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Broadband, Non-resonant Platform for Electric Field Enhancement

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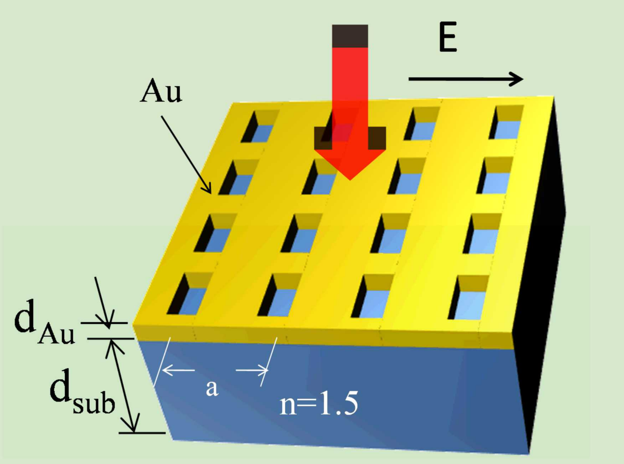
Challenge: Enhancement of Light-Matter interaction

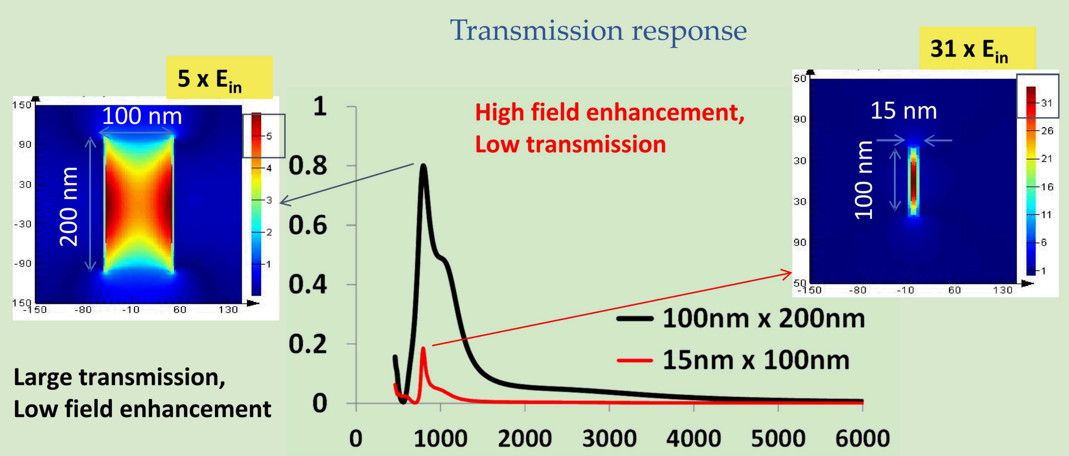
- Enhancing light-matter interaction is important for miniaturization of photonic and optoelectronics devices such as sensors and detectors.
- In order to achieve improved performance and enhanced portability some desired properties of such devices include:
  - Small size
  - High sensitivity
  - High efficiency
  - Broad spectral range of operation

Confining/ funneling light into small, sub-wavelength volumes can enable this.

Traditional approach: Plasmonic structures composed of a periodic array of subwavelength holes on a metal.



Schematic showing a periodic array of rectangular holes etched into a thin gold film as substrate.



Operational principle : Incoming light excites resonant surface plasmon polaritons in the metal due to the periodic hole arrays, causing the electric field to be confined in the subwavelength gap and enabling its transmission.

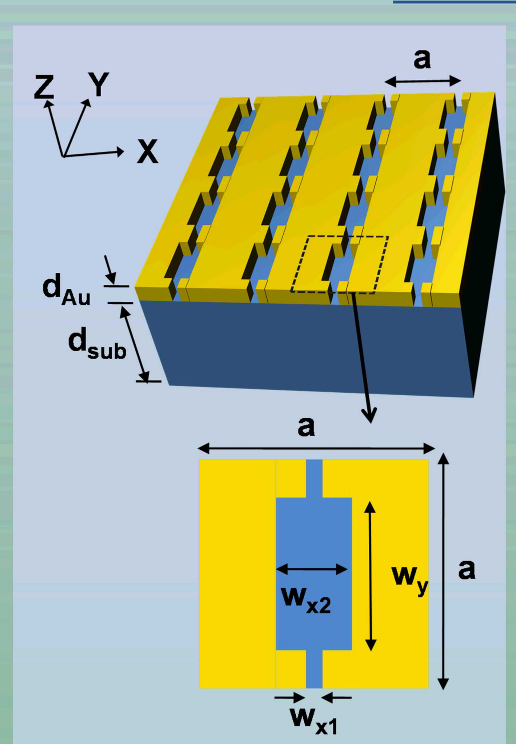
Key limitations :

