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All-Angle Polarization-Insensitive Infrared Absorbers for Detector Applications

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Introduction

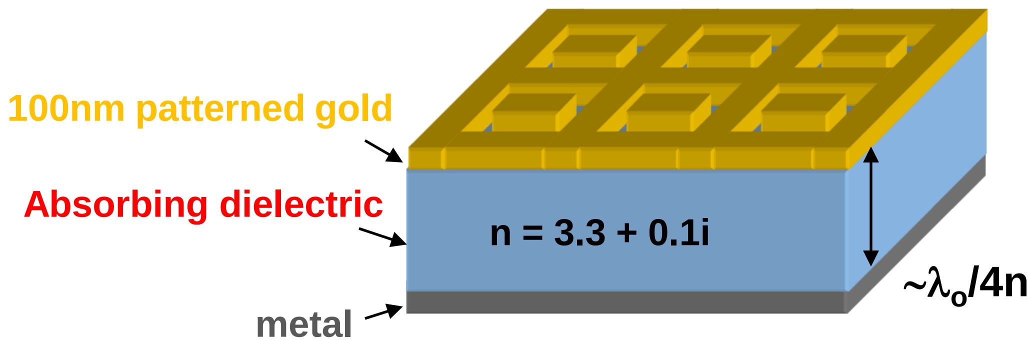
We demonstrate through simulation and experiment, an integrated nano-antenna with many highly desirable properties for infrared focal plane arrays (FPAs) and other applications.

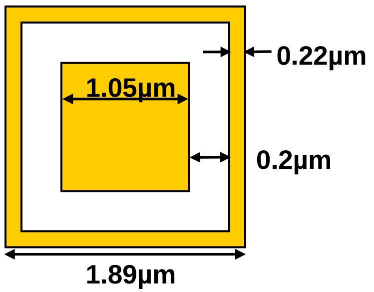
- **Highly absorbing (over 95%) antennas in the thermal infrared.**
- **Optically thin → much less than one freespace wavelength thick.**
- **Angularly insensitive.**
- **Polarization insensitive.**
- **Absorption band may be shifted by lithographic dimensional changes.**
- **Metal top and bottom layers allow for electrical contacts.**
- **Subwavelength design is highly flexible.**

Basic Geometry of Antenna

The antenna consists of three layers:

1. **Patterned metal layer** (a frequency selective surface (FSS), metafilm, or metamaterial)
2. **Thin absorbing dielectric layer** (HgCdTe or strained superlattice material).
3. **Metal ground plane.**





Subwavelength lateral dimensions: symmetric in x and y

Several geometrical parameters tune the central absorption wavelength.

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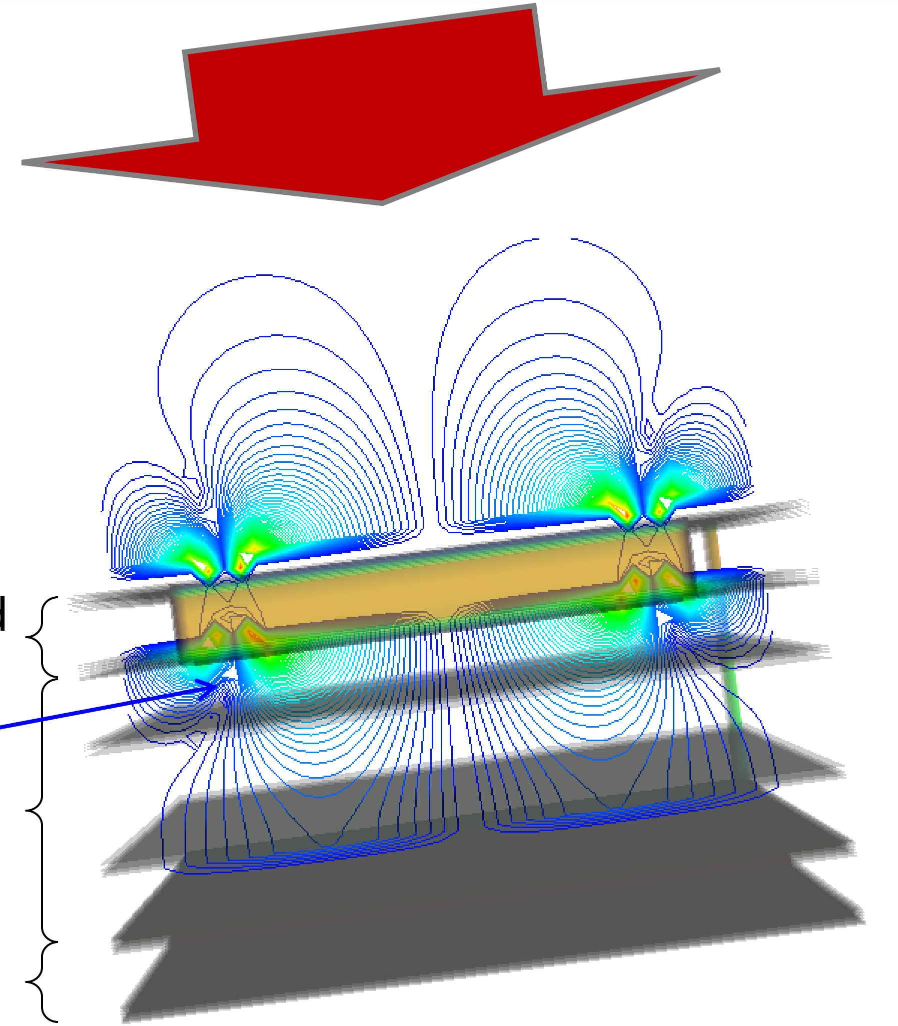
FDTD Simulation of Field Amplitude

