SAND2012-10366C

All-Semiconductor Plasmonic Perfect Absorbers

S. Law[1], L. Yu[1], T. Kilpatrick[1], T. Ribaudo[2], E. Shaner[2], and D. Wasserman[1]

[1]Department of Electrical and Computer Engineering, University of Illinois Urbana-Champaign; [2] Sandia National Labs

Background

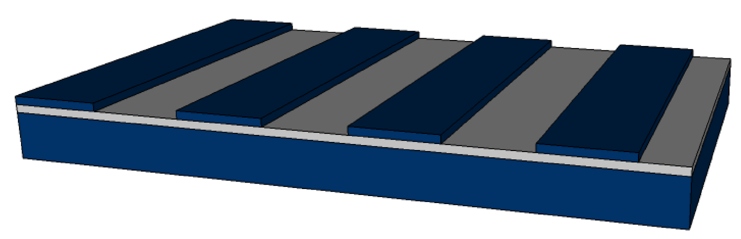
Perfect absorber (PA) structures show near 100% absorption at a pre-determined wavelength. Structures generally consist of a thin patterned metal top layer (usually stripes or disks) and a thick metal ground plane separated by a thin insulating spacer layer. PA occurs when light is coupled into the structure via a plasmonic, antenna, or metamaterial resonance in the top layer. The position and strength of the resonance is determined by the thickness of the spacer layer and the size and periodicity of the top layer patterning.

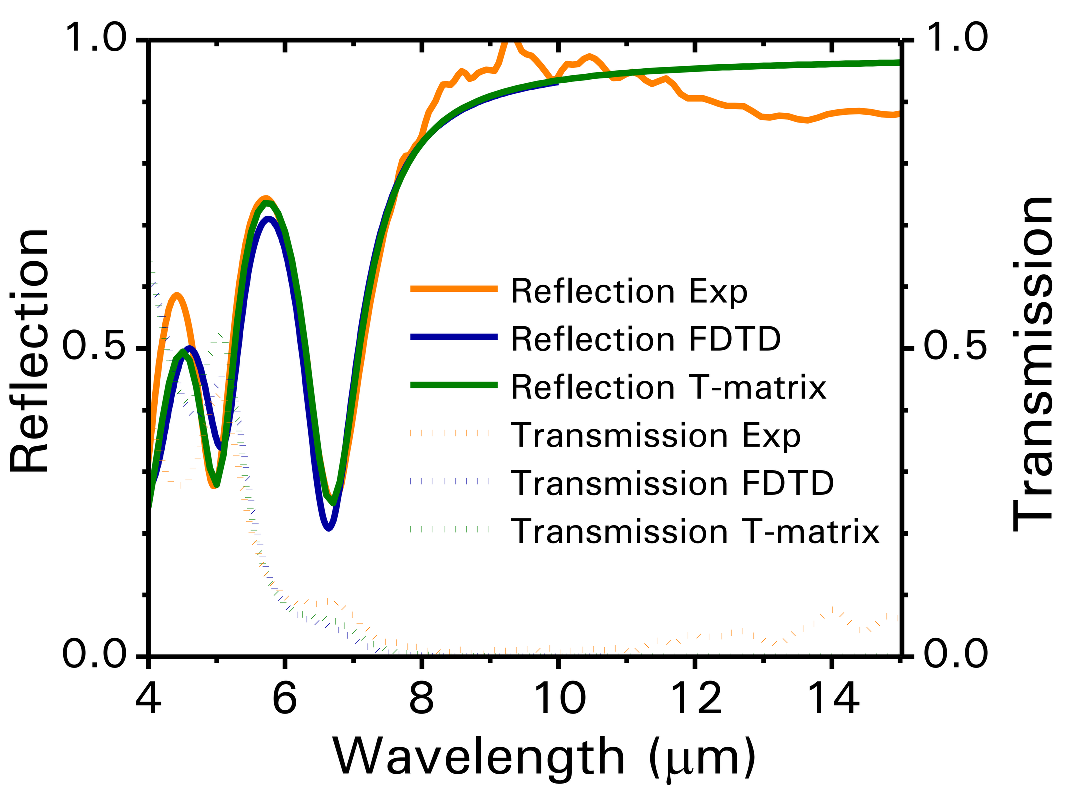
PA structures in the mid-infrared (mid-IR) could be used for selective thermal emission, enhanced sensing of chemical or biological samples, and enhanced photodetector (QWIP/QDIP) response. Previous mid-infrared PA samples used gold as the constituent metal[1-4] and had light coupling into the structure via an antenna or metamaterial resonance. However, a true subwavelength **plasmonic** PA cannot be fabricated in the mid-IR using traditional metals due to their large, negative permittivities. Doped semiconductors have been shown to behave like plasmonic metals in the mid-IR and can be used instead of gold[5]. We demonstrate an all-semiconductor mid-IR plasmonic perfect absorber which can be integrated with active semiconductor elements or exhibit an enhanced interaction with molecular species, depending only on the vertical patterning.

