Multi-Spectral Thermal Imaging with Inversely Designed Optical Filters for Material Recognition

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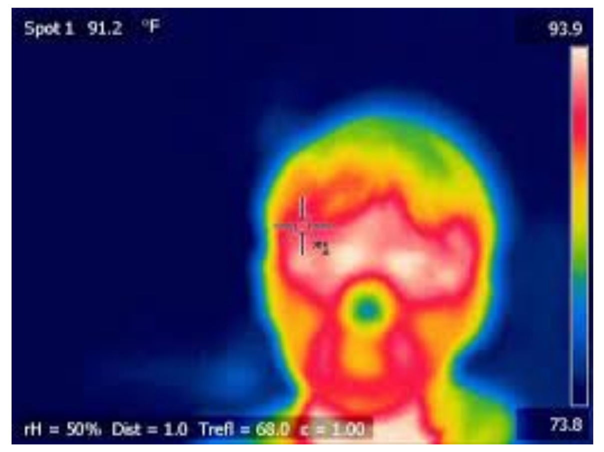
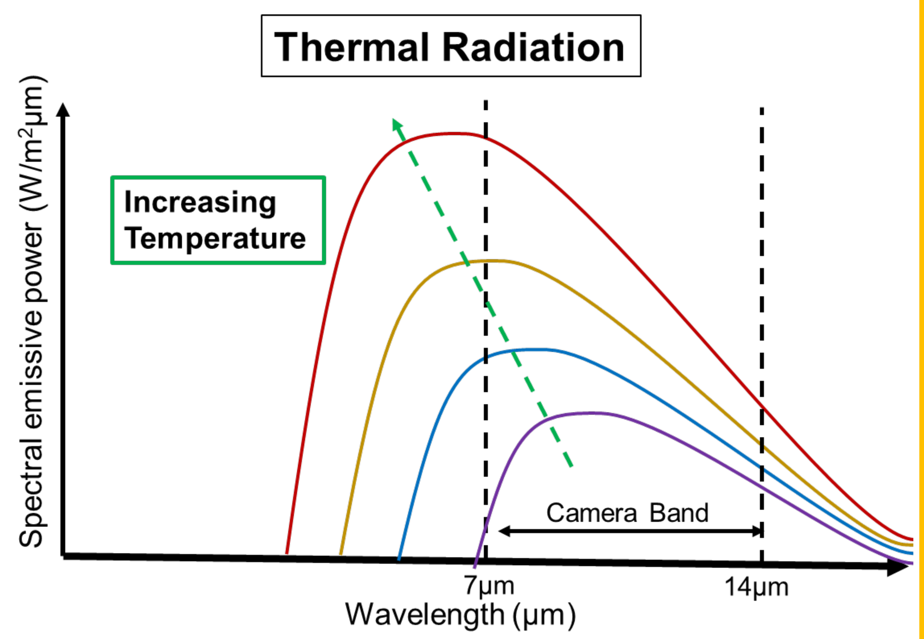
Background

- All materials above absolute zero emit thermal radiation.
- Objects with temperatures near or above room temperature (~300K) have peak emission at 7 µm-14 µm wavelengths.