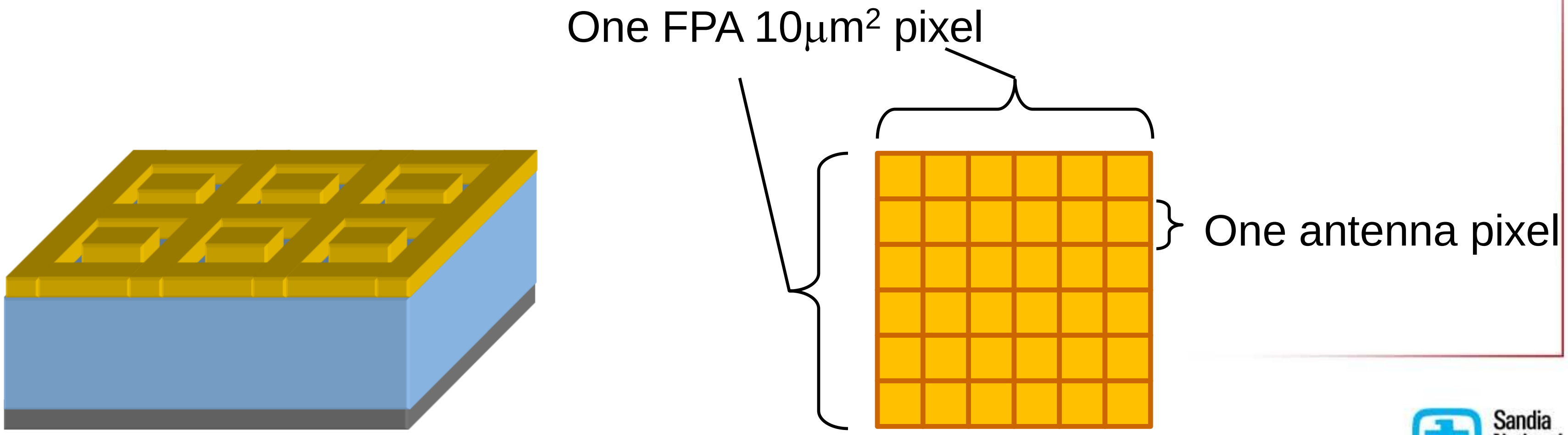
Incident radiation is coupled to surface modes with high field intensity.

Evanescently decaying surface waves do not require a great depth for total absorption.



Application to Focal Plane Arrays

- Thinner absorbing material leads to lower dark currents.
- Top and bottom contacts allow direct connection.
- Filtering can be changed from FPA pixel-to-pixel simply by changing the antenna pattern.
- Small antenna unit cell allows multiple unit cells per FPA pixel.



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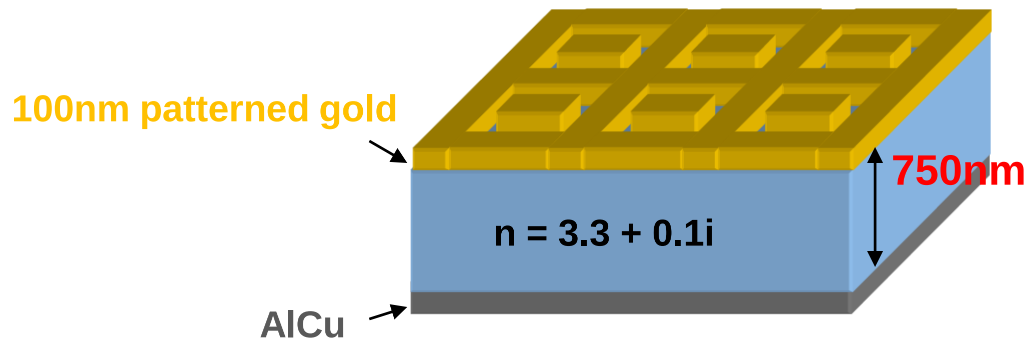
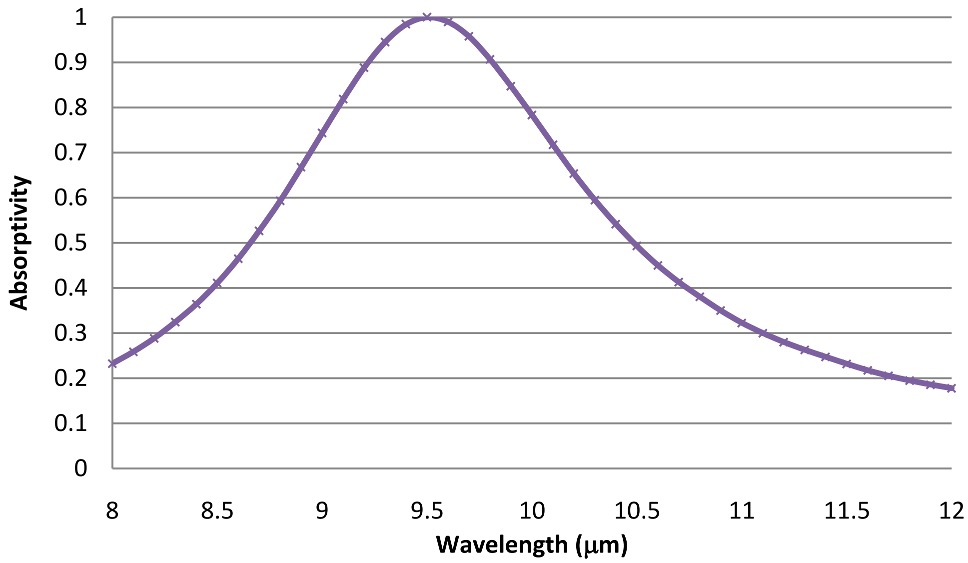
Simulation of Absorption

Rigorous Coupled Wave Analysis (RCWA)

Refractive index values for metals are taken from ellipsometry measurements of similarly deposited samples.

Leads to near-unity absorption (over 99%) at normal incidence for both polarizations.

