared thermal radiation through the atmospheric transparency window (8~13 μm) inspires people to use the outer space as a heat sink where the waste heat can be dumped without energy consumption. Here, based on the guidance of COMSOL simulation, we obtained high-performance multilayer material for daytime radiative cooling.

Introduction

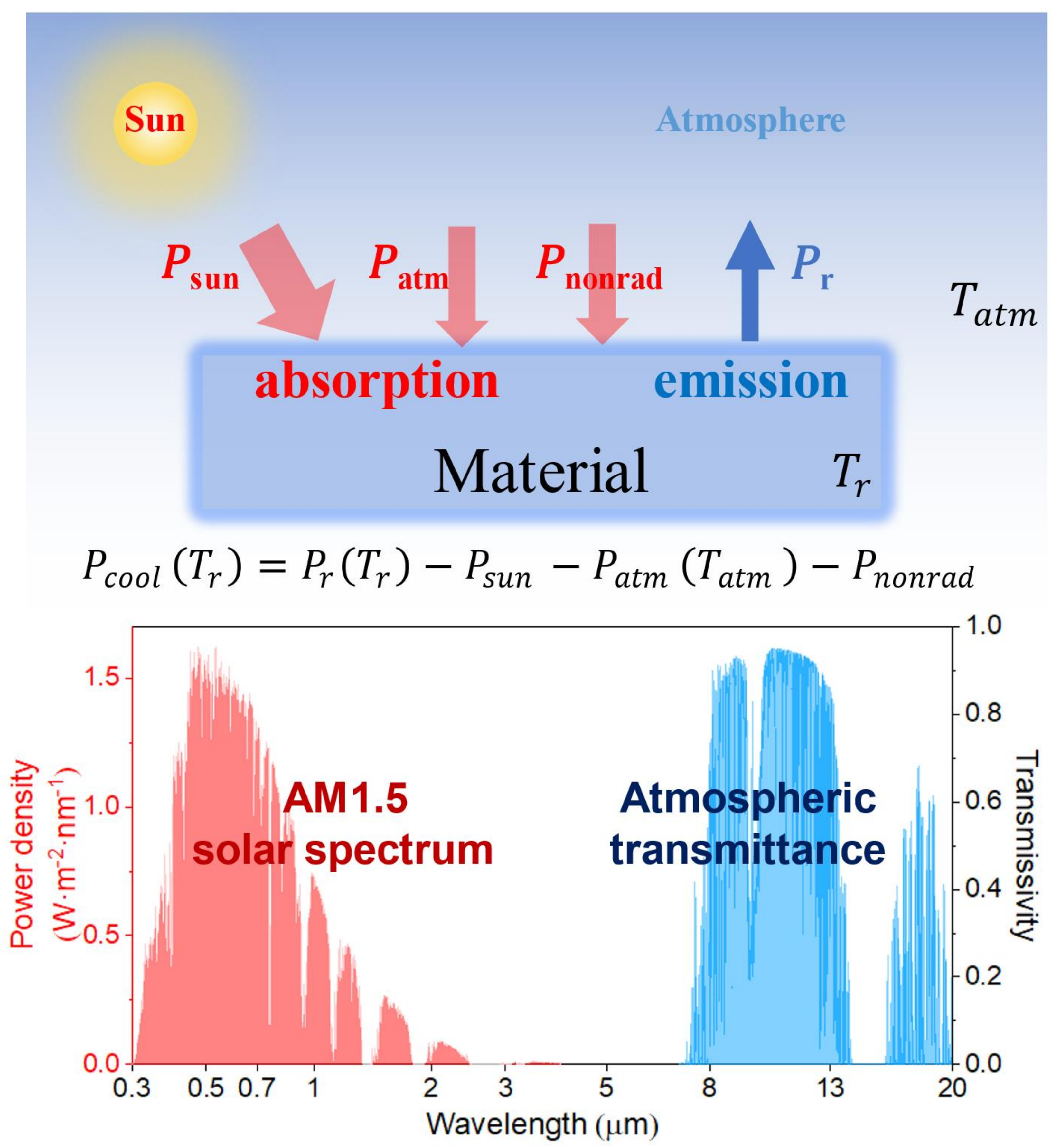


Fig. 1 | Schematic of daytime radiative cooling. Ideal daytime radiative cooling materials should have extremely low averaged absorptivity ($\bar{\alpha}$) within the solar spectrum (0.3-2.5 μm) for minimized absorption, while maintaining high averaged emissivity ($\bar{\varepsilon}$) in the atmospheric transparency window for effective thermal emission.