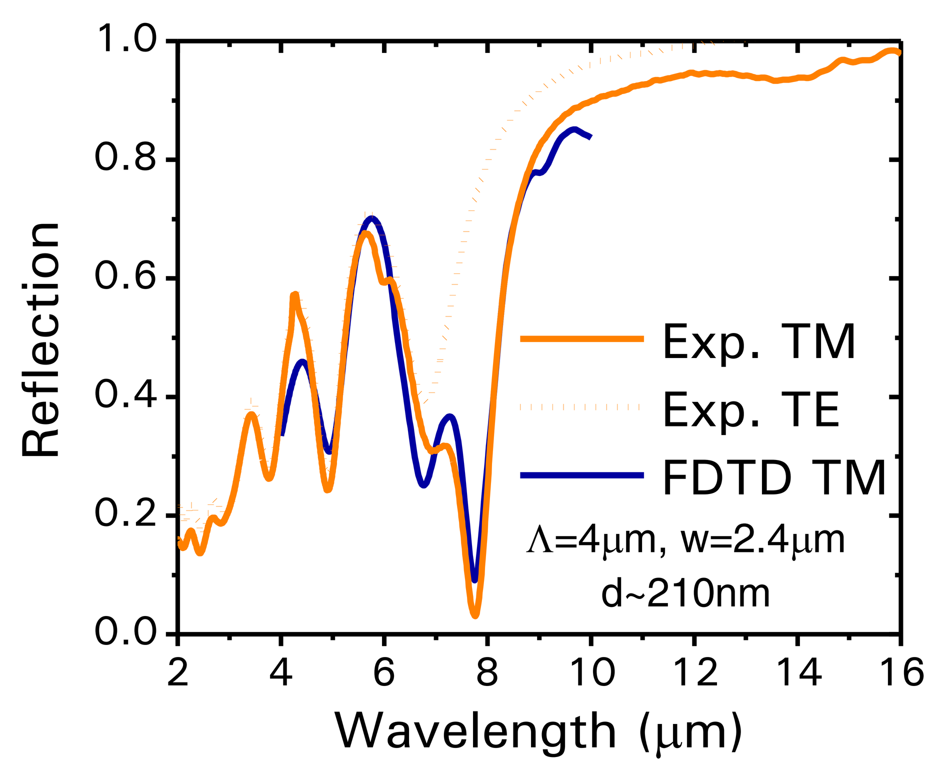
Experimental results

Sample fabrication

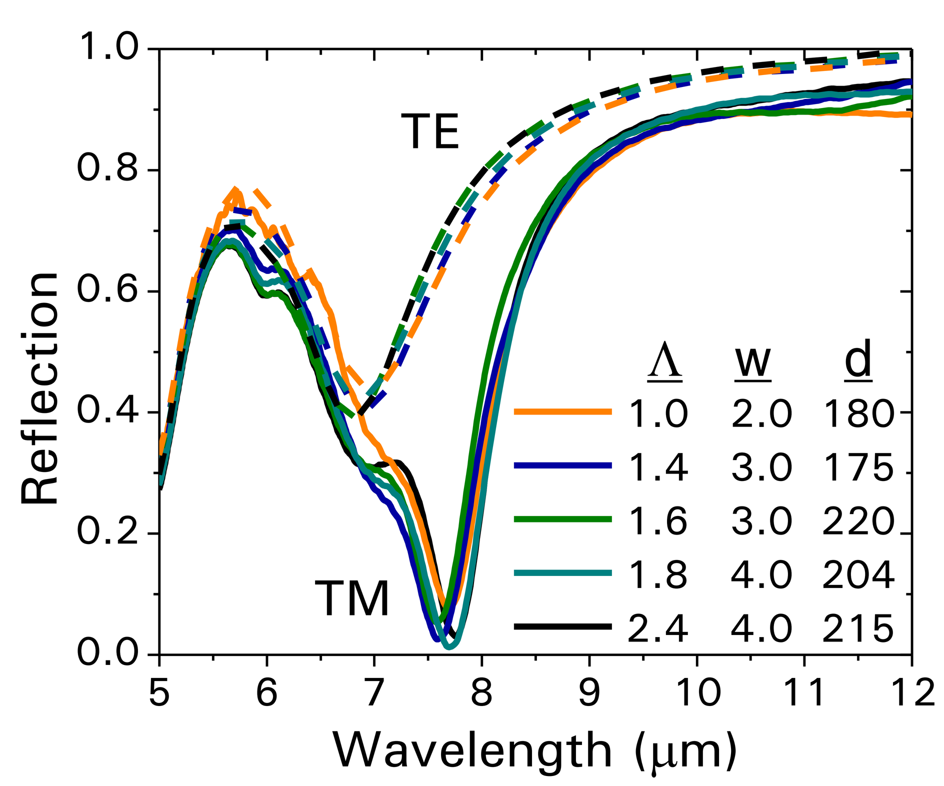
- Samples grown by molecular beam epitaxy on semi-insulating GaAs substrates
- 450nm InAs/1.5mm Si:InAs ground plane/220nm InAs spacer/220nm Si:InAs top layer
- Films patterned into stripes using standard photolithography and wet chemical etching
- Stripe width (w), periodicity (Λ), and etch depth (d) varied

