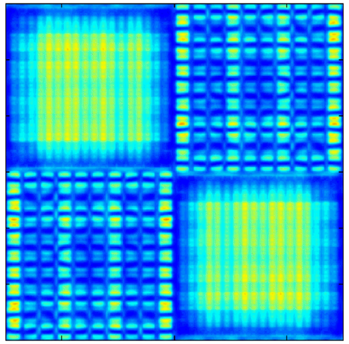
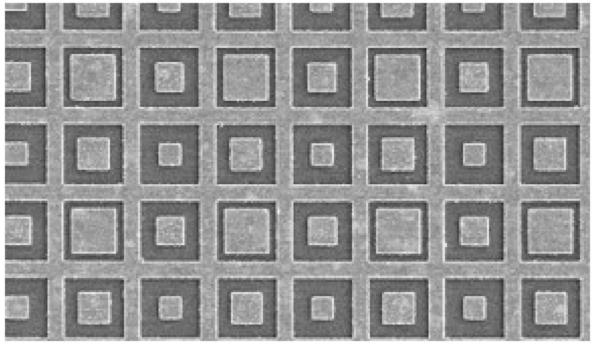
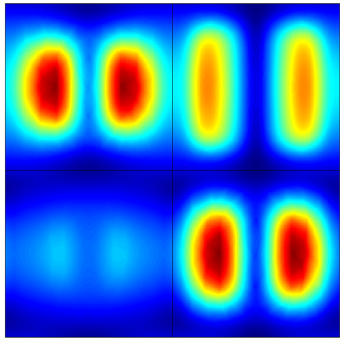
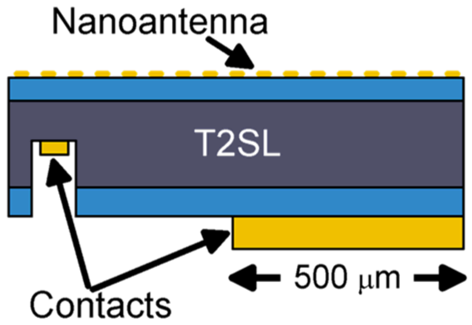
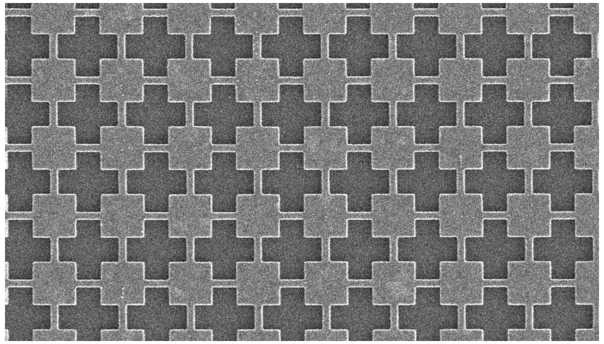
SAND2017-2397C



Next-Generation Infrared Focal Plane Arrays for High-Responsivity Low-Noise Applications

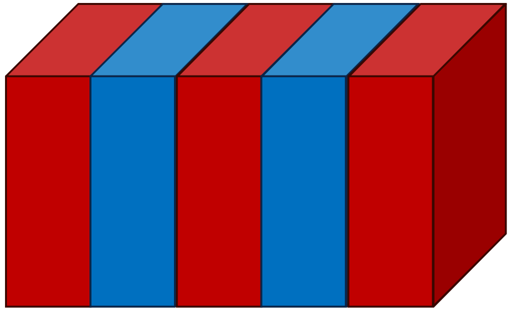
Michael Goldflam

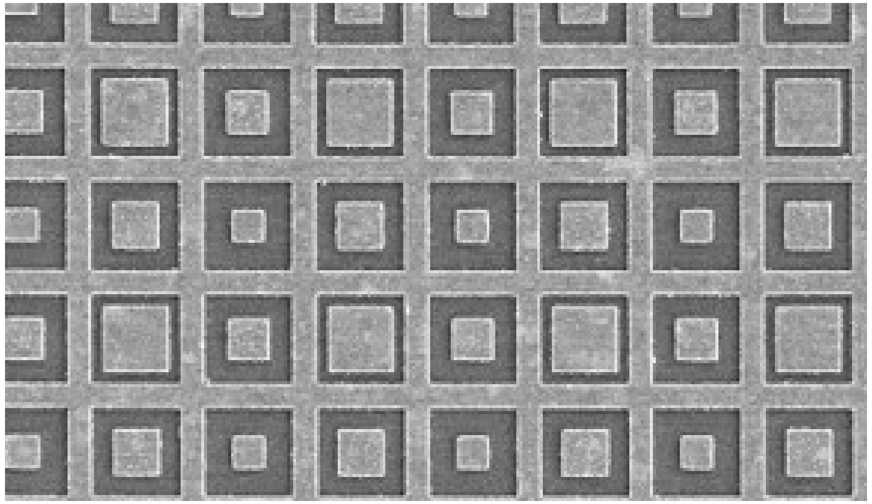
S. Campione, S. Parameswaran, P.S. Davids, E.A. Kadlec, G.A. Keeler, L.K. Warne, S.D. Hawkins, J.F. Klem, J.R. Wendt, W.T. Coon, A. Tauke-Pedretti, J.K. Kim, T.R. Fortune, E.A. Shaner, D.W. Peters

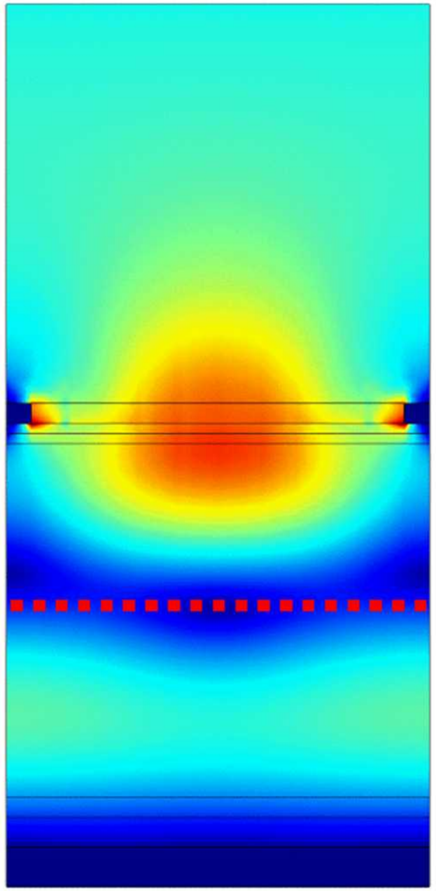
Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Outline

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







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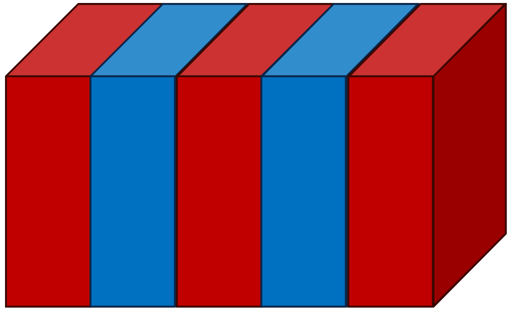
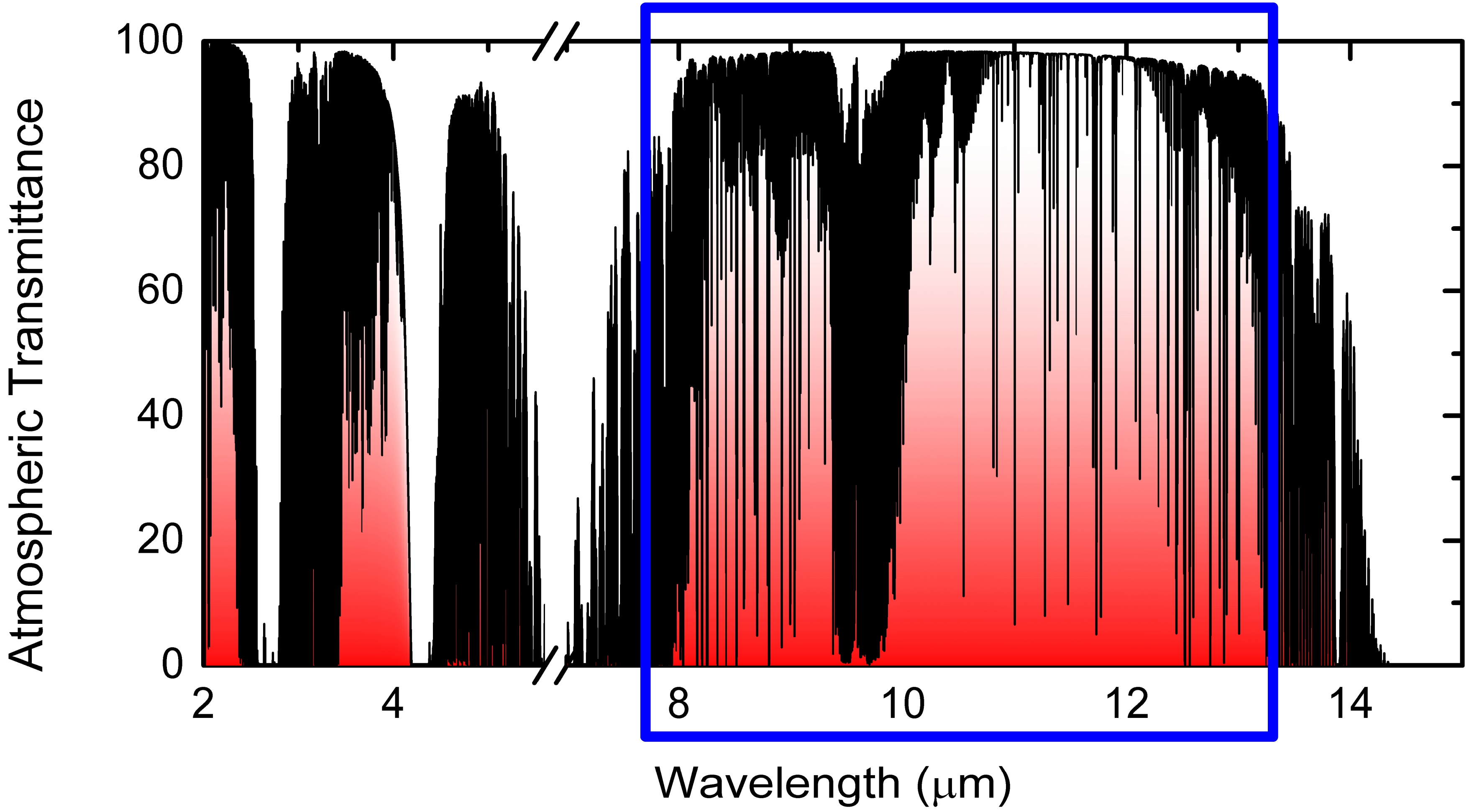


