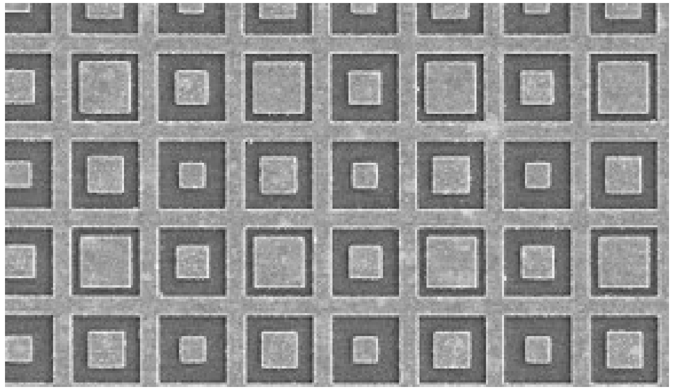
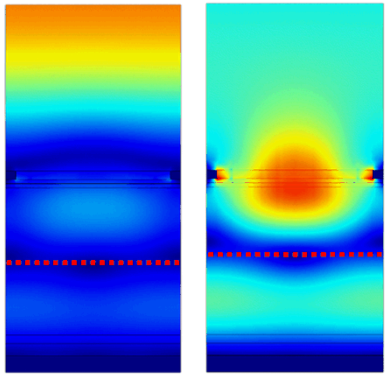
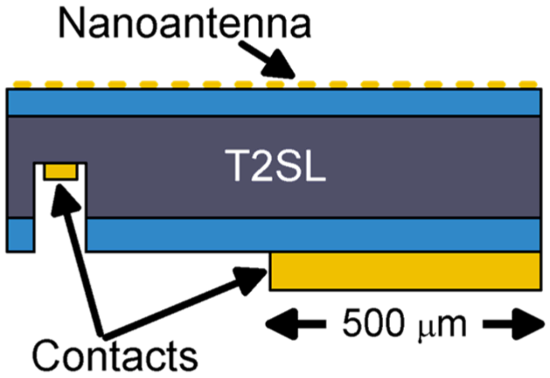
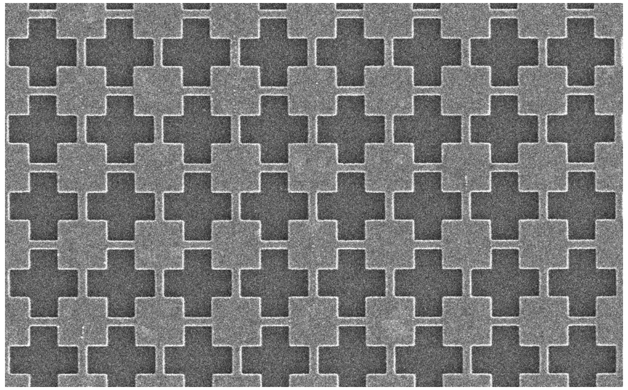
SAND2017-8308C









Resonantly enhanced infrared detectors based on type-II superlattice absorbers

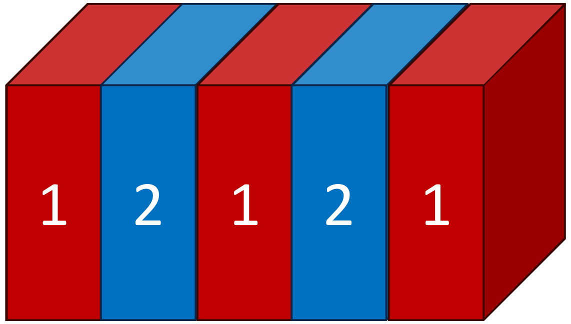
Michael Goldflam

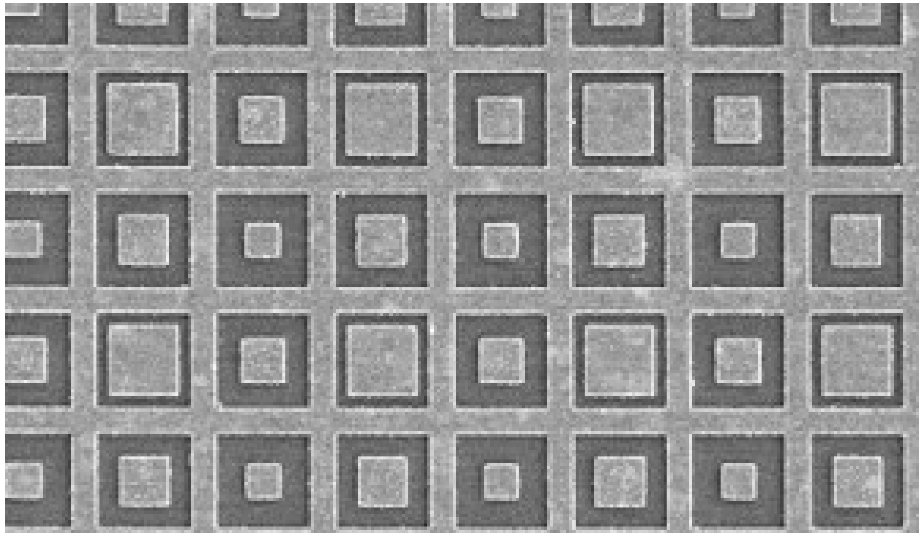
S. Campione, E.A. Kadlec, S.D. Hawkins, W.T. Coon, T.R. Fortune, S. Parameswaran, G.A. Keeler, J.F. Klem, A. Tauke-Pedretti, E.A. Shaner, P.S. Davids, L.K. Warne, J.R. Wendt, J.K. Kim, D.W. Peters

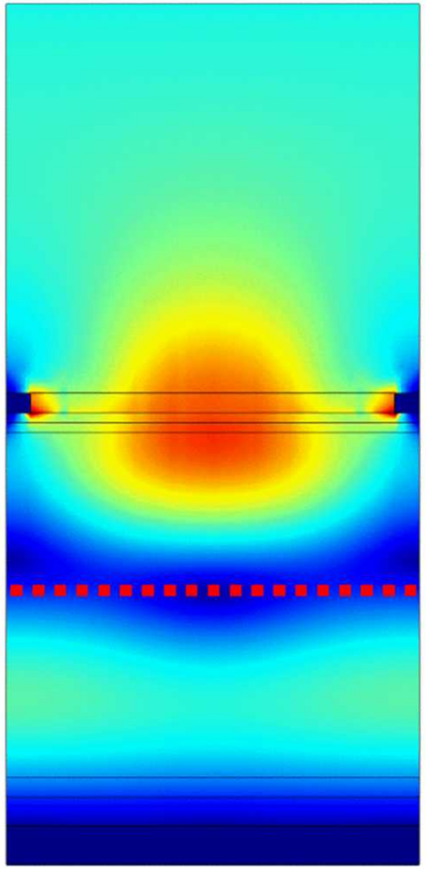
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

- Infrared detection
  - Type-II Superlattices
- Resonant detector structures
  - Single color
  - Two-color
- Summary







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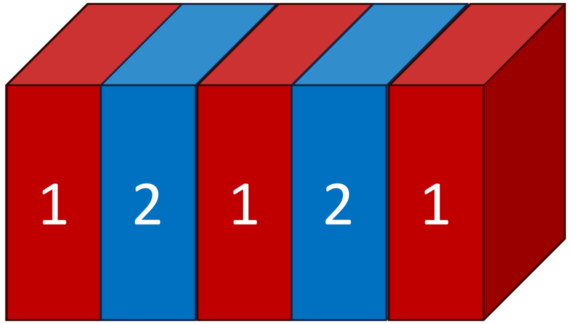
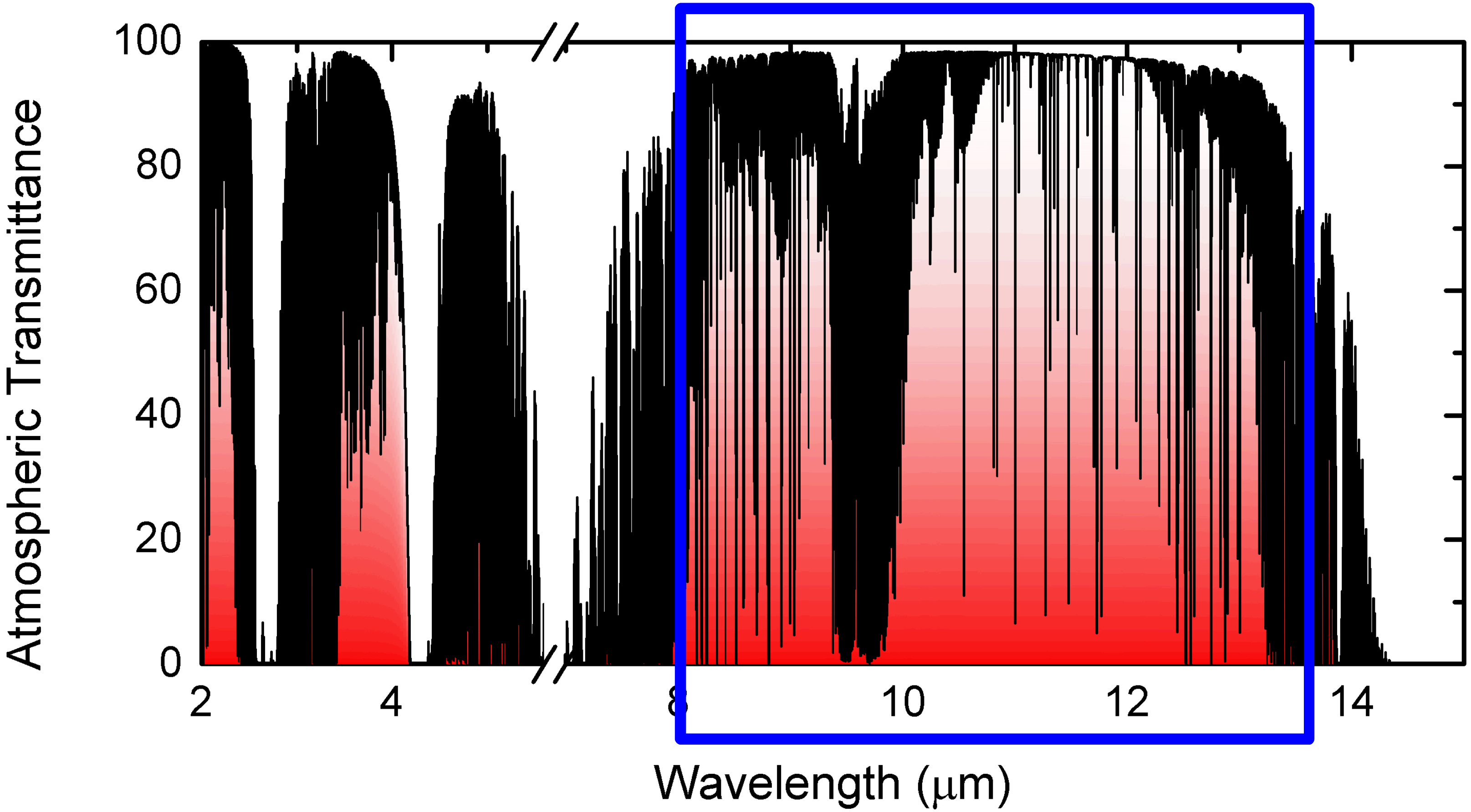