Methodology

Periodic boundary condition

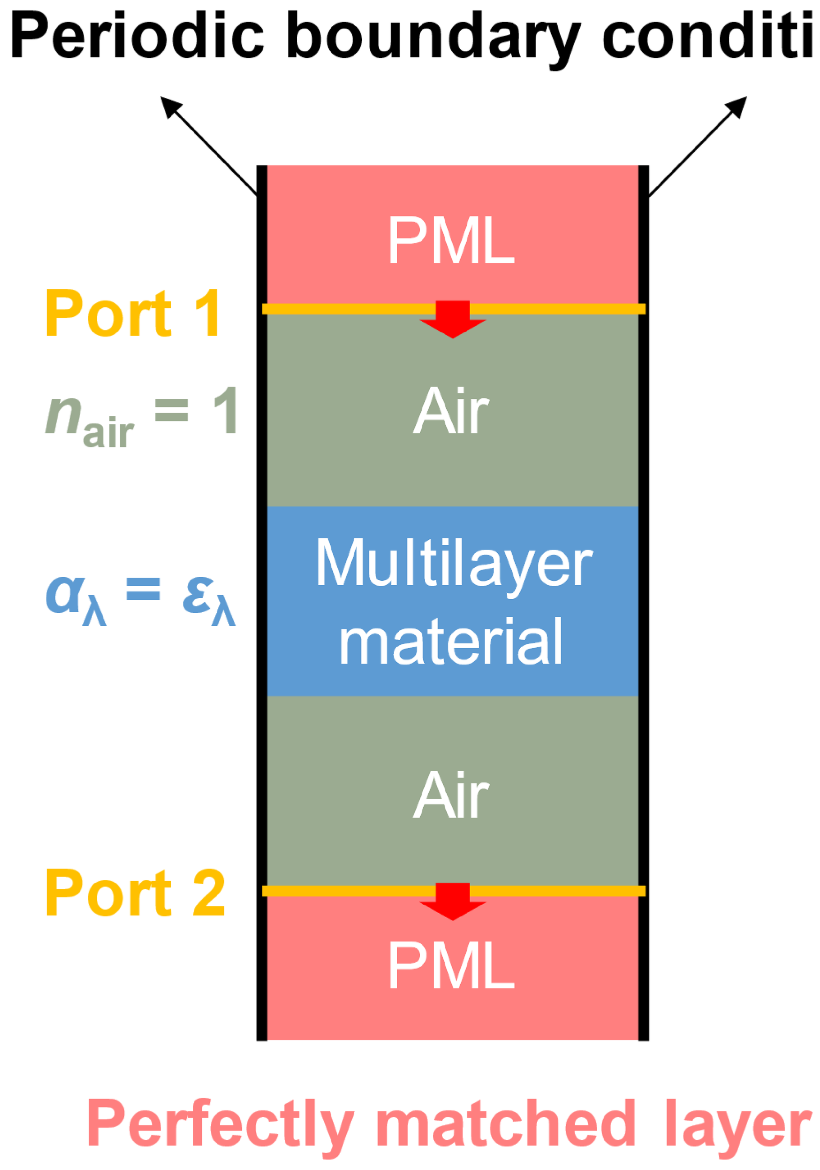
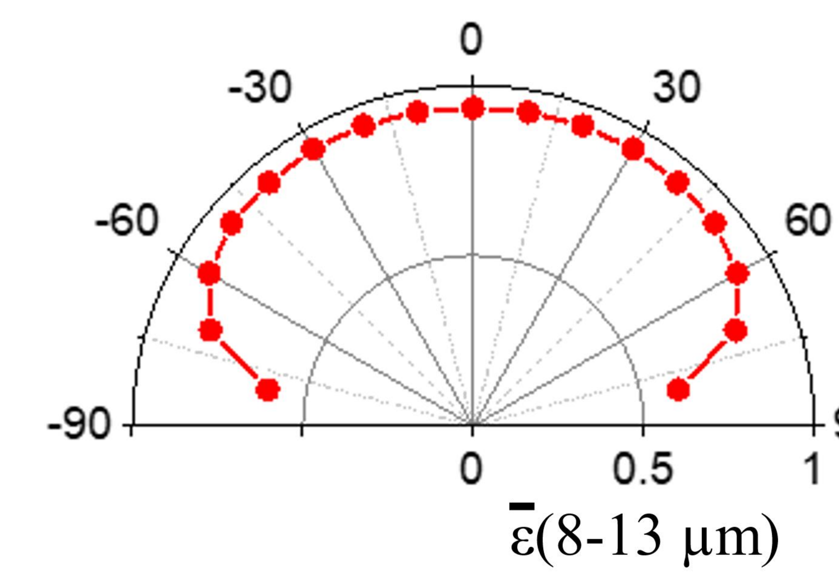