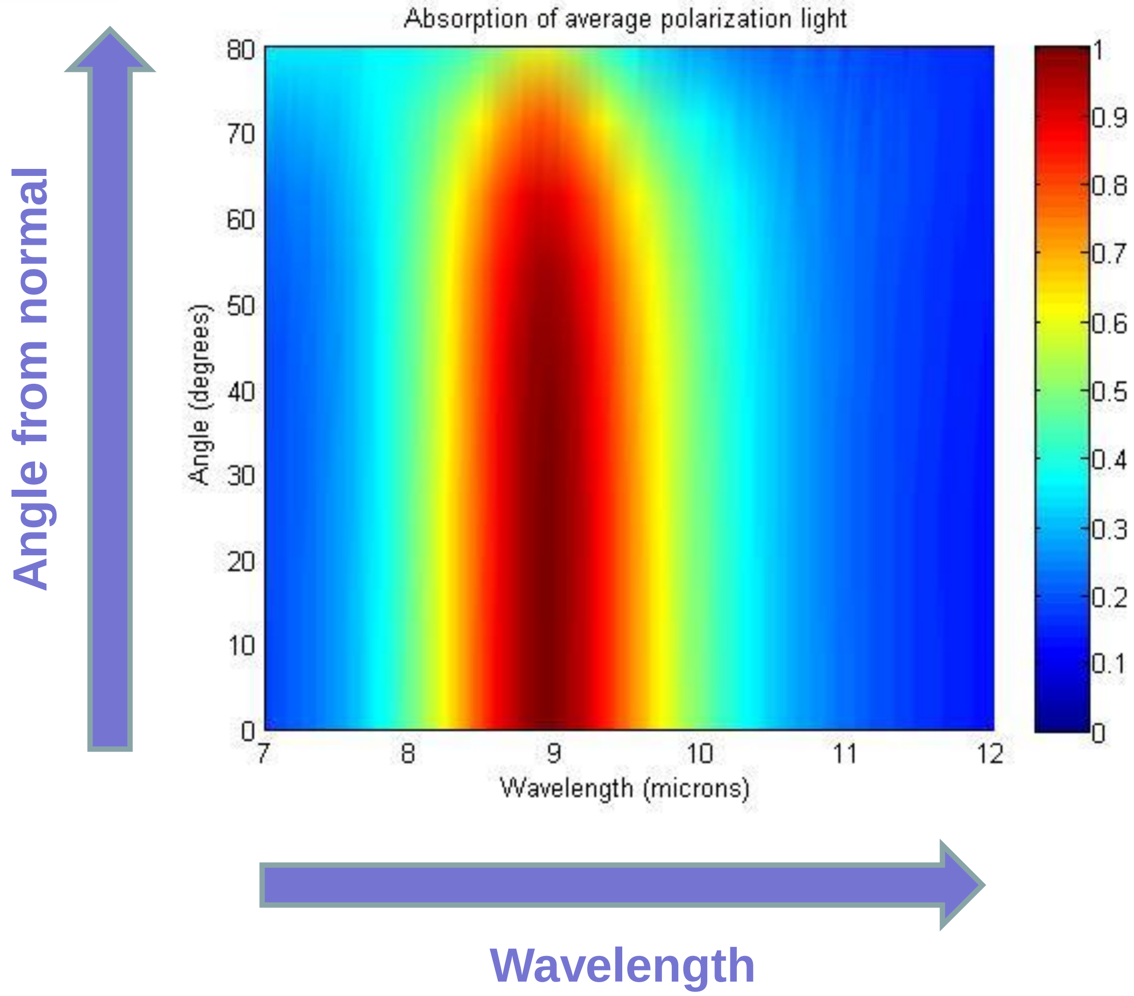




RCWA Simulation of Angular Response

Very high absorption for both polarizations out to 60° from normal incidence.

No change in center of absorption band.



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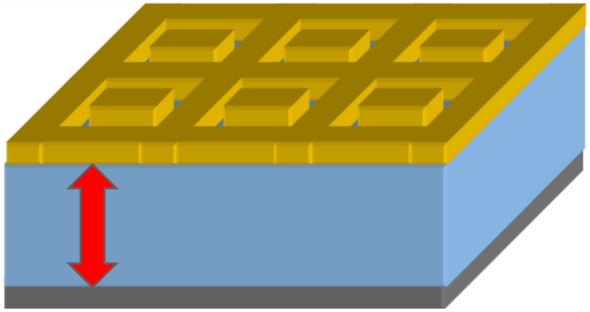
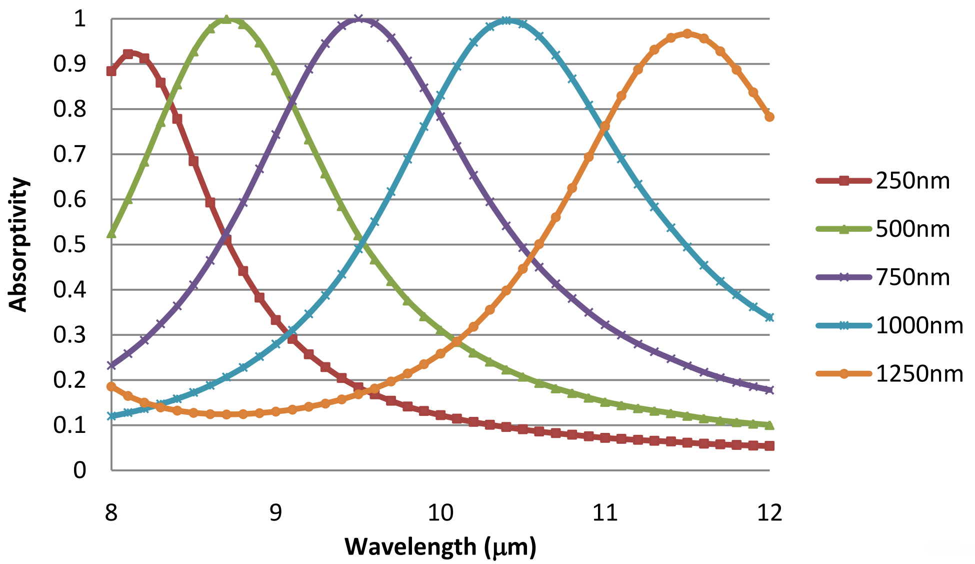
Tuning the Absorption: Function of Thickness

Here we investigate the effect of changing the thickness of the absorbing layer without any change to the lateral dimension of the FSS.

Even without adjusting the lateral dimensions, there is considerable latitude in shifting the peak wavelength.





However, tuning thickness is impractical on a pixel-to-pixel basis.