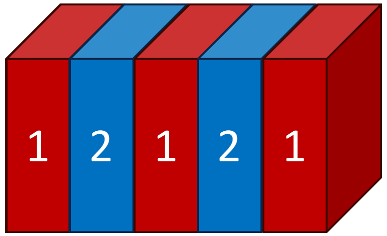
Infrared Detection



Lord, S. D., 1992, NASA Technical Memorandum 103957, Gemini Observatory

Type-II Superlattices

- InAs/(In)GaSb
- **InAs/InAsSb**
- InGaAs/InAsSb



- Easily controllable bandgap
- Wafer uniformity
- Predicted lower predicted dark current than MCT.

E.H. Steenbergen, et al., 10111, 1011104 (2017).

Type-II Superlattices

- InAs/(In)GaSb
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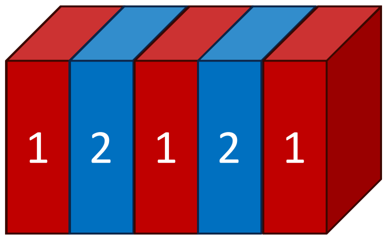
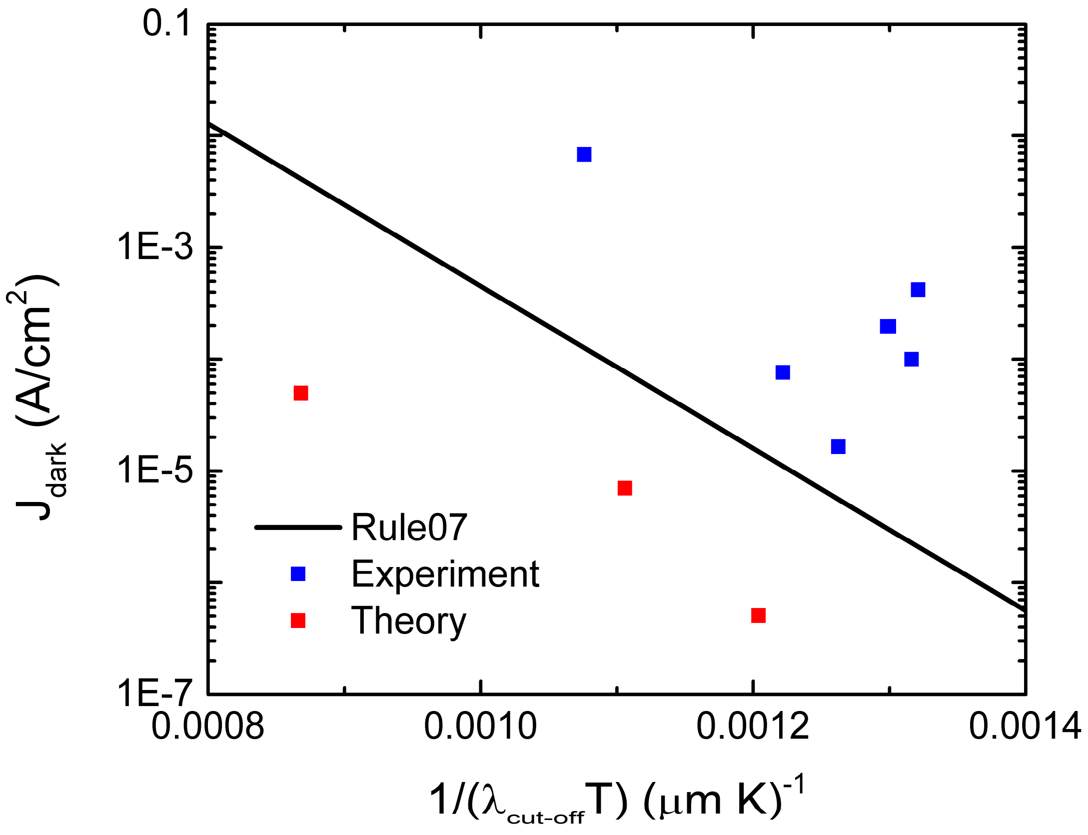


- Easily controllable bandgap
- Wafer uniformity
- Predicted lower predicted dark current than MCT.
- Lower absorption coefficient than MCT



W. E. Tennant, J. Electron. Mater. 39 (7), 1030 (2010).

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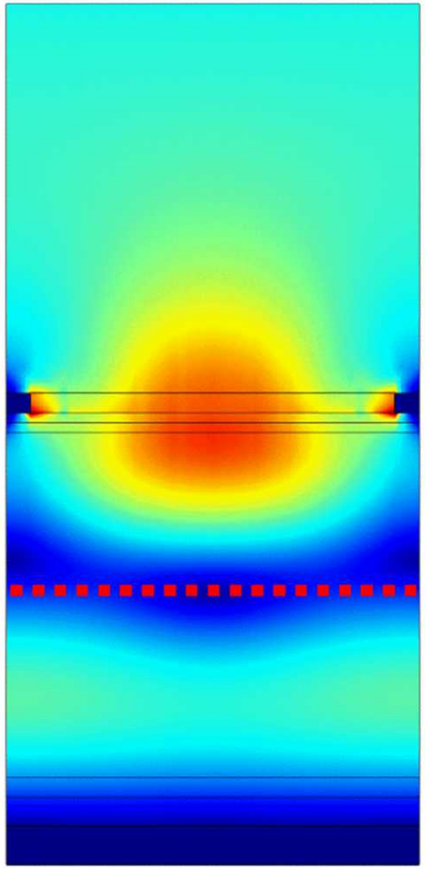
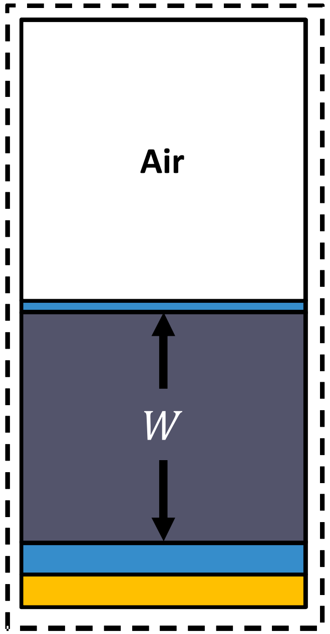
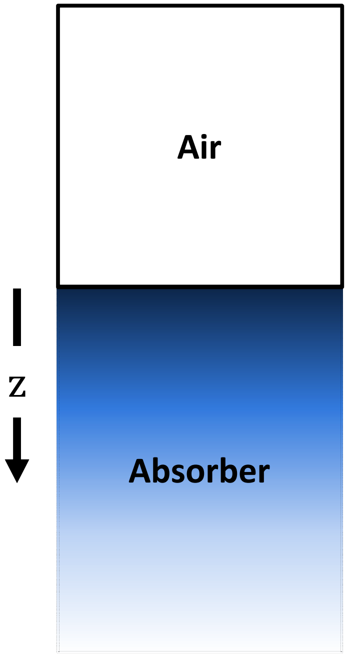


Detector structure

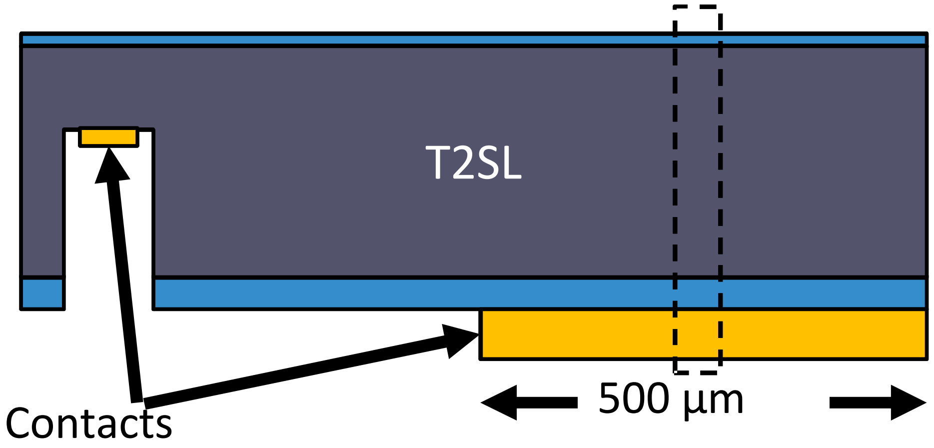




$$\text{Absorption} \propto e^{-\alpha z}$$

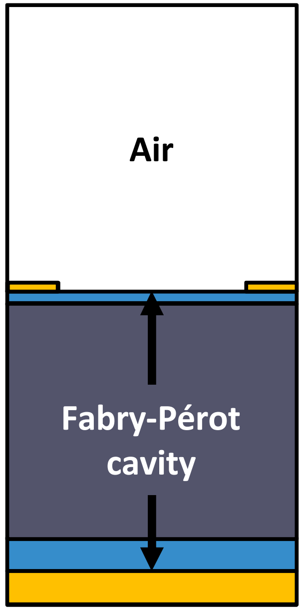
Dark Current: $J_{\text{diff}} \propto W$

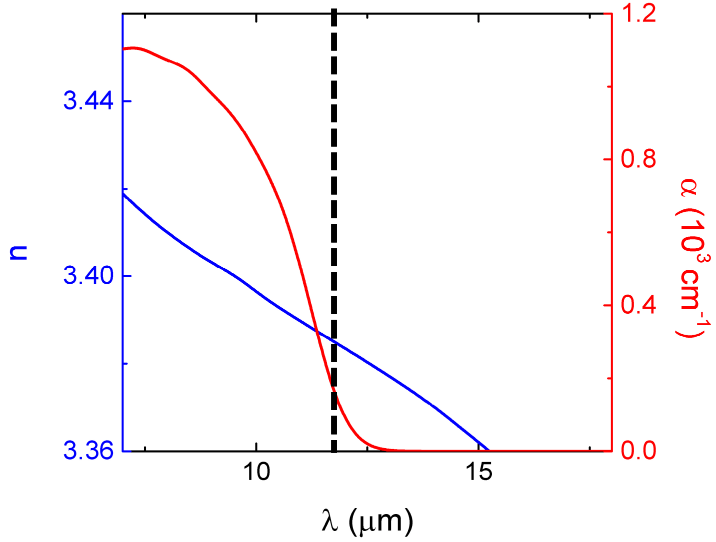
- Thick structures absorb more but have higher dark current.
- Enhance field in detector using resonant structures → increase absorption/QE.
- Enable higher operating temperature.



