

Nonresonant Broadband Funneling of Light via Ultrasubwavelength Channels

Ganesh Subramania

Sandia National Laboratories, Albuquerque, NM 87111

Collaborators:

Stavroula Foteinopoulou



Igal Brener



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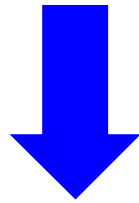


Light funneling through deep sub- λ apertures

- Enhance light-matter interaction through light confinement
- Improved performance for detector, sensor, photovoltaic, etc.

Enhanced Optical Transmission (EOT)

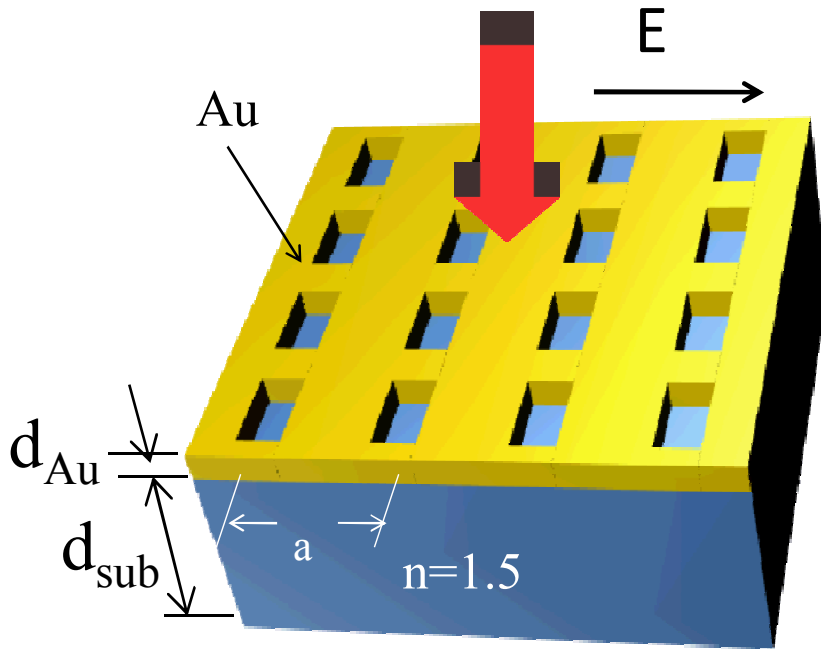
[T. W. Ebbesen et.al., Nature **391**, 667 (1998).]



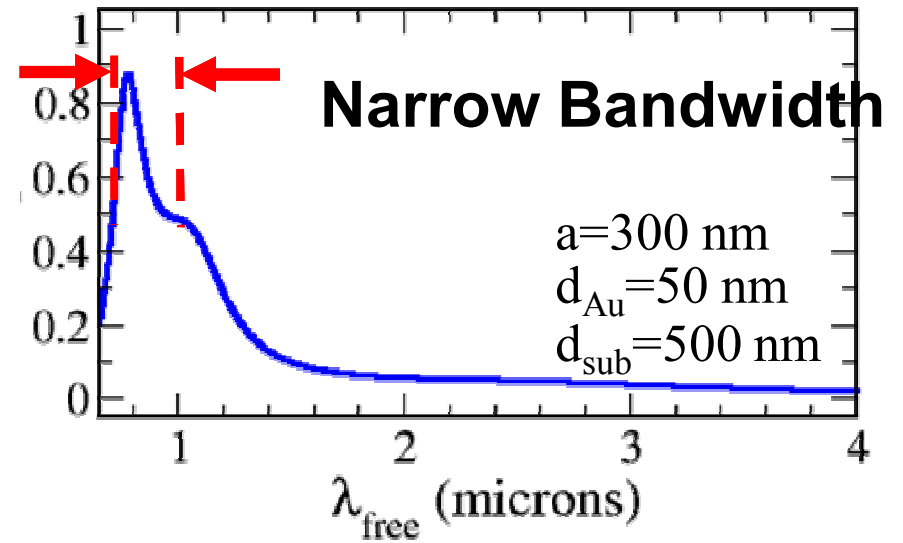
Funnel light through subwavelength hole arrays in metal by exciting structural surface plasmon polaritons

C. Genet and E. Ebbesen, Nature Reviews **445**, 39 (2007) and references therein. ; F. J. Garcia-Vidal, L. Martin-Moreno, T. W. Ebbesen, and L. Kuipers, Rev. Mod. Phys. **82**, 729 (2010) and references therein.

