Ultrathin Metal Based Mid-infrared Emitters for Radiative Cooling

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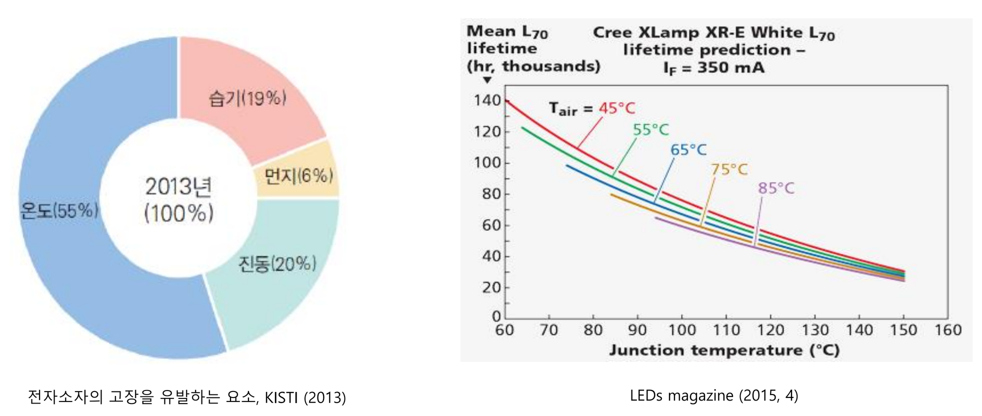
Abstract

One of the remarkable heat dissipation strategies, radiative cooler's performance can be greatly improved with increasing its emissivity over a broad range of mid-IR. This can be achieved by employing both dielectric materials and metals having the relatively larger penetration depth base on a tunneling effect. The simplest planar structure sandwiching an ultrathin metal between dielectric layers can lead an optical structure to be greatly close to blackbody. Furthermore, given the enhanced transmittance in visible spectrum, it will be applicable to a wide range of environments with different heat sources.

Introduction

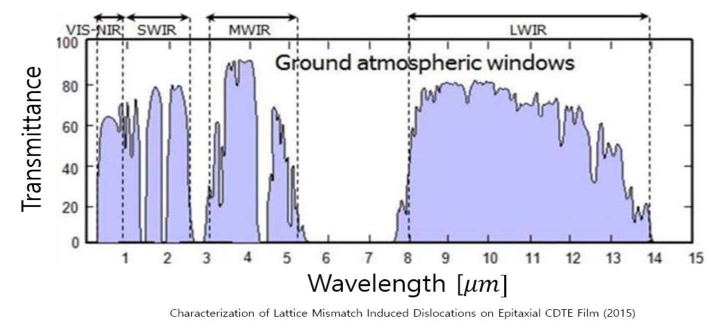
❖ The Necessity of Heat Dissipation



- For electronic devices, joule heating inevitably takes place
- The lingering heat has an adverse effects on a device

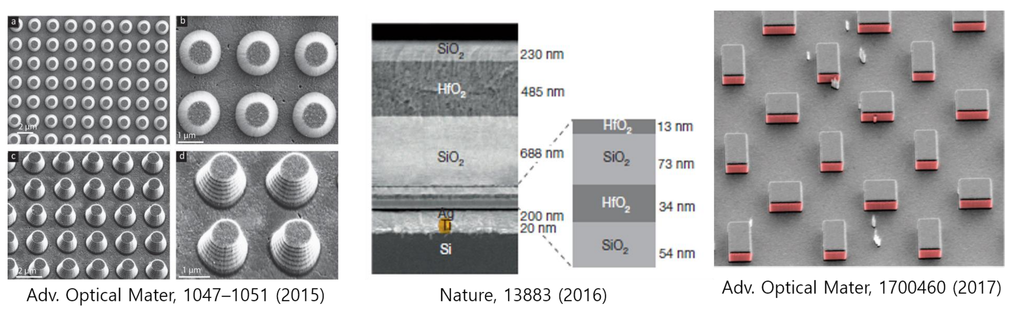
❖ Radiative Cooling

- a passive cooling strategy without any external input
- Mostly through the atmospheric window which refers to some certain wavelength ranges transparent to electromagnetic radiation.