M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

Detector structure





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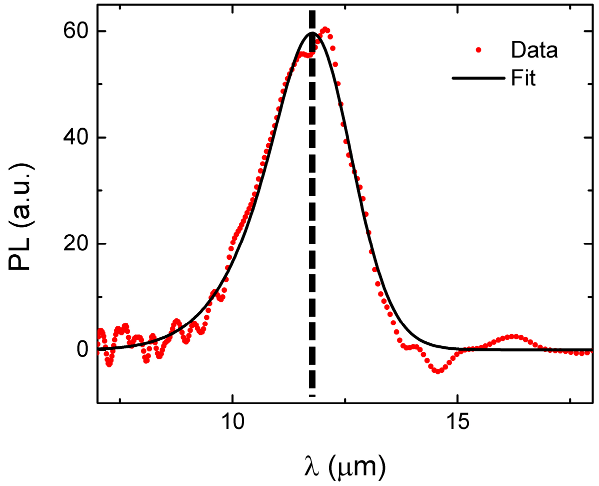
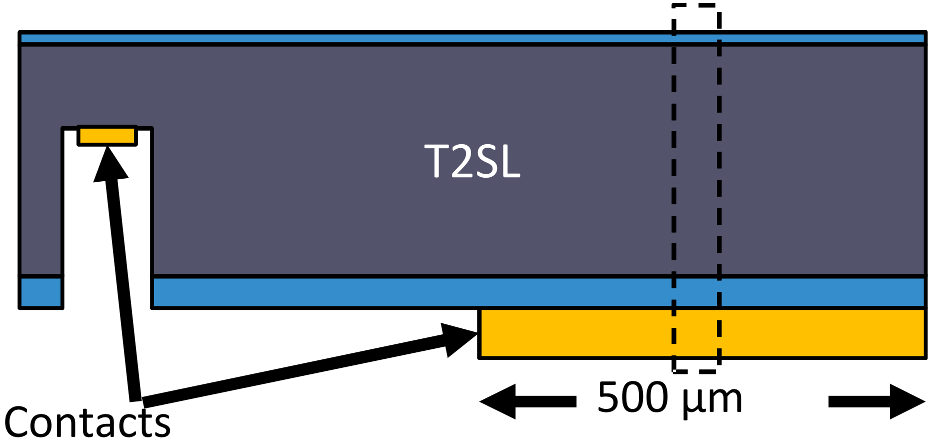
$$\lambda_{res}^{FP} = \frac{4nt}{2m-1}$$

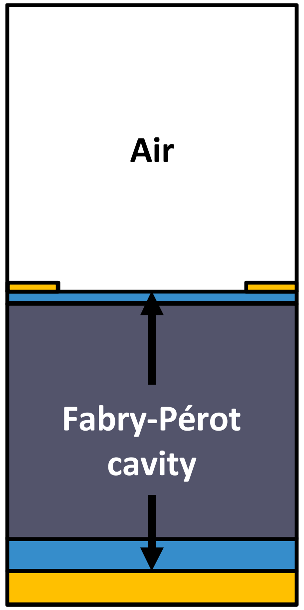
$$t \sim 2\ \mu\mathrm{m}$$





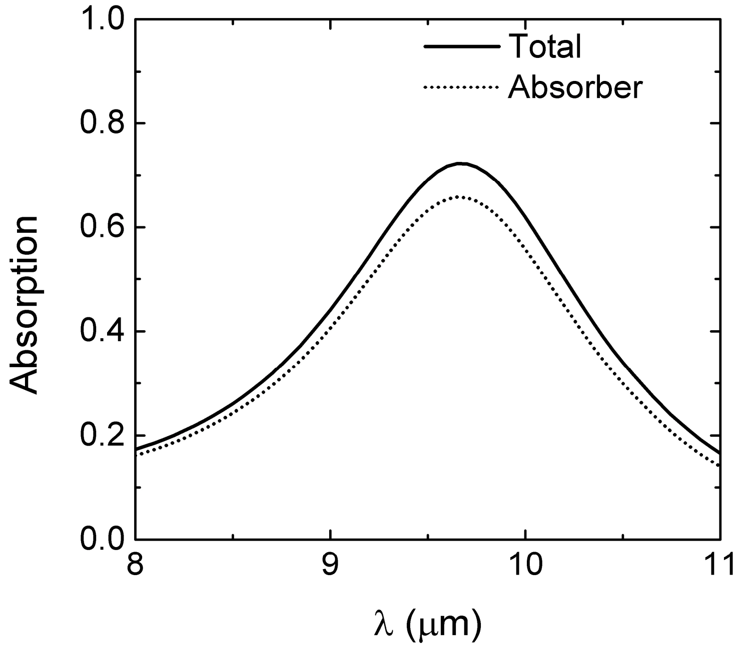
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