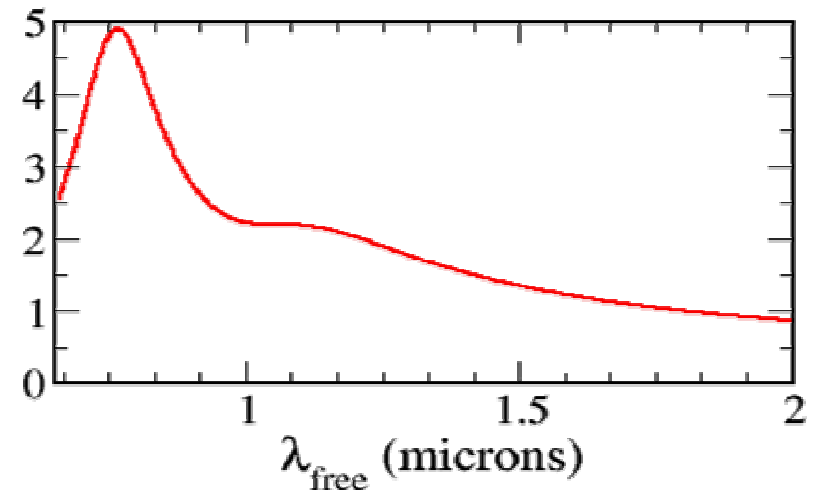
EOT platforms



Transmission

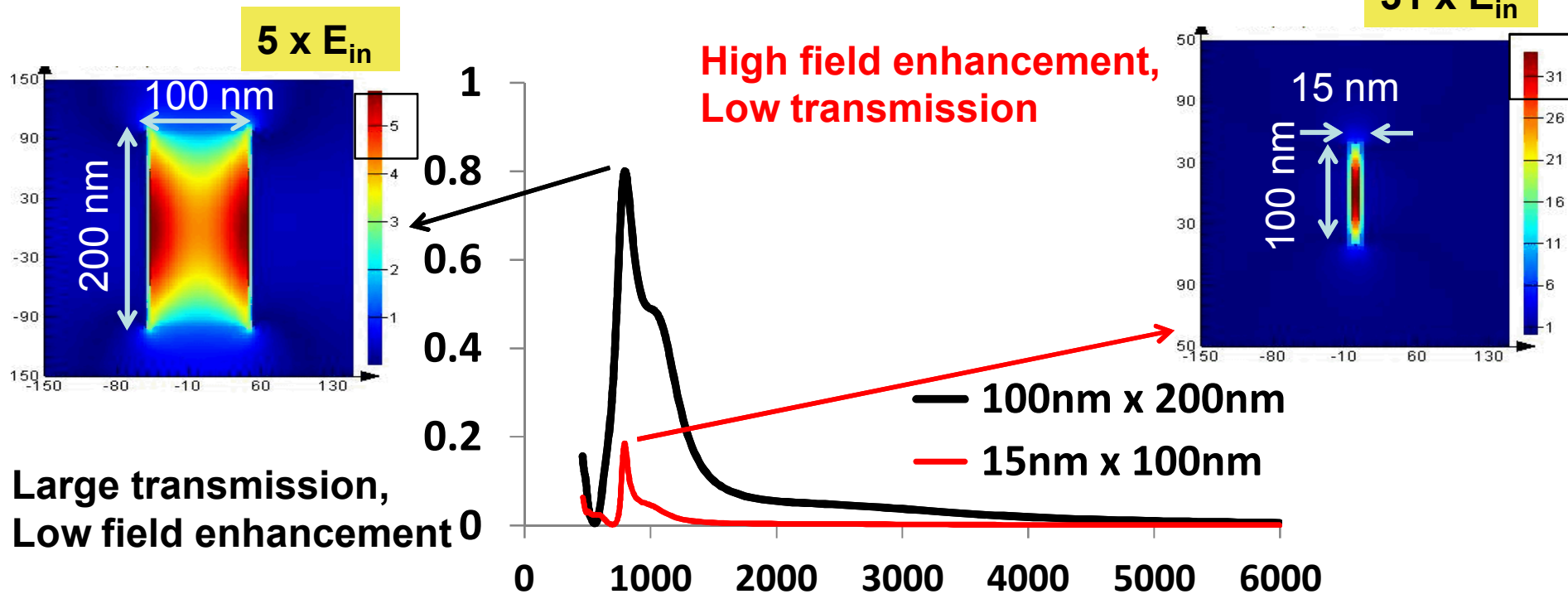


Near-field enhancement



Resonant

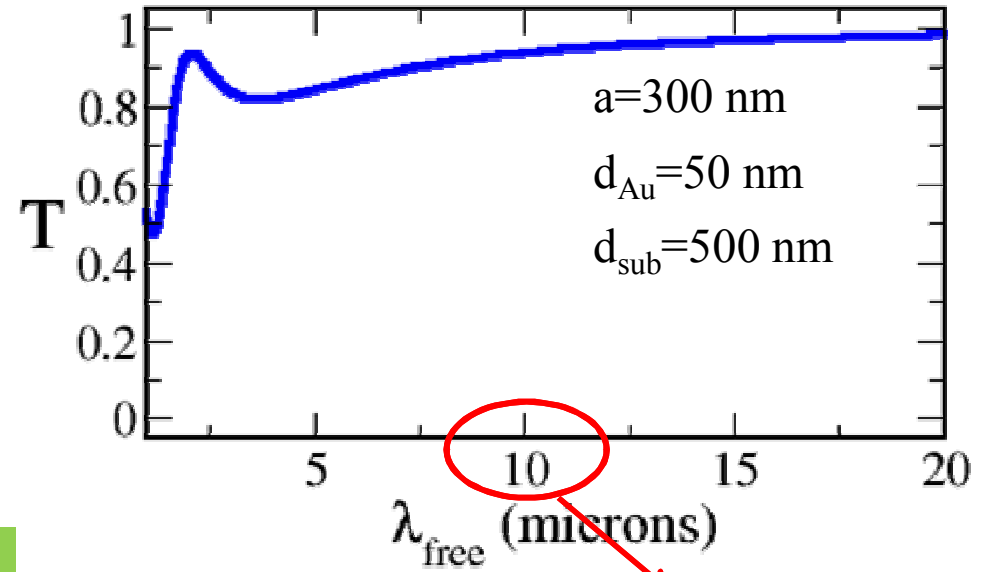
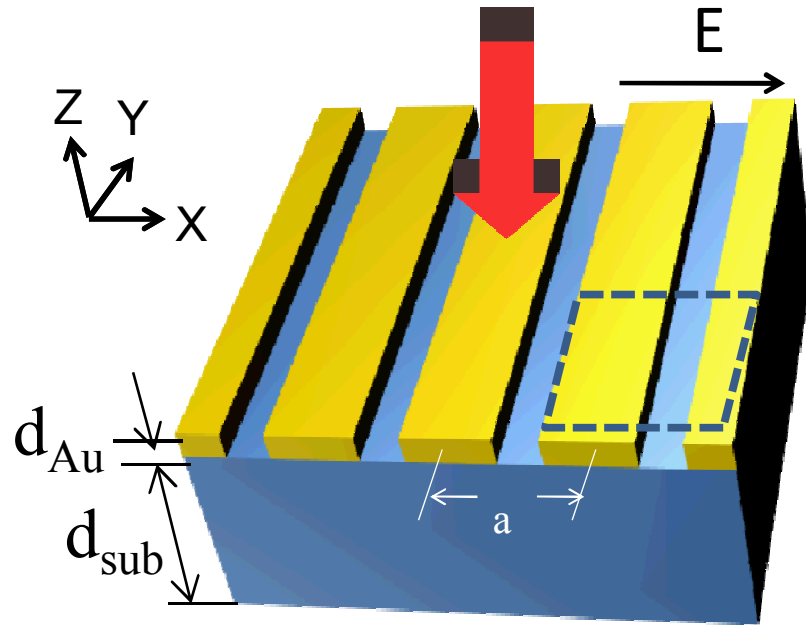
Resonant Approach



Can we achieve light confinement/field enhancement with broadband operation?

Non-Resonant Approach

Broadband: Wire grid structures



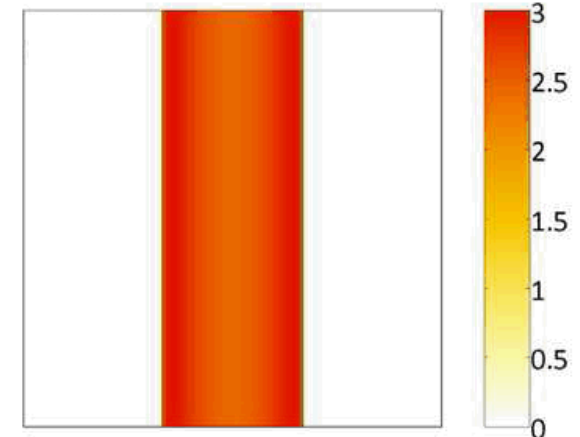
Pochi Yeh, Opt. Comm. 26, 289 (1978)

✓ Broadband, high transmission spanning the entire Mid-IR range.

