Designing and Optimizing a More Efficient and Inexpensive Optical Component for Thermal Cameras

Background/Literature Review

- Thermal Cameras are used to detect infrared radiation (Gade, Rikke, et al.)
- Typically used in various emergency situations:
  - Surveillance (Wong, Wai Kit, et al.)
  - Finding humans in fires (Aathithya, S., et al.)
  - Military operations (Gade, Rikke, et al.)
- Microbolometers have IR absorbers used to detect light within the infrared region (7-14 μm) (Gade, Rikke, et al.)

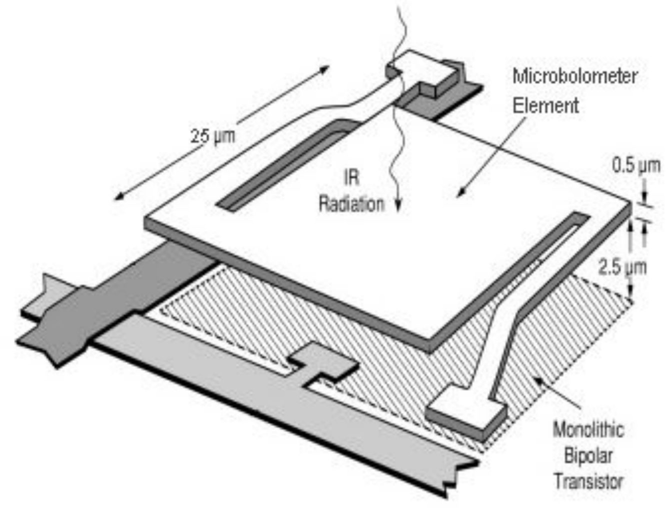

Figure 1: A schematic of a microbolometer, featuring the basic elements and dimensions (Optotherm Thermal Imaging)

- Microbolometers use absorbers in 3D structures (>100 nm in each dimension)
- 2D properties (<100 nm in one dimension, >100 nm in other dimensions) present more efficient optical properties (Kumbhakar, Partha, et al.)
- Some of which include graphene, hexagonal boron nitride, and molybdenum trioxide (MoO_3) (Álvarez‑Pérez, Gonzalo, et al.)

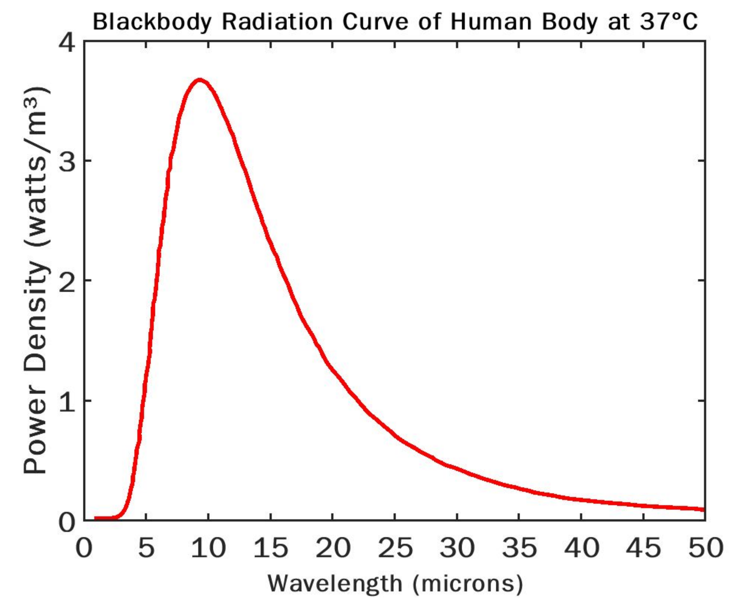

Figure 2: Power density of human radiation emission (Brady, David, et al.) Power Density scaled down by a factor of 1e7. Peaks at 9.5 microns.

- Human black body curve shows the intensity of radiation emitted by humans at certain wavelengths

Purpose

- Design and optimize a smaller and more efficient 2D optical component for a thermal imager.