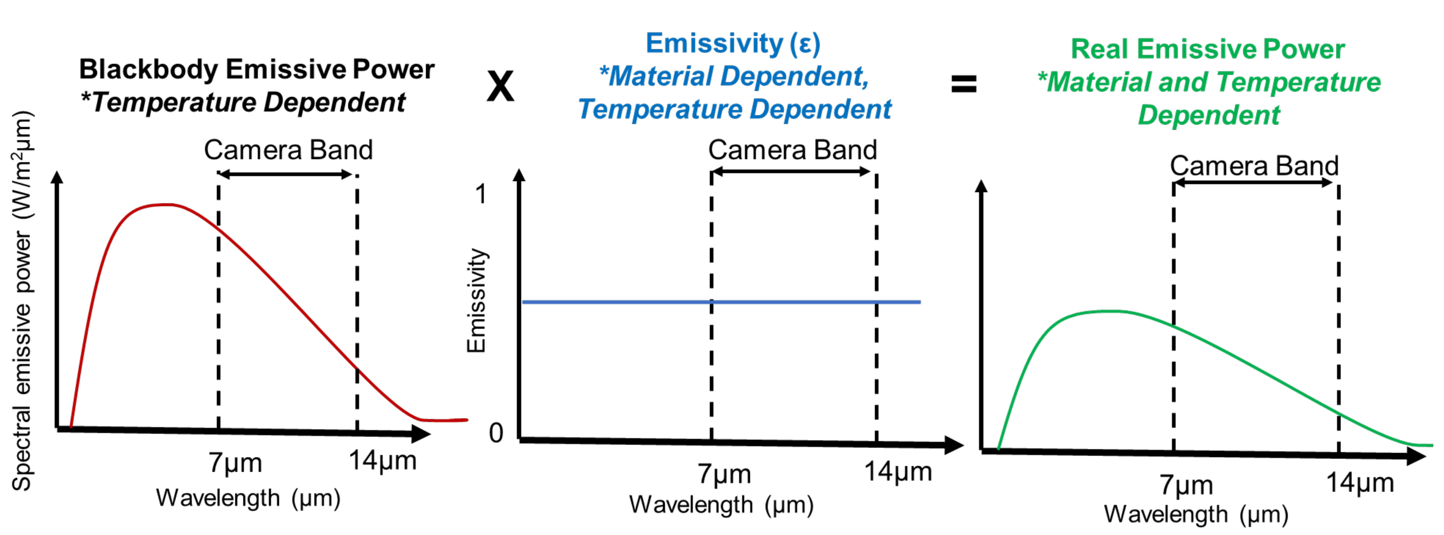
- A **Blackbody** is an object that emits a broadband of thermal radiation defined by Planck's Blackbody Radiation Law.



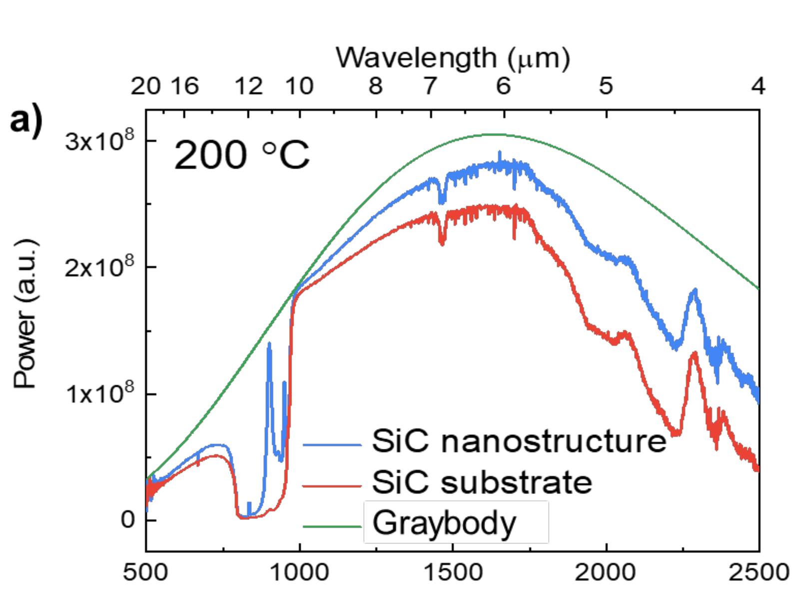
- A **graybody** is an object that emits light with the same spectral shape, but scaled to lower powers by a factor called the **emissivity**.