- Emissivity ε is a measure of how closely a surface approximates a blackbody
- Kirchhoff's law of thermal radiation : $\varepsilon(\lambda, T, \theta) = \alpha(\lambda, T, \theta)$

❖ Conventional Research

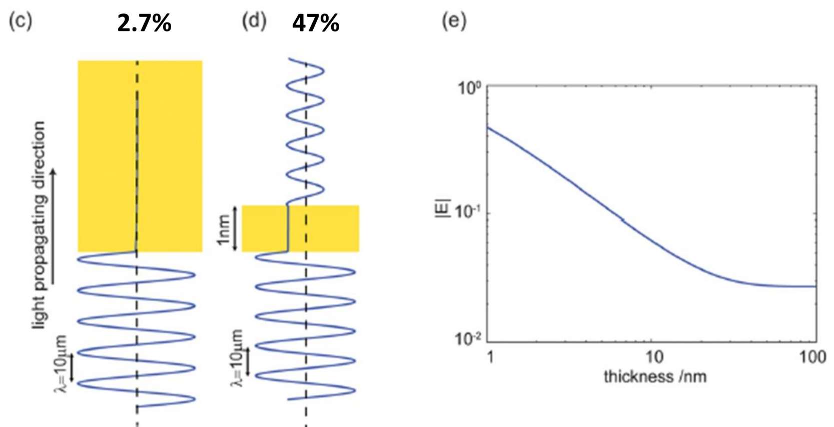


- Their complex structures increase production cost and make it hard to be applicable and enlargeable
- have high absorptivity selectively through the main atmospheric transparency window between $8\mu m - 13\mu m$
- Consist of dielectrics to make the best use of their resonances

Fundamentals of Design

❖ Introduction of a Metal Layer

❖ Tunneling Effect

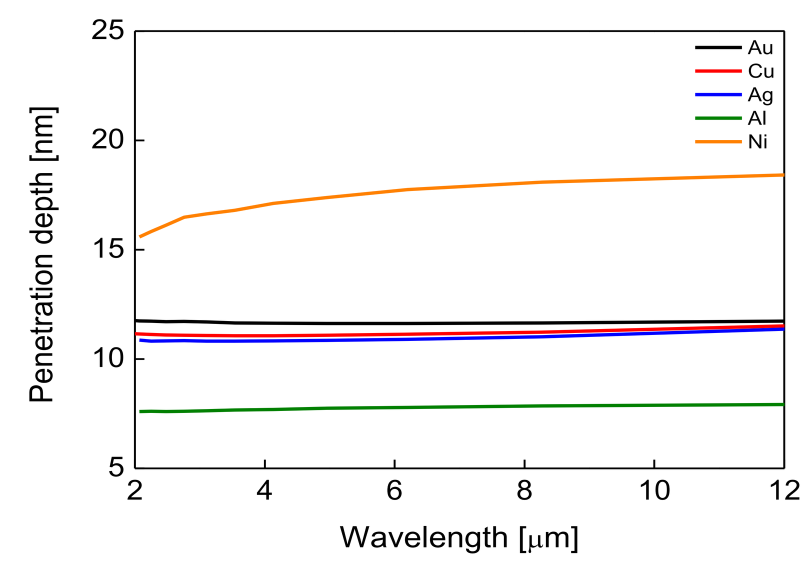


Appl. Phys. Lett. 106, 101104 (2015)

- Even at the cost of rebounded emission from atmosphere, expanding the spectral range of high absorptivity is beneficial for a device operating above ambient temperature