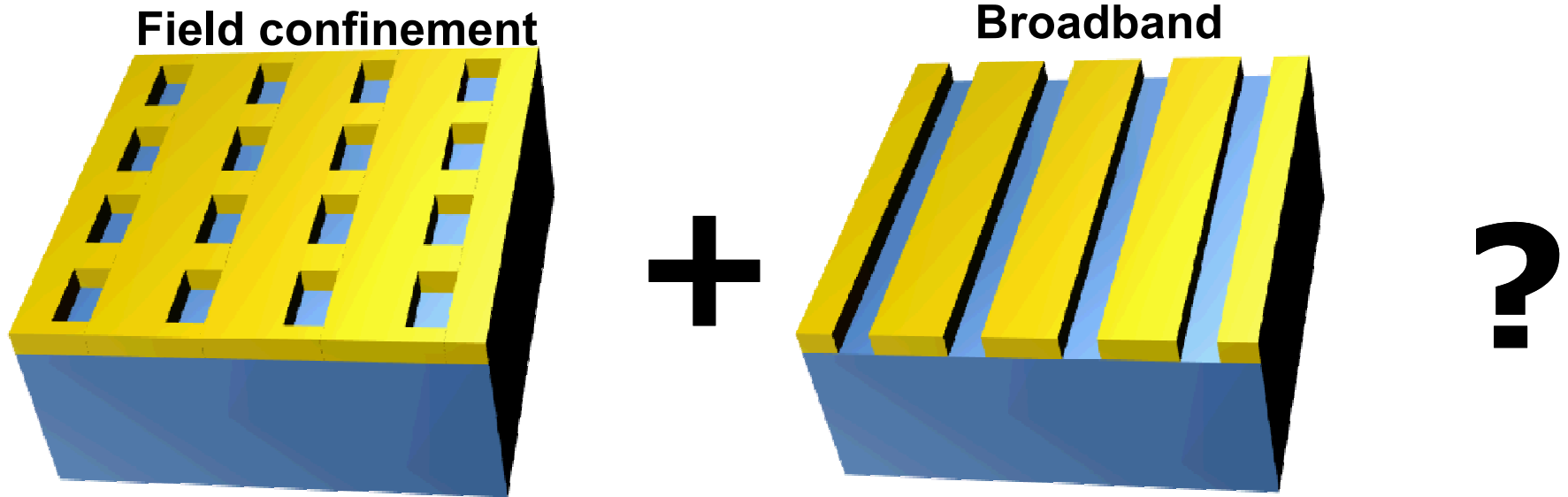
X Poor light confinement and enhancement



$|E_x|$



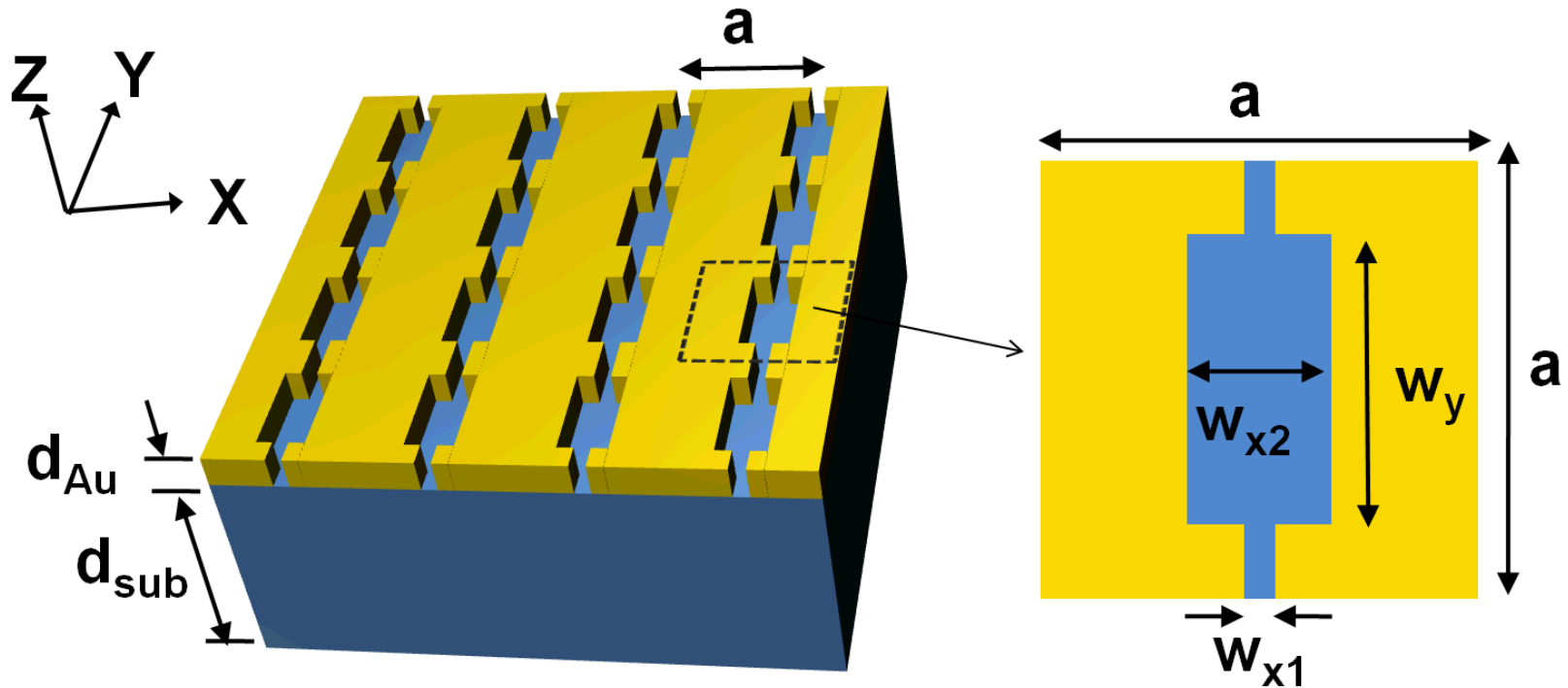
Can we combine the merits of EOT platforms and wire grids?