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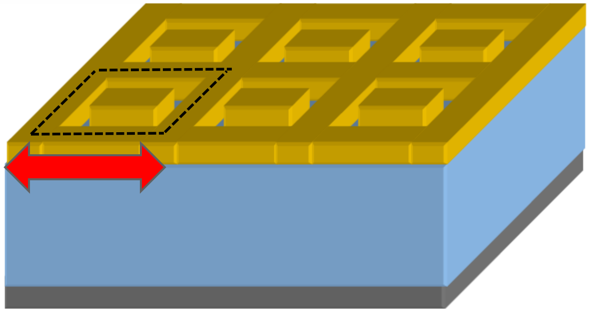
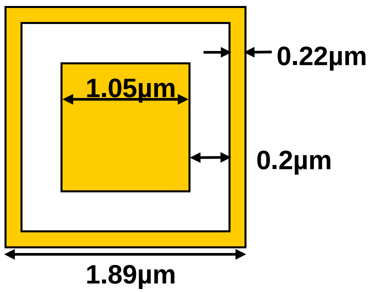
Tuning the Absorption: Function of Lateral Size of Unit Cell

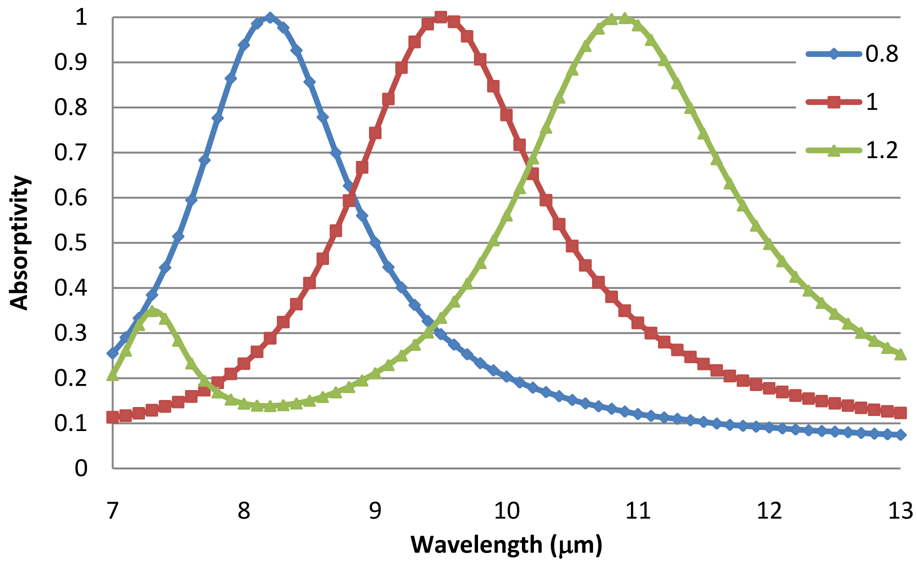
Scaling of the unit cell by ±20% has a similar effect without having to change the film thickness.

~1.4µm shift in either direction with the 20% change in unit cell size.



Unscaled dimenisons



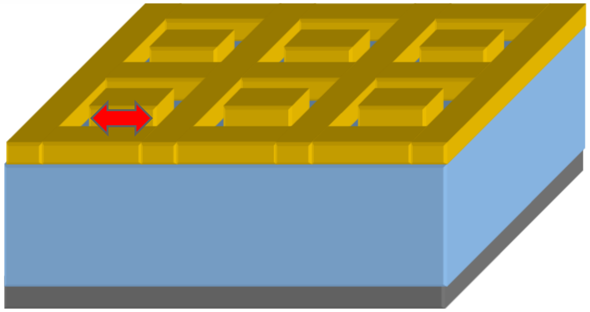


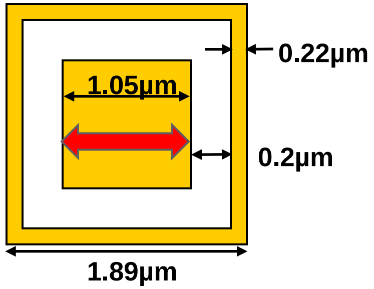
However, it is still difficult to place arrays of different sized unit cells on adjacent FPA pixels.

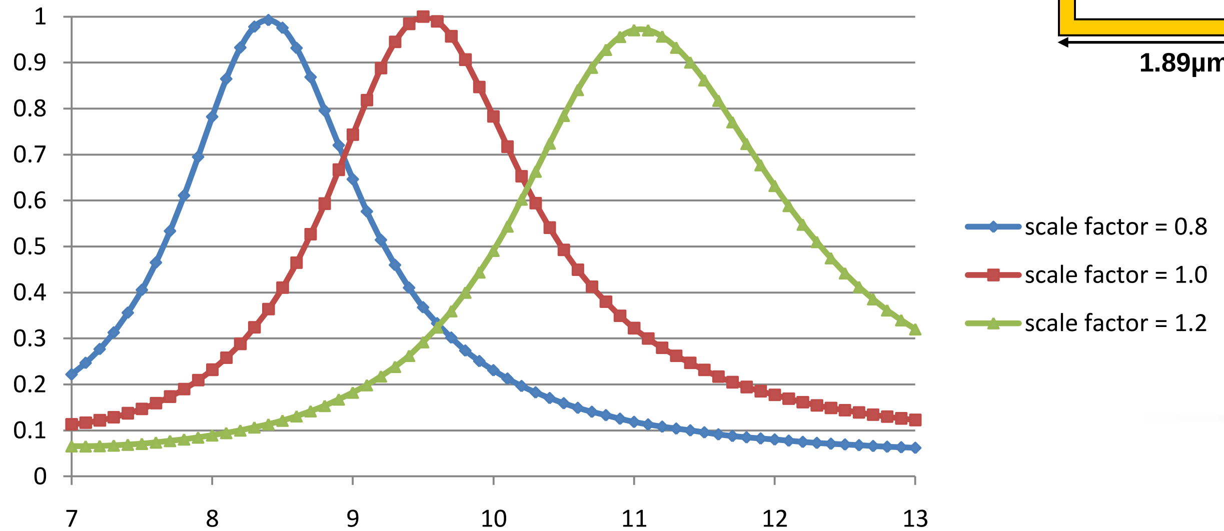
Tuning the Absorption: Function of Central Square Size

Changing the central square by trading off area with the open aperture also shifts the central wavelength.