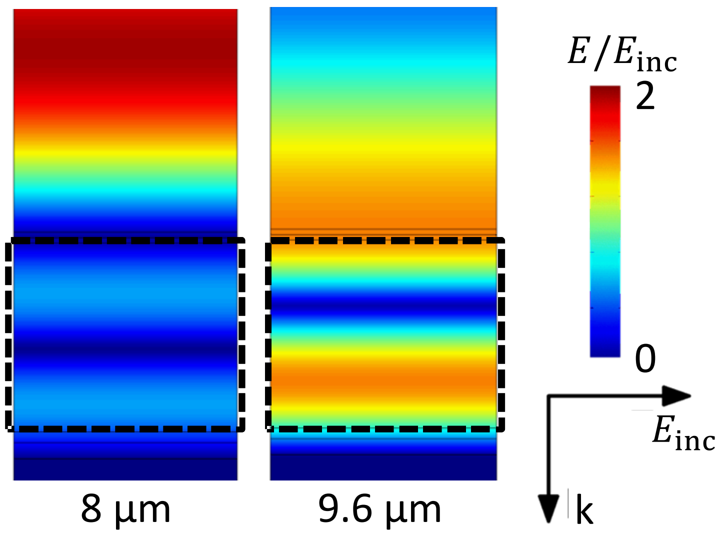
Resonant detector: Fabry-Pérot



$$\lambda_{res}^{FP} = \frac{4nt}{2m-1}$$

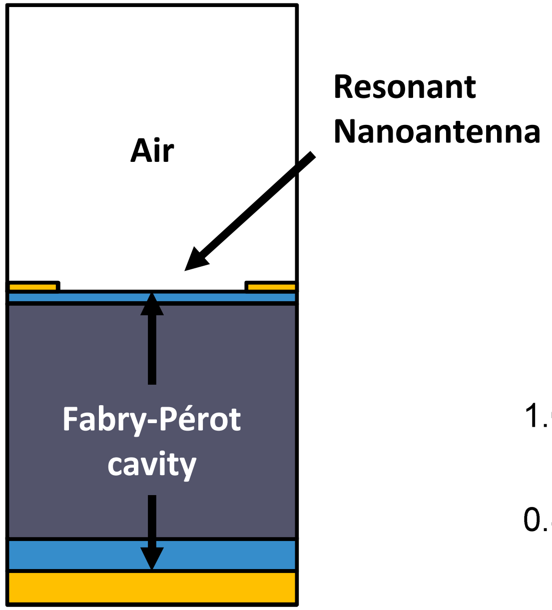
$t \sim 2\ \mu\text{m}$

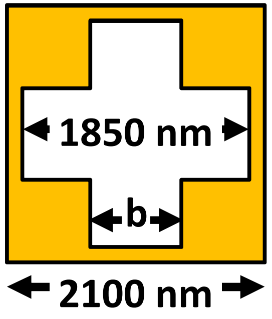


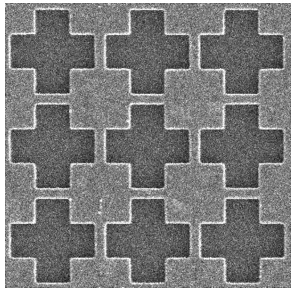


M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

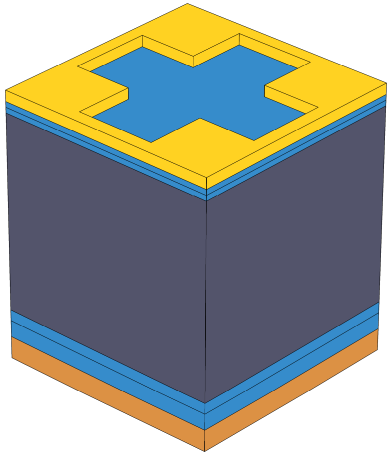
Coupled Resonances

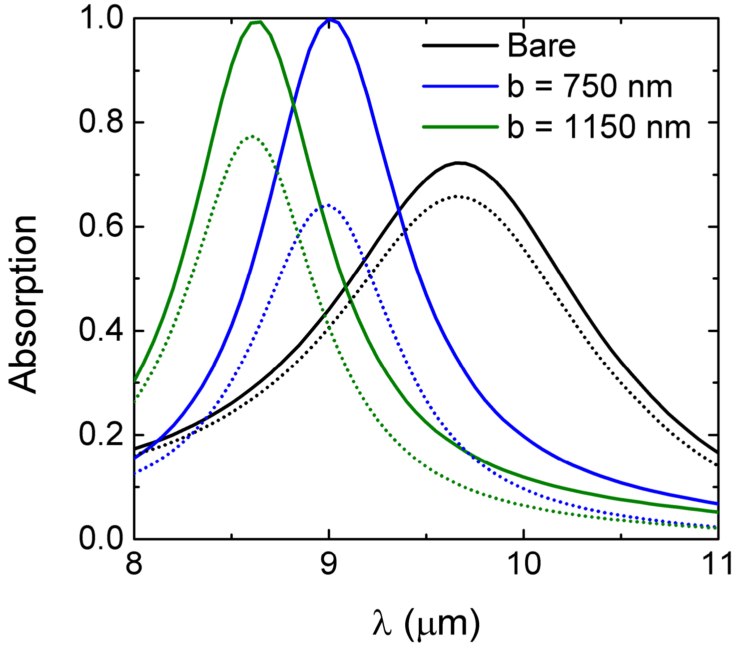


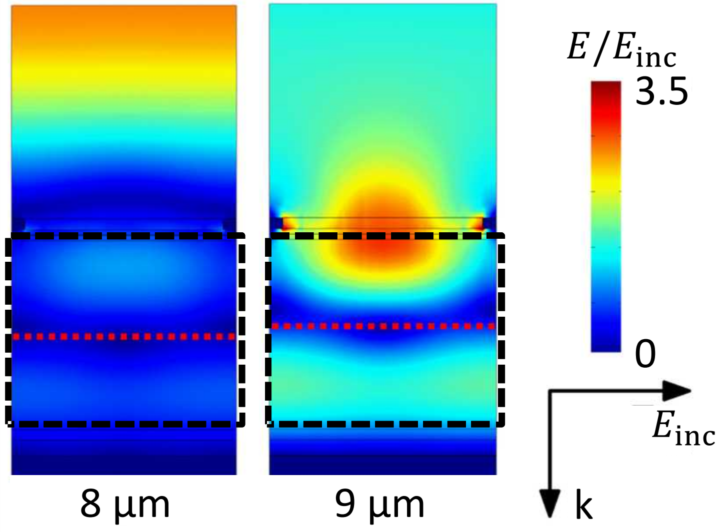




- Employ coupled resonances: Fabry-Pérot cavity with metal nanoresonator.
- Variable response in fixed detector by modifying nanoantenna only.



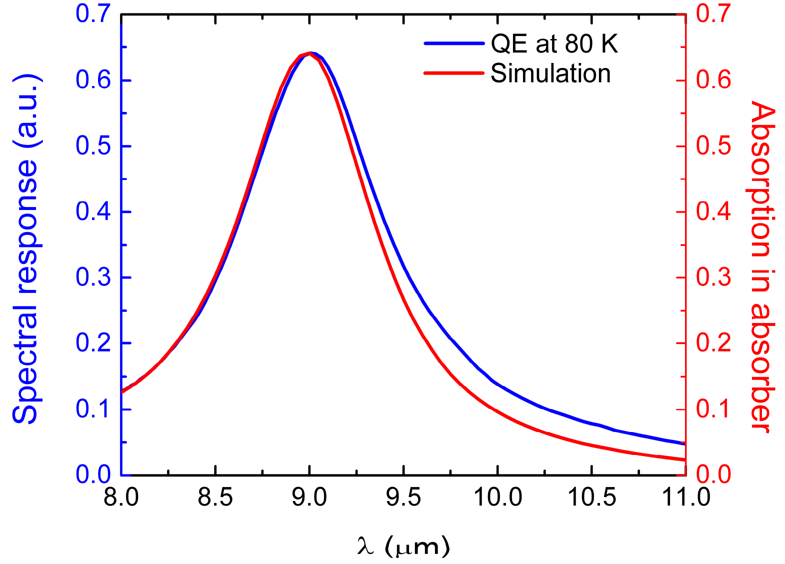


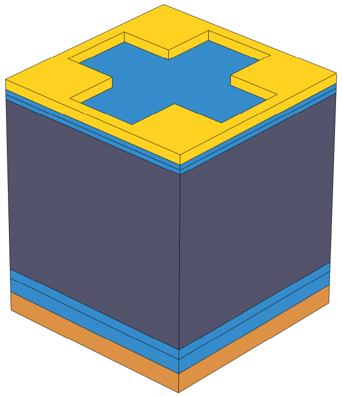


Majority of “lost” absorption is in the nanoantenna

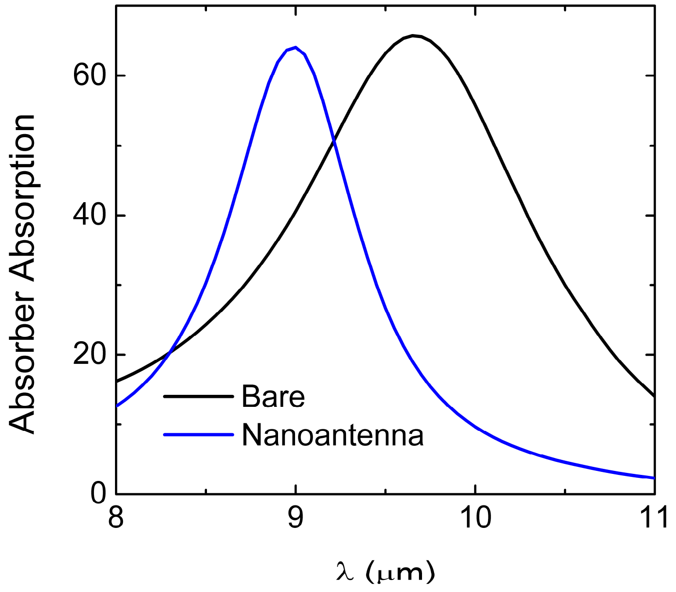
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

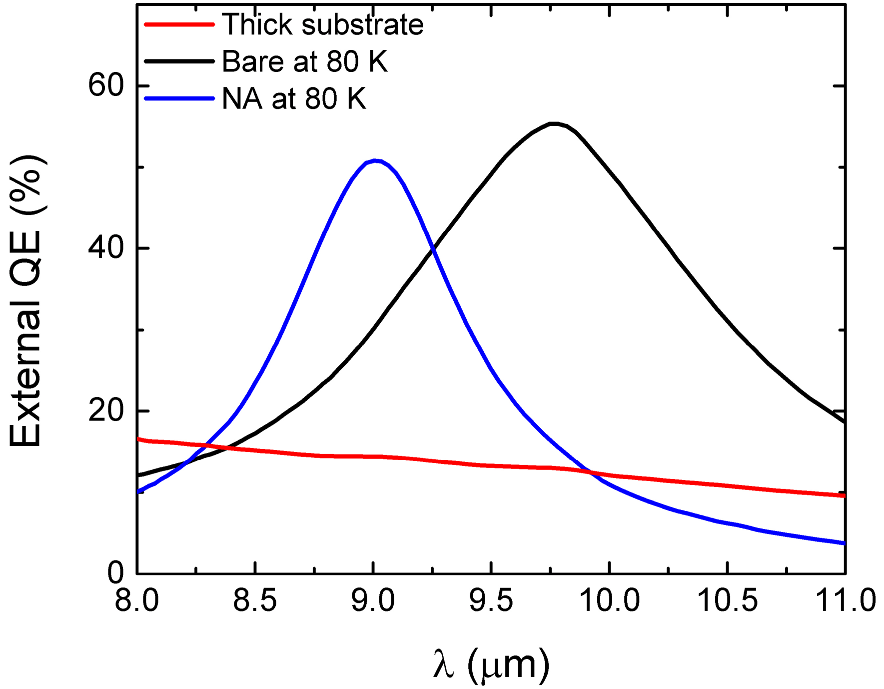
Measured Quantum Efficiency





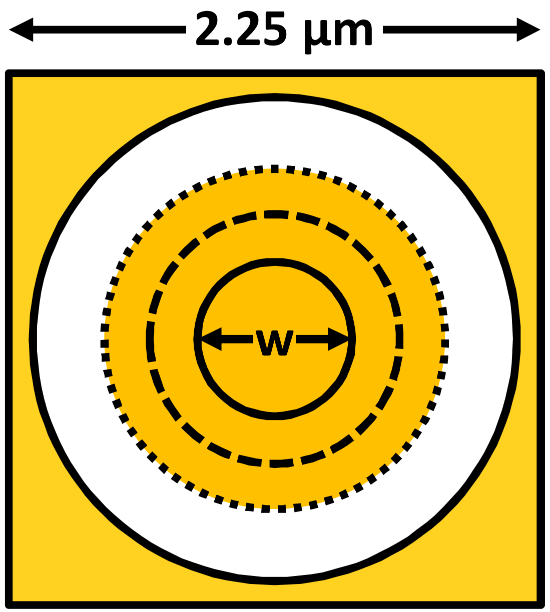
- QE>55%: 4-5x improvement compared to non-resonant detector.
- Similar to conventional filter but improves performance
- Temperature independent spectral response: lower cooling requirements.