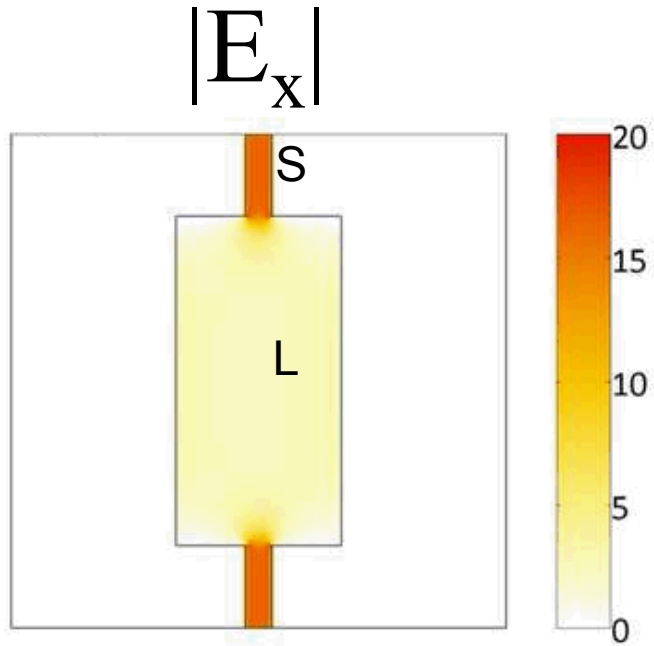
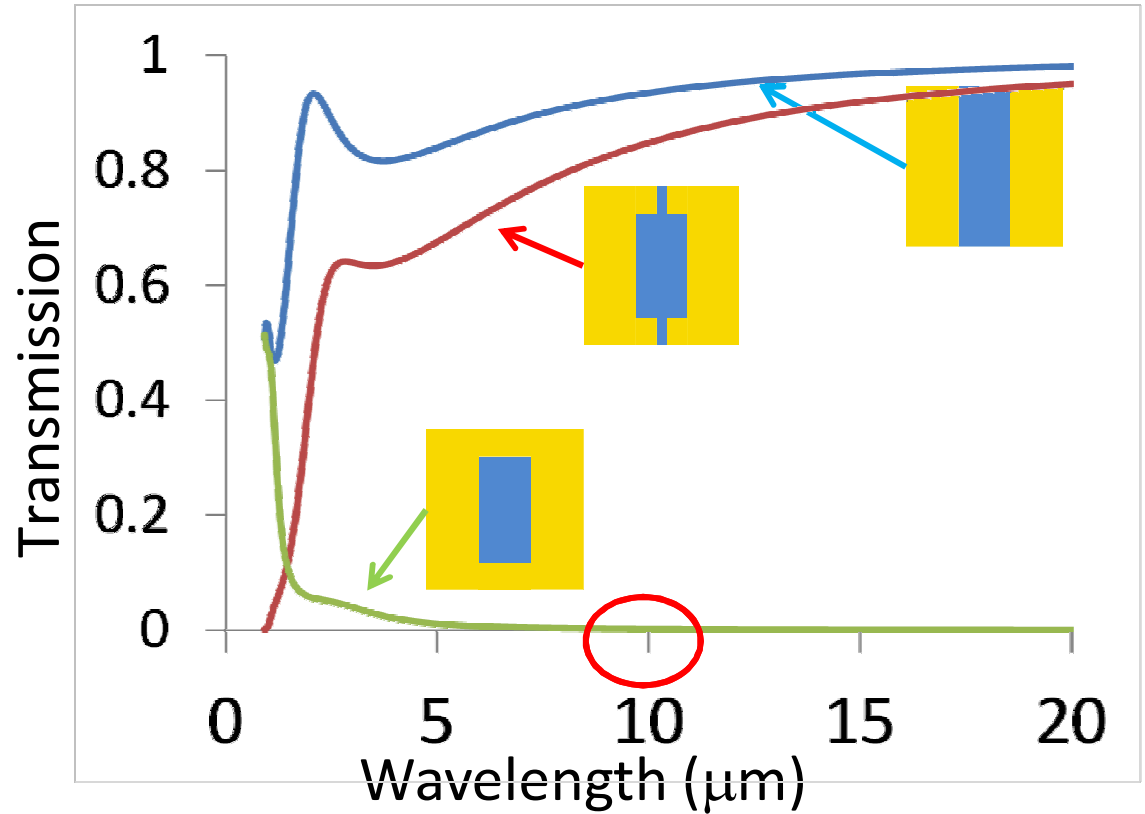
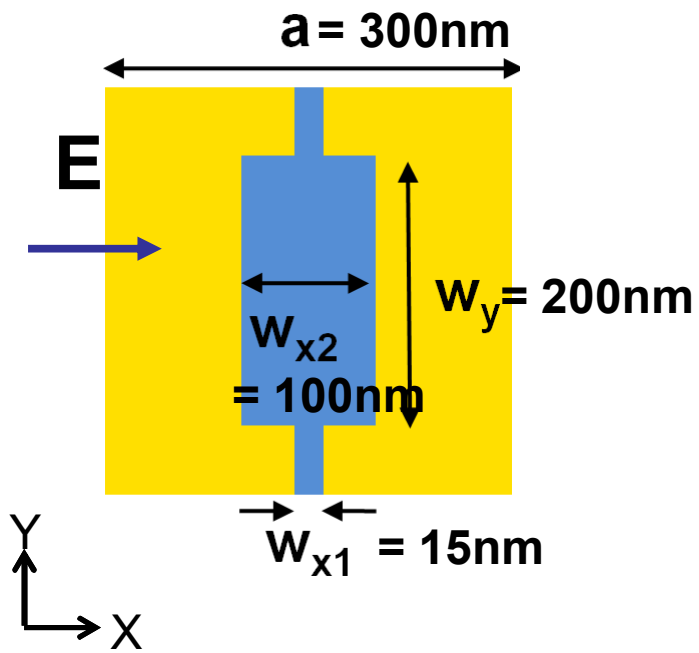
Goal:

- Broadband transmission
- Sub-wavelength power confinement
- E-field enhancement

Double-groove structure

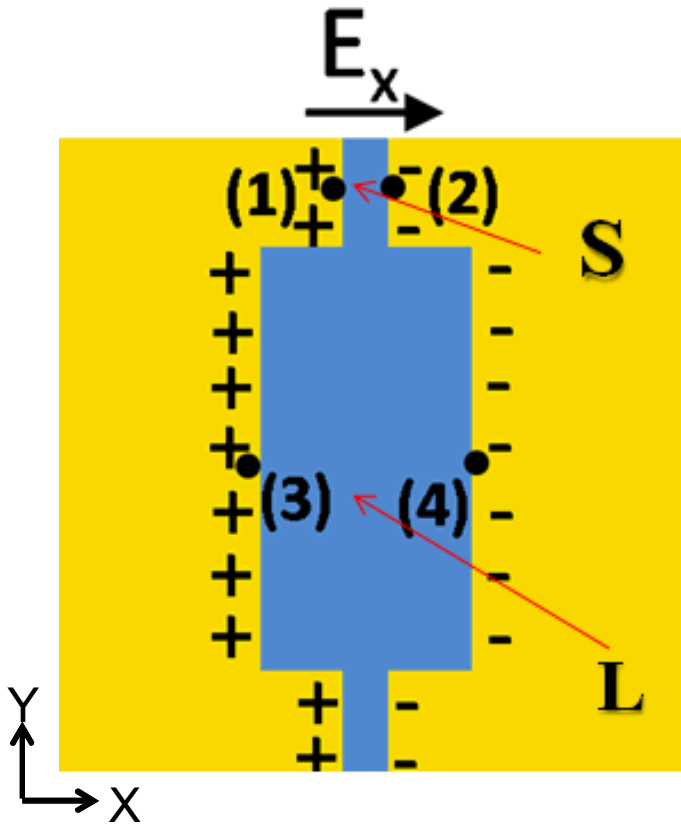


G. Subramania , S. Foteinopoulou, & I. Brener, "Nonresonant Broadband Funneling of Light via Ultrasubwavelength Channels," *Phys. Rev. Lett.* **107**, 163902 (2011).