Motivation

Emitted Power Measurement Process



Approximating SiC's Emitted Power

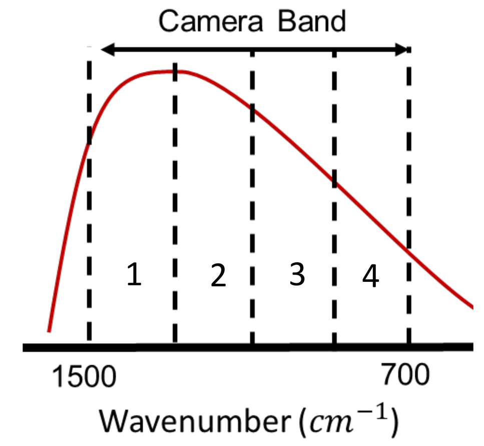


- Real materials don't exactly follow Planck's Blackbody Radiation Law
- Instead, material properties such as vibrations and conductivity change the IR absorption/emission properties
- Thus, lower emissivity and/or spectrally varying emissivity makes objects appear different temperatures than they are

How do can we more accurately identify materials with a Thermal Imaging Camera? → By spectrally selective imaging to more accurately image emitted power.

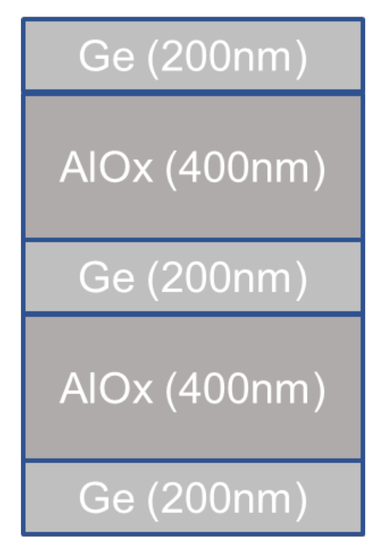
Approach

Desired function of our filters



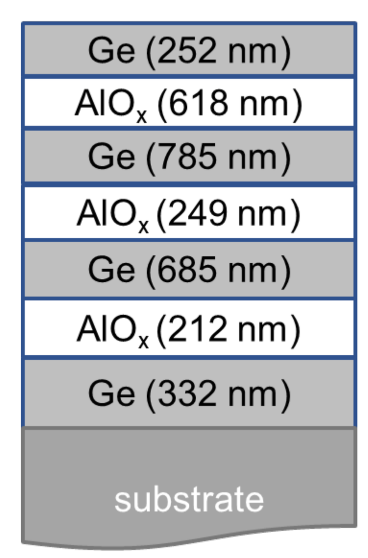
- Divide camera imaging range (7 µm-14 µm) into four equal energy/ frequency bands
- Transmit one of four bands while reflecting the other three.
- Design material specific filters to only transmit where select materials are highly absorptive.

Distributed Bragg Reflector (DBR)