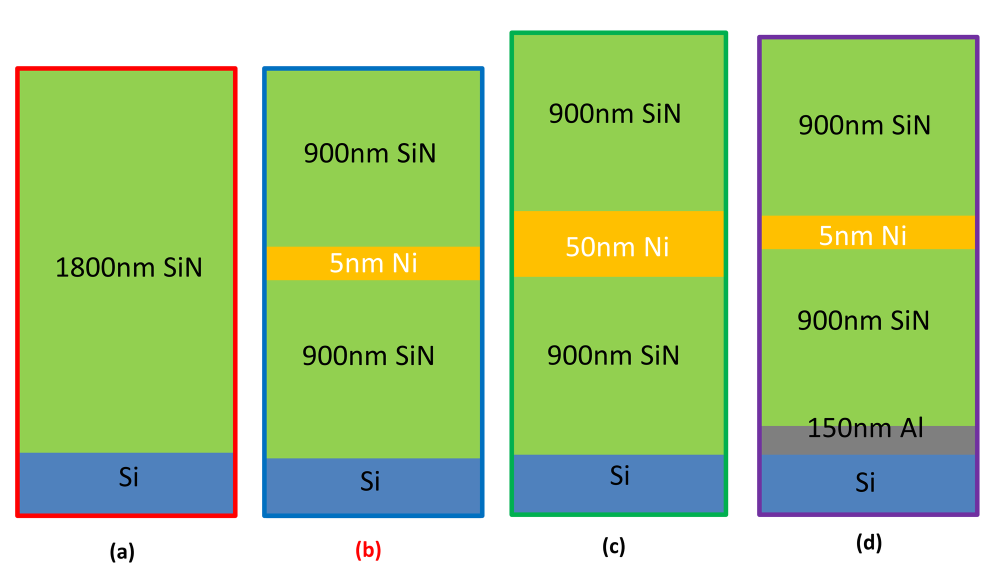
- The tunneling occurs when the thickness of a layer is much thinner than the wavelength of incident light
- Due to the thin thickness, the film does not have enough charge to screen the oscillation current inside the metal
- the emissivity can be enhanced over a broad range of spectrum because the tunneling effect does not rely on optical resonance