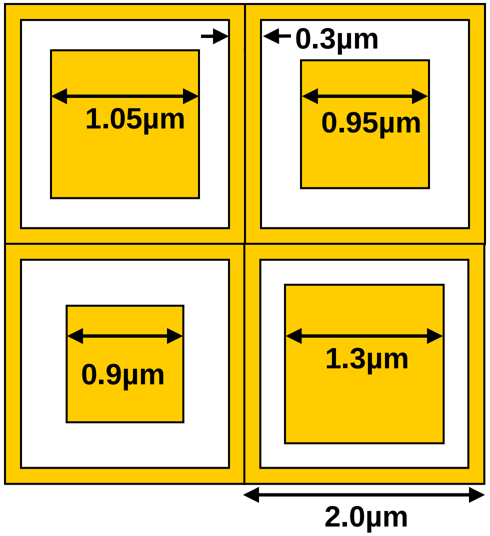
This allows the unit cell size to be fixed, making adjacent FPA pixels have same-sized antenna arrays.

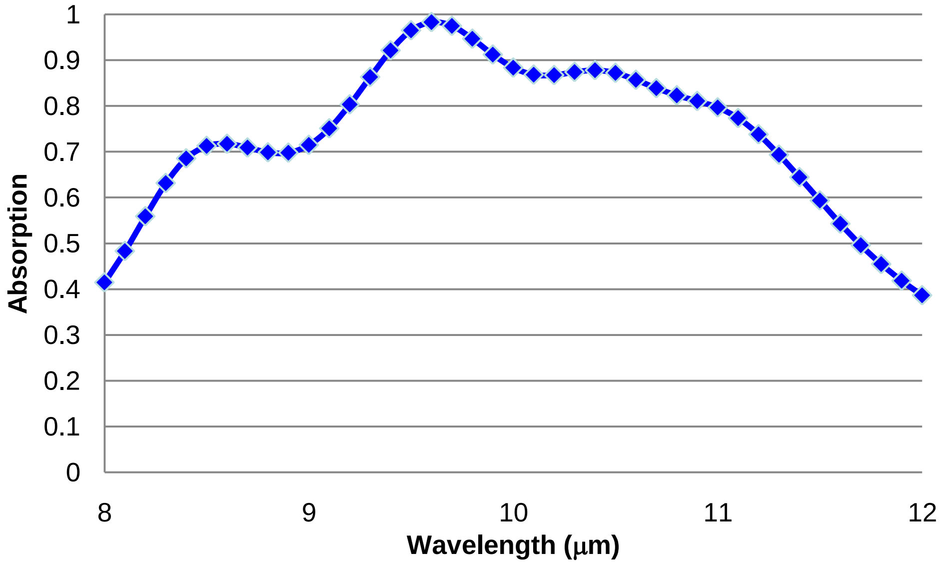






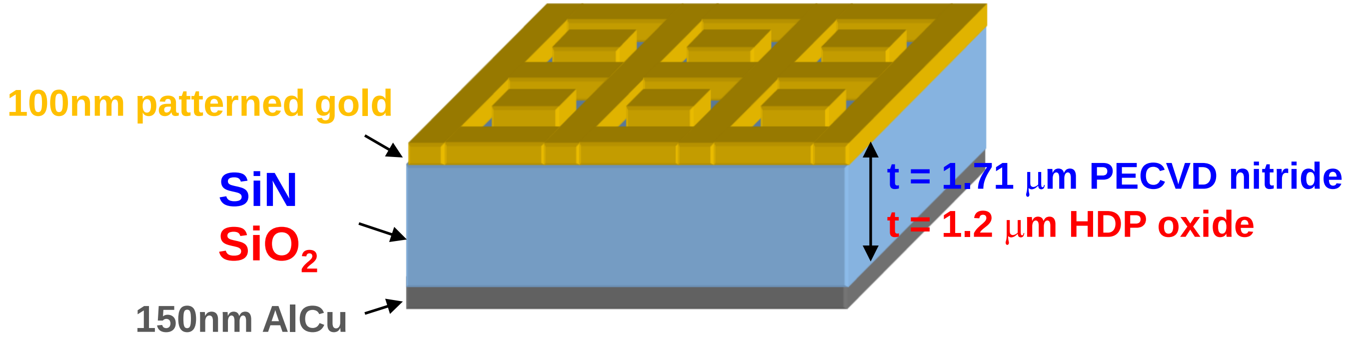
Supercell for Bandwidth Broadening



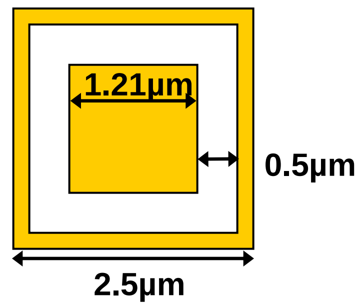


- An intra-FPA pixel supercell allows broadening of the bandwidth.
- Supercell with identical outer grids but different inner cell sizes.
- Widens bandwidth considerably.
- Further optimization required.

Experimental Devices



In place of the semiconductor layer we use readily available materials with absorption bands in the thermal infrared: SiN and SiO_2.



Subwavelength lateral dimensions

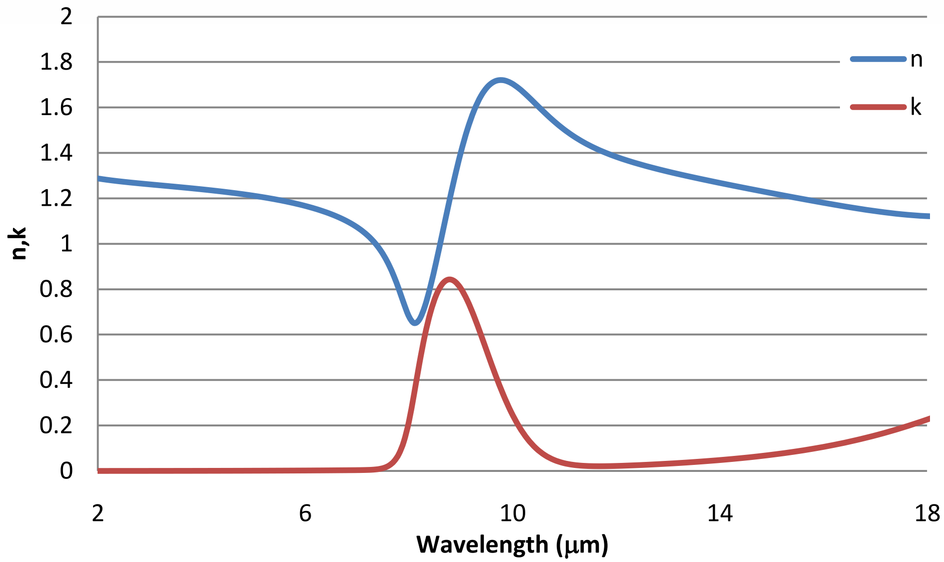
Refractive index profiles for SiN and SiO_2

Measured refractive index of SiO_2 and SiN films.