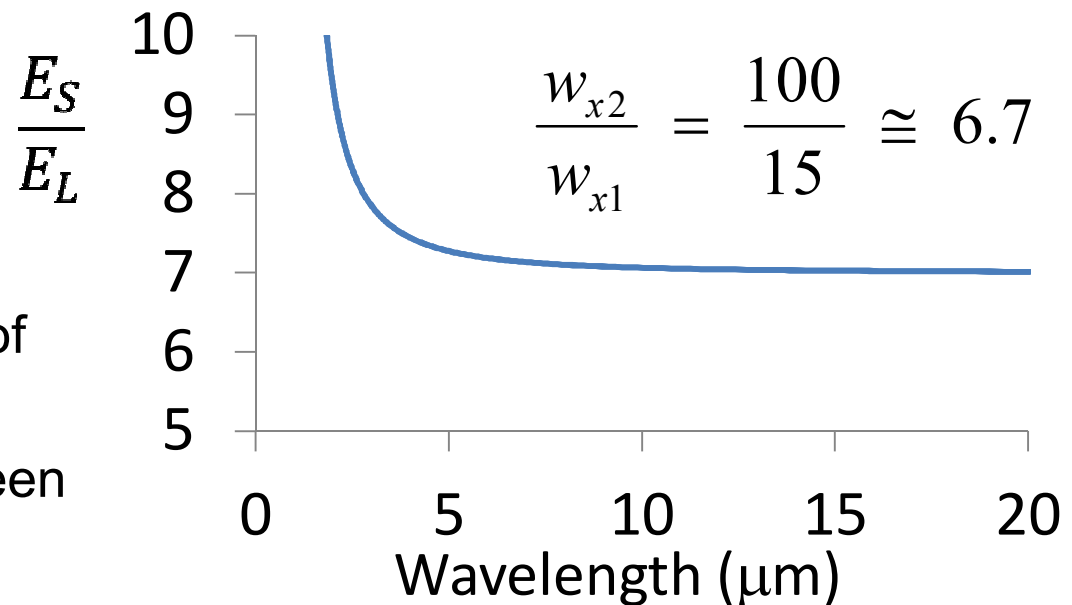
PRL. 107, 163902 (2011).

Mechanism: Quasi-static response



- Voltage across the small and large gaps are nearly equal

$$V_S \cong V_L \Rightarrow \frac{E_S}{E_L} = \frac{w_{x2}}{w_{x1}}$$

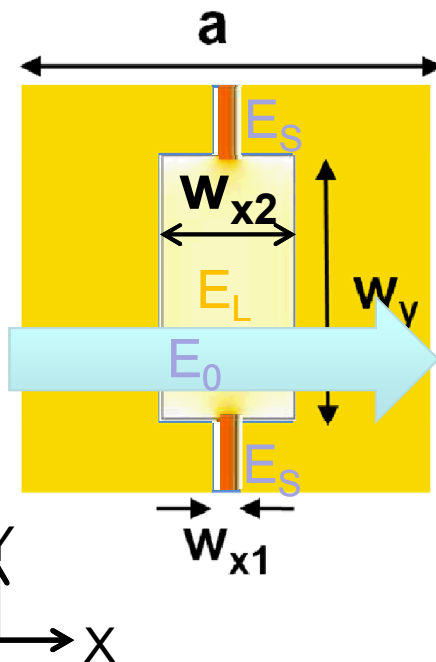


- Near-instantaneous response of charges even at mid-IR
- No effective current flow between small and large gap region on either side

Quasistatic calculations- long λ limit

Neglecting reflection and applying avg. E-tangential within a unit cell is continuous

