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Broadband Non-resonant Platform for Electric field Enhancement

Ganesh Subramania* and Stavroula Foteinopoulou#

* Sandia National Laboratories, Albuquerque, NM 87111
# Univ. of New Mexico, Albuquerque, NM

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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.

Field enhancement with Resonant EOT platforms

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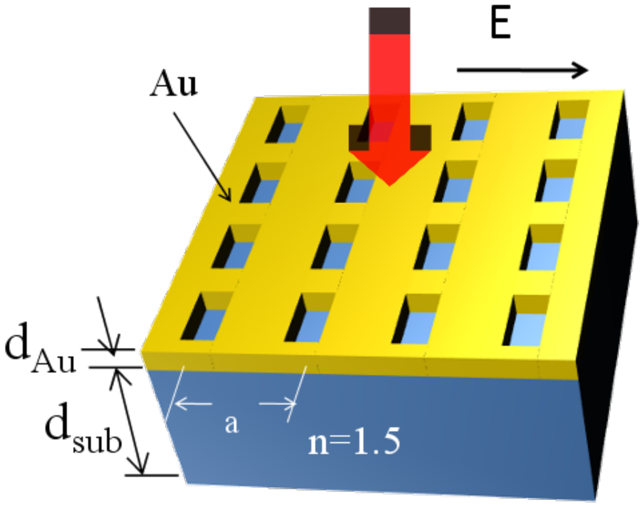
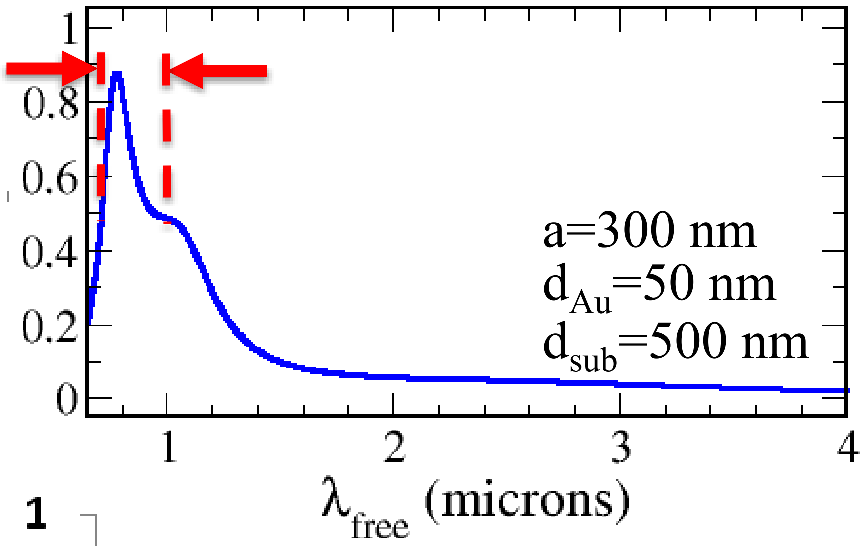
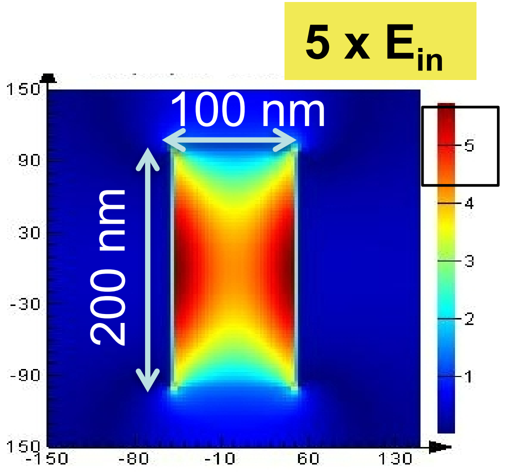