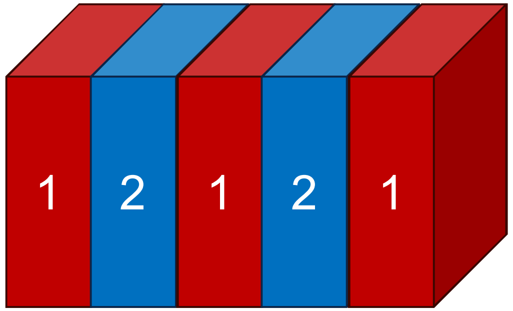
Infrared Detection

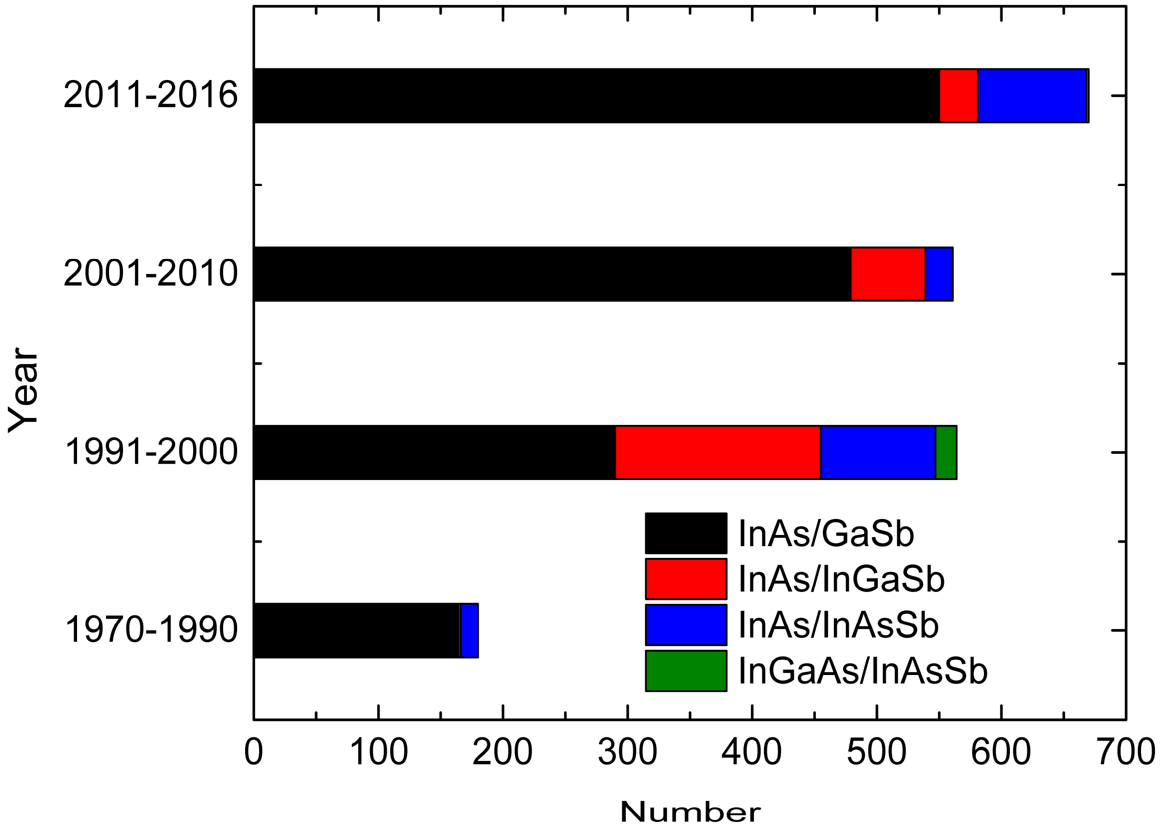


Lord, S. D., 1992, NASA Technical Memorandum 103957, Gemini Observatory

Type-II Superlattices

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



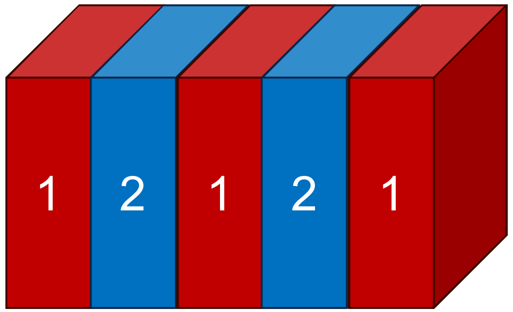


- Wafer uniformity
- Easily controllable bandgap
- Predicted lower predicted dark current than MCT.

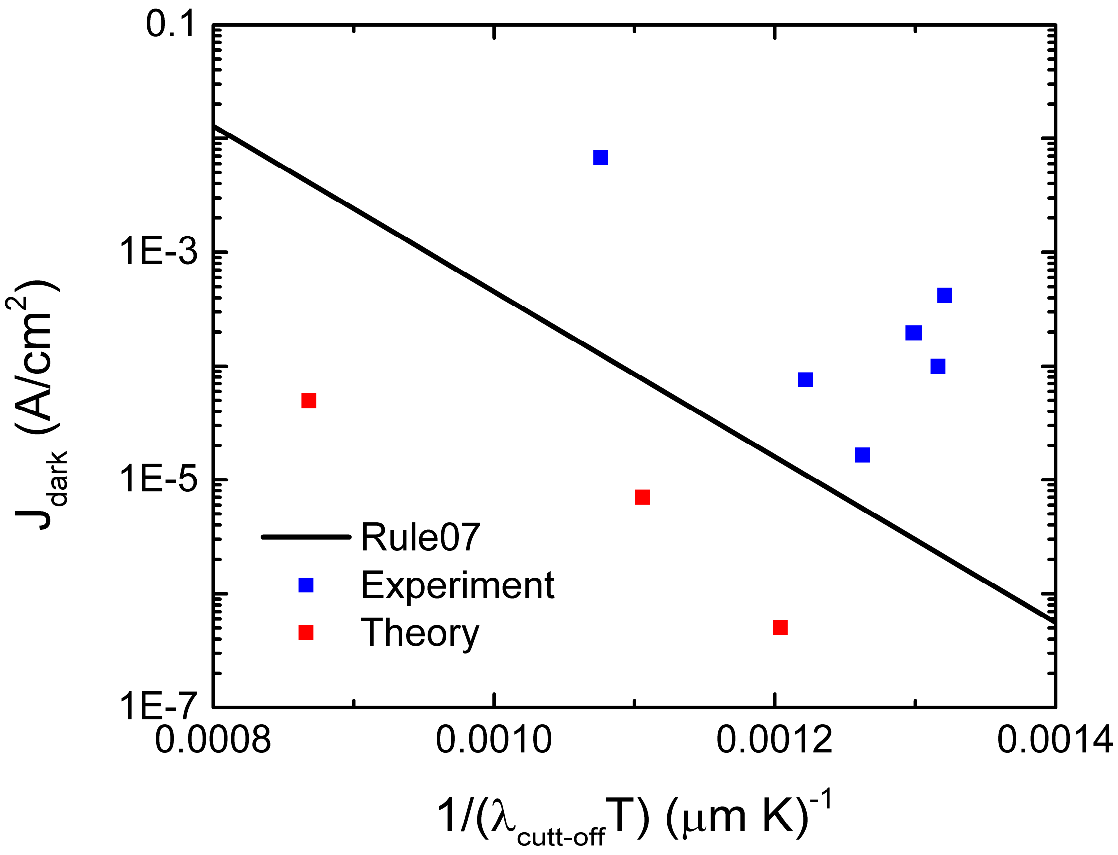
E.H. Steenbergen, et al., 10111, 1011104 (2017).

Type-II Superlattices

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



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



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

Outline

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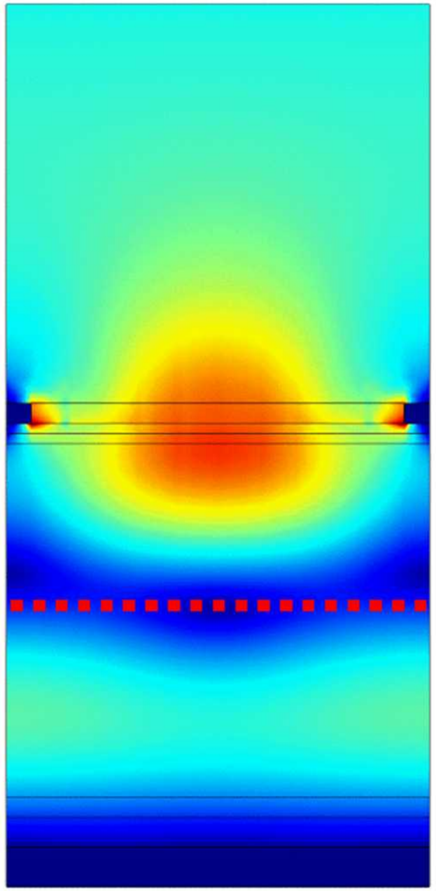
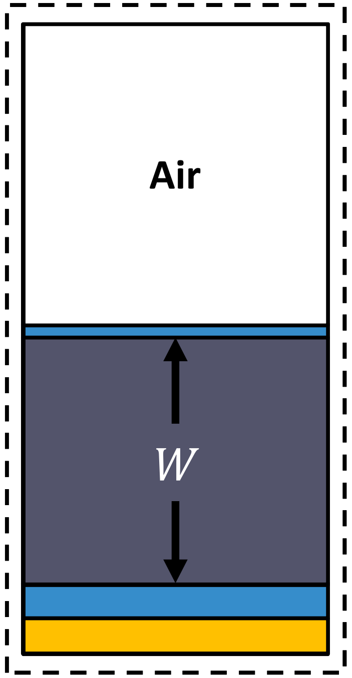
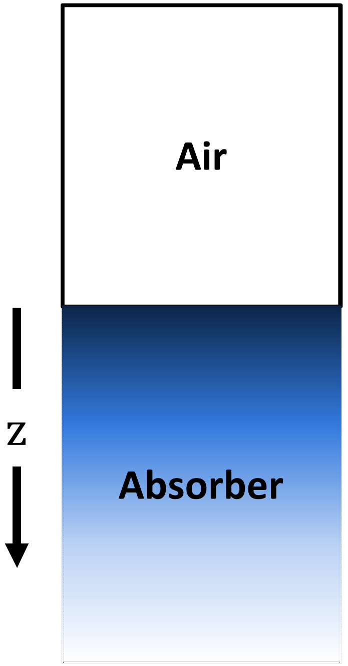


Detector structure

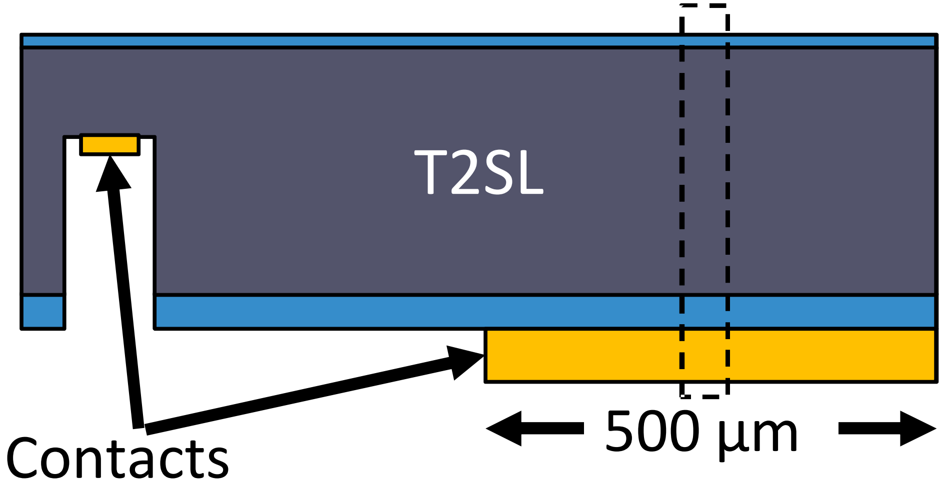




$\text{Absorption} \propto e^{-\alpha z}$

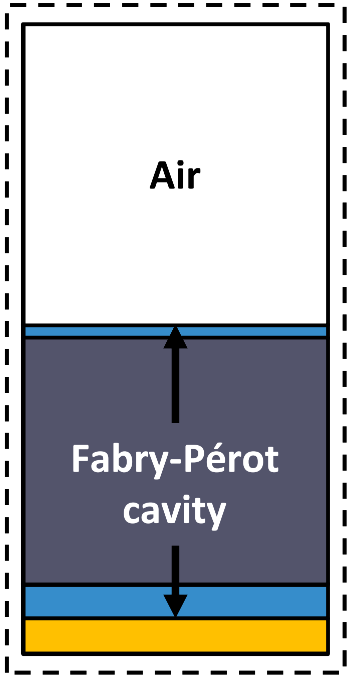
$J_{diff} \propto W$

- Thick structures absorb more but have higher dark current.
- Enhance field in detector using resonant structures → increase QE.
- Important in low background applications.
- Enable higher operating temperature.