Criteria and Constraints

- Criteria: Successfully absorb light at the peak of human radiation emission (around 10-14 um) but not at other wavelengths and to use a 2D layer for MoO_3
- Constraints: Inability to physically fabricate the optical component, as there is no access to laboratories in the current pandemic
- An assumption that simulation data is similar to that of experimental data

Workflow

Brainstorm/Possible Solutions

- Purchase materials and attempt to fabricate a film
  - Gives experimental data, but too expensive and too long to fabricate
- **Simulate light going through the film onto a substrate**
  - Inexpensive and allows for quick data, but does not provide experiential data
  - Chose this solution

Create Basic Solution

- Use an FDTD Simulator called Lumerical
  - Finite Difference Time Domain (FDTD)
  - Solves differential equations to simulate optical properties through a spectrum of wavelengths
- Create a substrate with constant properties (final layer, which the light hits) under a film of molybdenum trioxide
- Vary the thickness and periodic arrangement of geometries
- Plot data and attempt to match human black body curve
- Mentor guides and solves problems that arise, mentee does experimentation themselves

Developing Solution/Methods

- Create the anisotropic MoO_3 material in Lumerical
  - Needs real and imaginary permittivities of material in three dimensions (x,y,z)
  - Develop script in Matlab to solve permittivity equations (Álvarez-Pérez, Gonzalo et al.)

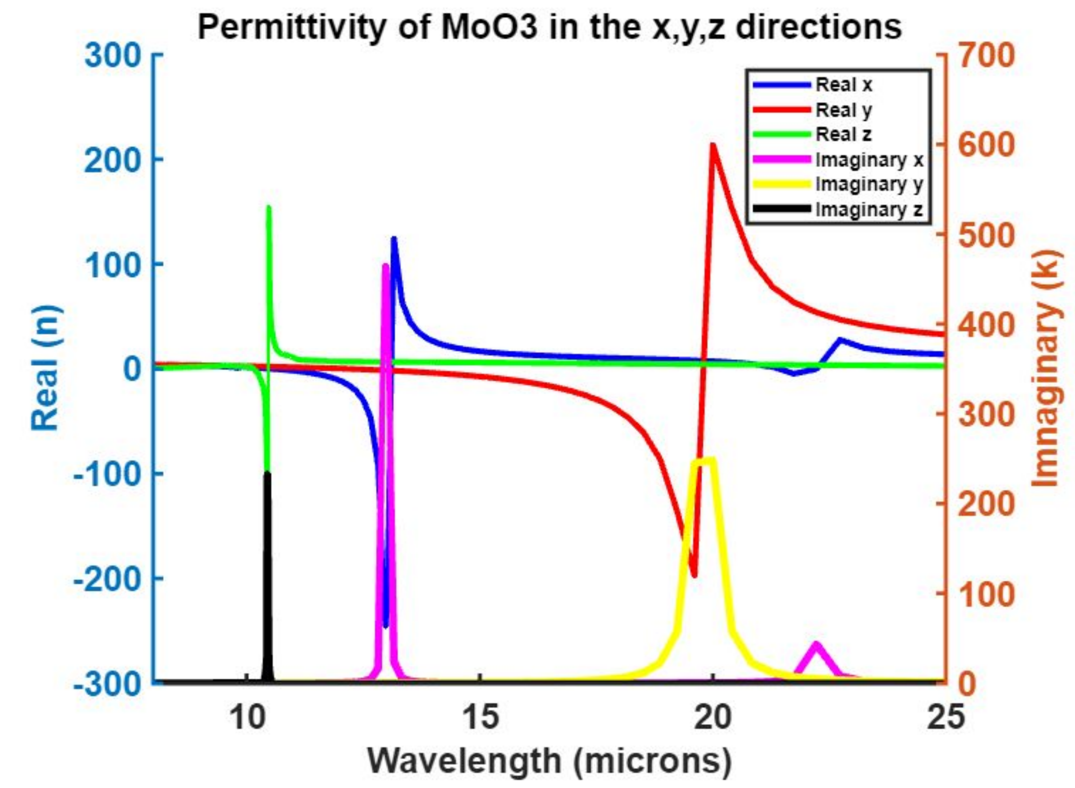

Figure 3: Permittivity of MoO_3

- Material is then used as film for the simulation
- Create a light source within a wavelength range
  - 6-16 micron to capture broad range
- Create and place monitors which capture the light source at those moments
  - Transmission after film, to measure the light that passes
  - Reflection before film, to measure reflected light