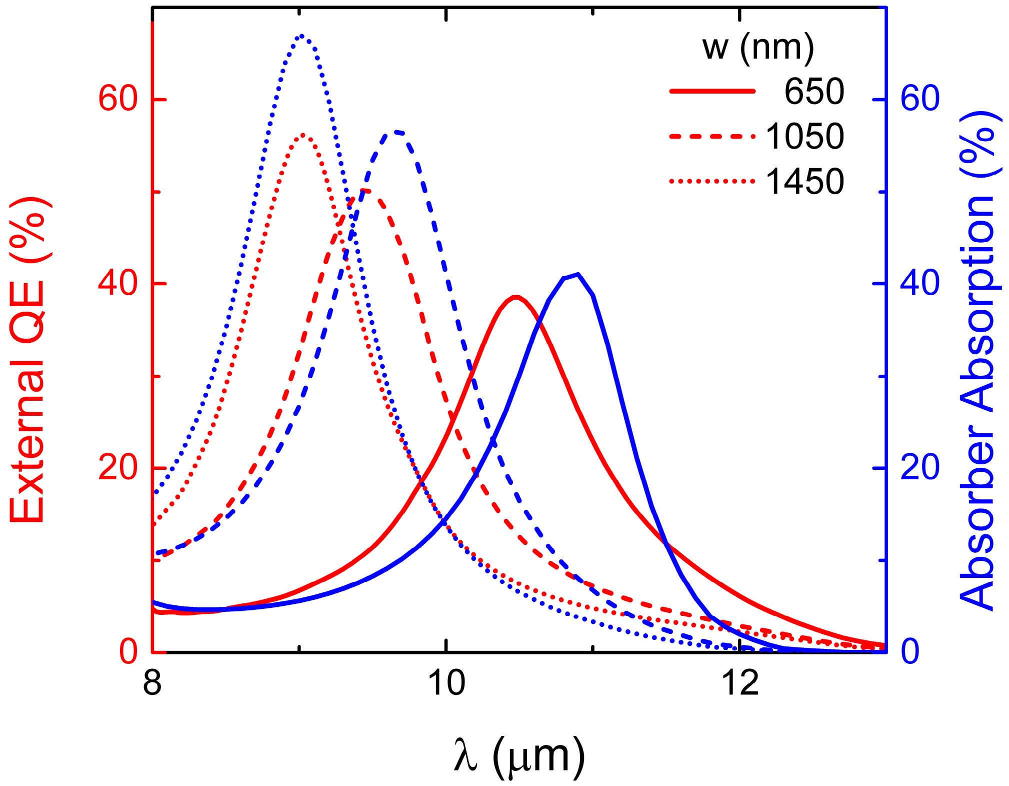




M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

Resonance Wavelength Modification





Nanoantennas enable a fixed detector stack to be resonant at multiple wavelengths without changing detector itself.

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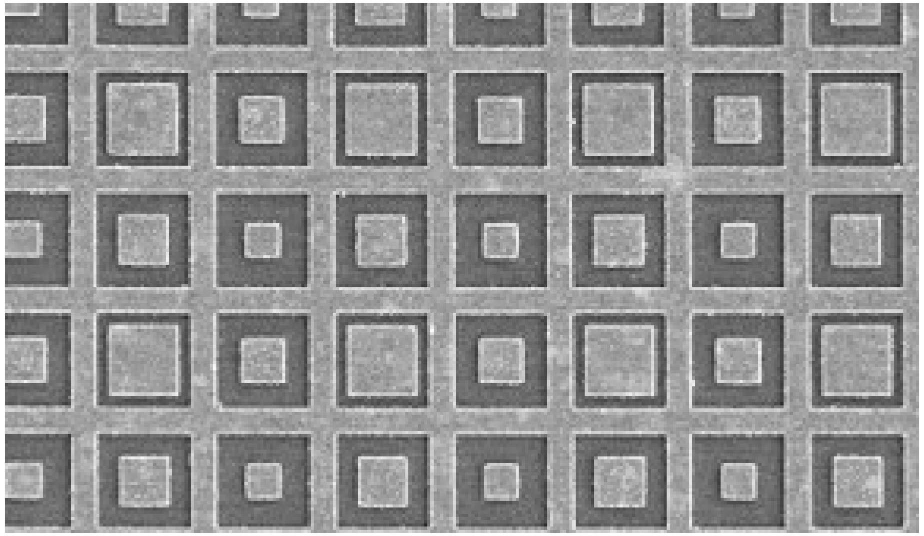
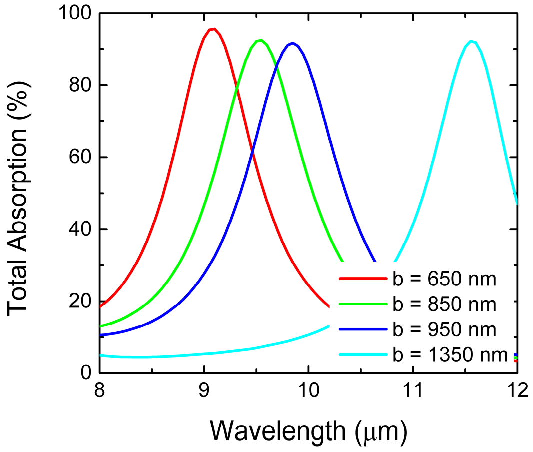
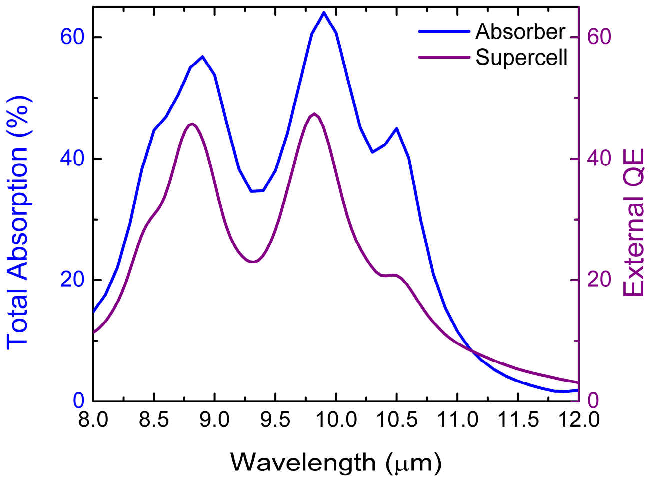
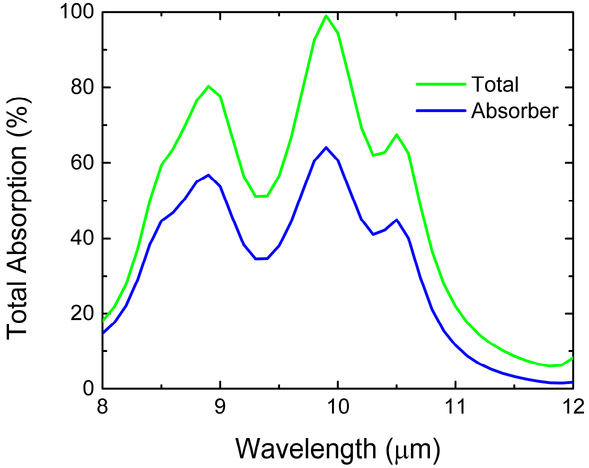
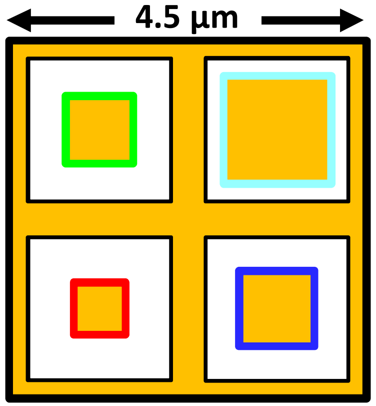