Transmission

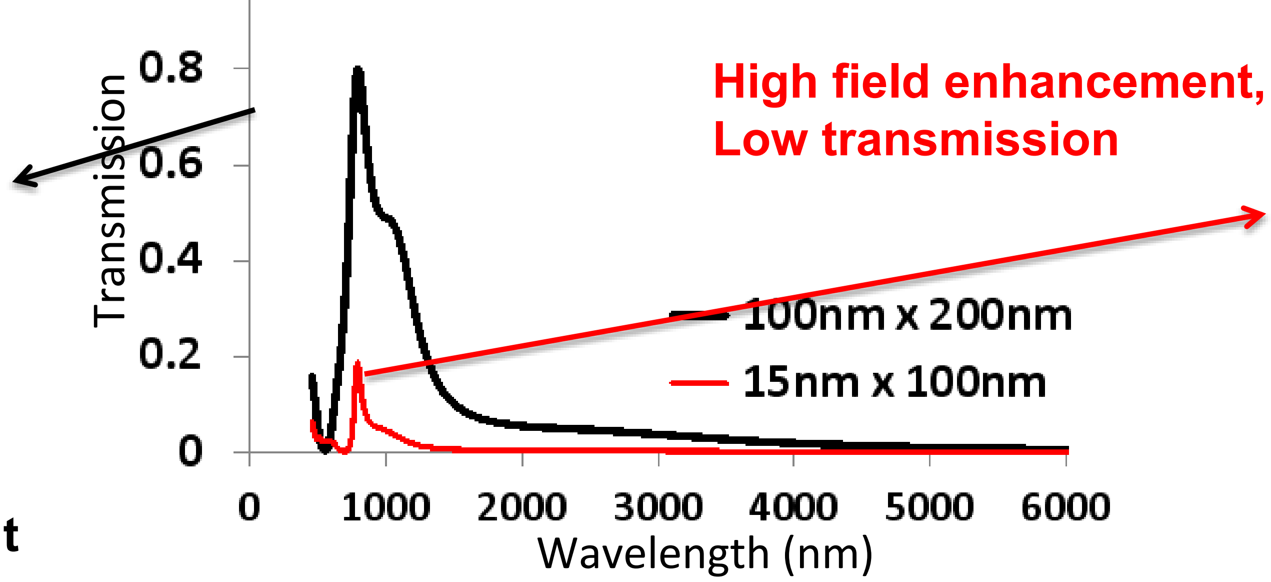


- ➢ **Narrow Bandwidth**
- ➢ **Resonance based**

5 x E_{in}

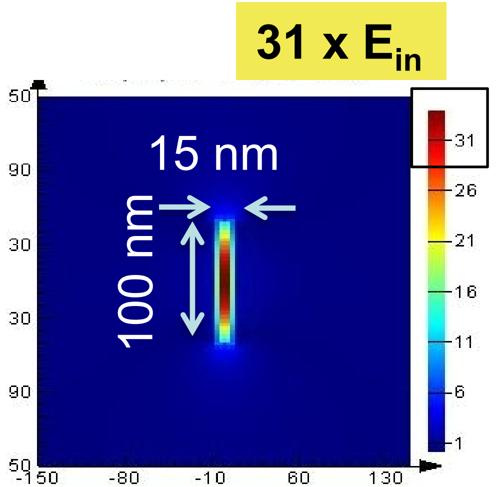


Large transmission, Low field enhancement



High field enhancement, Low transmission

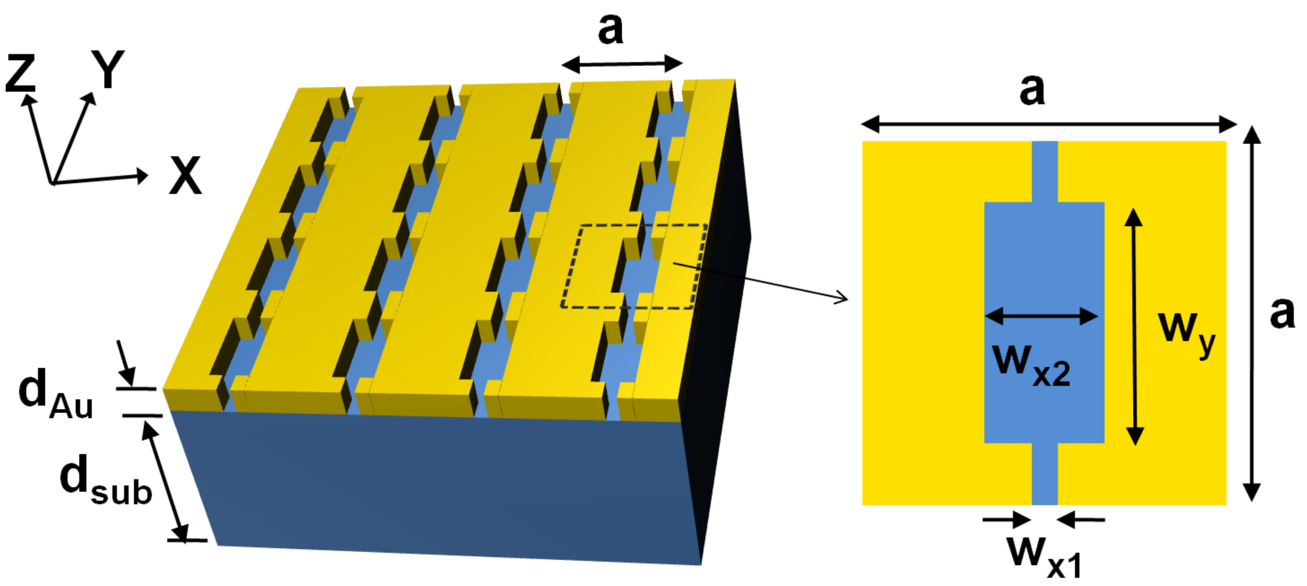
31 x E_{in}

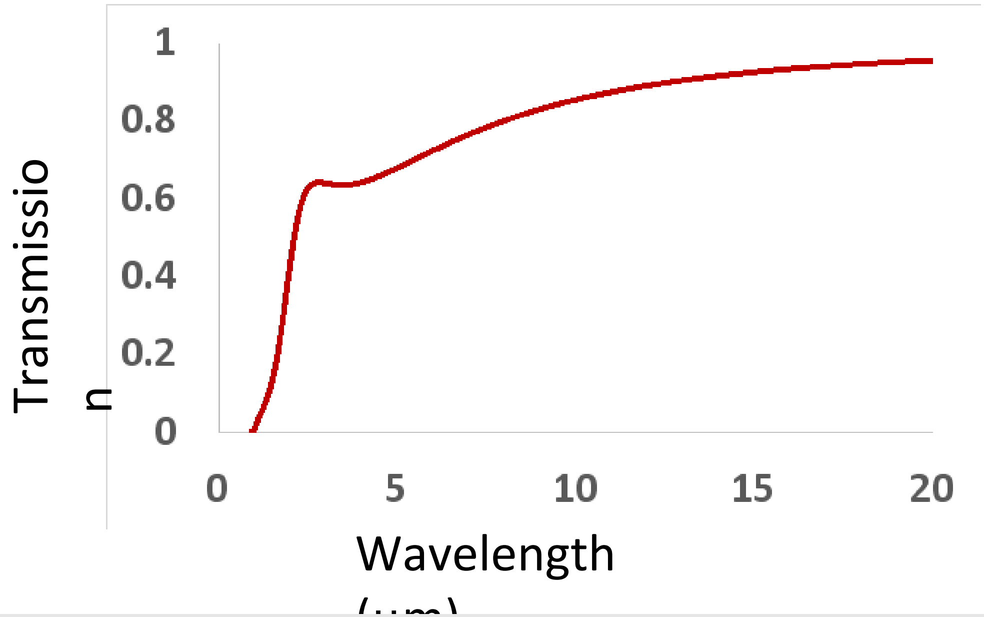


Can we achieve light confinement/field enhancement with broadband operation?