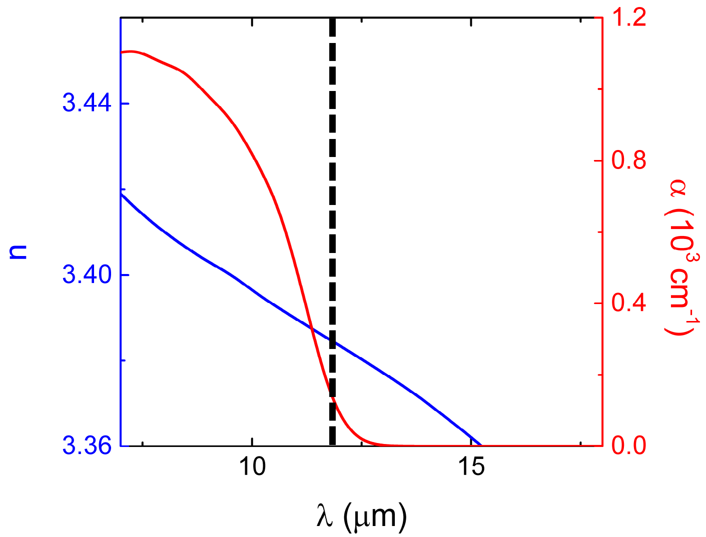
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

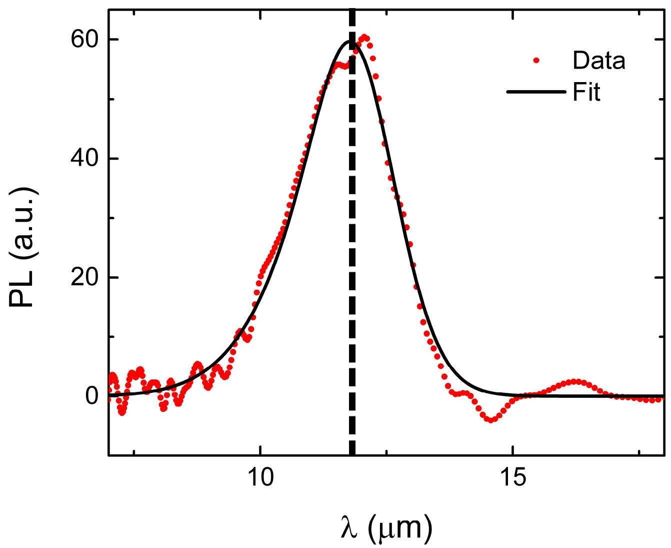
Detector structure



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

$$t \sim 2\ \mu m$$





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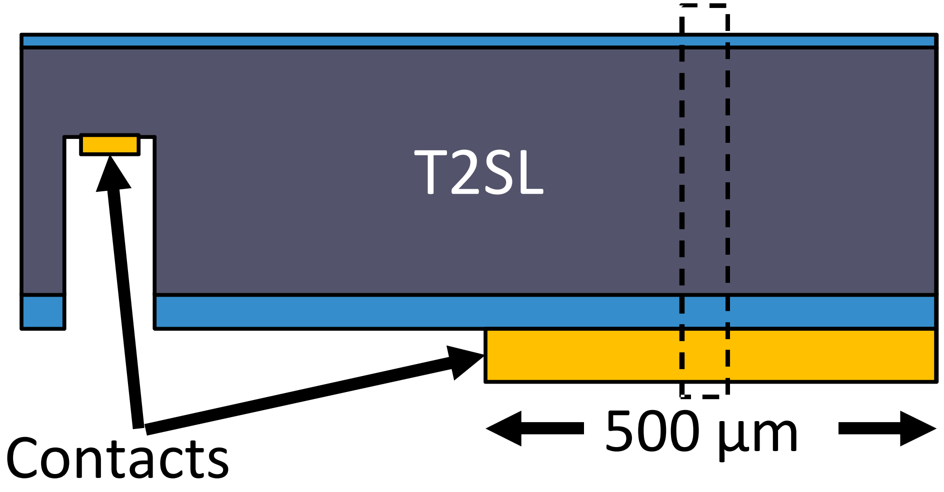
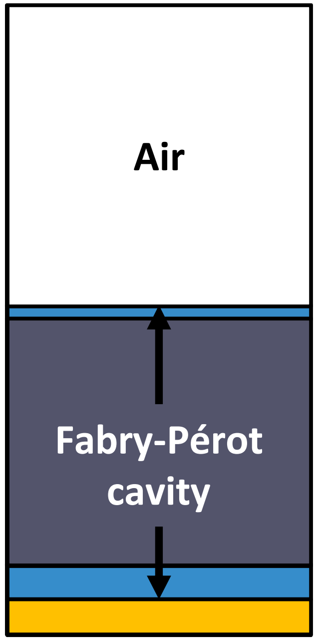


M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

Resonant detector: Fabry-Pérot



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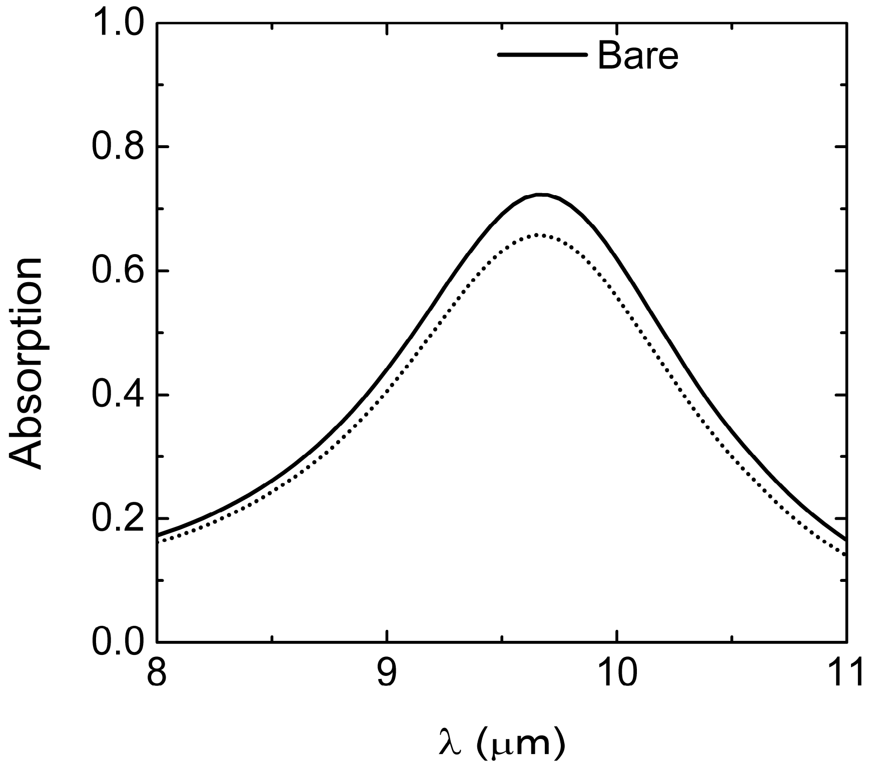
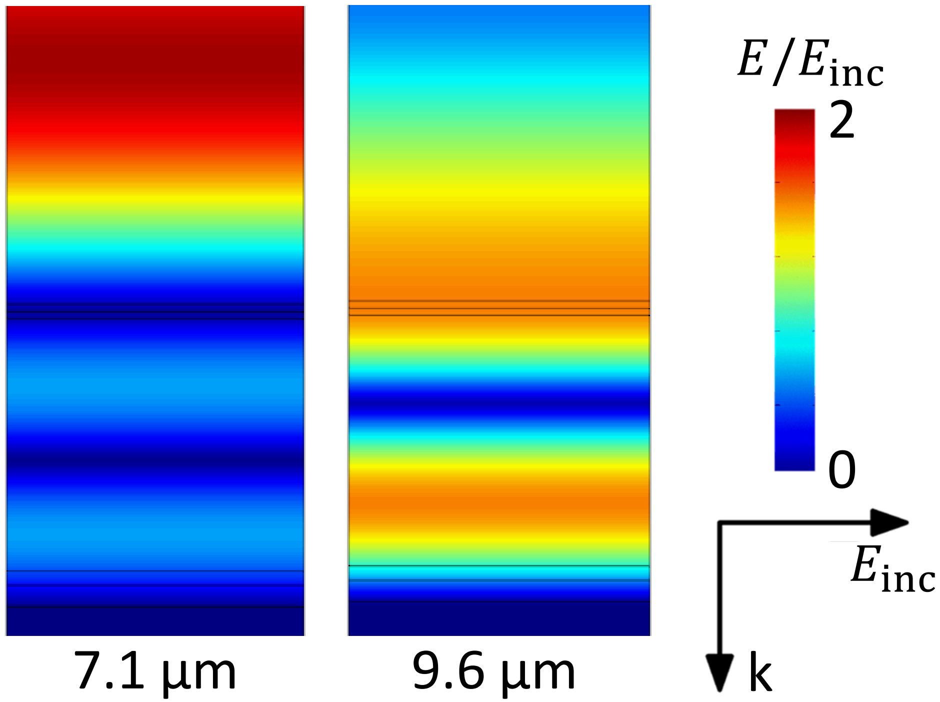
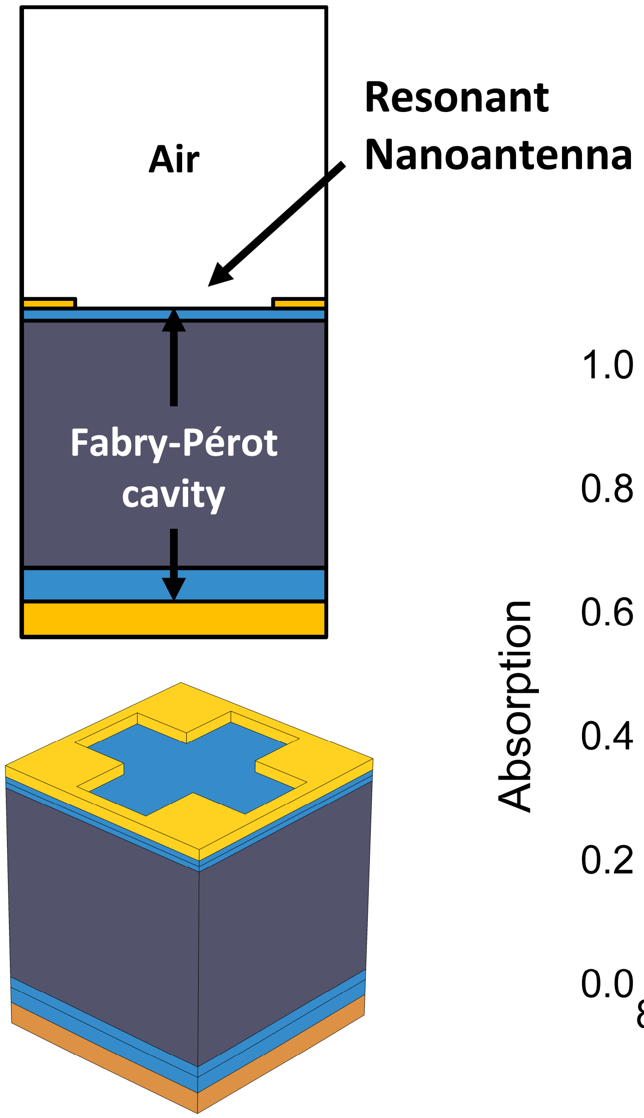
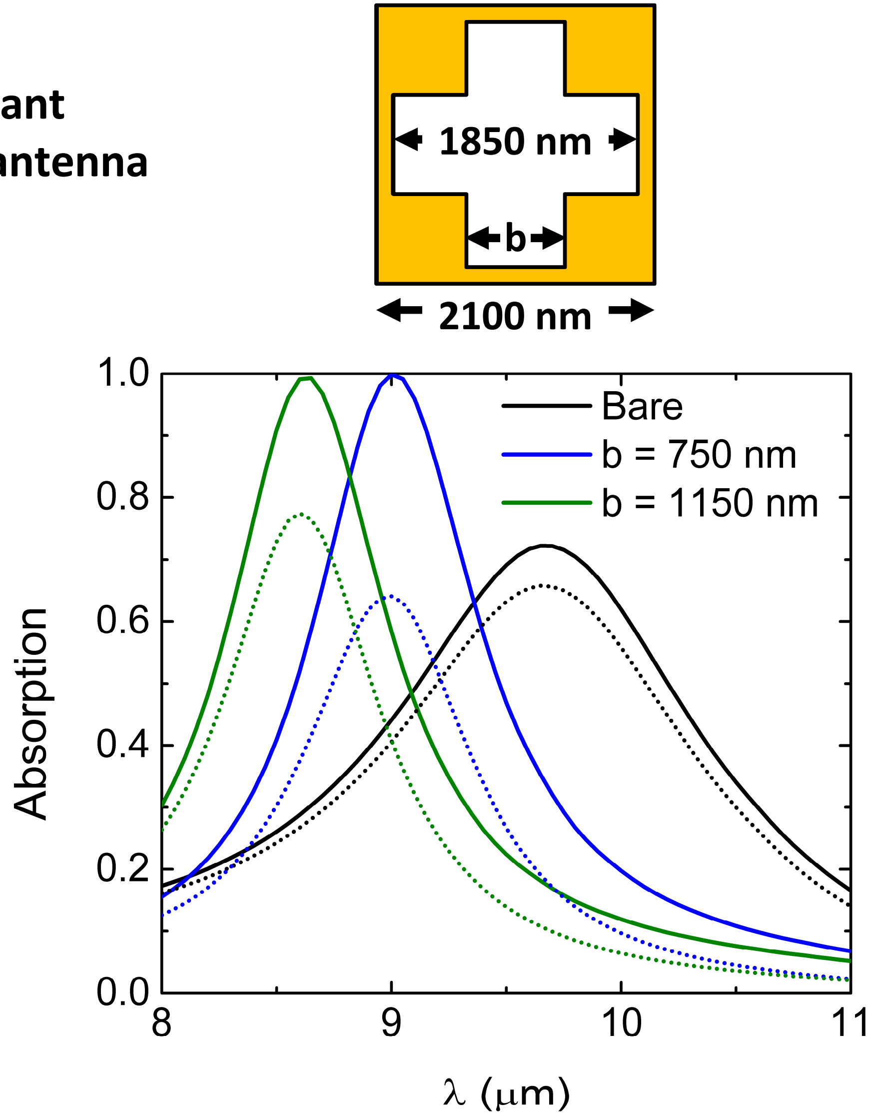