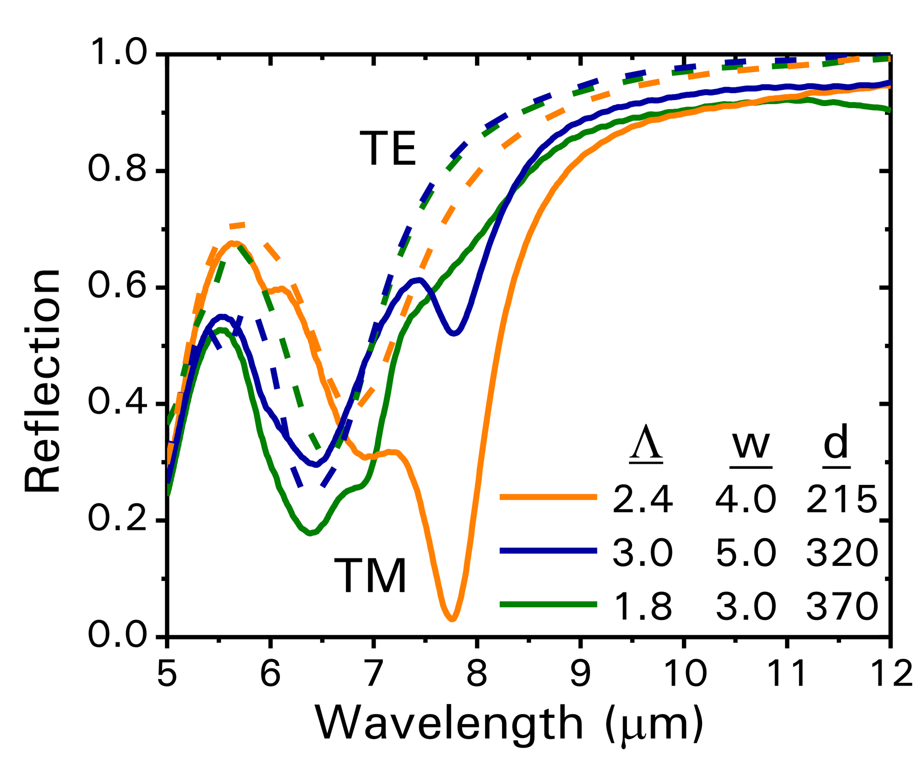






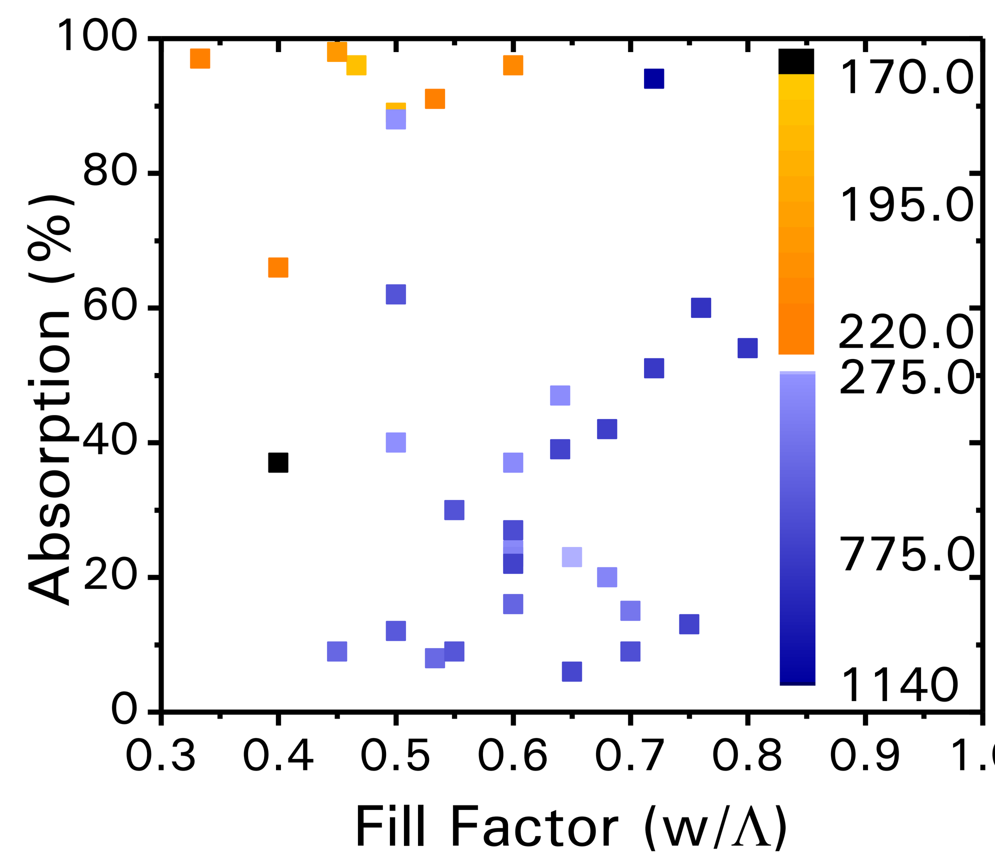
- Reflection and transmission data taken on unpatterned film (left) and all patterned films (example shown on right)
- Unpatterned film modeled with T-matrix and finite-difference time-domain (FDTD) methods with plasma wavelength $\lambda_p = 5.9\mu m$, scattering rate $\Gamma = 1.2\times10^{13}$ s^{-1}
- FDTD modeling of patterned films (right) quite accurate