A Non-Resonant Approach…

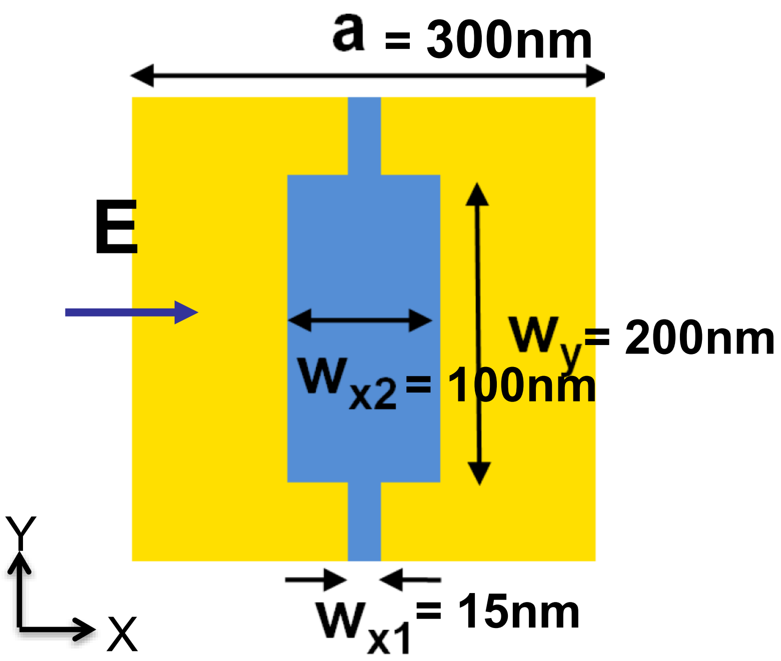
Double grooved periodic metal array

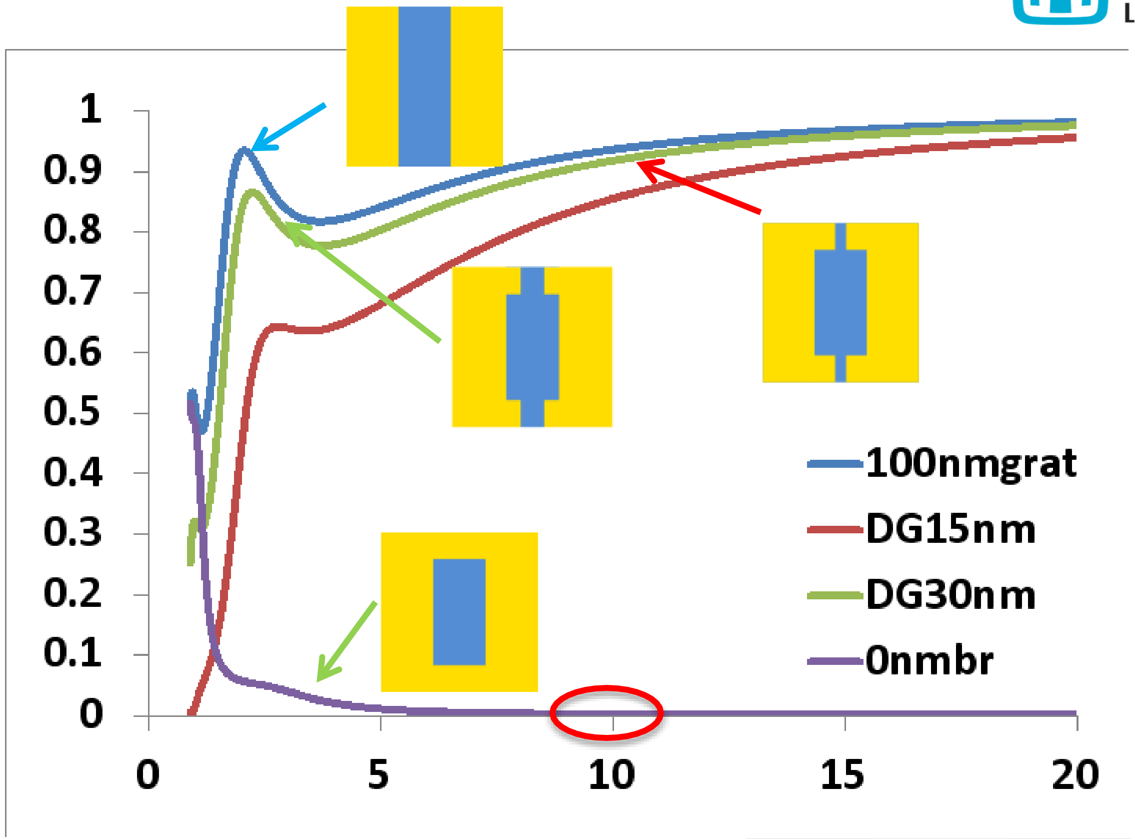




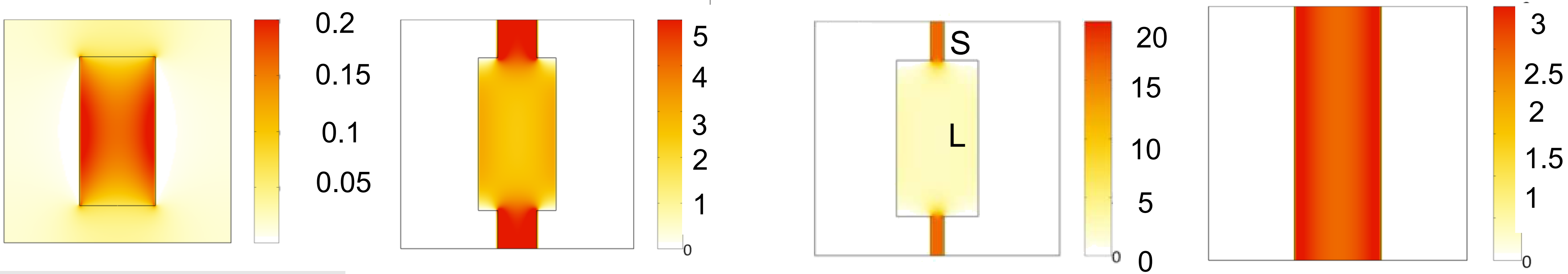
G. Subramania , S. Foteinopoulou, & I. Brener, “Nonresonant Broadband Funneling of Light via Ultrasubwavelength Channels,” *Phys. Rev. Lett.* **107**, 163902 (2011).

Transmission and Electric field distribution


a = 300nm
E
W_y= 200nm
W_{x2}= 100nm
Y
X
W_{x1}= 15nm

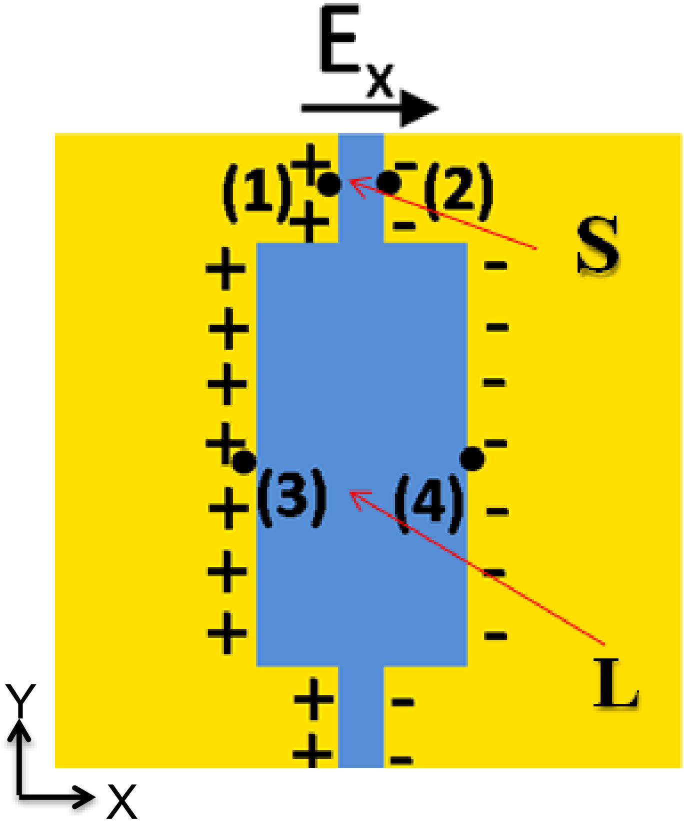


$|E_x|$



PRL. **107**, 163902 (2011).