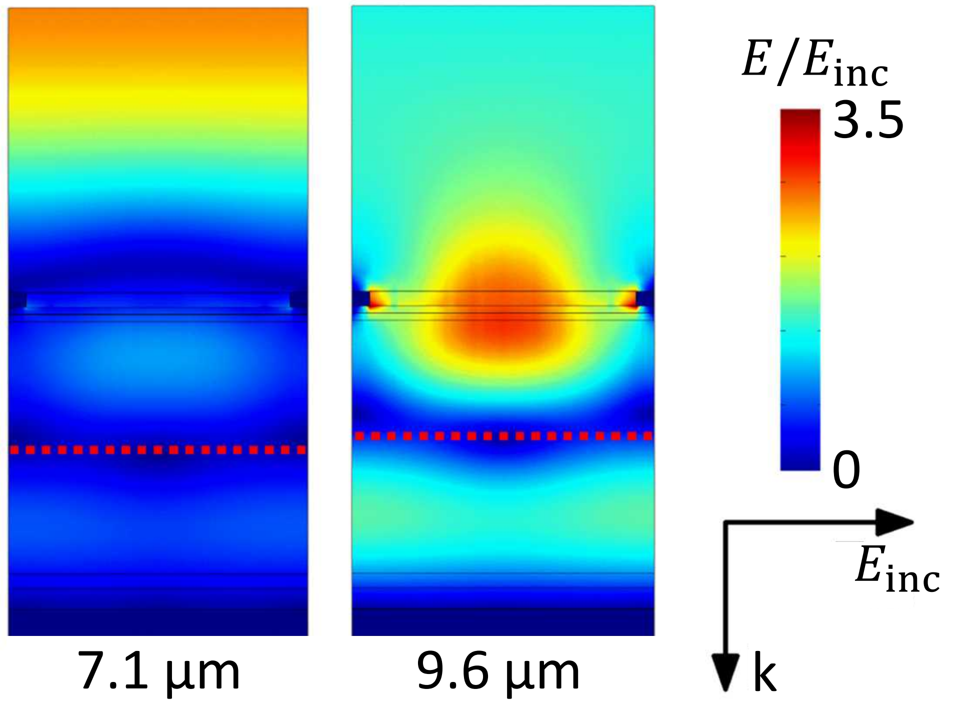
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

Coupled Resonances



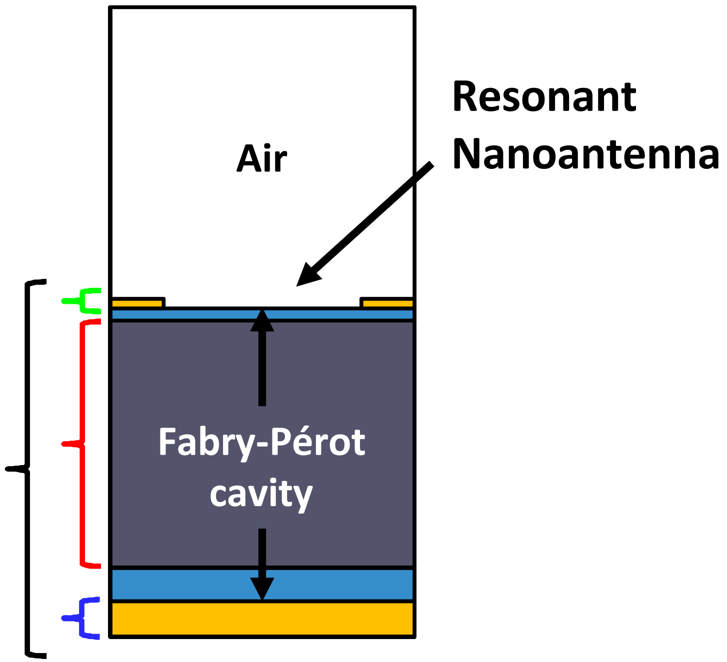


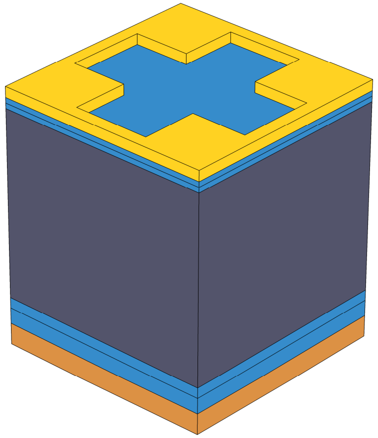
- Employ two coupled resonances: Fabry-Pérot cavity with metal nanoresonator.
- Variable response in fixed detector through variation of nanoantenna only.

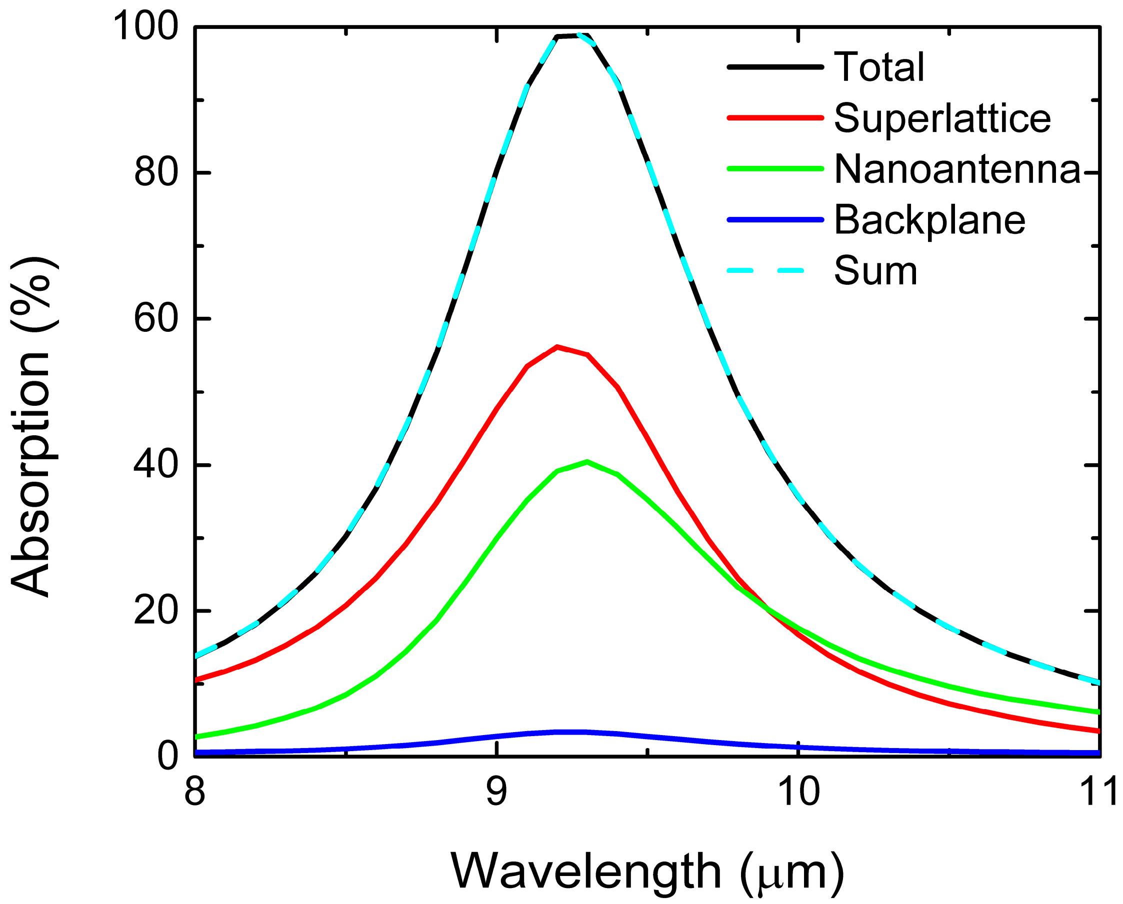


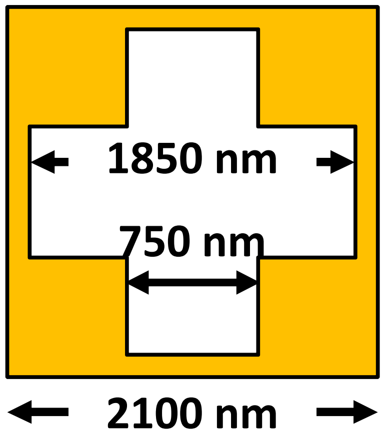
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