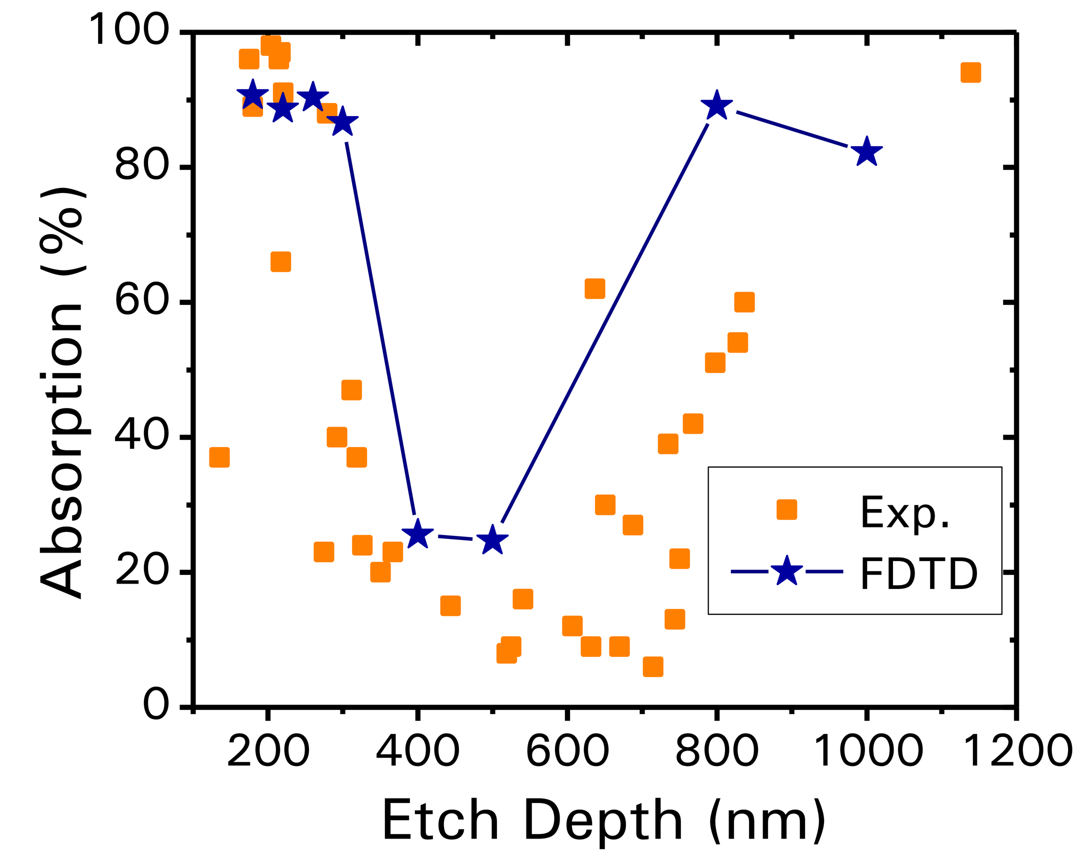




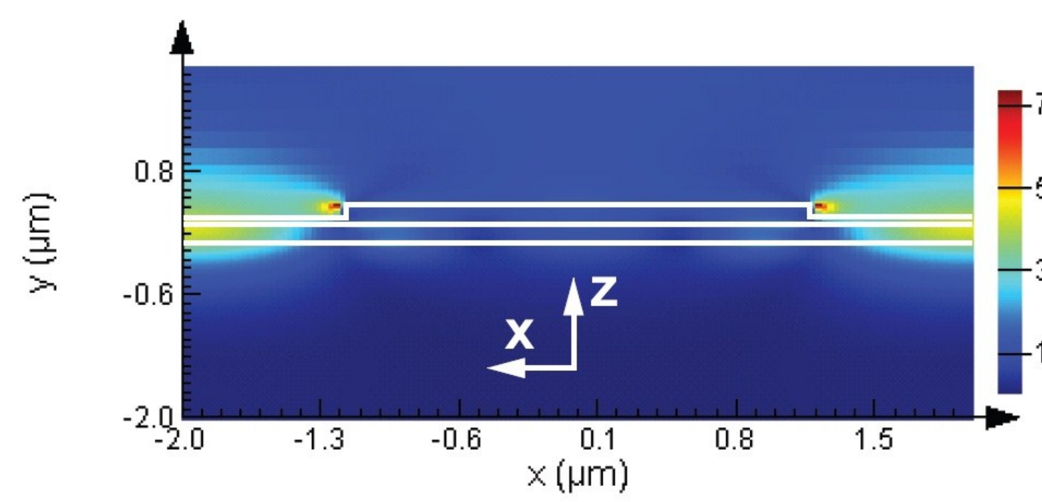
- For samples with similar etch depths (left), **position and strength of absorption do not depend on period (Λ), stripe width (w) or fill factor (w/Λ)**—contrary to other PA results
- For samples with similar fill factors (right), strong dependence of absorption strength on etch depth (d)