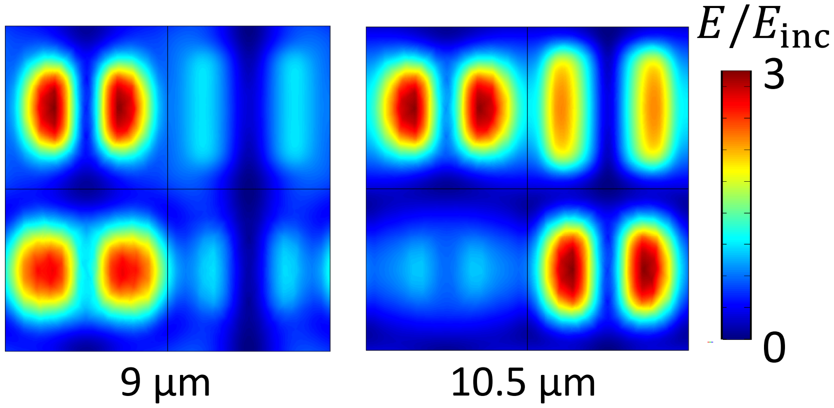
Tailored resonance





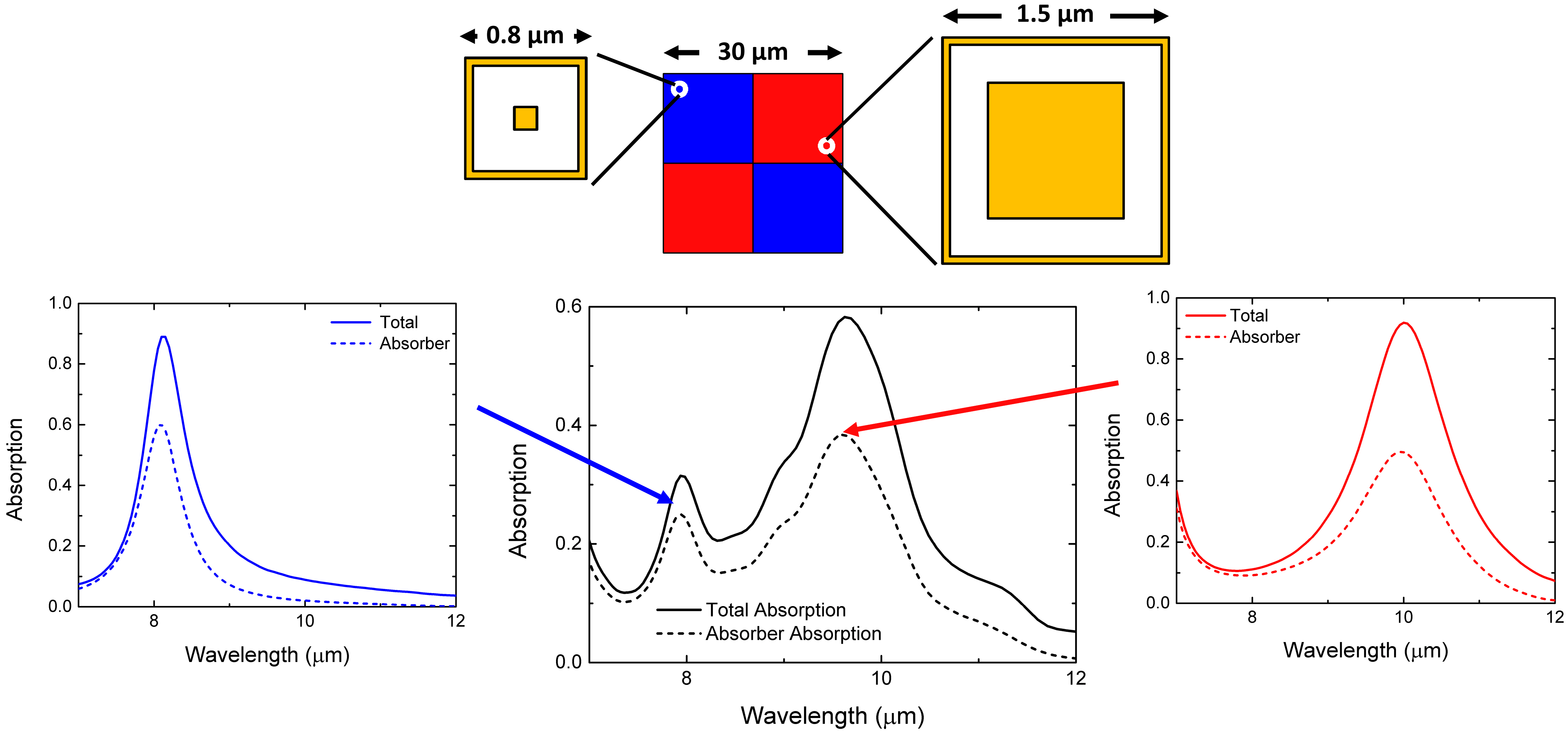






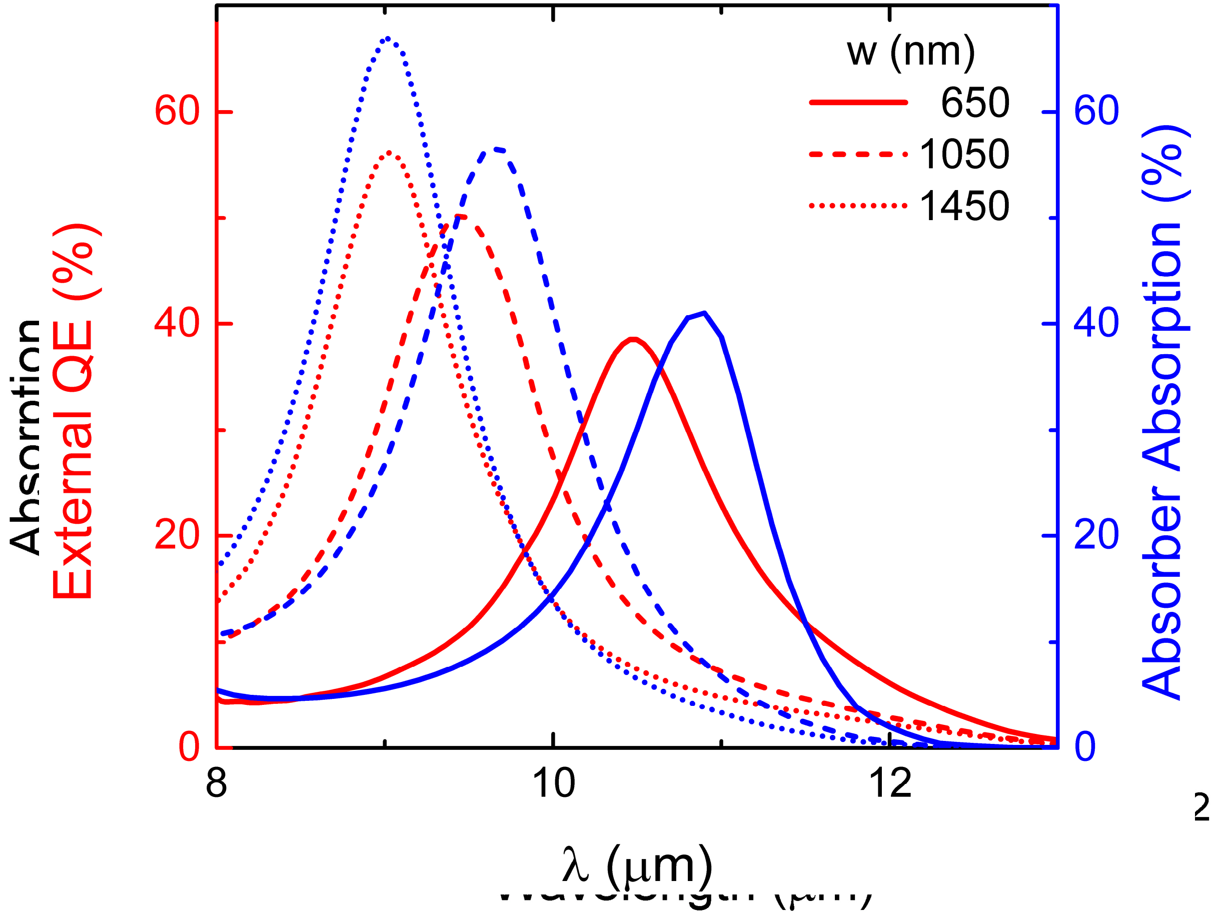
- Double FWHM of resonance.
- Polarization dependent response.
- Enables improved QE over a broader range of frequencies.

Two-Color Detection



Conclusion

- Demonstrated significant gains in QE with reduction in absorbing volume.
- Control of detector response with integrated filter.
- Potential for two color detectors and tailored resonances.



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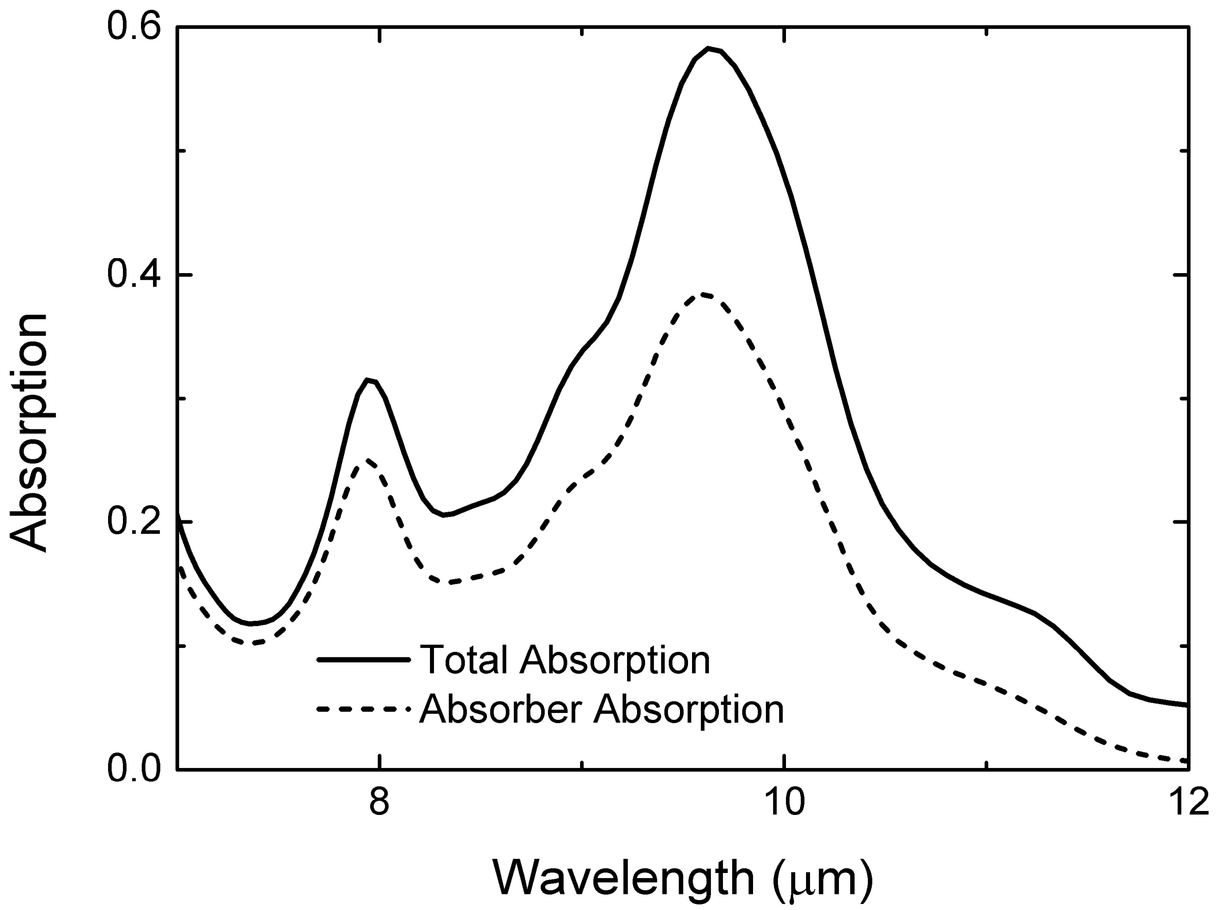
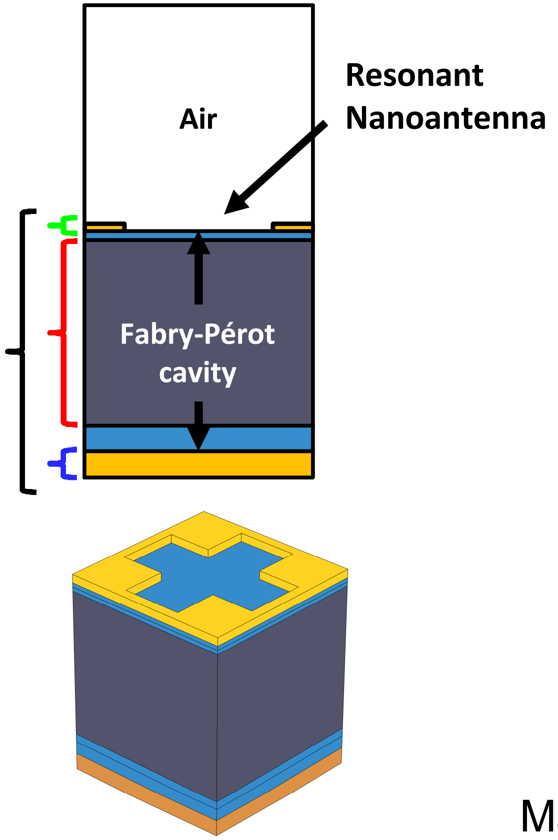
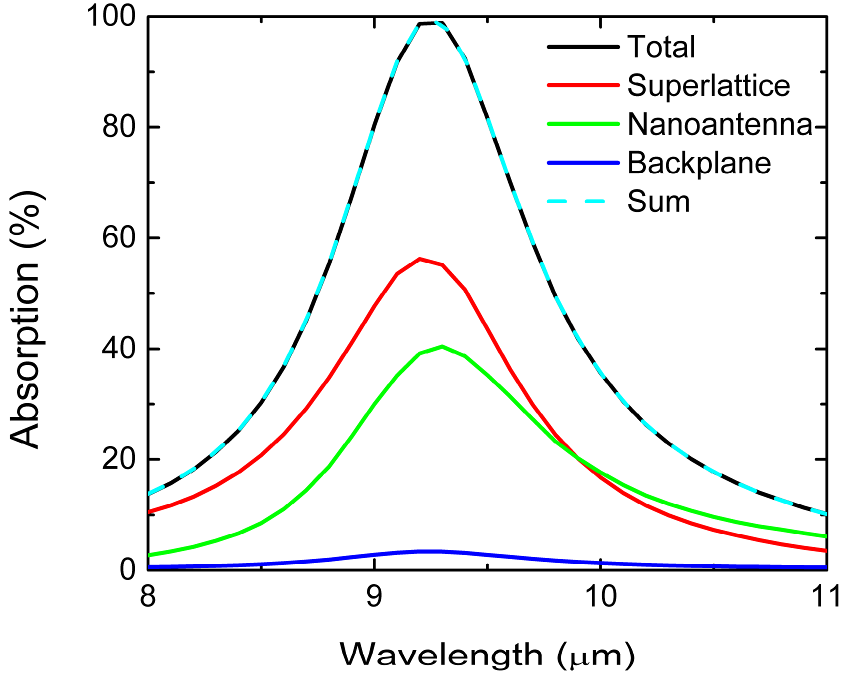
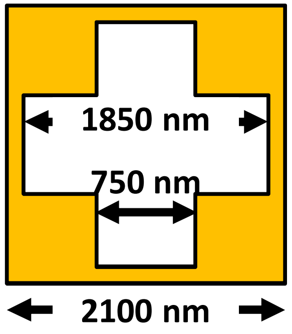