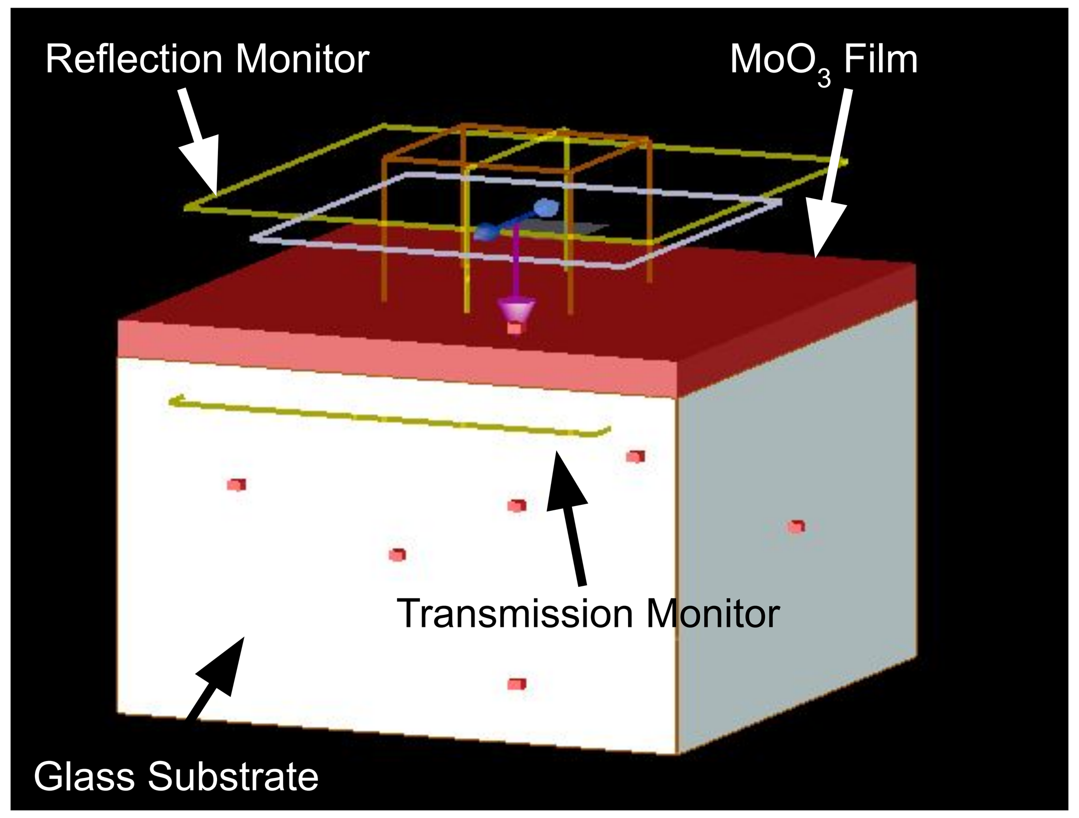

Figure 4: Perspective view: Example of one simulation setup with 1.2 x 1.2 x 0.1 (x,y,z) micron thick film and no geometrical arrangements

Results

- Constants:
  - Temperature of system = 300° K
  - Plane wave source = 6-16 microns directed perpendicular to film
  - X and Y dimensions of every material
- Current model's properties:
  - 0.01 micron thick MoO3 film
  - 1.2 x 1.2 x 1 (x,y,z) microns
  - No geometrical arrangements