$$E_0 a^2 \cong E_L w_{x2} w_y + E_S w_{x1} (a - w_y)$$

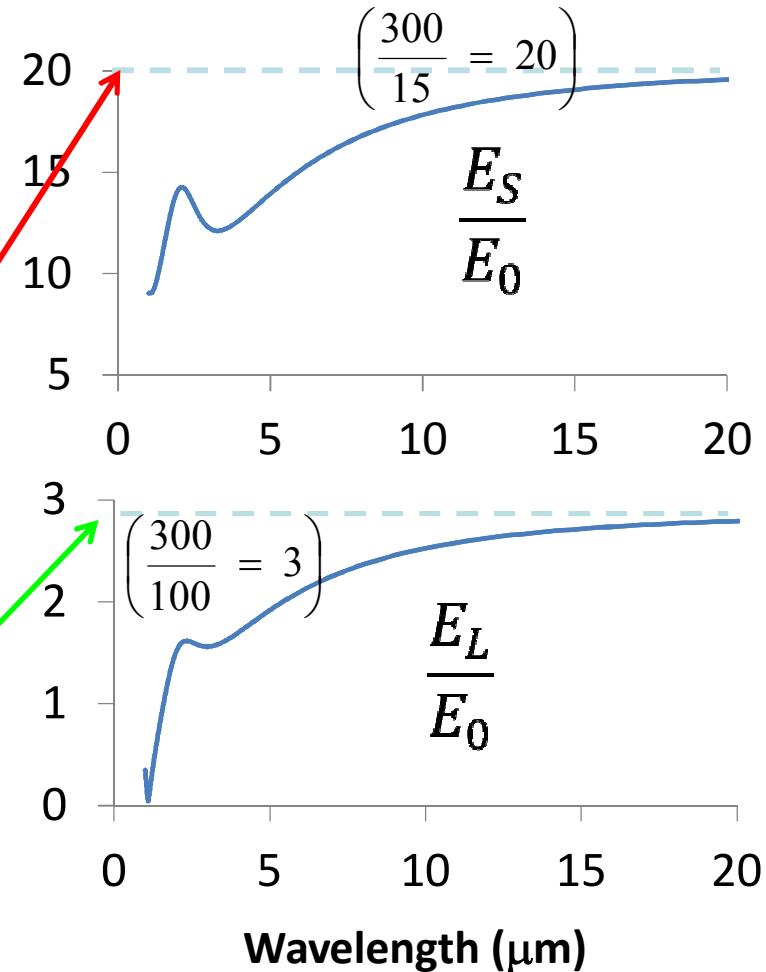


$$\frac{E_S}{E_L} = \frac{w_{x2}}{w_{x1}}$$



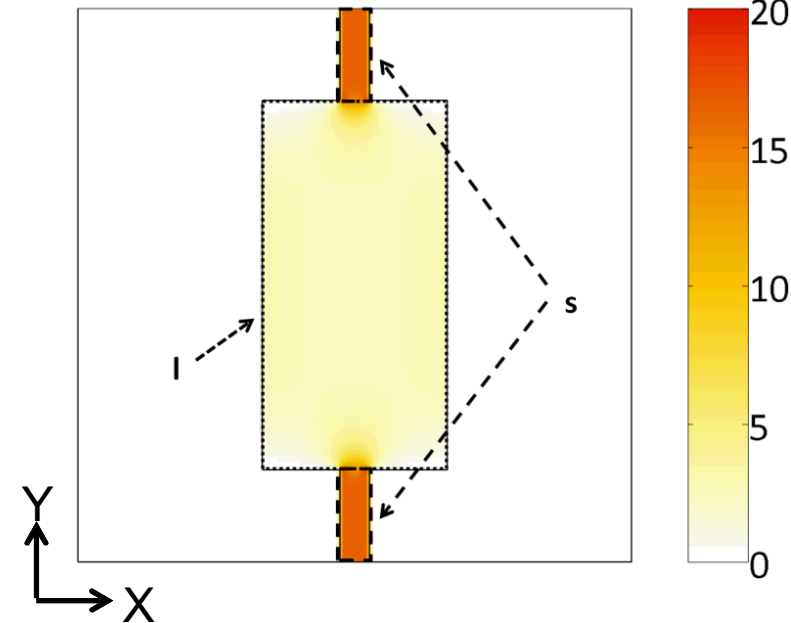
$$\frac{E_S}{E_0} = \frac{a}{w_{x1}}$$

$$\frac{E_L}{E_0} = \frac{a}{w_{x2}}$$

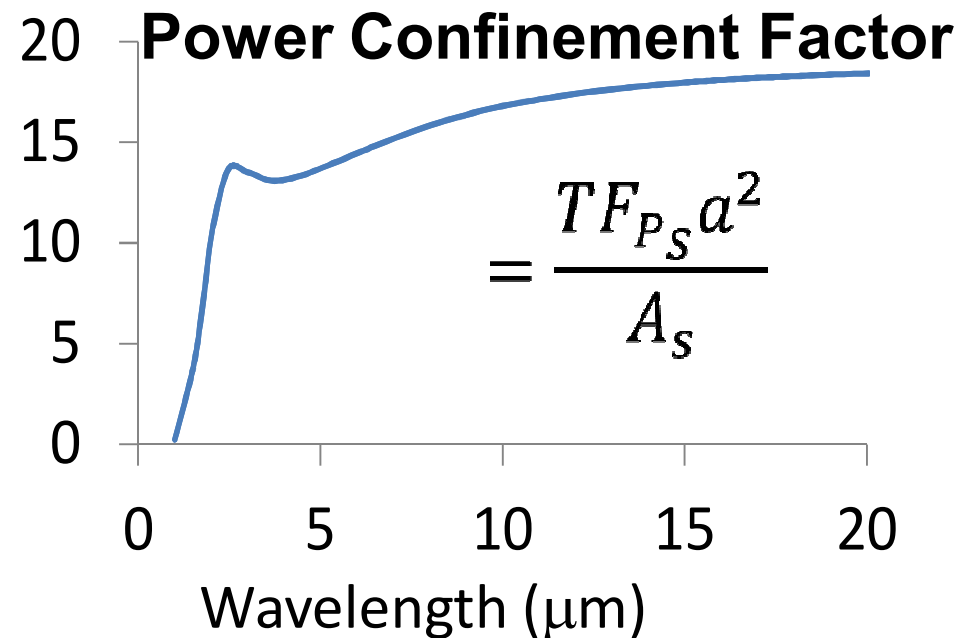
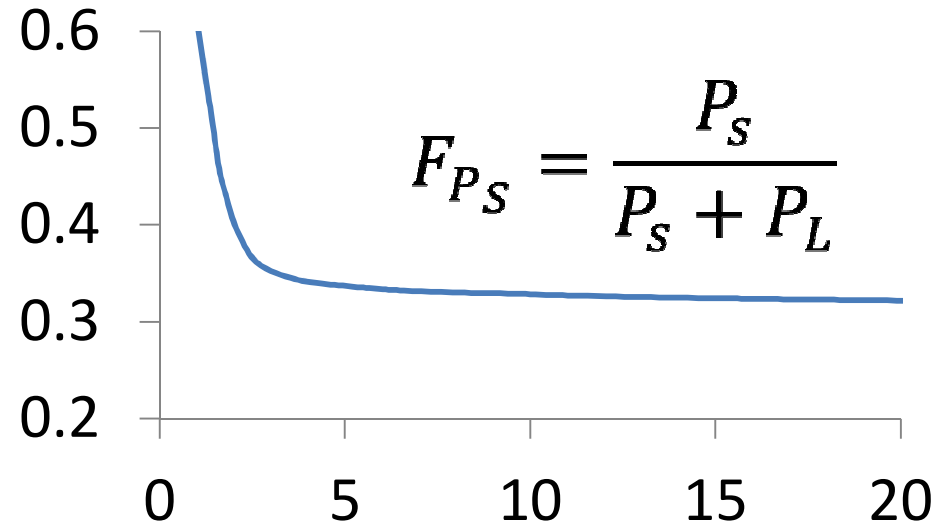


Power Distribution and Confinement Factor

$S_z @ \lambda \sim 10 \mu\text{m}$

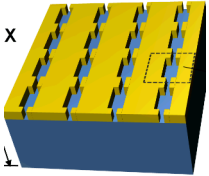


Nearly 30% of the transmitted power is channeled through an area $\sim (\lambda/250)^2$ that is **1/60th** of the unit cell area.



Summary

- Broadband transmission ($\lambda \sim 20 \mu\text{m}$ range)
- The mechanism based on instantaneous electron response- **Non-resonant**
- Large electric field confinement in the narrow gap possible ($>20X$)
- Subwavelength confinement $\sim \lambda^2/500^2$

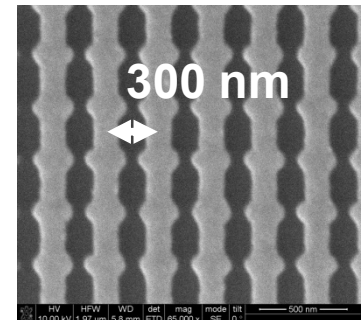


Impact

- PDOS enhancement – MidIR sources, Energy conversion, midIR based sensing and detection
- Non-linear enhancement – Switching, SHG, Parametric conv., Raman