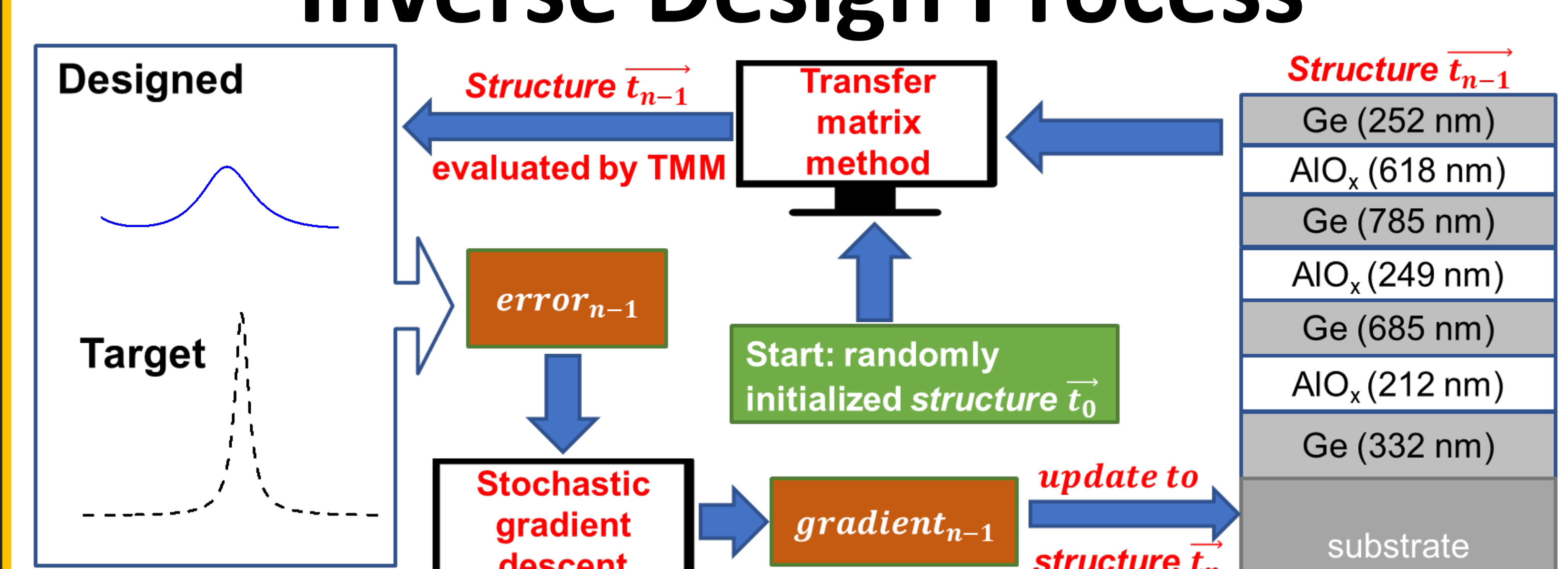
- A DBR is a spectrally selective, highly reflective optical structure
- Each interface partially reflects incident light resulting in constructive interference
- Tunability of reflection band limited by material choice and layer thicknesses

Aperiodic Distributed Bragg Reflector (aDBR)



- Aperiodic DBR designs allow for different thicknesses of the various materials
- With different thicknesses and material arrangements, the aDBR can reflect, transmit, and absorb at different wavelengths
- Great tunability in design!
- Designs are too complex for intuition