Loss Mechanisms







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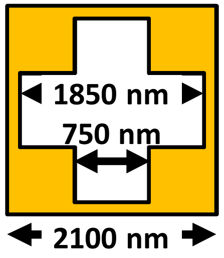
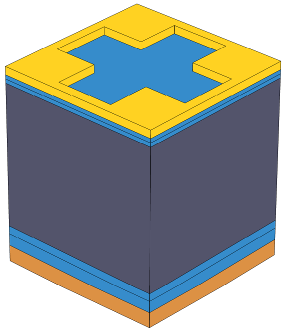
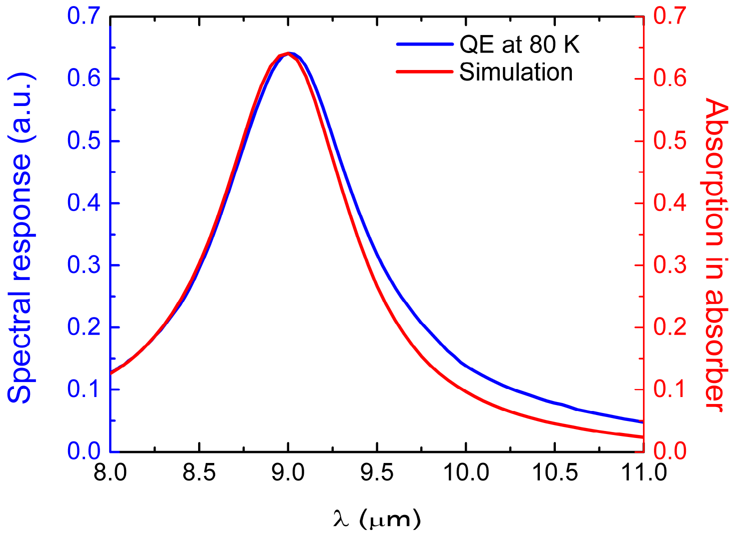


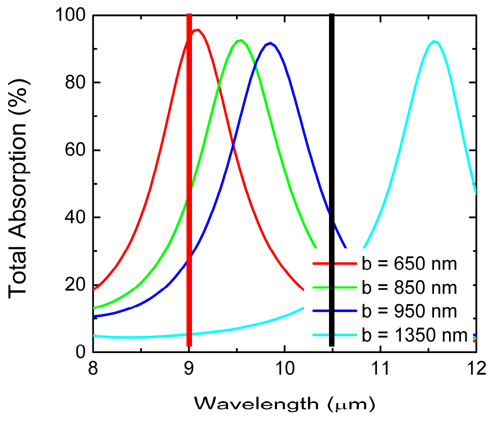


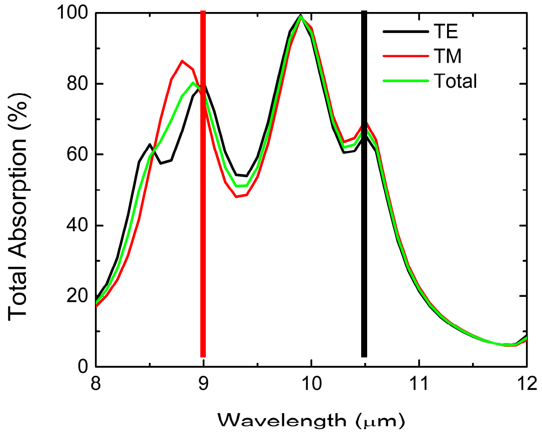
- QE>55%: 4-5x improvement compared to non-resonant detector.
- Temperature independent spectral response that matches with simulated response.

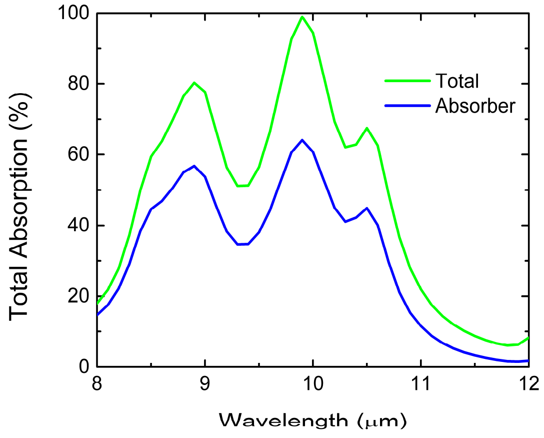


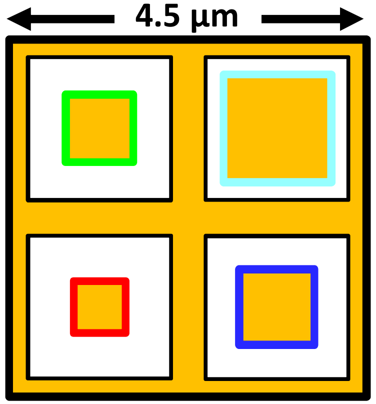
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