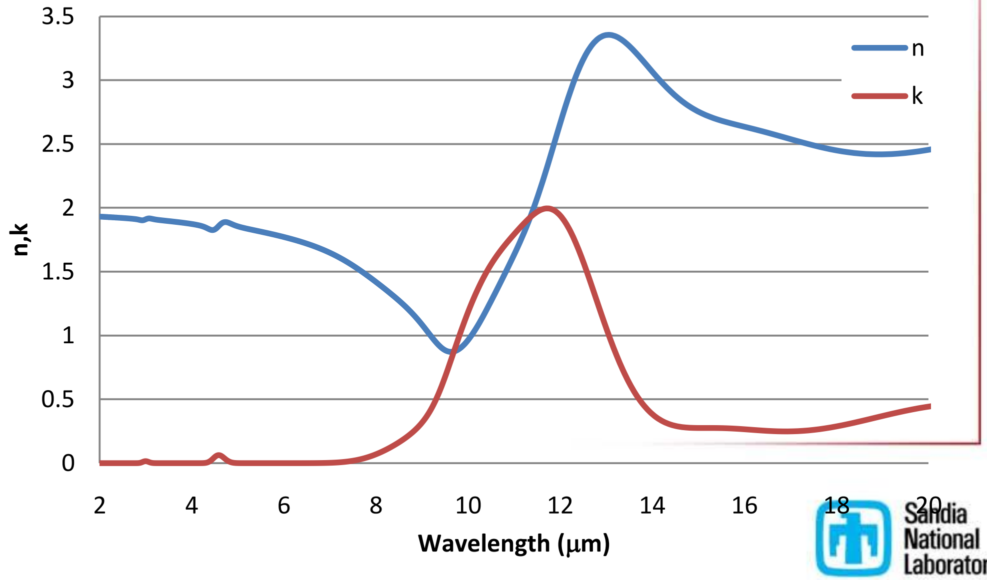
Absorptive feature in middle of thermal infrared band.

Refractive index is not ideal as k is quite large and n drops below 1.

SiO_2



SiN



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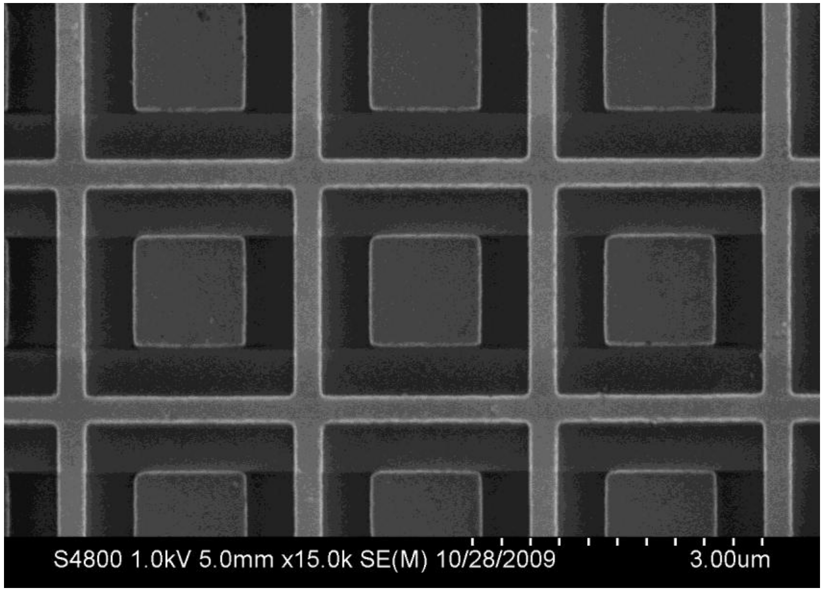
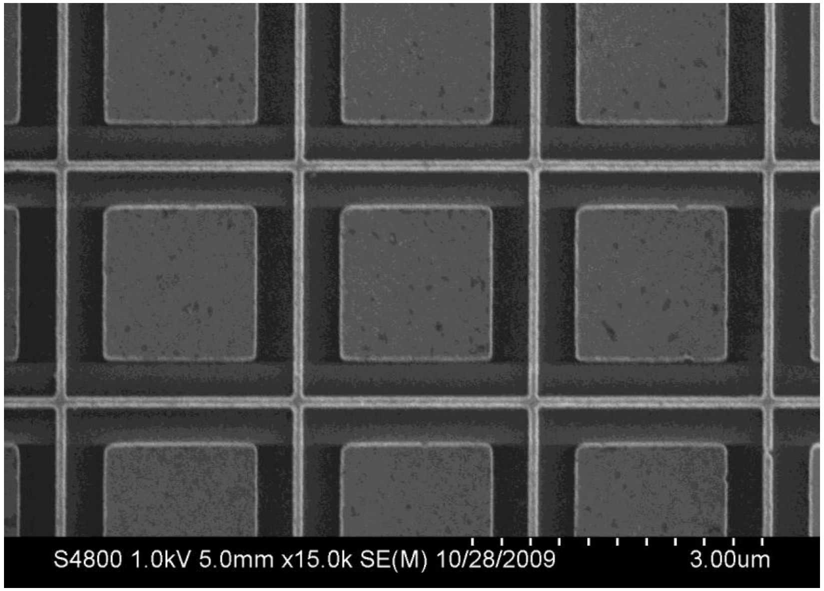
SEMs of Experimental Devices