Loss Mechanisms





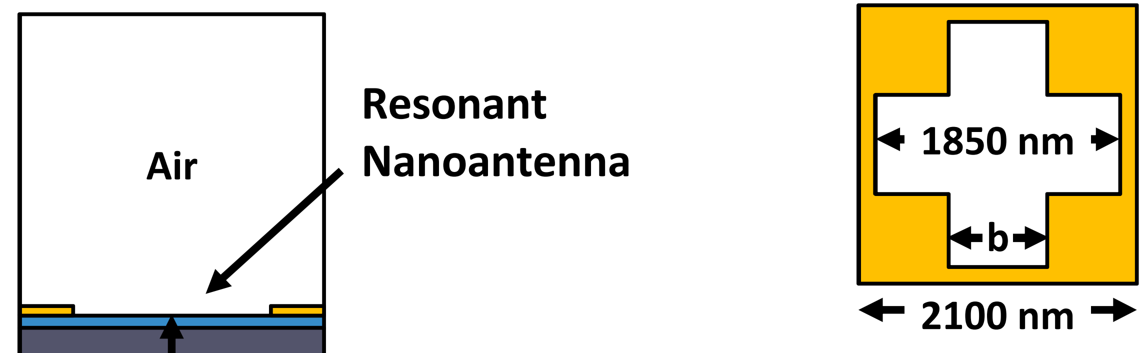


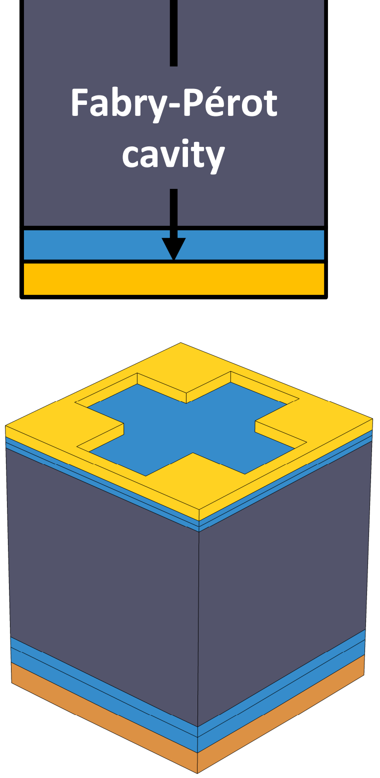


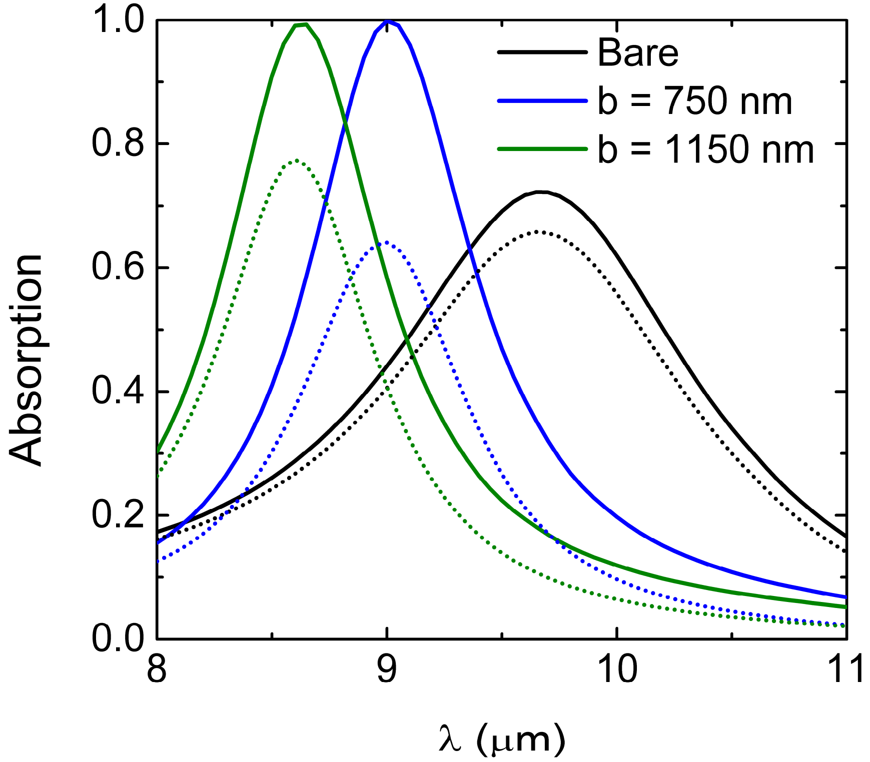
Majority of "lost" absorption is in the nanoantenna

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

Coupled Resonators







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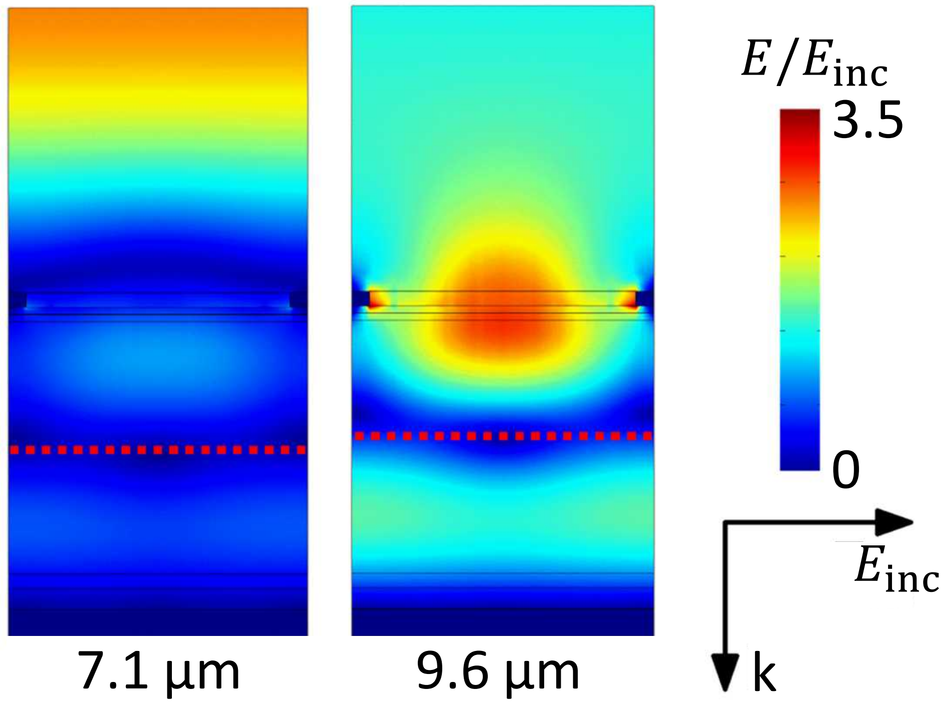
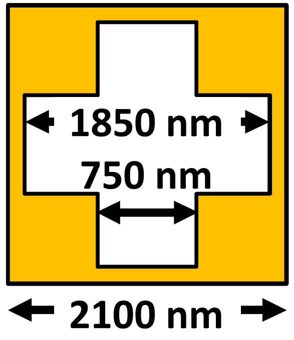
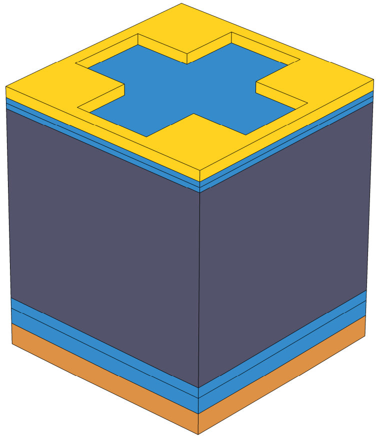


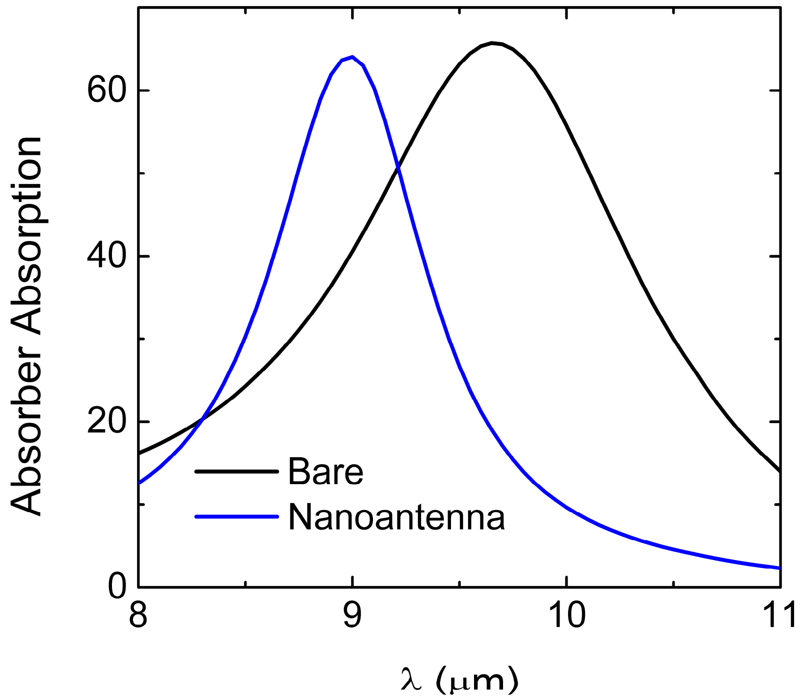
M. D. Goldflam, D. W. Peters et al., Appl. Phys. Lett. 109 (25), 251103 (2016).

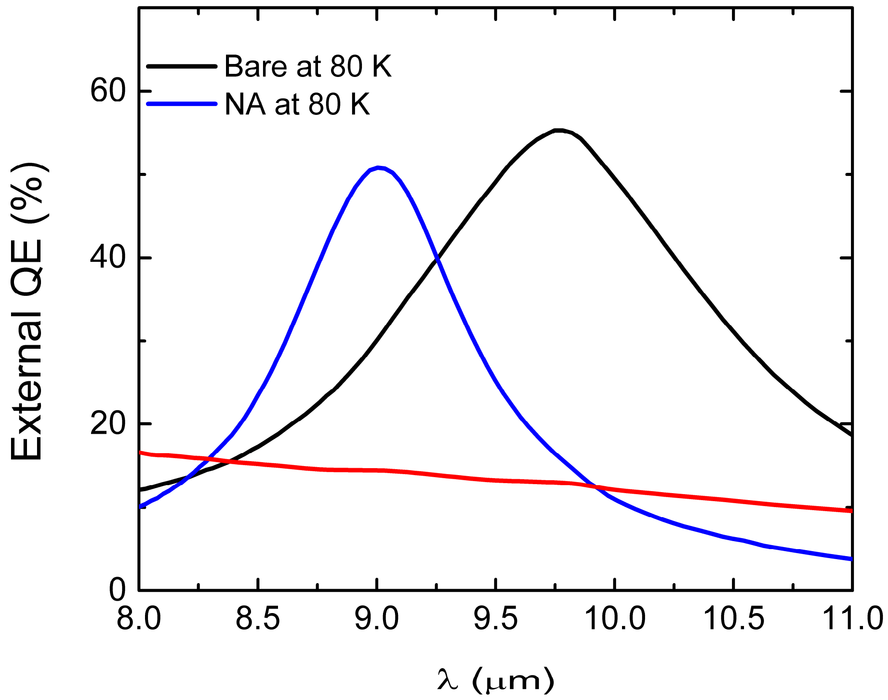
Measured Quantum Efficiency





- QE>55%: 4-5x improvement compared to non-resonant detector.