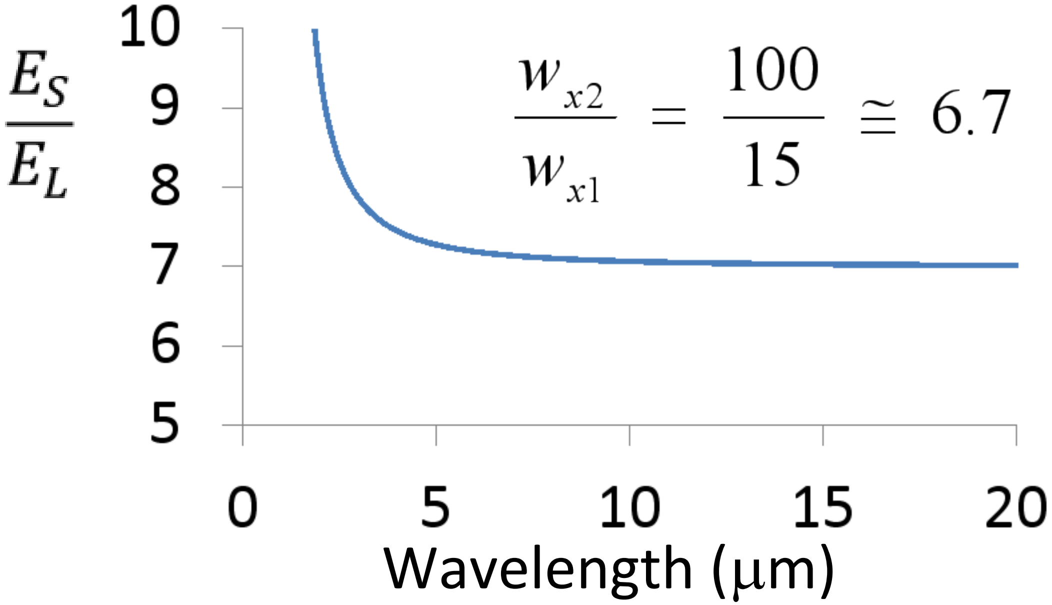
Mechanism: Quasi-static response



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

- Voltage across the small and large gaps are nearly equal

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



Quasistatic calculations- long λ limit

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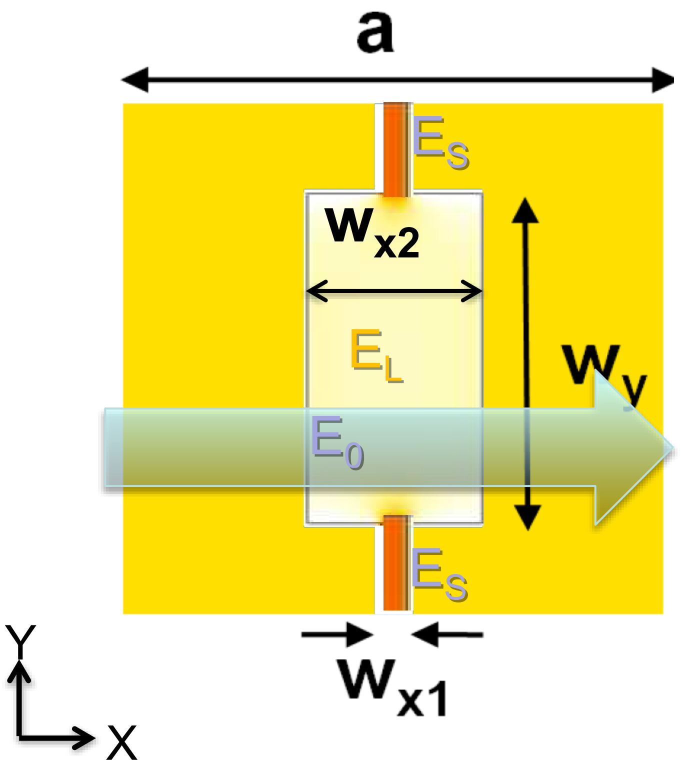
Neglecting reflection and applying avg. E-tangential within a unit cell is continuous

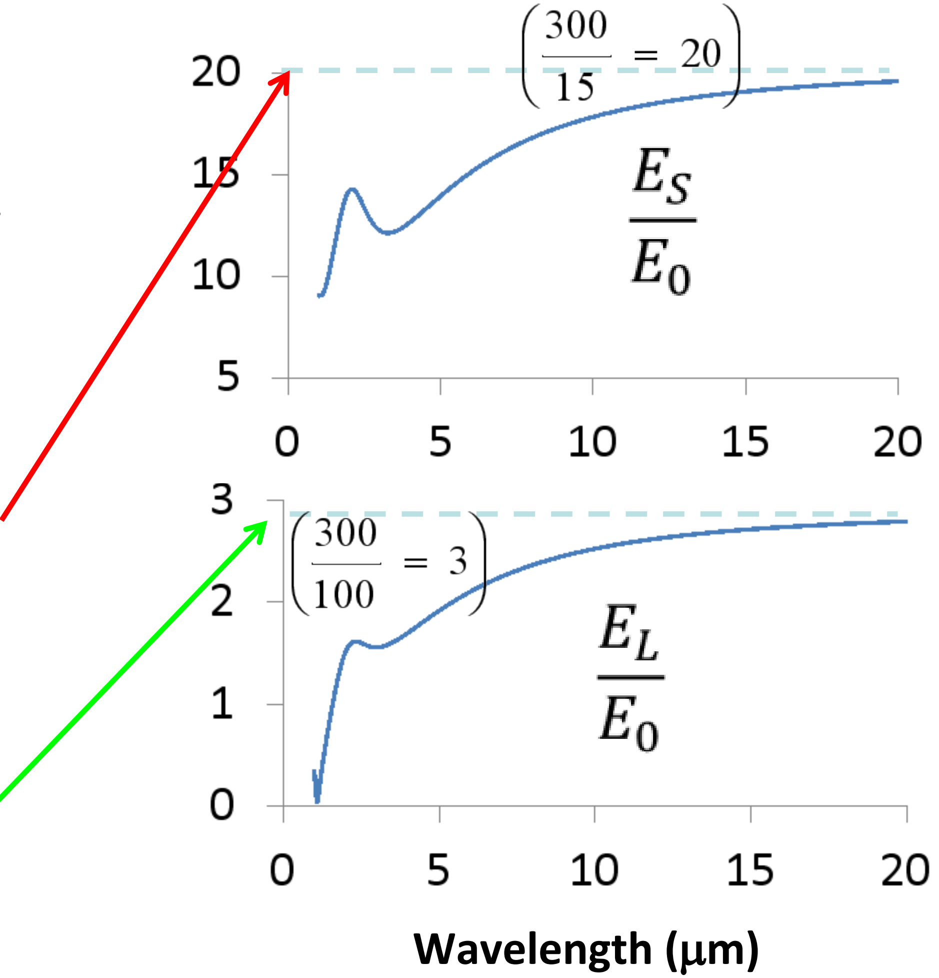
$$E_0 a^2 \cong E_L w_{x2} w_y + E_S w_{x1}(a - w_y)$$