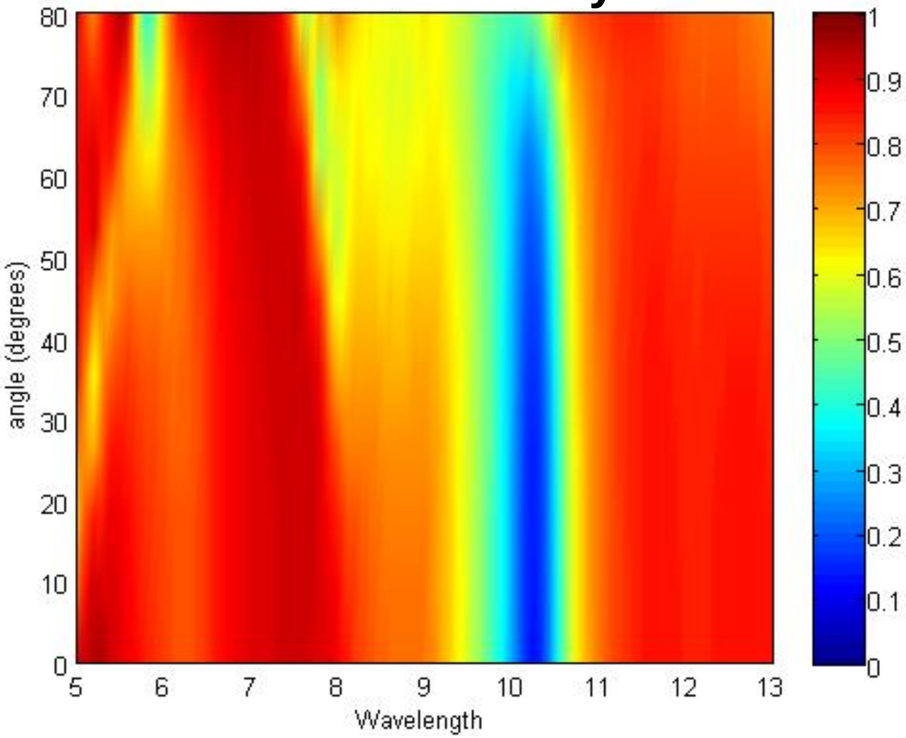
SiO_2



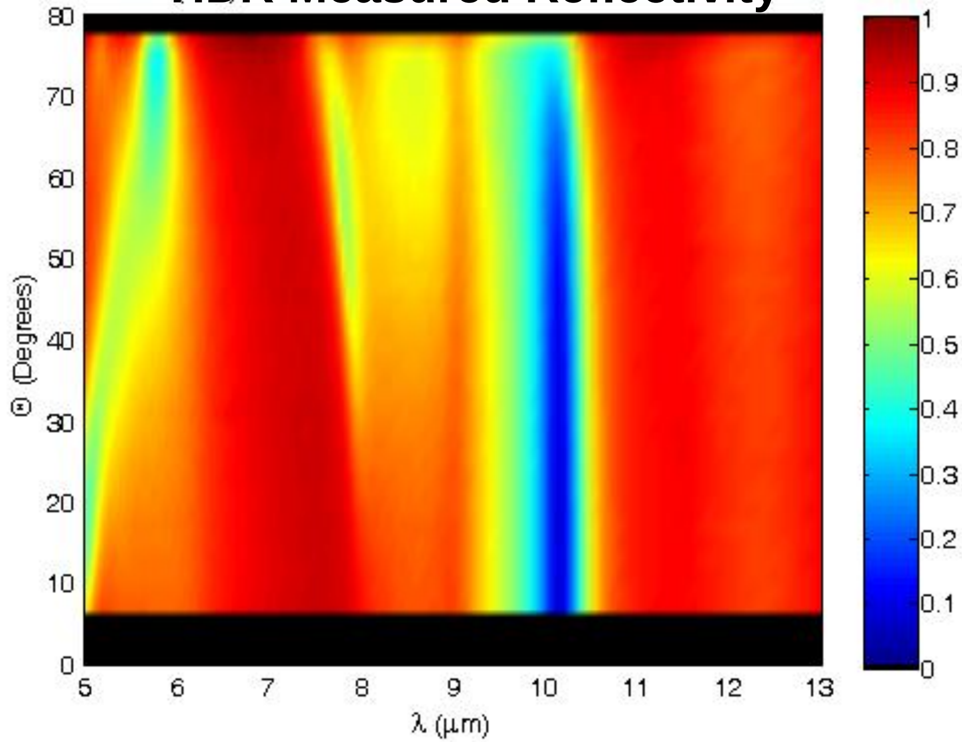
SiN

SiO_2 Results: 10μm Design

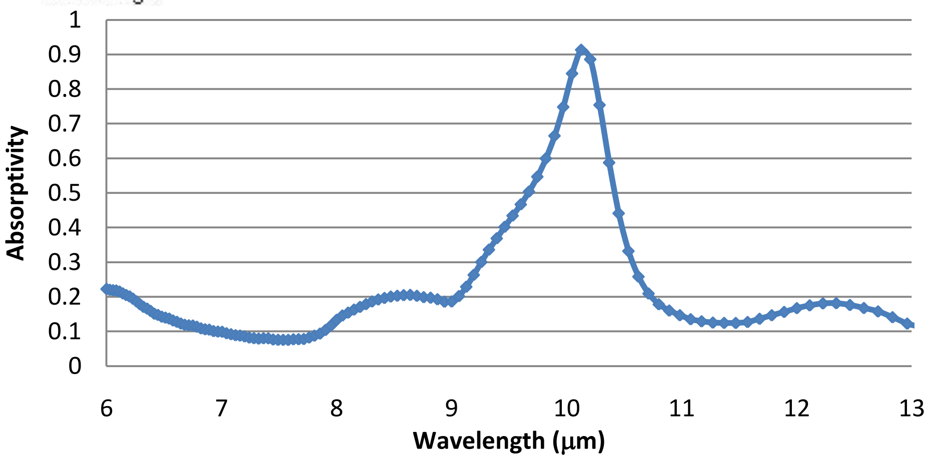
RCWA Reflectivity

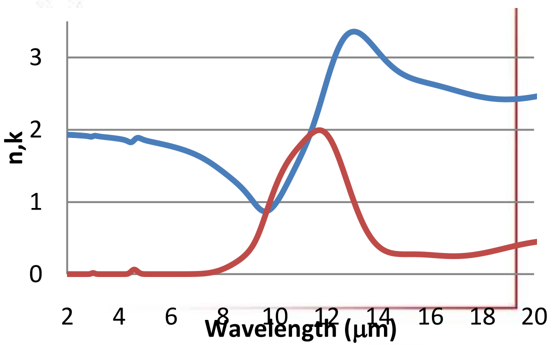


HDR Measured Reflectivity



Near-normal absorption