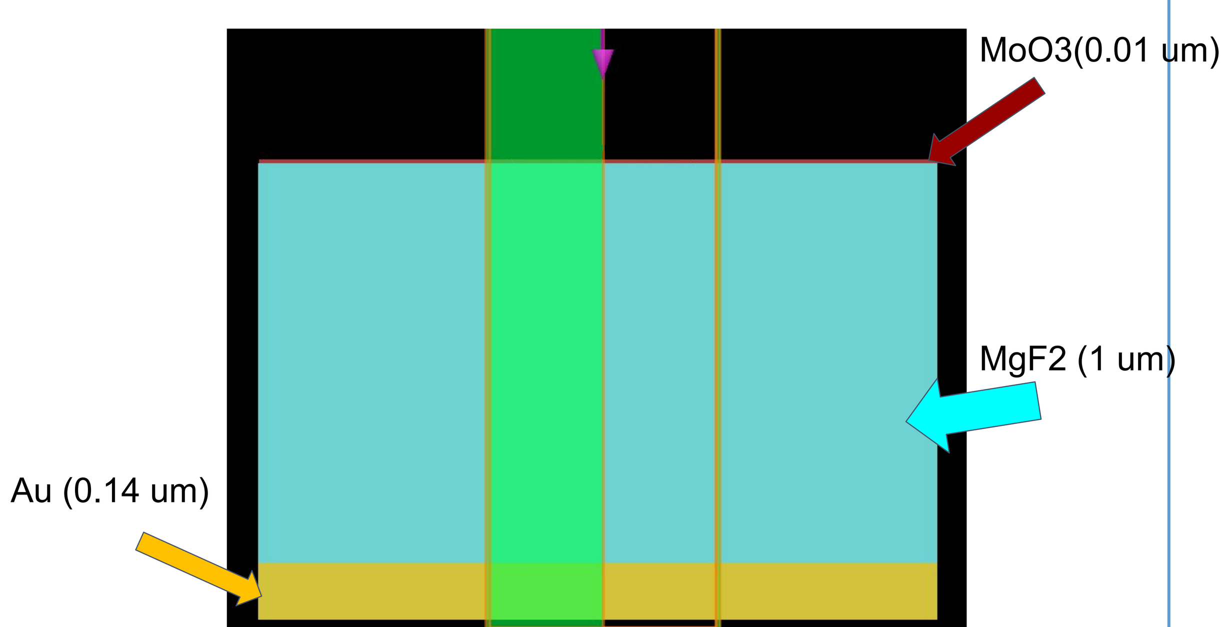

Figure 5: From the XZ View: Final simulation model with 1.2 x 1.2 x 0.01 (x,y,z) micron thick film and a periodic 0.02 thick golden ring arrangement

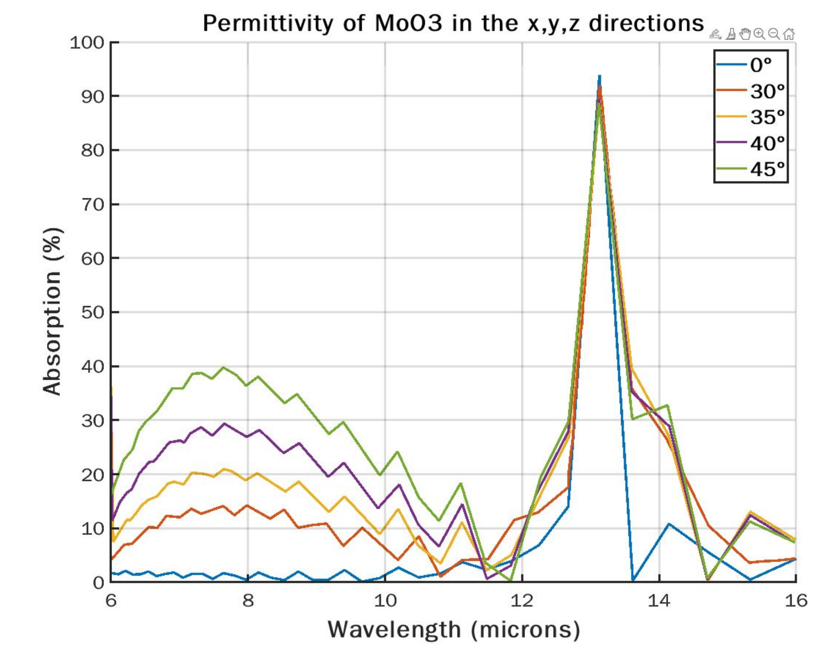

Figure 6: Absorption of light at different angles through a MoO_3 Film. Peaks at 93.8%

Conclusions

- Higher the thickness of MoO_3, the lower the absorption
  - A lower thickness = light more likely to scatter
- Spike at around 13 microns, similar to permittivity
- Placing gold below 'doubled' the absorption, since it is fully reflective at these wavelengths
  - Light passed through (absorbed once) and bounced back up to be absorbed again by MoO_3
- Not using geometrical arrangements worked the best
- Matches human black body curve well
  - Peaks at ~13 microns, high emission from humans
- Although faster than real life, each simulation took long time to complete
  - Limited ability to gather data (~25 minutes per run at the end)
- The less perpendicular the light is to the film, the more absorbent it is of other wavelengths
- Can be less expensive than some IR Absorbers
  - 99.5% Pure Vanadium ~$348/kg
  - 99.95% Pure Molybdenum ~$60/kg
  - *As of February 24, 2022*

Implications/Future Research

- Not as efficient when from angled light
  - Spend time adding to model to fix for future
- Experimental Results using FDTD may be similar to that of real data (Aizenberg, Joanna et al.)
- Absorption that peaks similar to human radiation = greater ability to detect humans than pre existing methods
- Smaller optical component = easier to fit in thermal imager = easier to carry imager around
- Can be used for detecting humans in situations like fires, military operations, or other events
- Future work to change polarization angle to test the abilities of the anisotropic material, since it has different permittivity at different polarization directions
- In the future potentially fabricate the film and test it in real life
  - Would be able to confirm the accuracy of FDTD
- Turn into fully functional IR Absorber, such as adding P-N Junctions

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