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

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

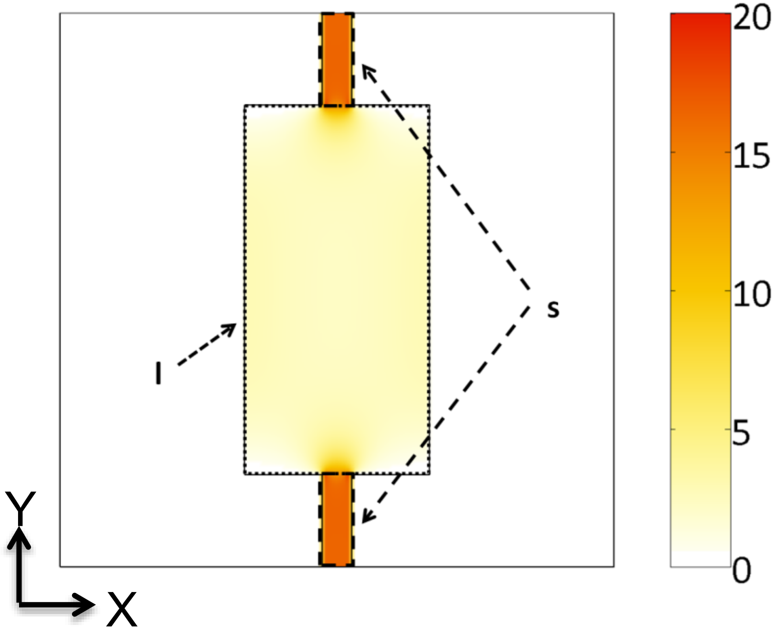
$$\frac{E_L}{E_0} = \frac{a}{w_{x2}}$$



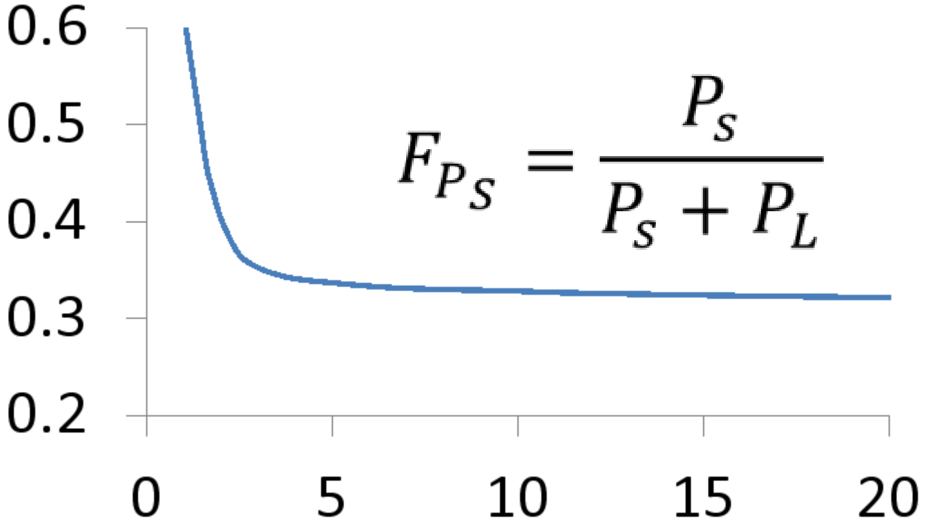
PRL. **107**, 163902 (2011).

Power Distribution and Confinement Factor

S_z @ λ ~ 10 μm

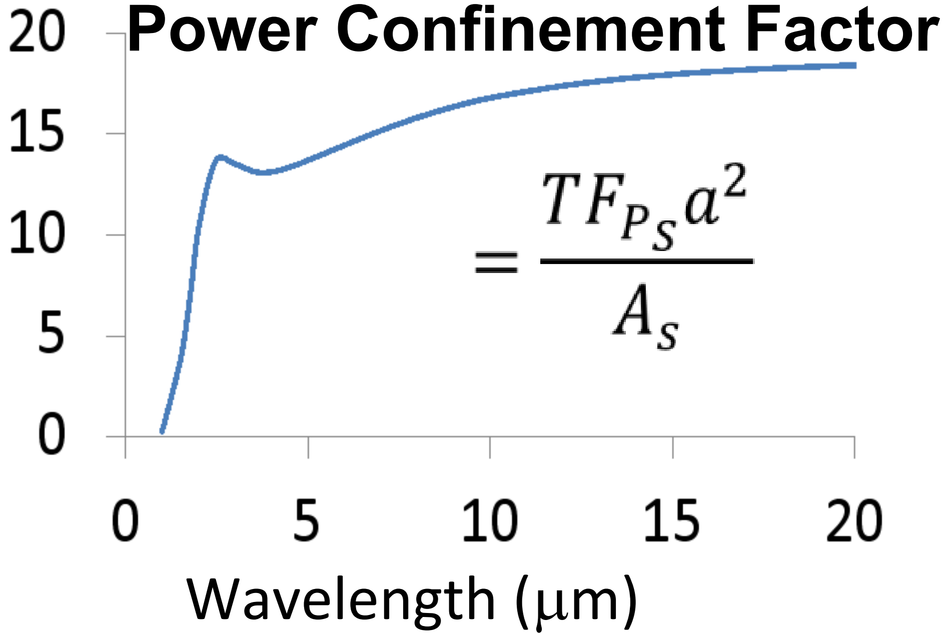


Nearly 30% of the transmitted power is channeled through an area **~ $(\lambda/250)^2$** that is **1/60th** of the unit cell area.