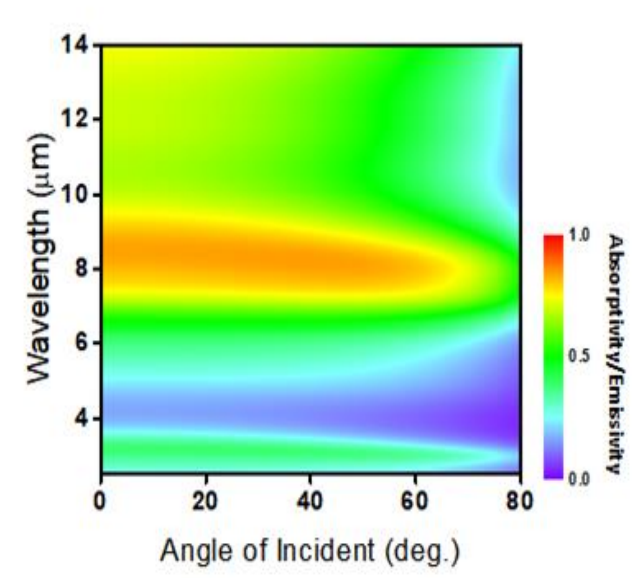
❖ Penetration Depth

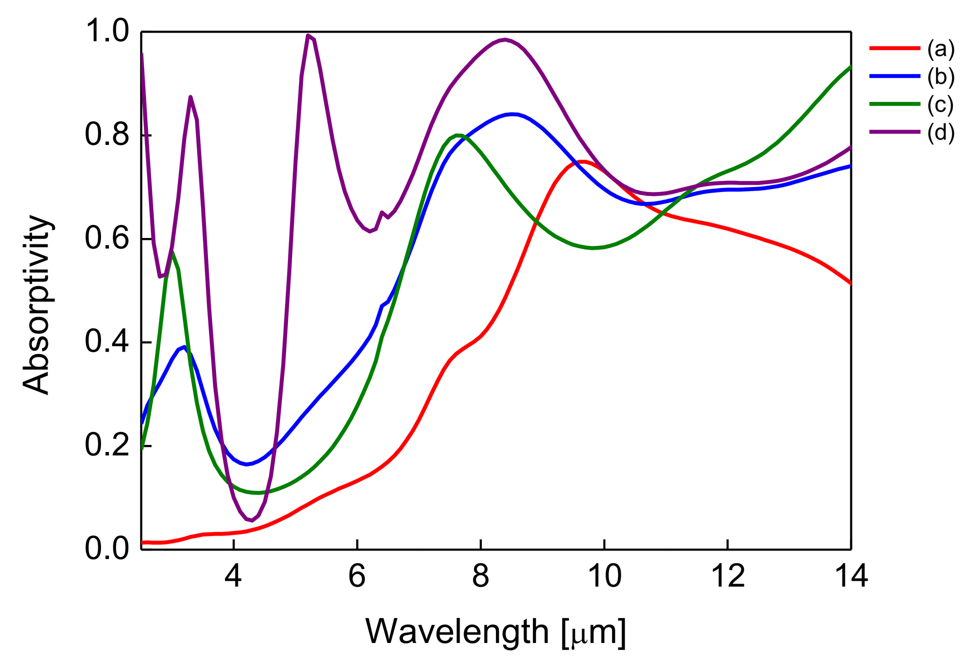


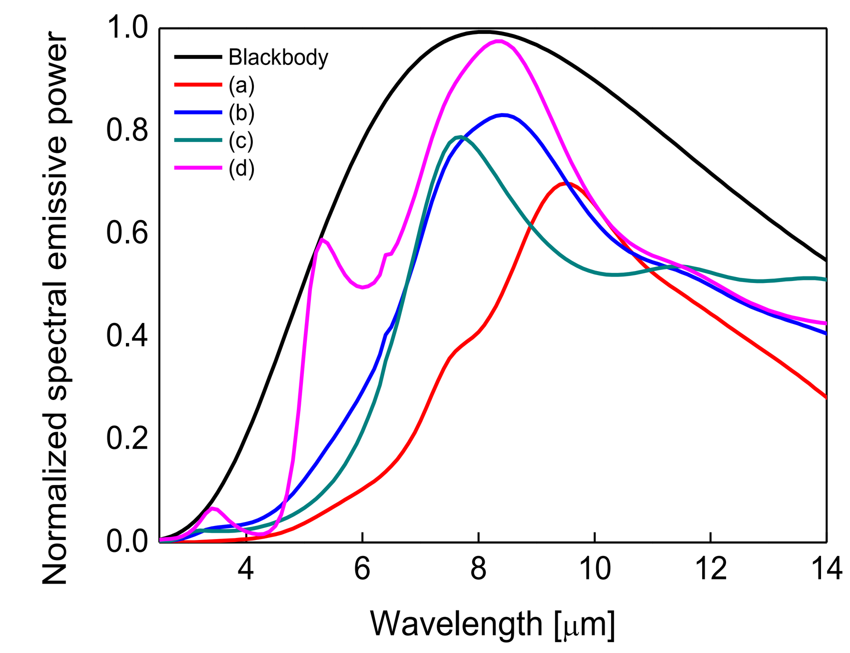
- The penetration depth D : $\frac{1}{D} = \frac{4\pi k}{\lambda}$
- Some metals show the relatively larger penetration depth, meaning that they allow photon much more easily tunnel through