Fig. 2 | COMSOL simulation modeling diagram. We used "Electromagnetic waves, Frequency Domain" physics interface of the Wave Optics module. The postprocessing tools enable us to compute S-parameter matrices, transmission properties, reflection properties. Since the sum of absorptivity (α), transmissivity (τ) and reflectivity (ρ) is 1, and absorptivity is equal to emissivity at same wavelength by using Kirchhoff's radiation law. We can obtain absorptivity and emissivity spectrum at incident angles and different wavelengths.

Results and Discussion

Fig. 3 | Simulation of angular emissivity. Averaged emissivity ($\bar{\varepsilon}$) of the multilayer material between 8 μm and 13 μm (the atmospheric transparency window) plotted as a function of polar angle of incidence. It reveals high emissivity even at remarkably large angles of incidence.



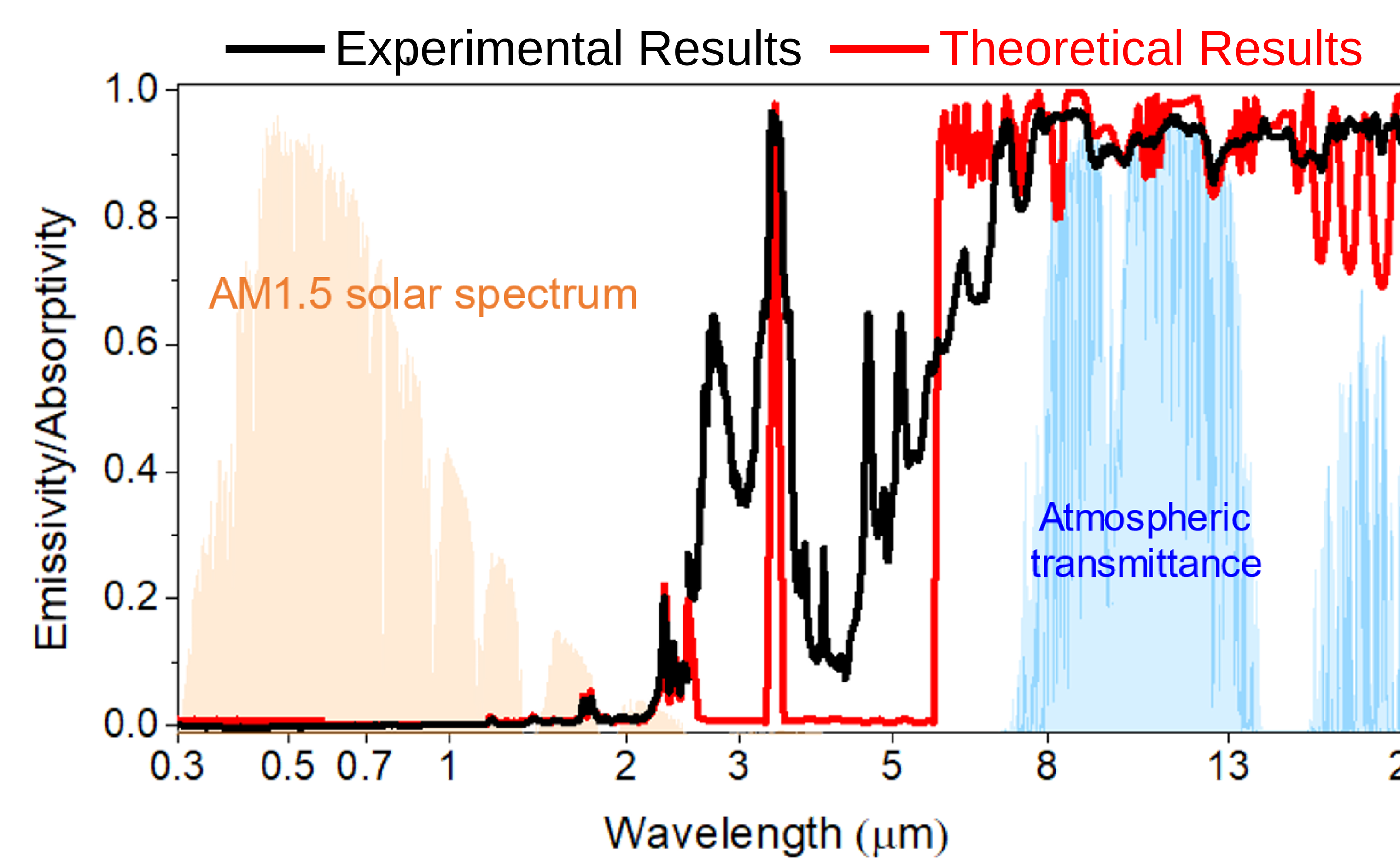


Fig. 4 | The measured (black curve) and theoretical (red curve) emissivity/absorptivity spectrum from 300 nm to 20 μm. The experimental result is consistent with the simulation result.