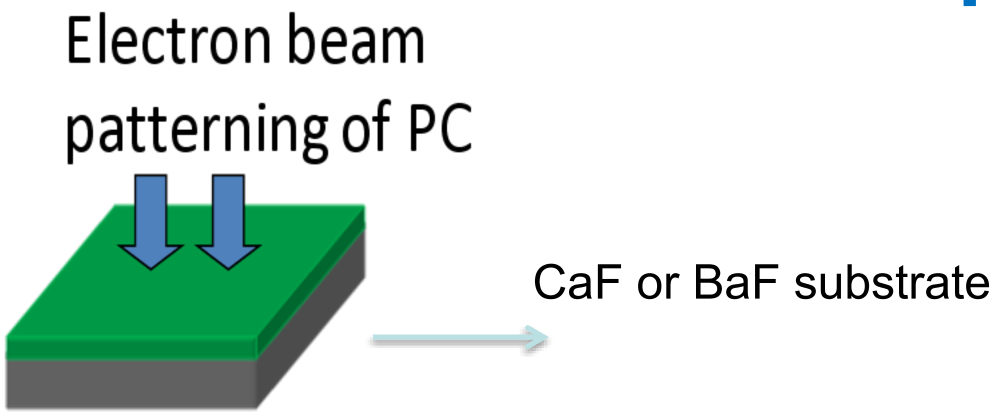
$$F_{P_S} = \frac{P_S}{P_S + P_L}$$

Power Confinement Factor

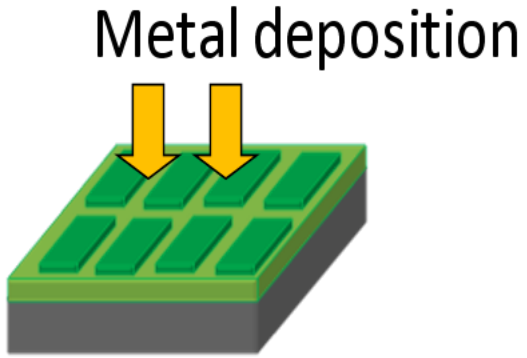


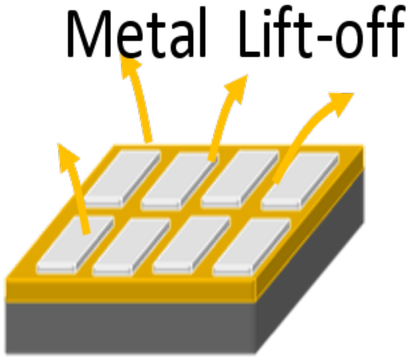
$$= \frac{T F_{P_S} a^2}{A_S}$$

Fabrication


Electron beam patterning of PC

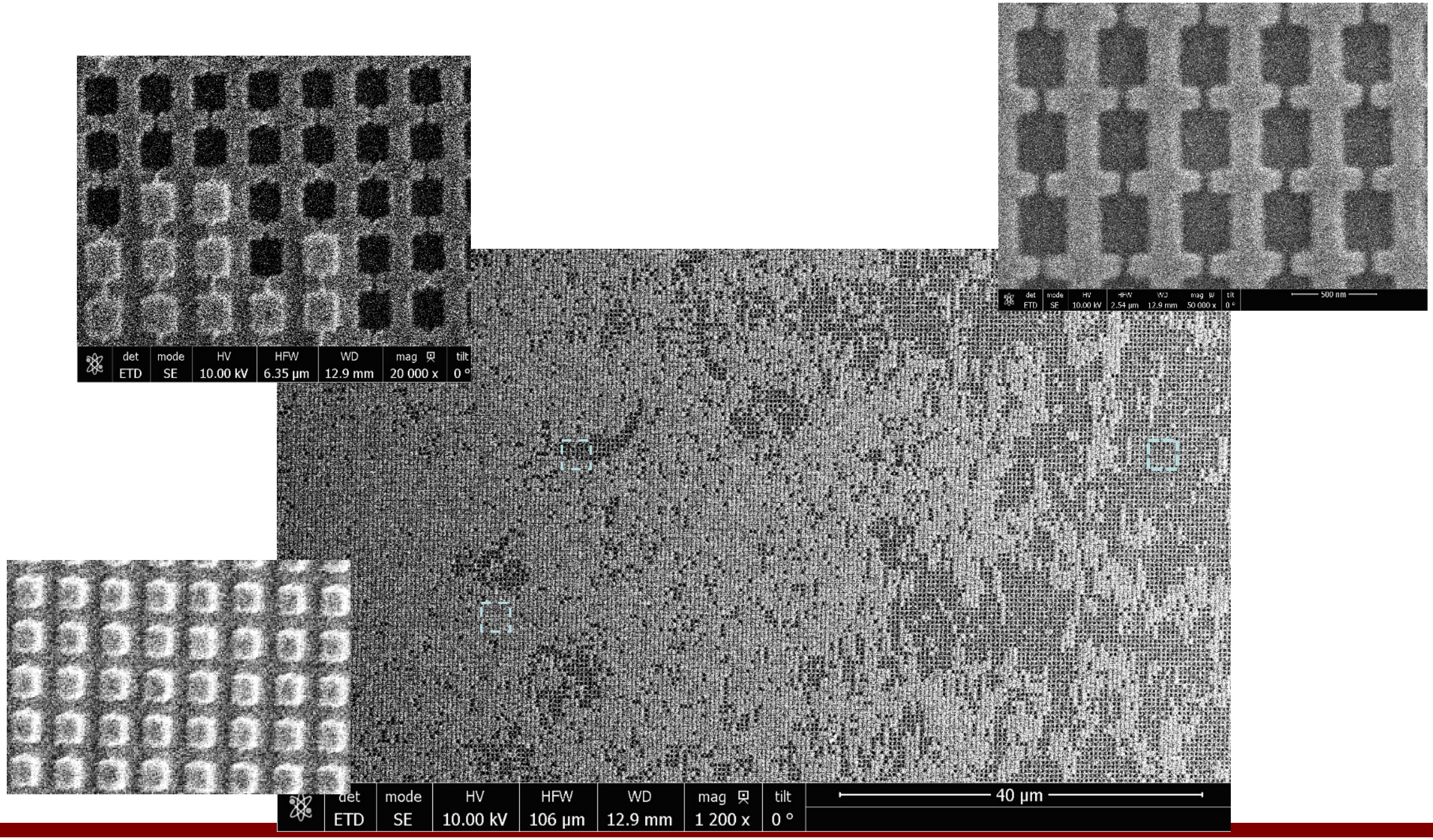
CaF or BaF substrate


Metal deposition

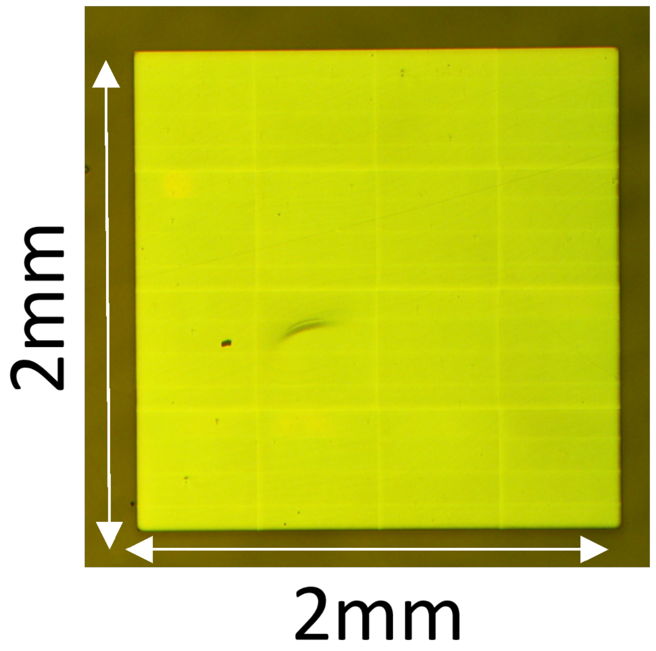

Metal Lift-off

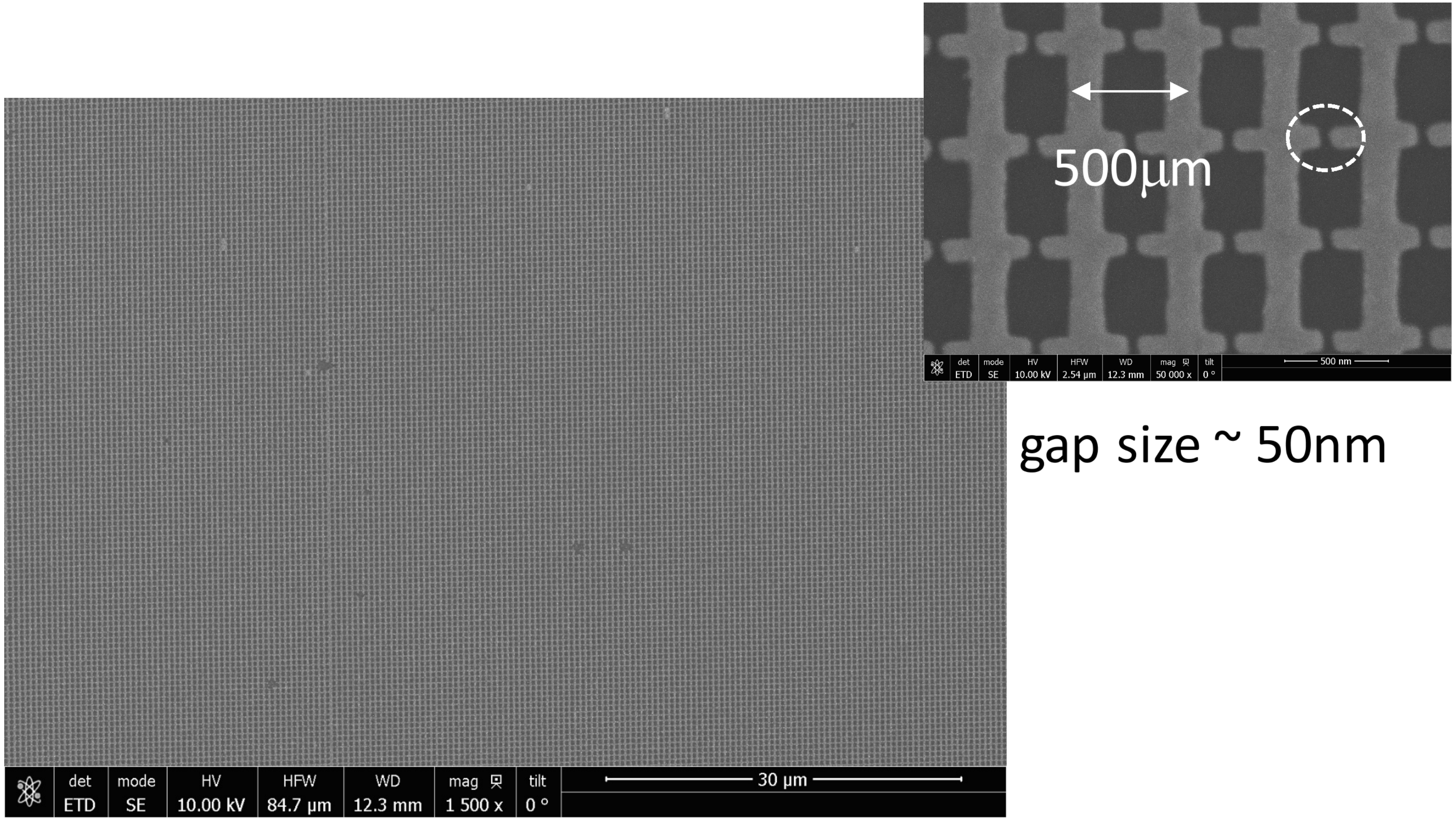
Challenges:

- Optimizing resist thickness for small 10s of nm gap
- Large area device ~ mm x mm size


det ETD
mode SE
HV 10.00 kV
HFW 6.35 µm
WD 12.9 mm
mag 20 000 x
tilt 0 °
det ETD
mode SE
HV 10.00 kV
HFW 2.54 µm
WD 12.9 mm
mag 50 000 x
tilt 0 °
500 nm
det ETD
mode SE
HV 10.00 kV
HFW 106 µm
WD 12.9 mm
mag 1 200 x
tilt 0 °
40 µm

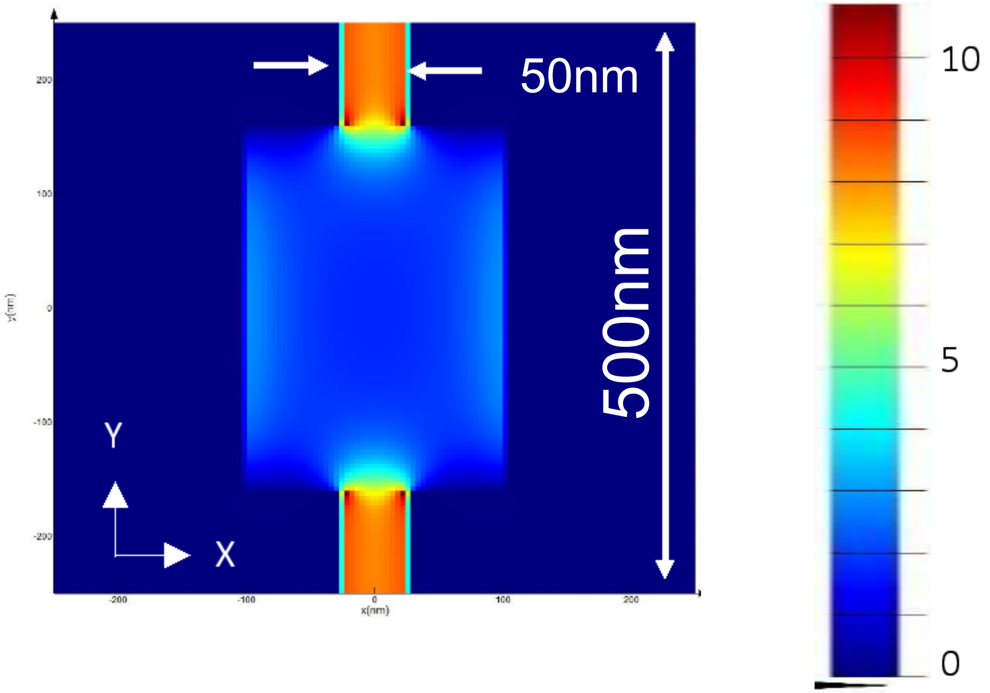
With optimized processing …

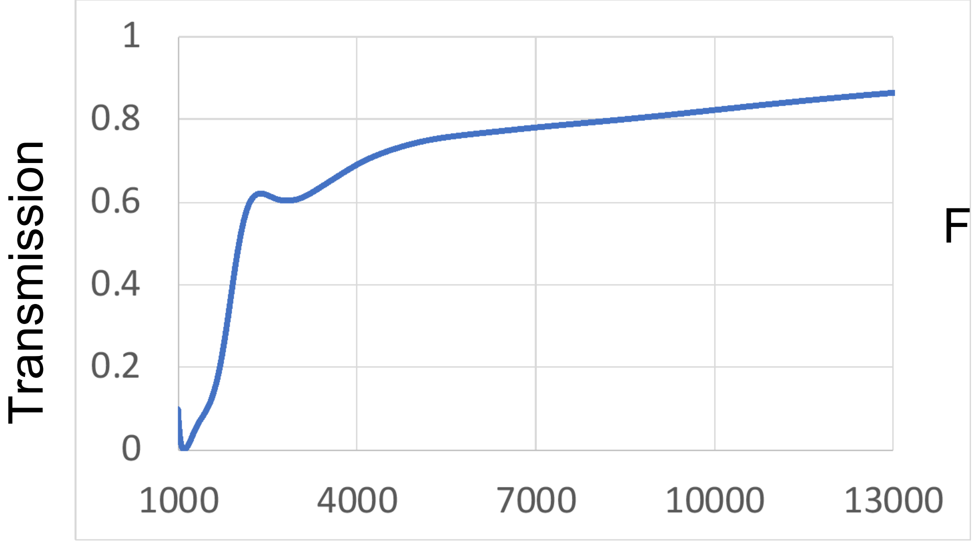



500µm
det ETD
mode SE
HV 10.00 kV
HFW 2.54 µm
WD 12.3 mm
mag 50 000 x
tilt 0 °
500 nm
det ETD
mode SE
HV 10.00 kV
HFW 84.7 µm
WD 12.3 mm
mag 1 500 x
tilt 0 °
30 µm