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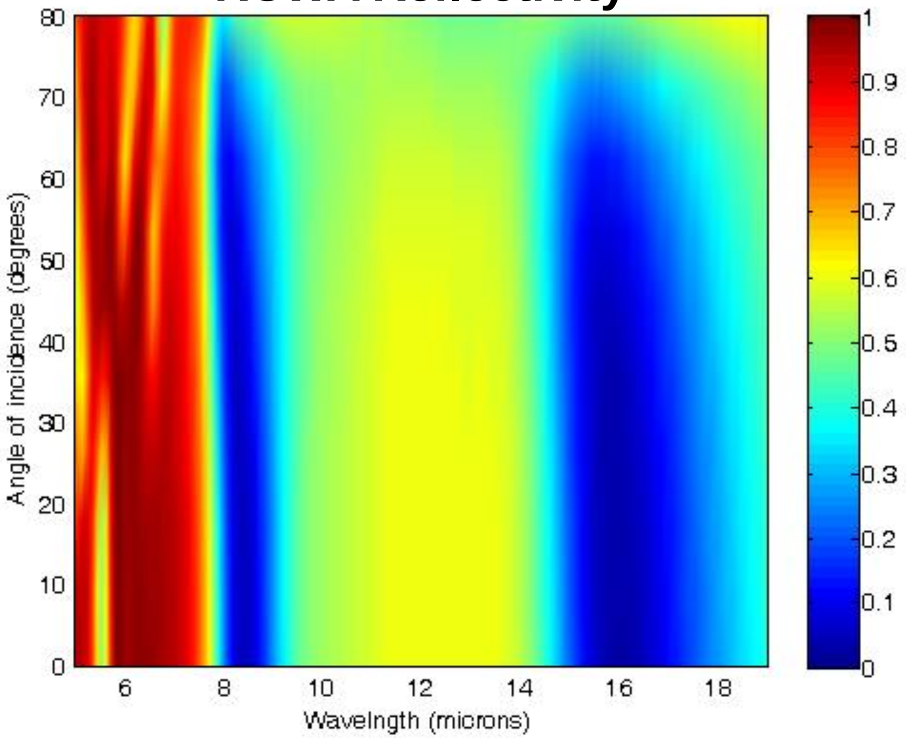
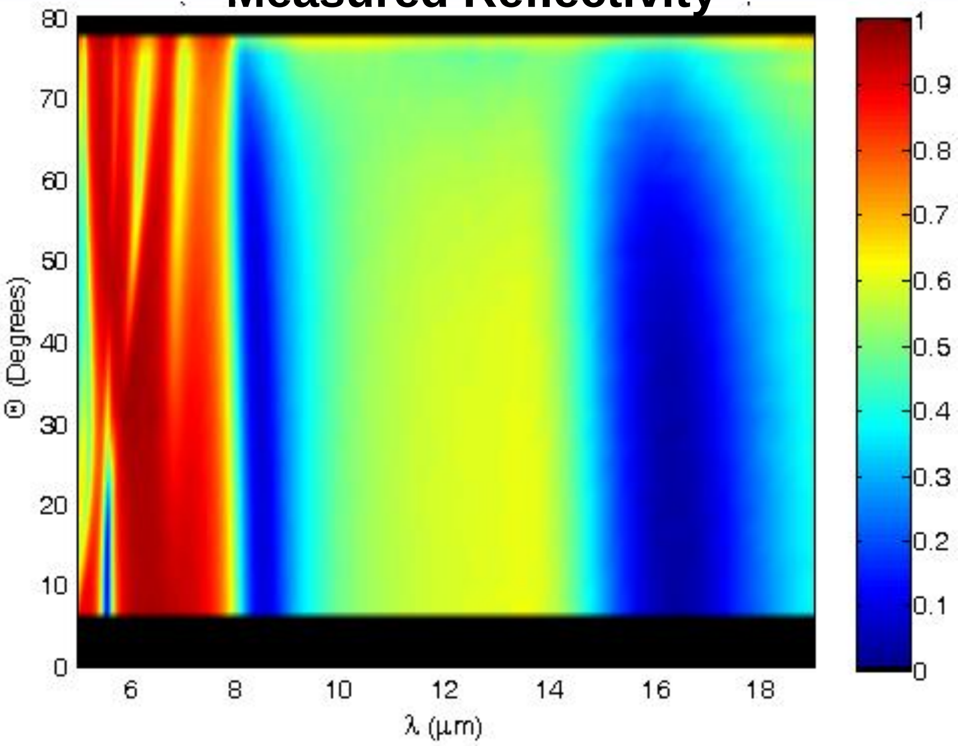
SiN Results

RCWA Reflectivity



Measured Reflectivity



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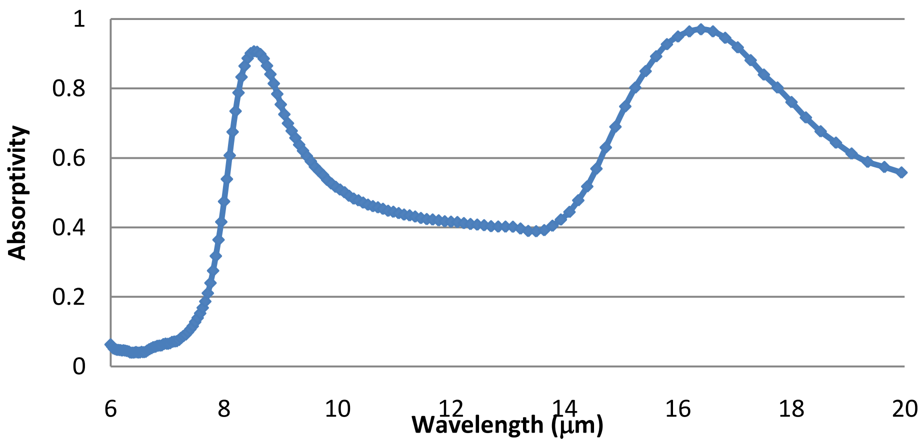

Conclusions

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