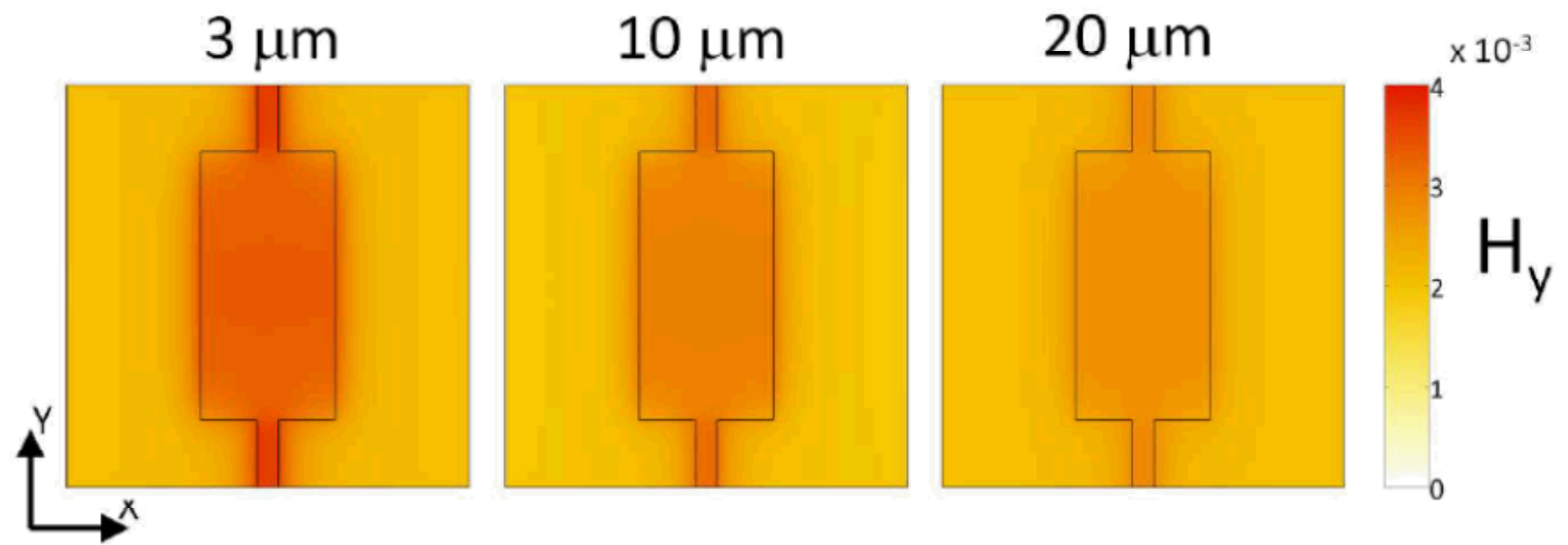
The next step is fabrication ...

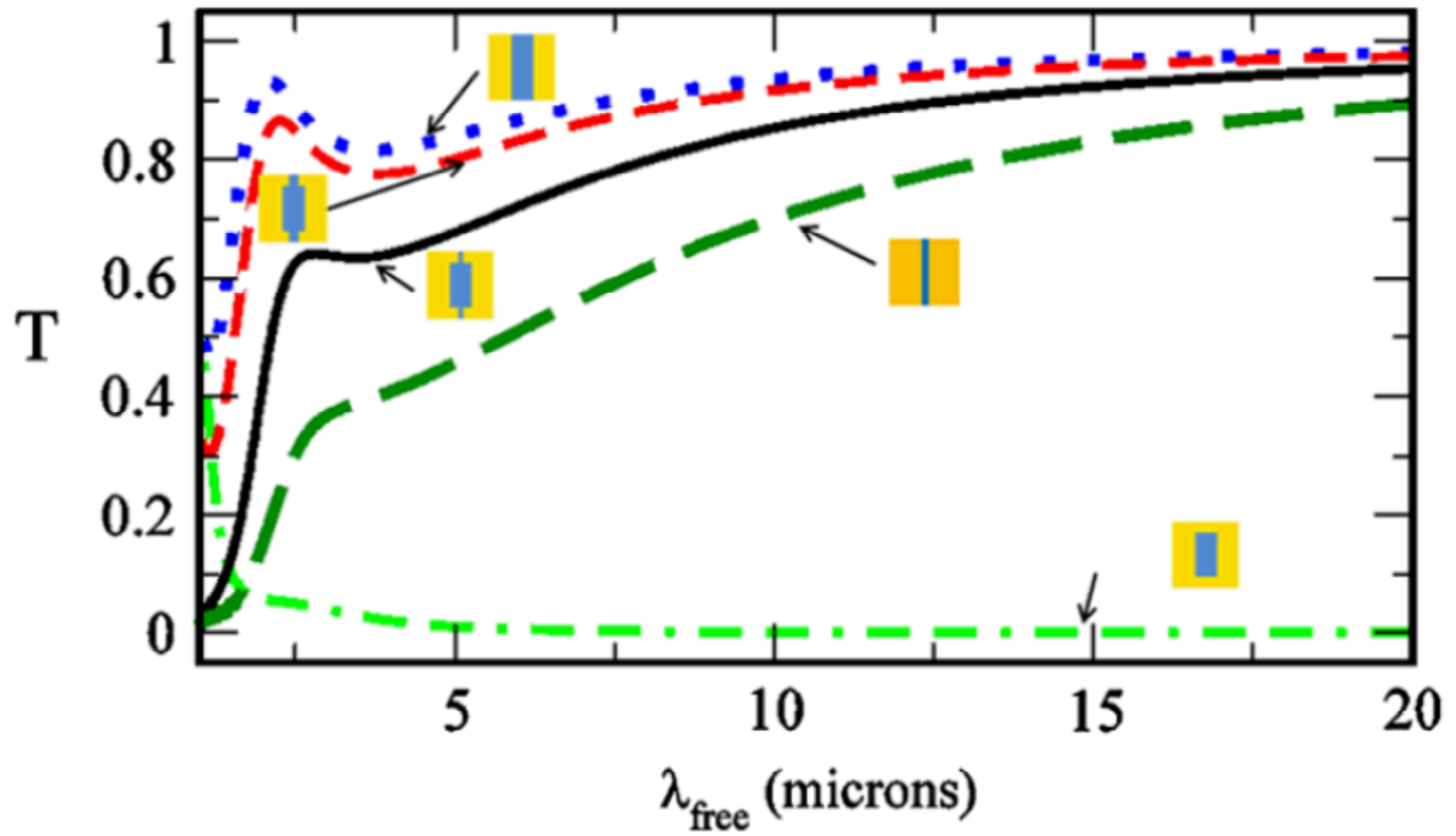
– Key challenge : achieving uniform $\sim 10\text{-}15\text{nm}$ gaps across large area devices $\sim 1\text{mm} \times 1\text{mm}$