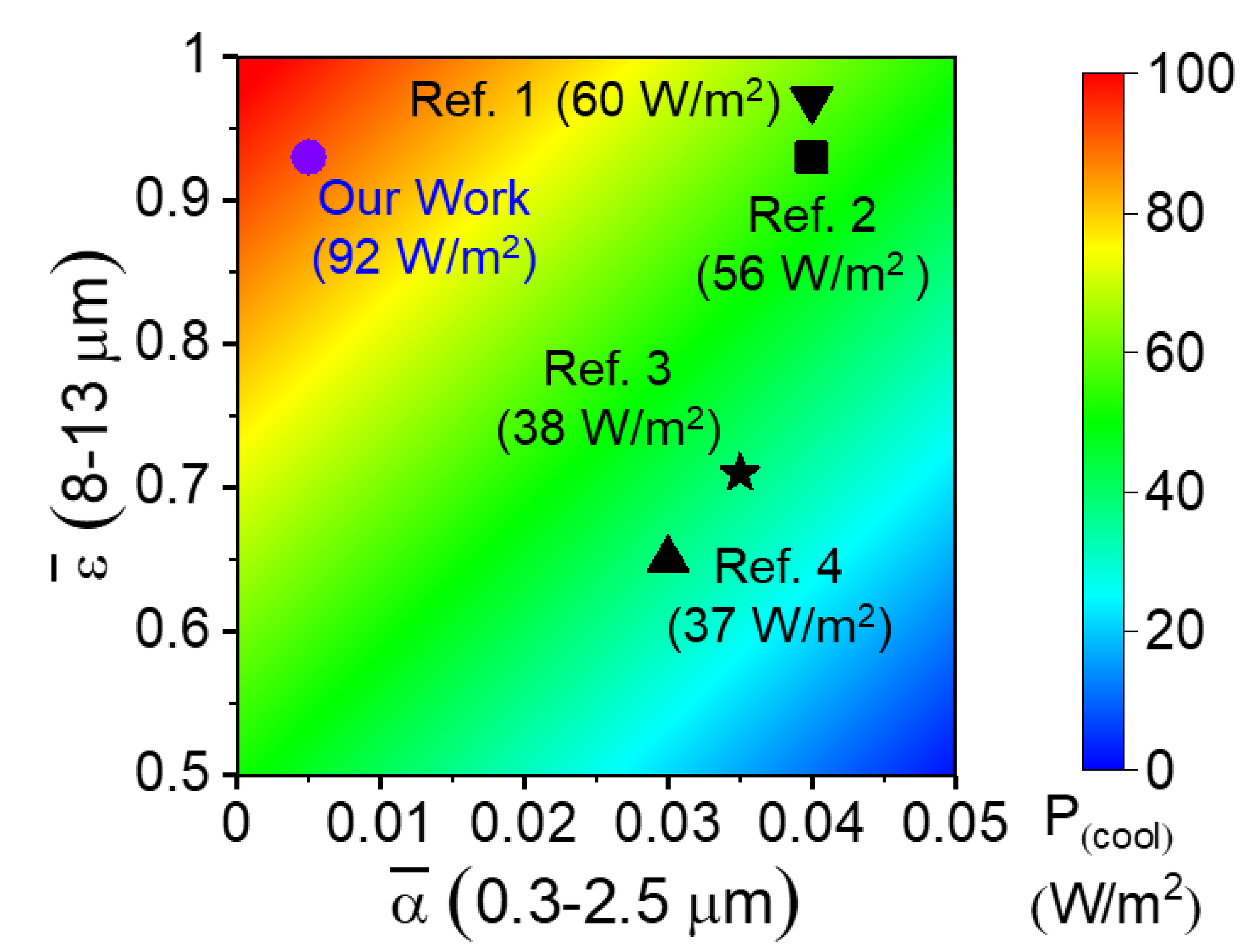


Fig. 5 | The cooling power comparison of our multilayer material with other references based on the intrinsic spectrum under the same solar irradiance (AM 1.5) and atmospheric transmittance (water vapor column of 10 mm).

References

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