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

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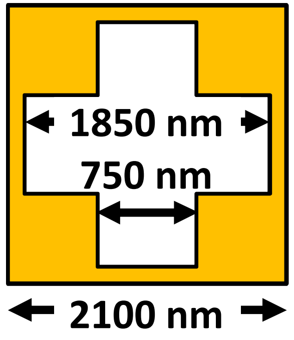
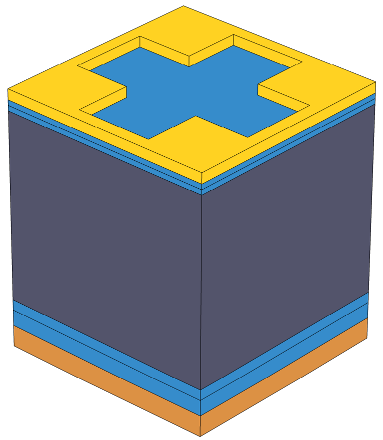
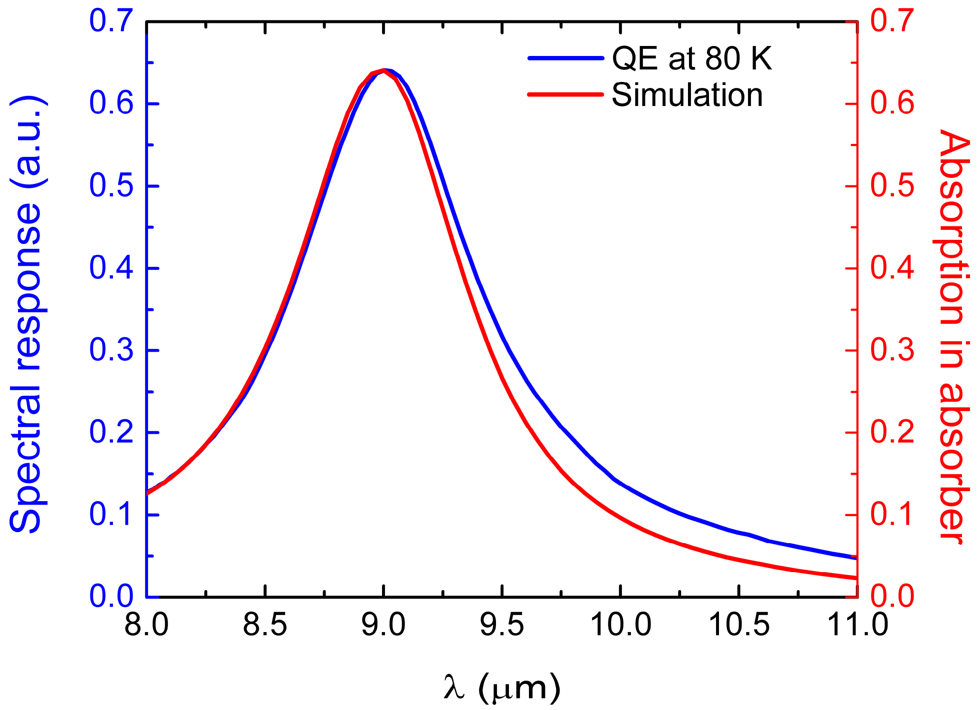


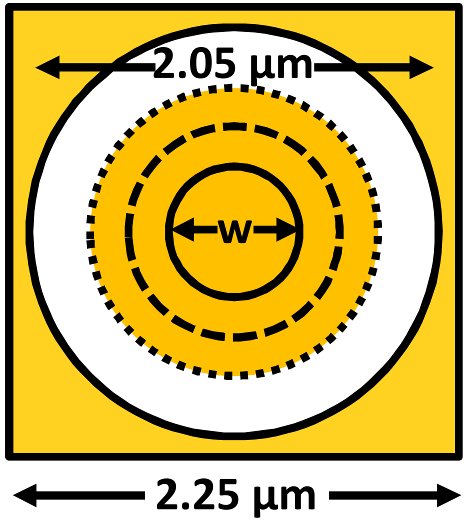


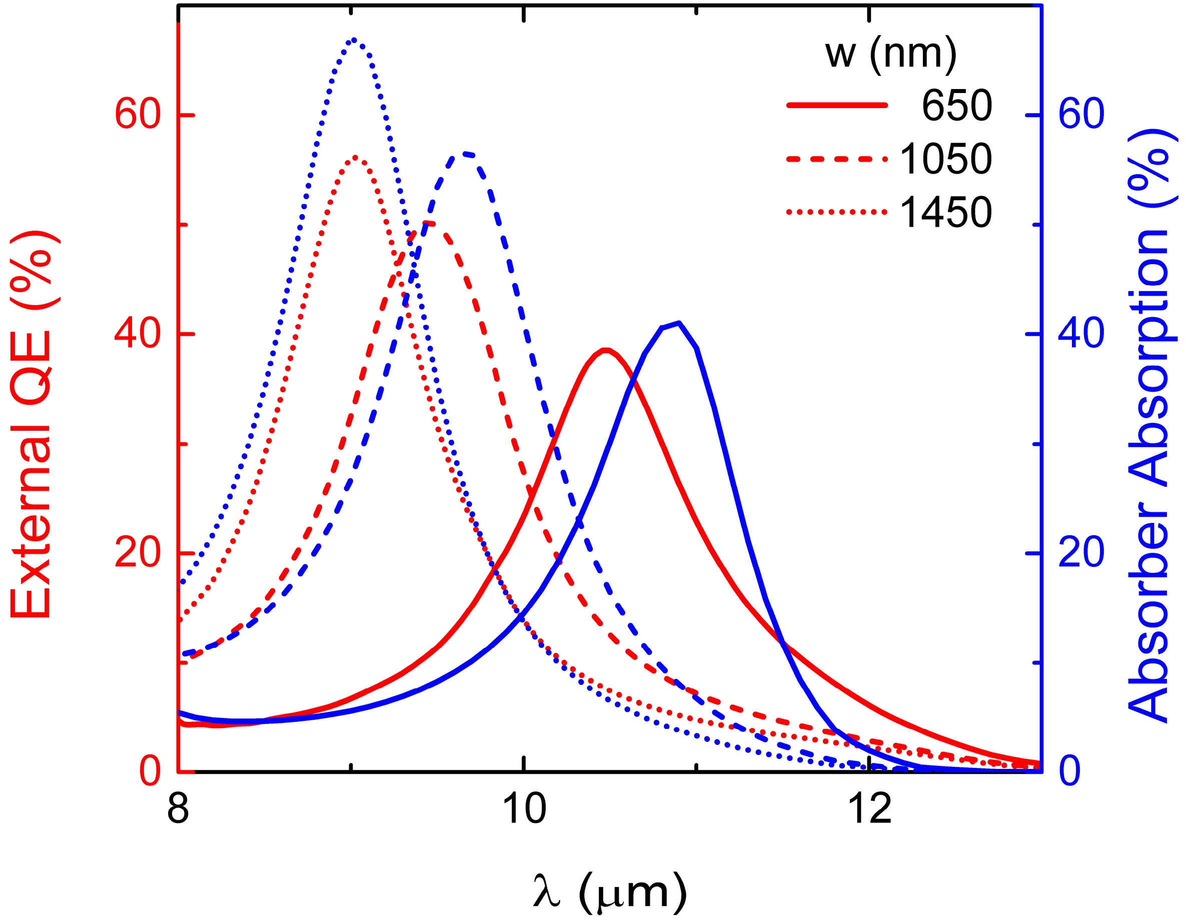
- QE>55%: 4-5x improvement compared to non-resonant detector.
- Temperature independent spectral response that matches with simulated response.