Emissive Properties in Mid-infrared



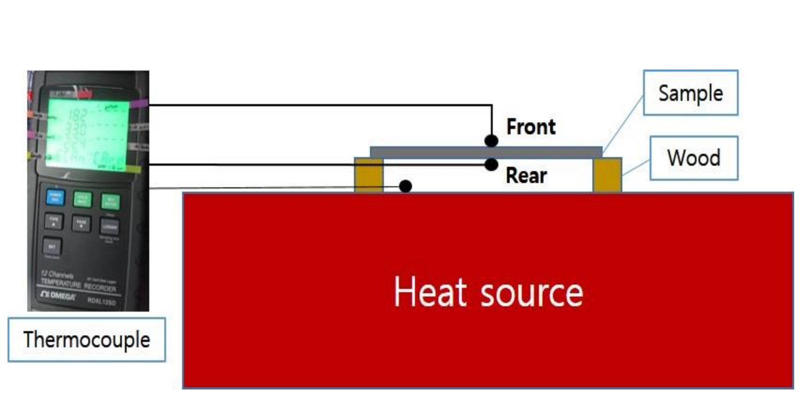


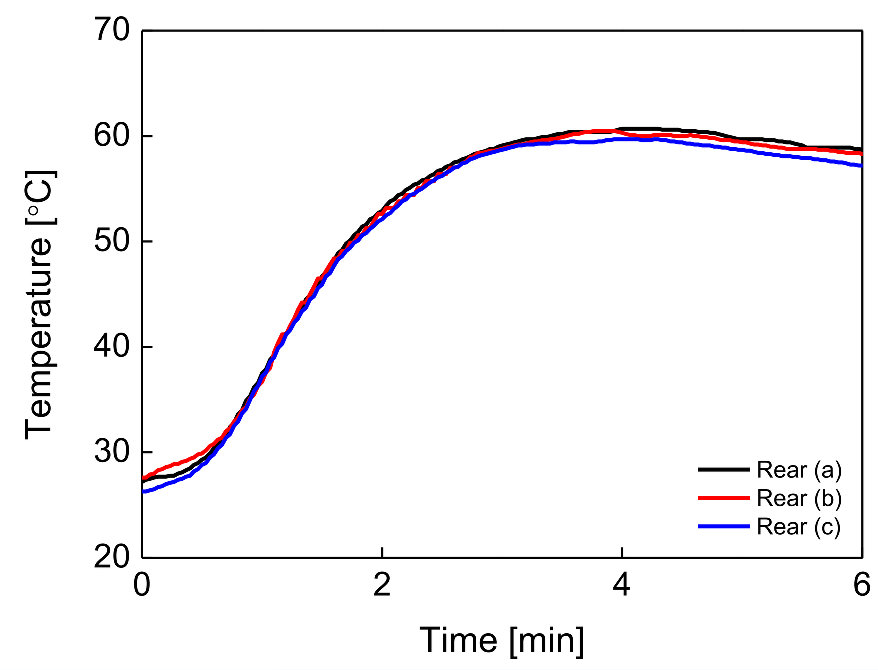


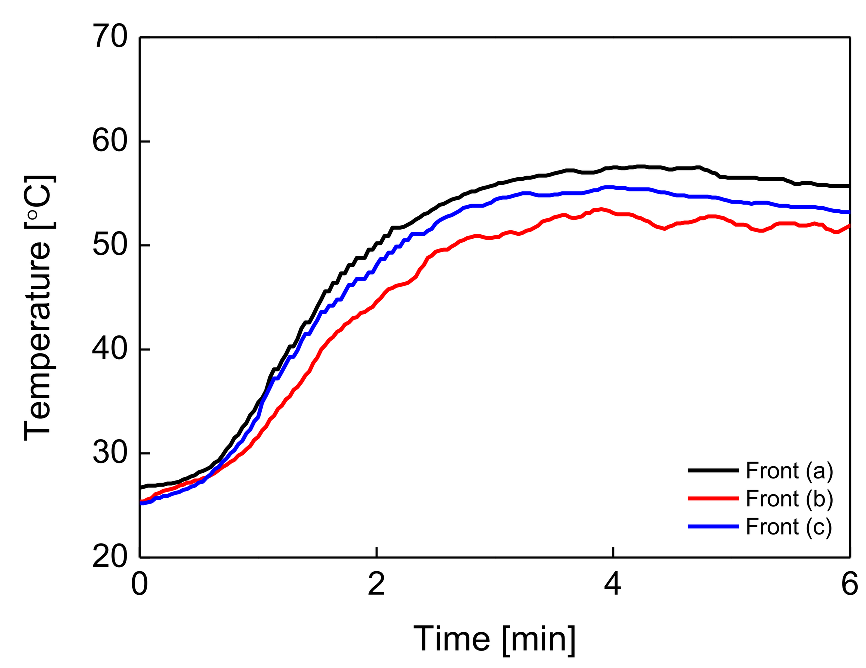


Cooling Performance

❖ Measurement Setup





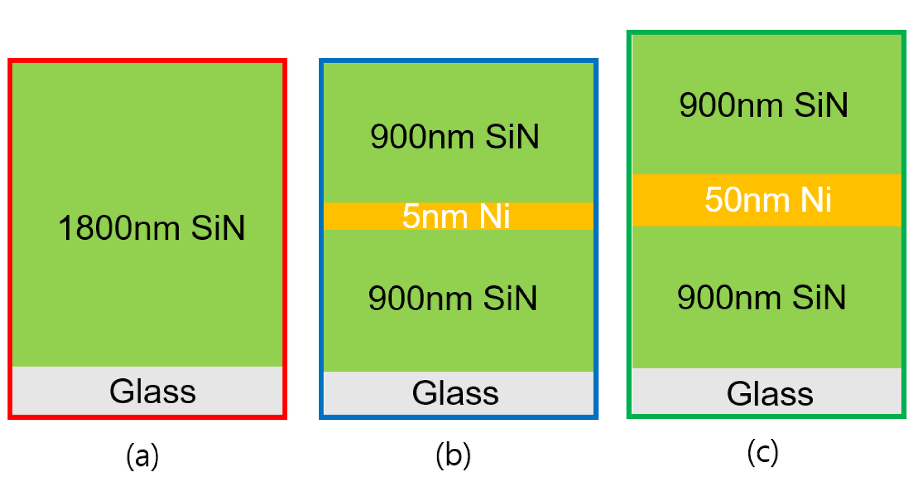


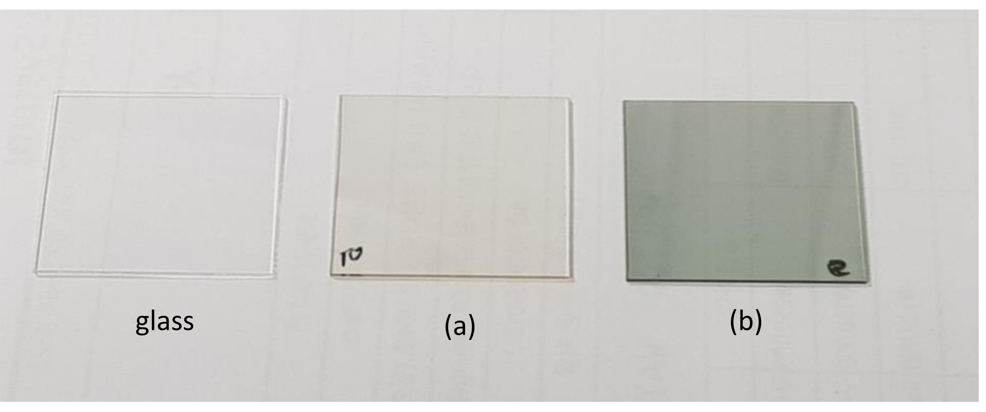
	Emissive Power to Blackbody		
Structure	(a)	(b)	(c)
w/o mirror	0.42	0.64	0.59
w/ mirror	0.54	0.78	0.60