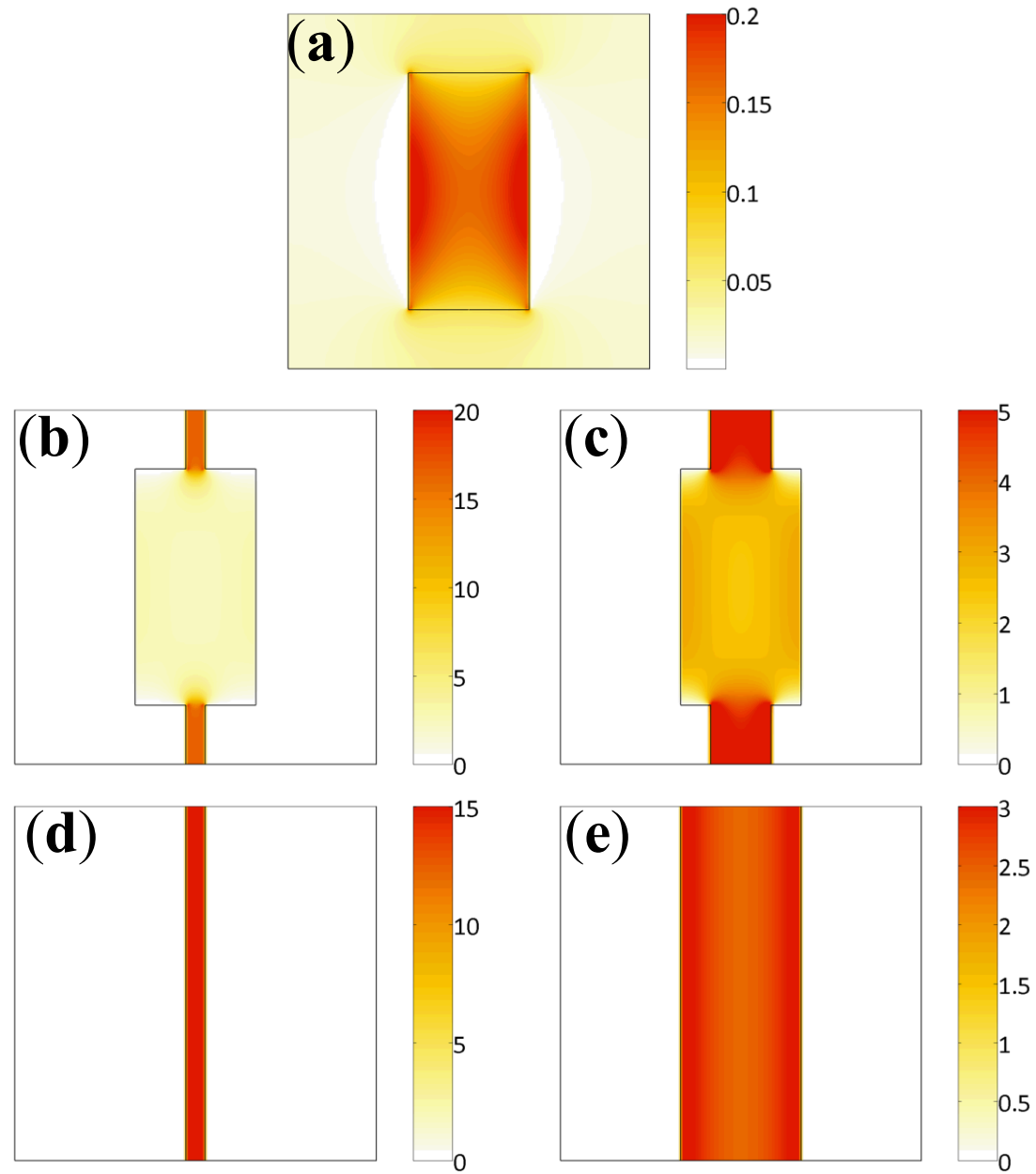


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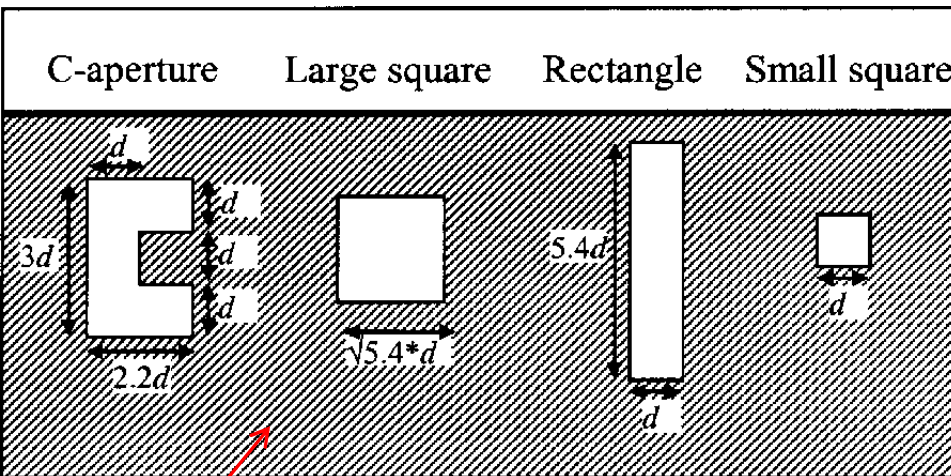
Extra slides



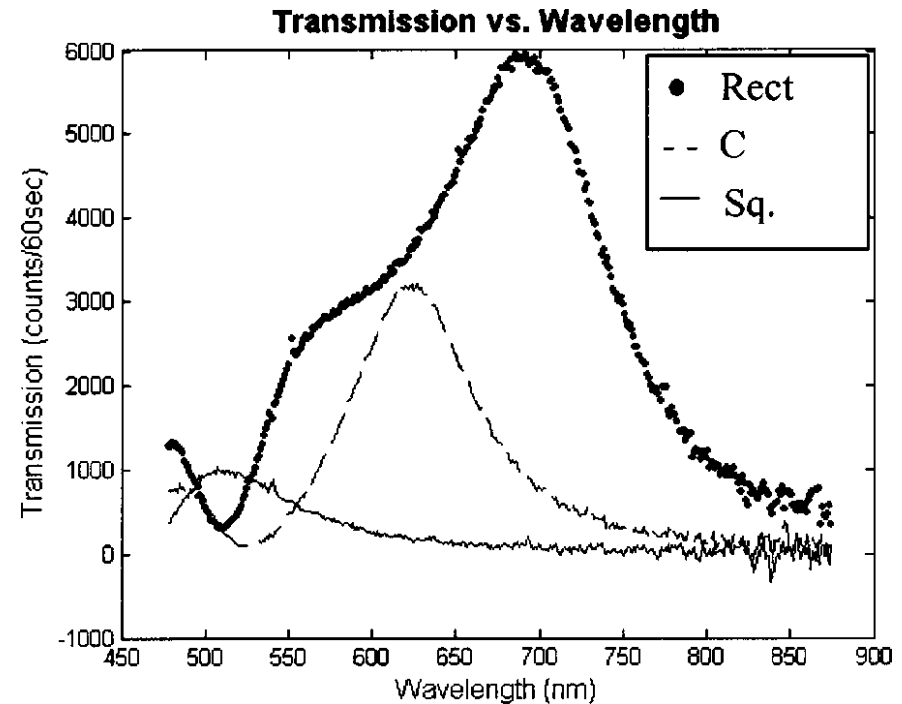




Single isolated slits



Au



Resonant phenomenon

Lambertus Hesselink group,
Stanford University, APL **85**, 649 (2004)