Inverse Design Process

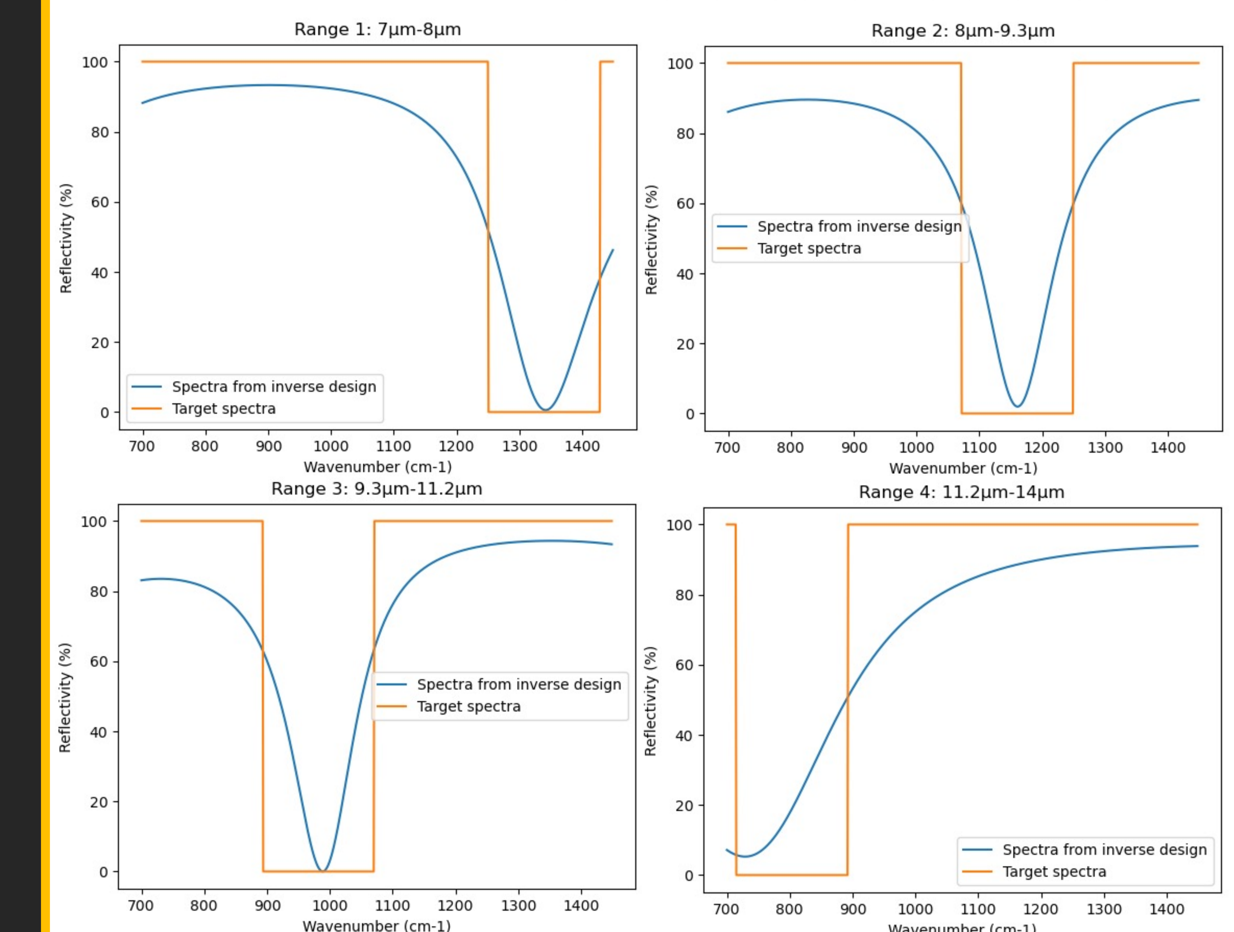


Inverse Design Algorithm

- Written in Python with API TensorFlow
- Target spectrum chosen to match desired response
- aDBR structure is randomly initialized
- Reflection spectra of aDBR is calculated via Transfer Matrix Method (design spectrum) and compared to target spectrum
- Based on difference b/w them (error) structure is modified
- Repeat progress until set iterations