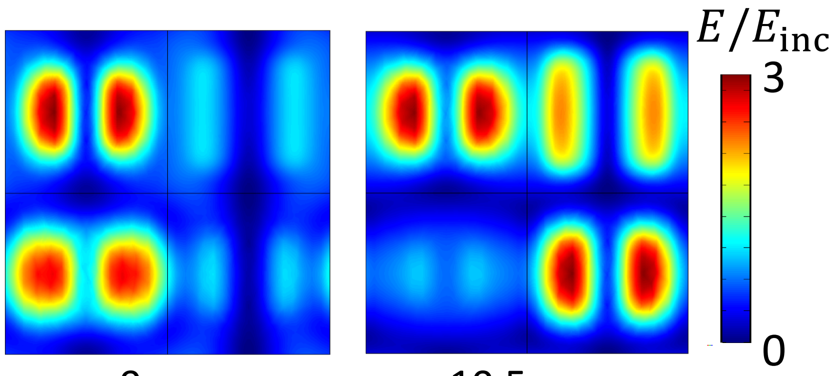
Supercell: Broadened Resonance











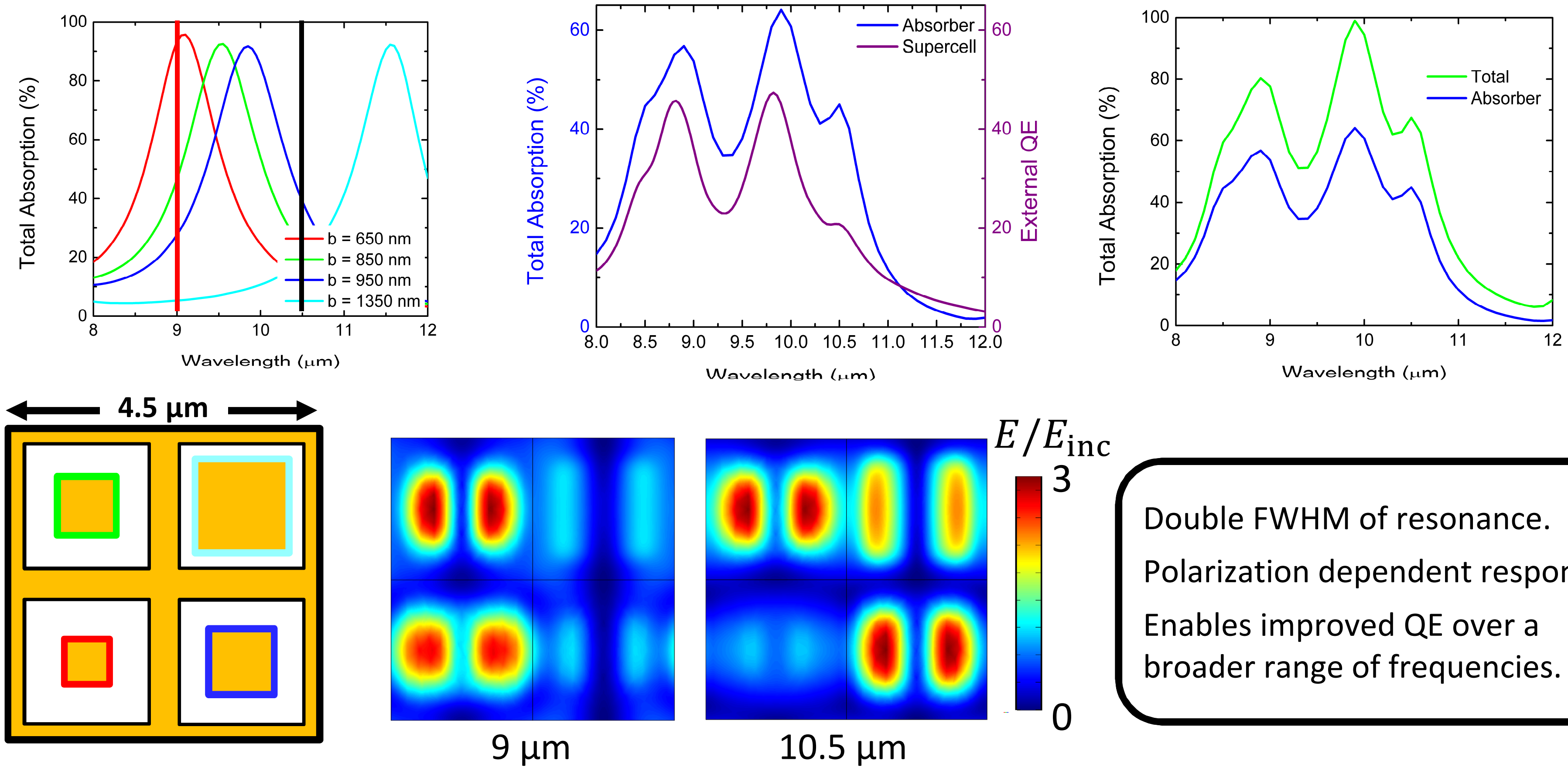
9 μm

10.5 μm

Double FWHM of resonance.

Polarization dependent response.

Broadened resonance



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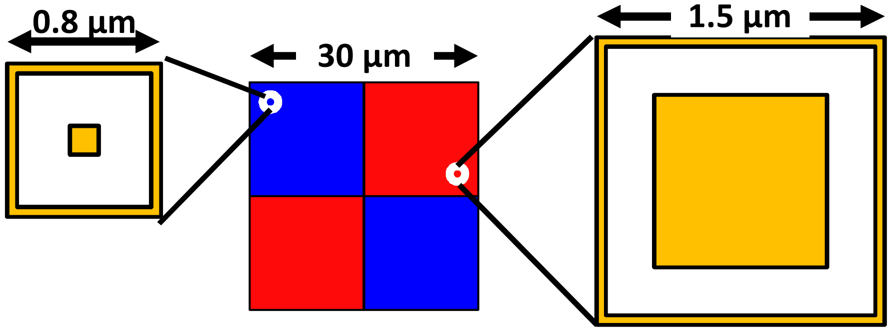
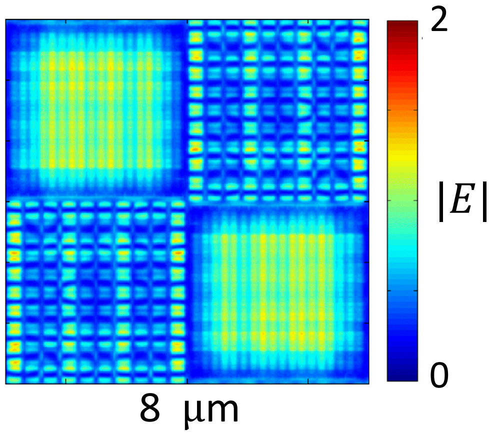
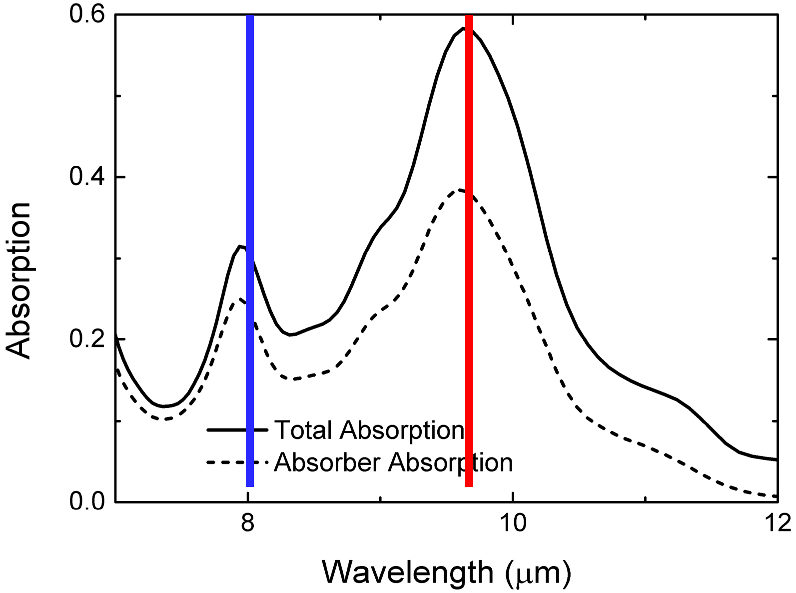
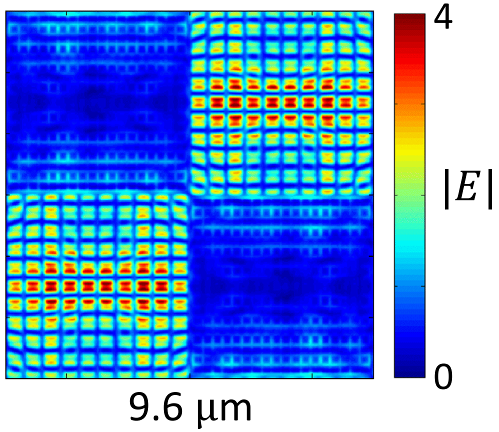
Electromagnetic Crosstalk Analysis





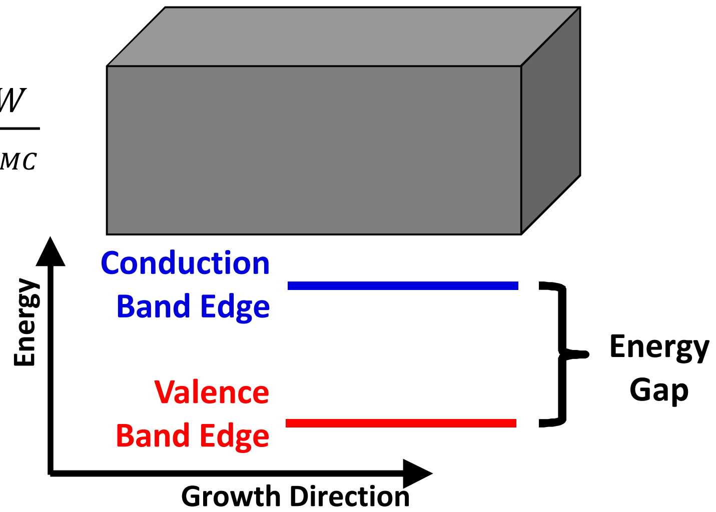




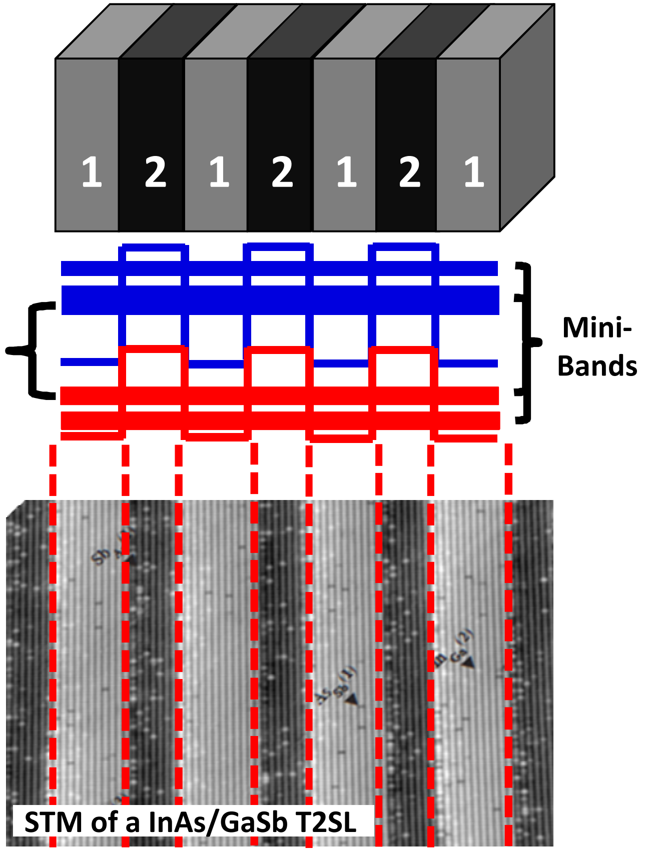
Type-II Superlattices (T2SLs)

$$J_{diff} = q\frac{n_i^2 W}{n_0 \tau_{MC}}$$

Bulk Semiconductor



Type-II Superlattice



STM of a InAs/GaSb T2SL

We use InAs/InAsSb T2SLs for the absorber

- Change bandgap by changing layer thicknesses
- Engineer/optimize intrinsic properties
- <u>*Performance is predicted to surpass HgCdTe, the current industry standard for IR detection*</u>