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

Resonance Wavelength Modification





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

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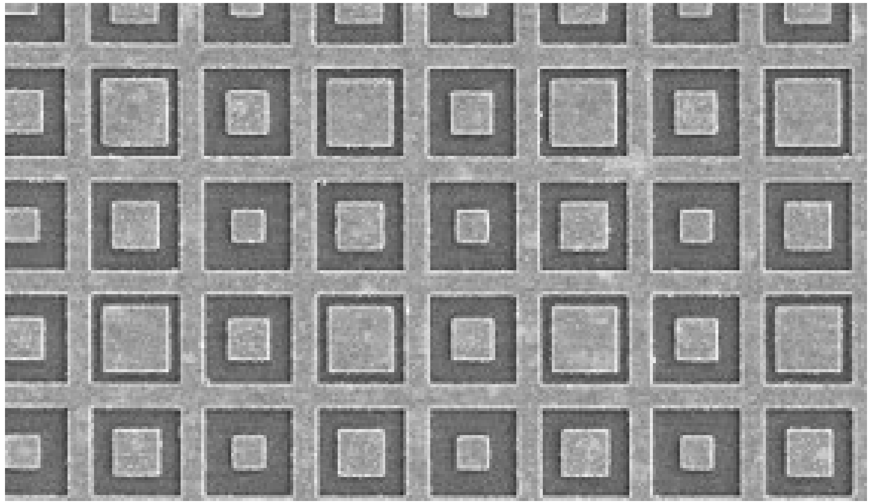
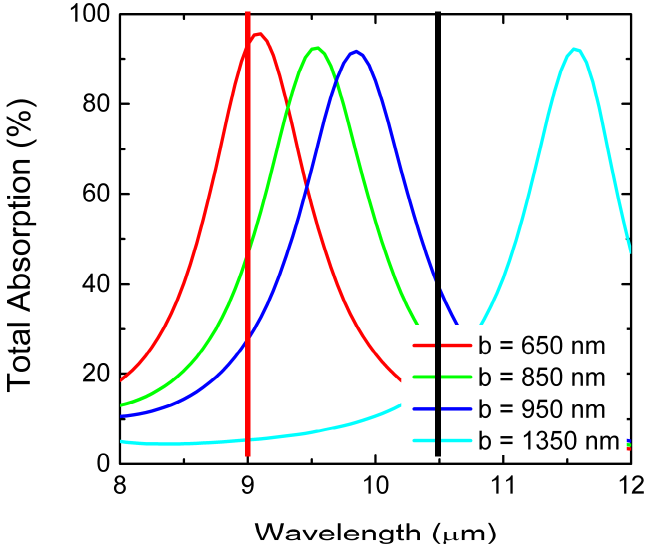
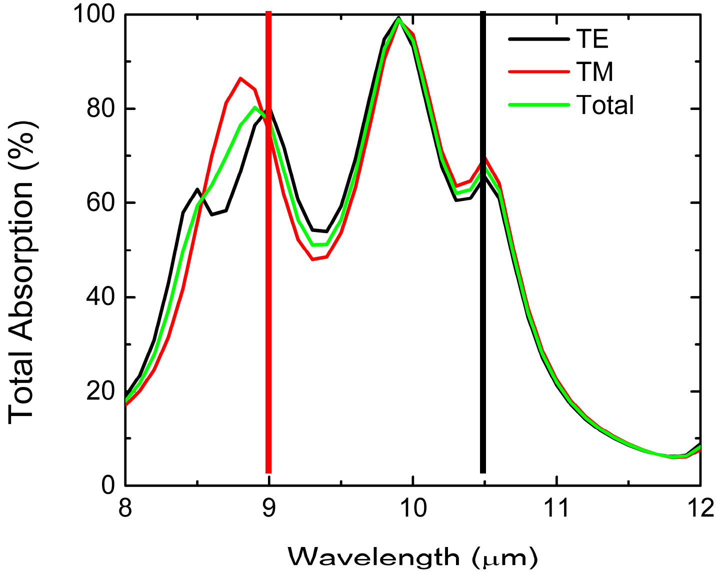
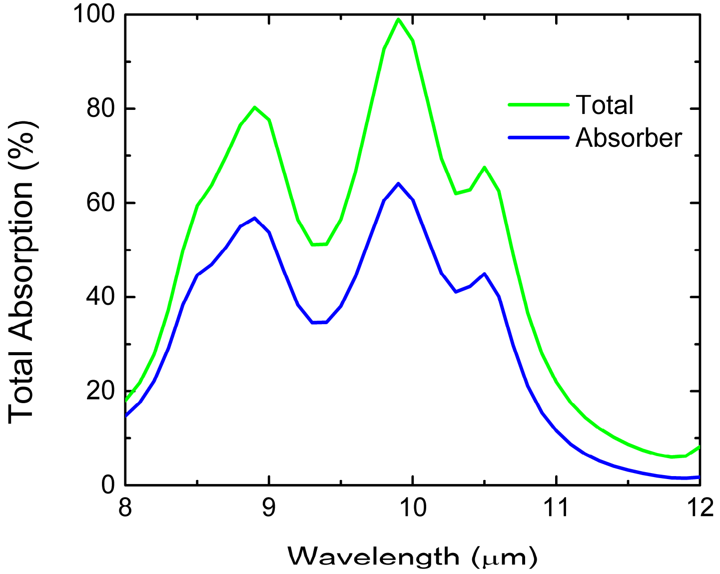
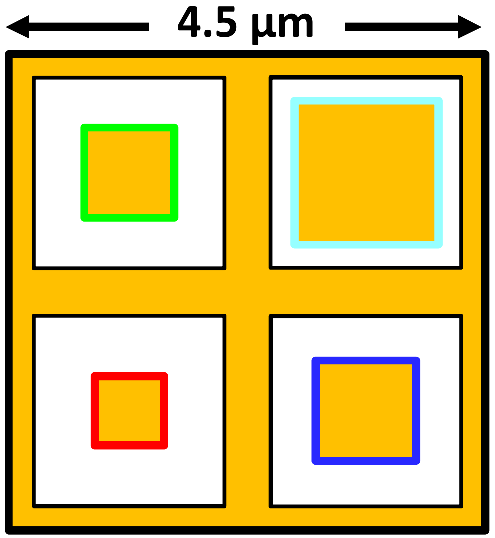


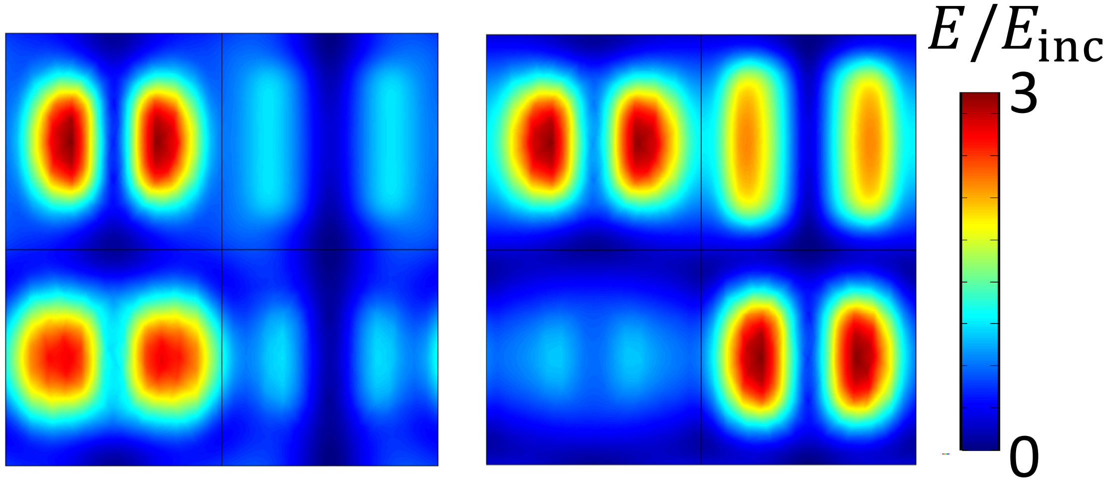
Supercell: Broadened Resonance









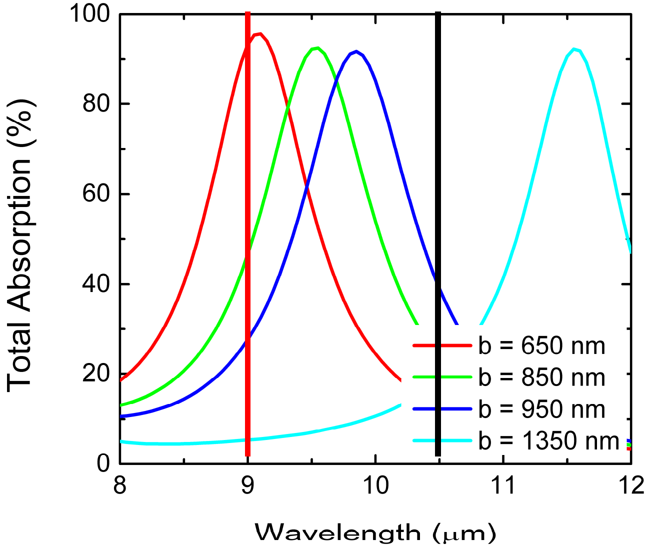


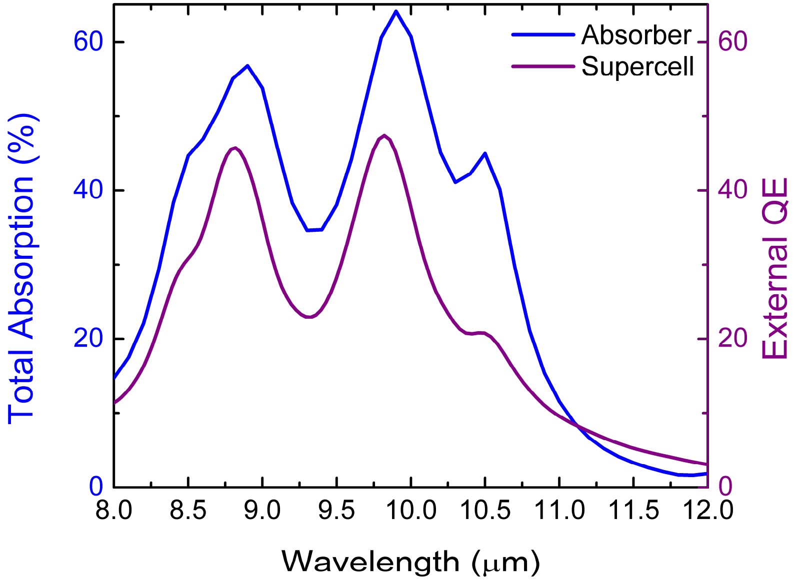
9 μm   10.5 μm

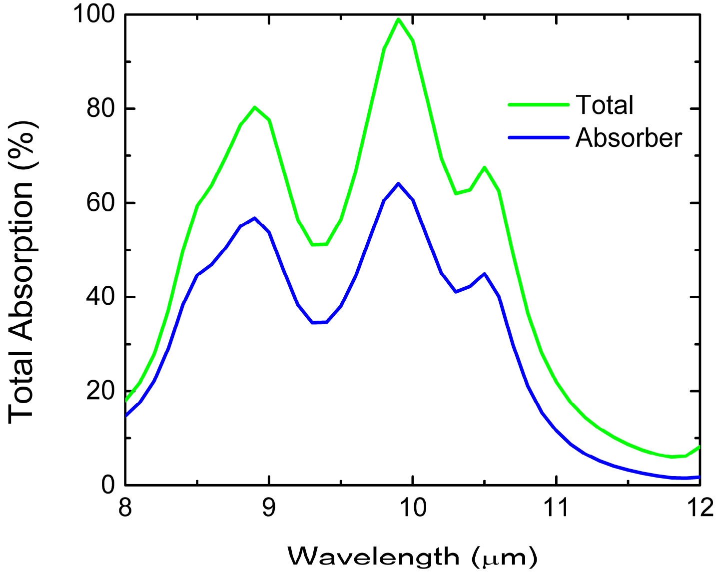
Double FWHM of resonance.

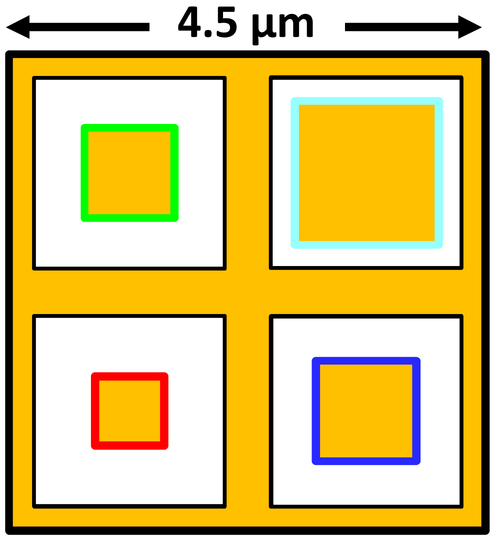
Polarization dependent response.