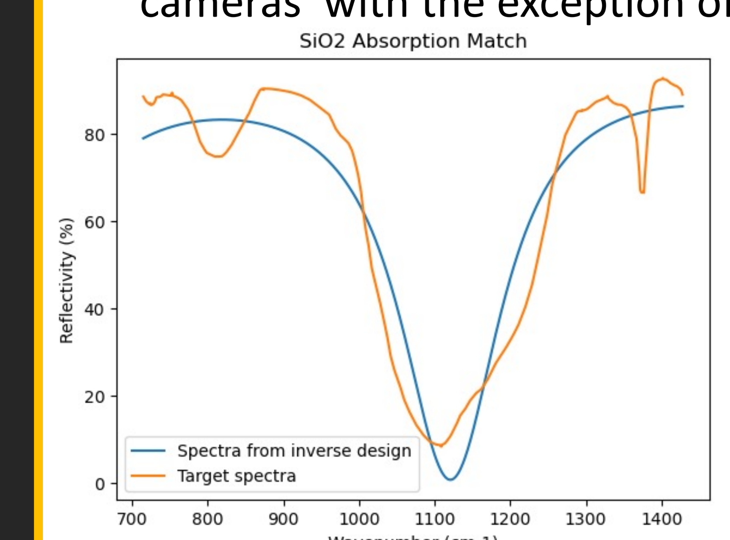
Results

Simulated Structures



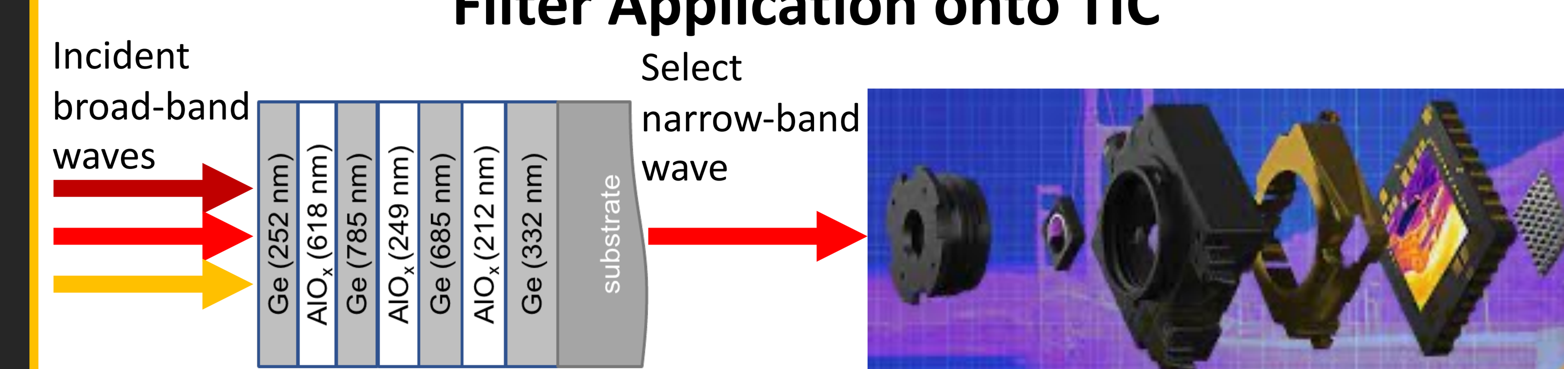
- Each narrow-band filter enables the thermal camera to detect its own peak emitted power
- Employing each of these filters with the thermal camera will allow for spectrally selective imaging
  - More accurate temperatures
  - More accurate material identification

- Glass(SiO_2) is highly reflective over much of the spectral range of thermal cameras with the exception of a narrow range with high absorption.



- Creating a filter tuned to high absorption band:
  - SiO2 can be more easily identified
  - Its emitted power can be more accurately plotted and temperature extracted
  - Avoids imaging reflections (analogous to imaging a mirror with a visible camera)

Filter Application onto TIC



Current Status on Filter Growth

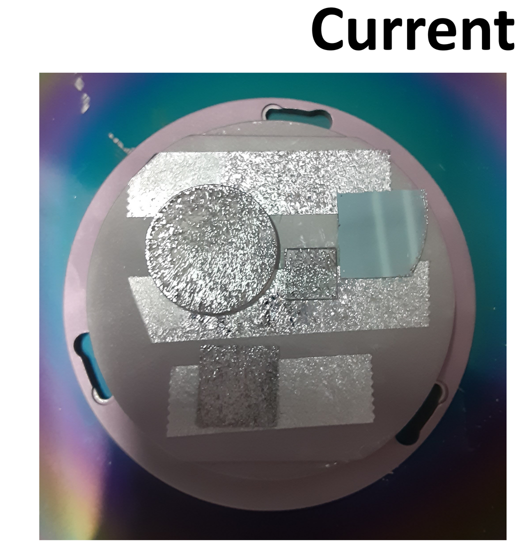


Image taken by Josh Nordlander

- Due to backorder on substrates, filter growth had been delayed.
- Currently during the filter's growth process, the surfaces start to become roughened/delaminated.
- Work is ongoing to reduce strain in the films.

References and Acknowledgements

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