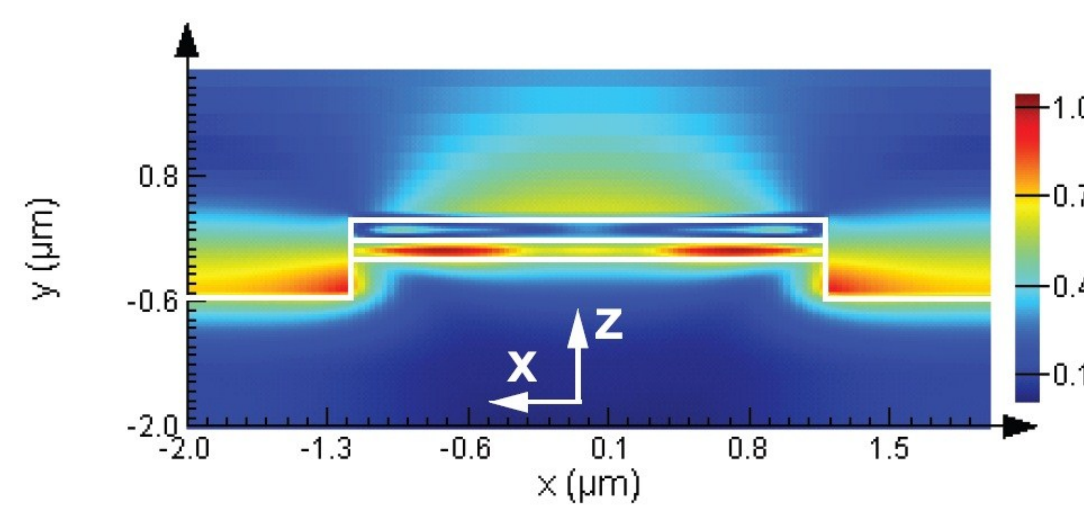
Modeling





- Absorption as a function of fill factor is shown on left, with etch depth encoded the color scale—no dependence on fill factor
- Absorption as a function of etch depth is shown on right along with FDTD simulations, which match well
- **Etch depth is controlling absorption strength**





- Shallow etch depth simulations of E_x (shown on left) reveal the electric field is concentrated between the stripes
  - Useful for biological/chemical sensing
- Deep etch depth simulations of H_y (shown on right) reveal the magnetic field is concentrated in the stripe spacer layer
  - Useful for QWIP/QDIP enhancement

Conclusions

- Demonstrated all-semiconductor plasmonic perfect absorber
- Periodicity, stripe width, and fill factor do not influence position or strength of absorption
- Shallow-etched samples show strong absorption, electric field between stripes
- Mid-etched samples show no absorption
- Deep-etched samples show strong absorption, magnetic field in spacer layer under stripe
- Useful for biological/chemical sensing or enhancing QWIP/QDIP sensitivity

References and Acknowledgments

1. Z. Jiang, S. Yun, F. Toor, D. Werner, and T. Mayer, ACS Nano. **201**, 4641 (2011).
2. X. Liu, T. Tyler, T. Starr, A. Starr, N. Jokerst, and W. Padilla, Phys. Rev. Lett. **107**, 045901 (2011).
3. J. Mason, S. Smith, and D. Wasserman, Appl. Phys. Lett. **98**, 241105 (2011).
4. J. Mason, G. Allen, V. Podolskiy, and D. Wasserman, IEEE Phot. Tech. Lett. **24**, 31 (2012).
5. S. Law, D. Adams, A. Taylor, and D. Wasserman, Opt. Express **20**, 12155 (2012).