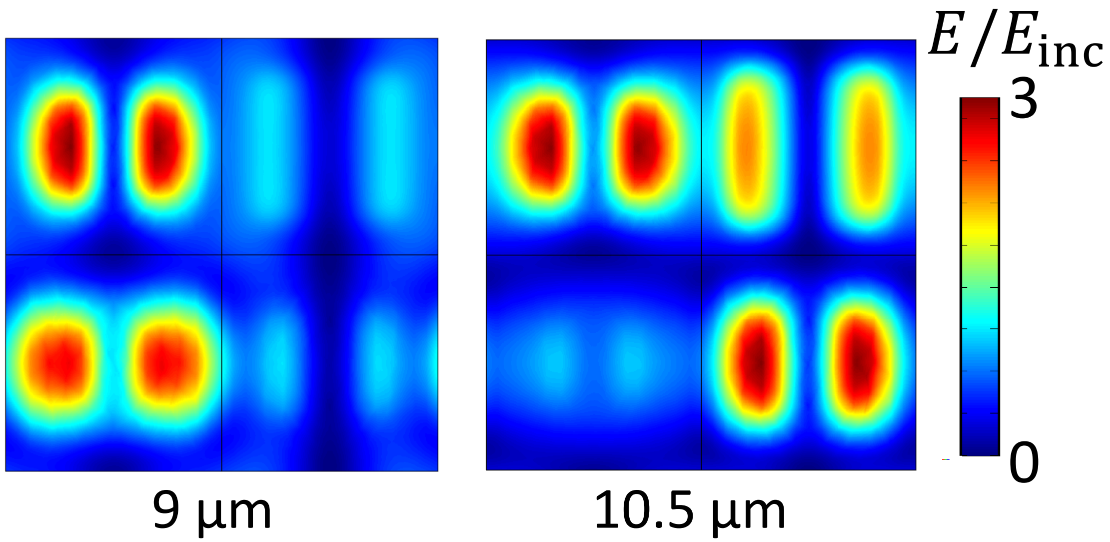
Broadened resonance









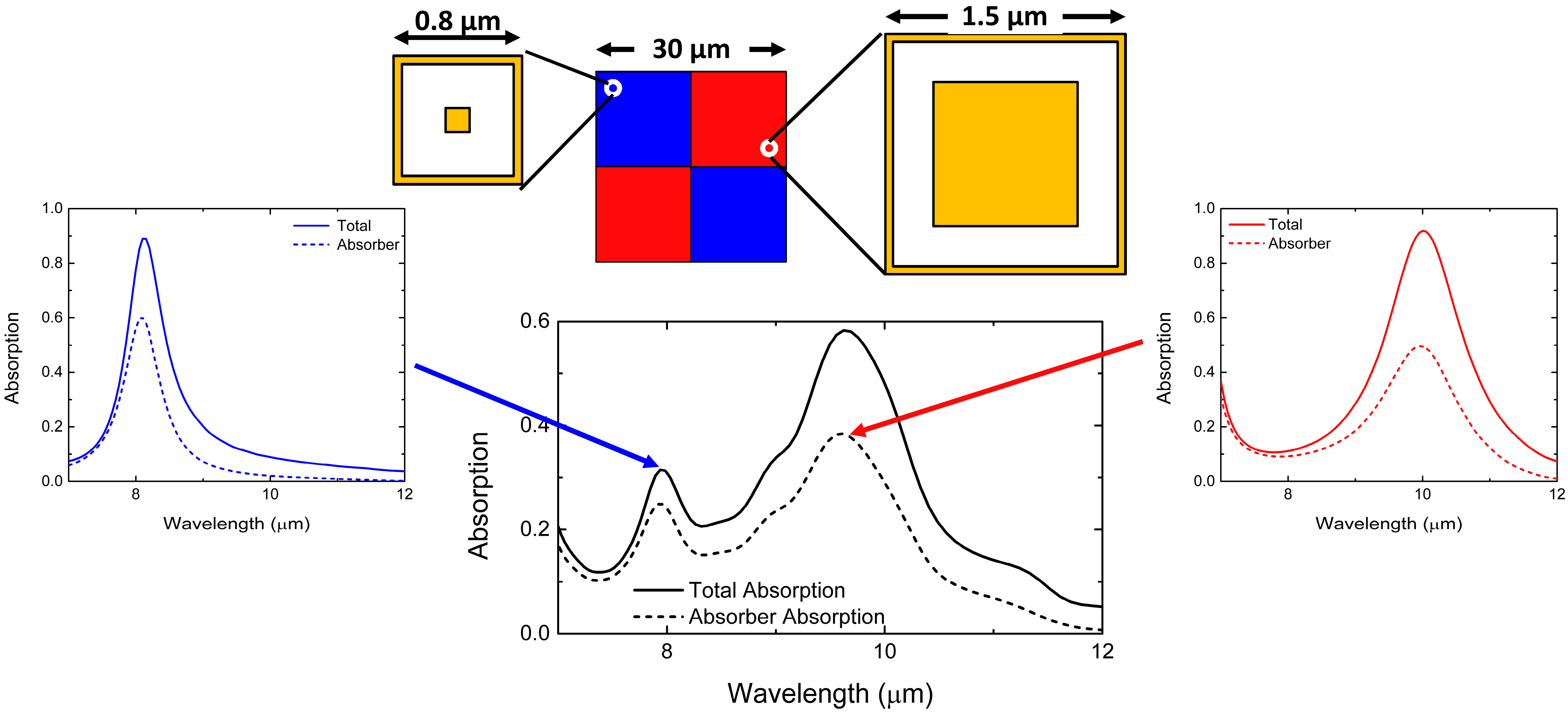


Double FWHM of resonance.

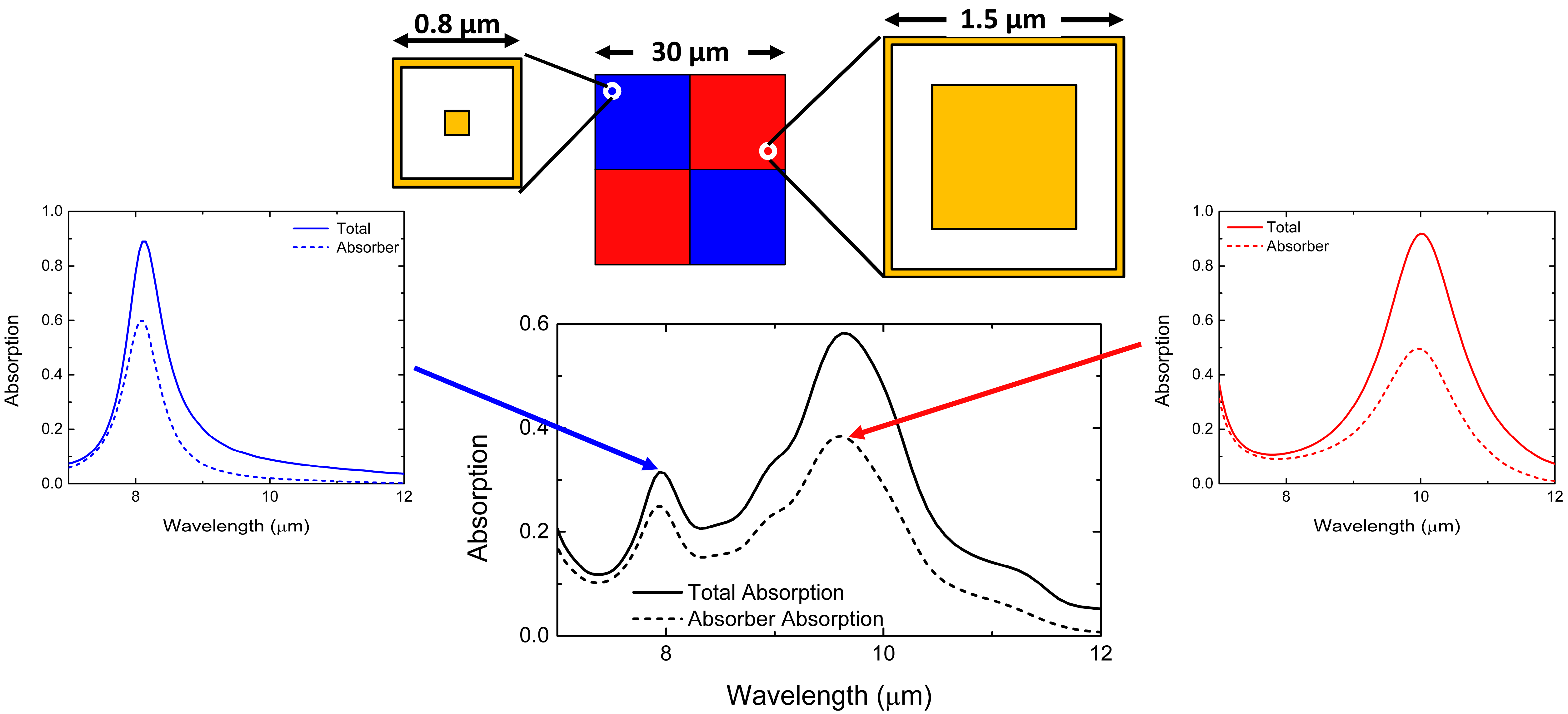
Polarization dependent response.

Enables improved QE over a broader range of frequencies.

Two-Color Detection



Electromagnetic Crosstalk Analysis



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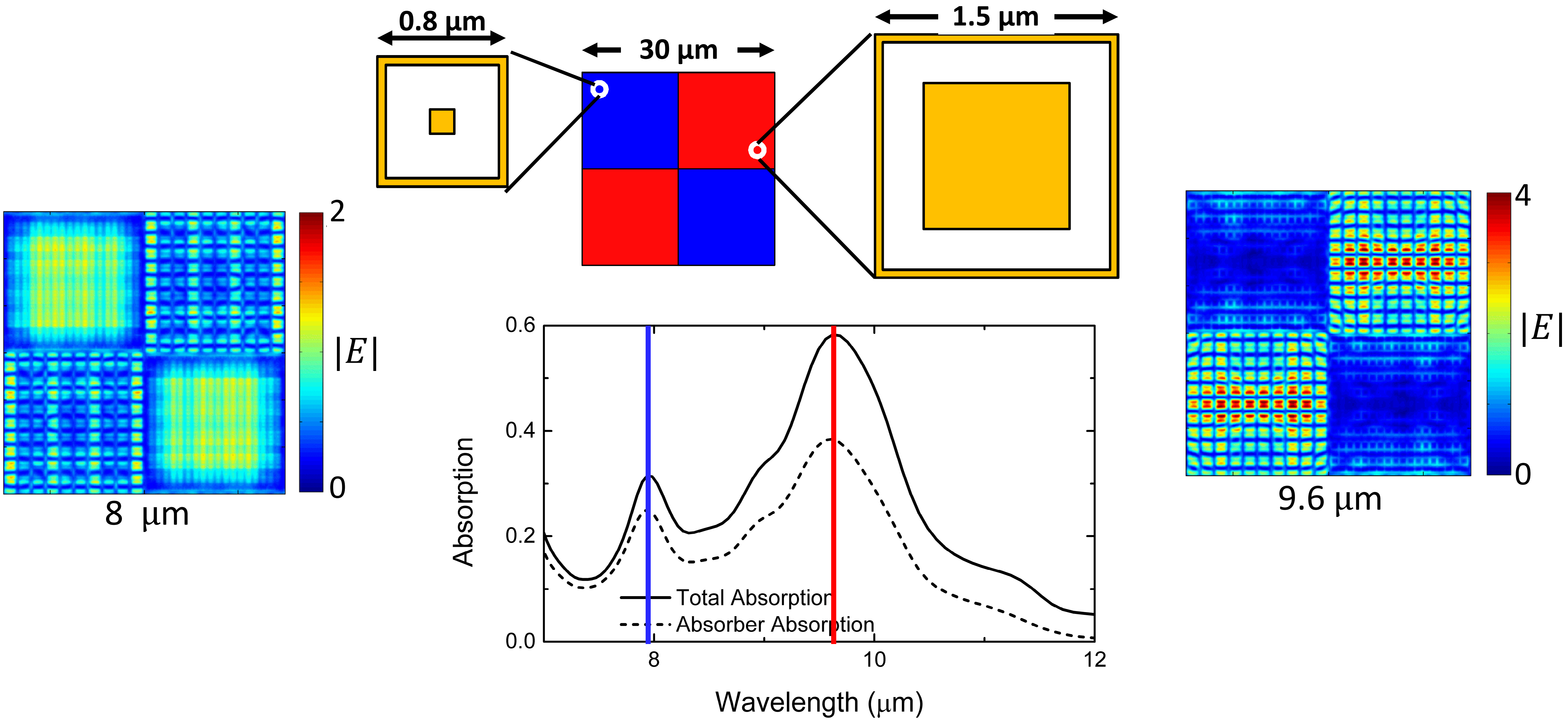

Conclusion

- Demonstrated significant gains in QE with reduction in absorbing volume.
- Control of detector response without changing detector itself.
- Broadband resonant response
- Examination of two color detectors