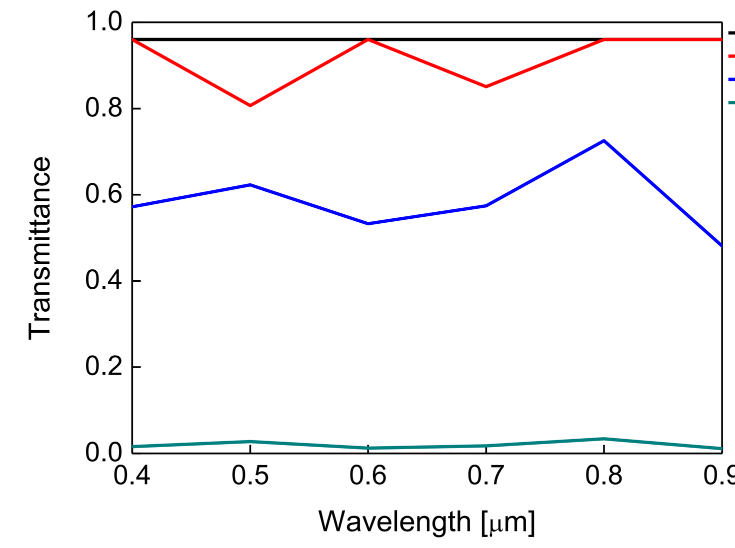
	Temperature [℃]		
Structure	(a)	(b)	(c)
2s	50.2	44.6	48.1
3s	55.8	50.8	54.4

- The front side of (b) is the coldest
- About 5°C less than the others

Transmittance in Visible Spectrum







- The thin metal layer make it semi-transparent
- Broadening applicability to visible light source can be achieved with the enhanced transparency in visible spectrum
- Solar cell, LED, etc.