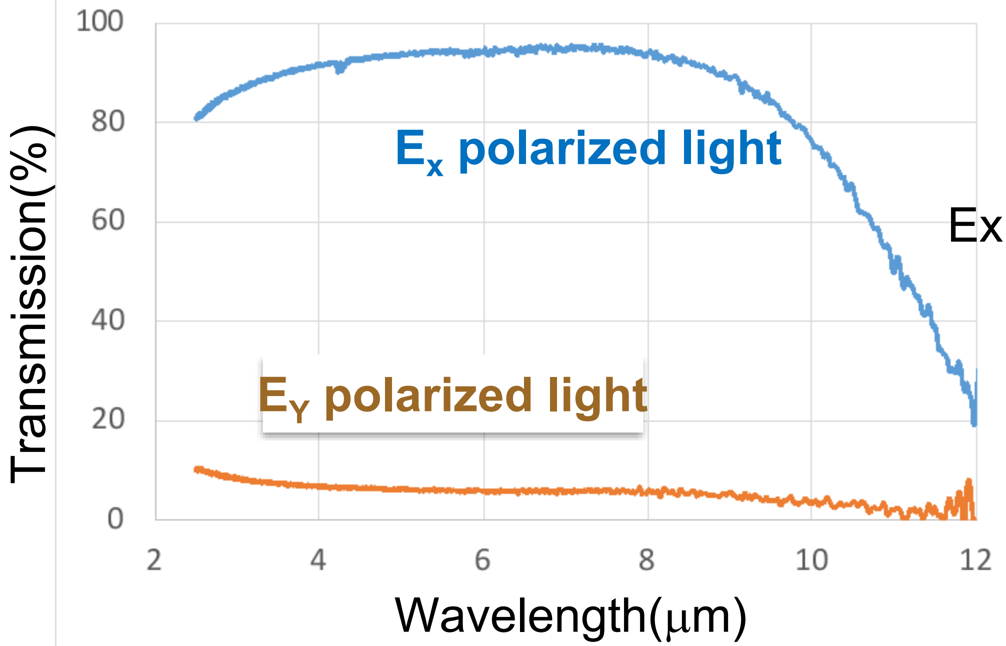
gap size ~ 50nm

Optical Measurement





FDTD simulation



Experiment

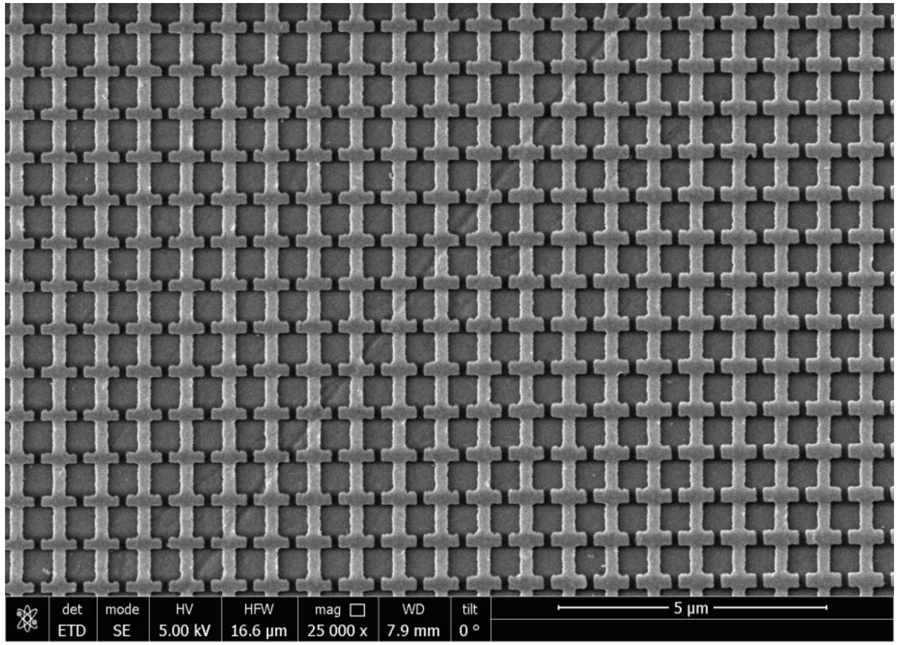
- ✓ ***Optical measurement in FTIR shows broadband transmission response as predicted***

Summary

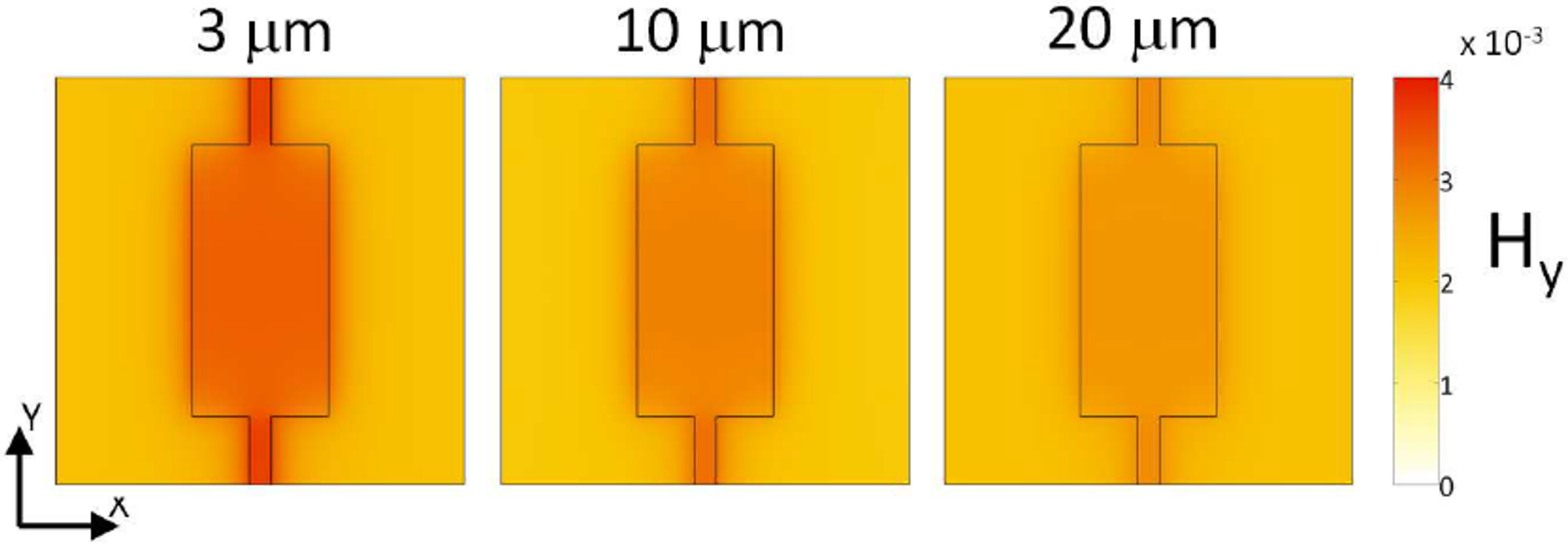
- The mechanism based on instantaneous electron response- **Non- resonant**
- Broadband transmission ($\lambda \sim 20\ \mu m$ range)
- Geometrical parameters (a, w_{x1}, w_{x2},w_{xy}) - suitably manipulated for high field enhancement + bandwidth

Potential applications

- **Power confinement**– MidIR sources, Energy conversion, midIR based sensing and detection
- **Field confinement** - Non-linear enhancement –Switching, SHG, Parameteric conv., Raman


det
ETD
mode
SE
HV
5.00 kV
HFW
16.6 µm
mag ☐
25 000 x
WD
7.9 mm
tilt
0 °
5 µm

Thank you for your attention !


3 μm
10 μm
20 μm
x 10-3
4
3
2
1
0
Hy
Y
X