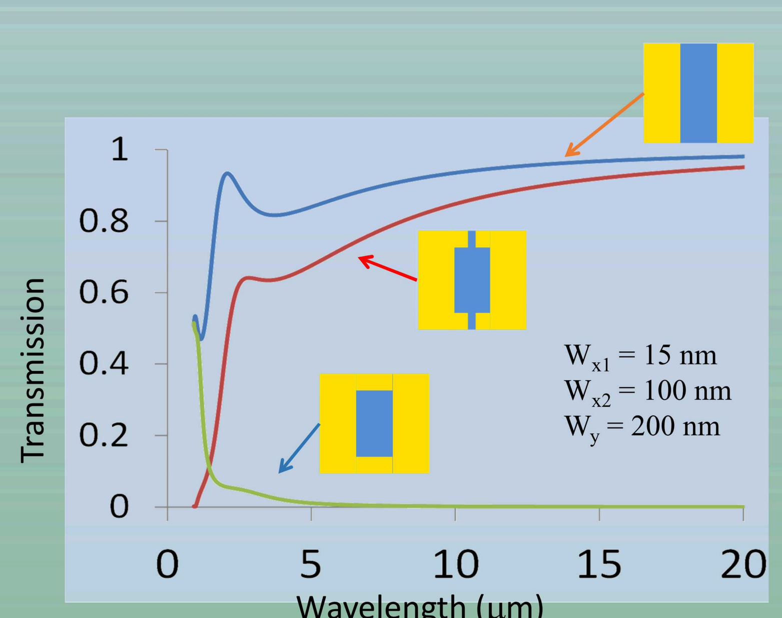
- Relies on resonance — so narrow operating bandwidth
- Electric field confinement, inversely related to light transmission.

Can we achieve light confinement and electric field enhancement with broad wavelength of operation?

Solution : Non-resonant Structure for Broadband Electric Field Enhancement

Double-groove metal-optic structure

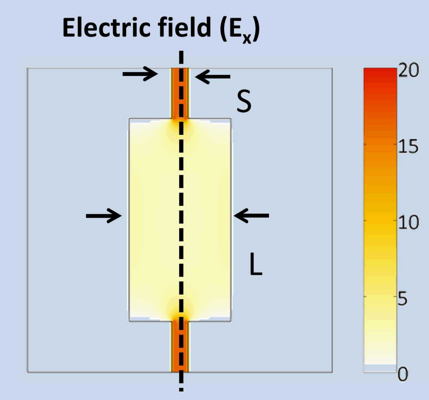


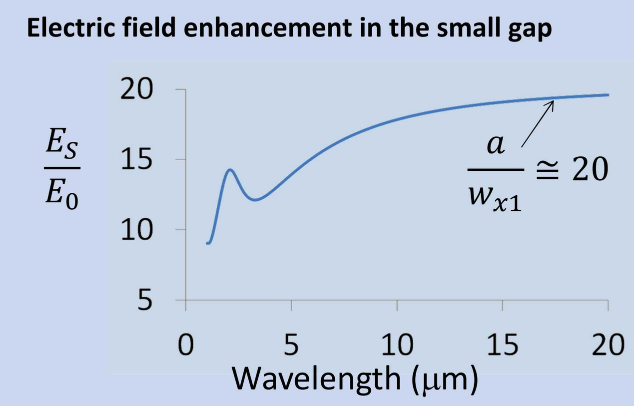


- ✓ Broadband transmission
- ✓ Electric field enhancement/confinement

Key features

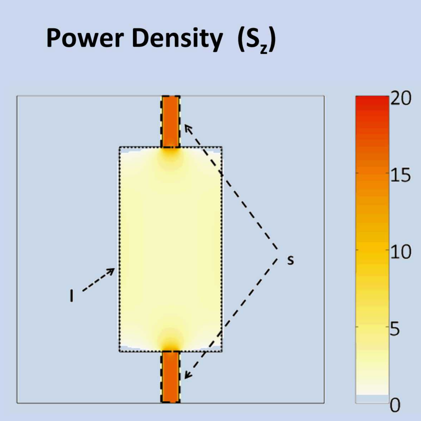
- We can achieve large electric field enhancements in an ultra-subwavelength area (~ $(\lambda/250)^2$) across broadband.
- Disproportionately large amounts of incident power (~20X) can be channeled through this area also across a broad wavelength band..

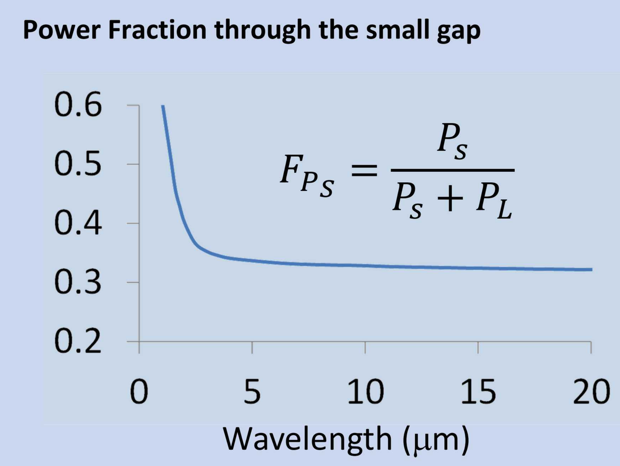




The electric field in the small gap is enhanced across a broad wavelength range approaching an asymptotic value determined by the geometry of the structure.

Enhancement factor can be controlled via structural geometry.



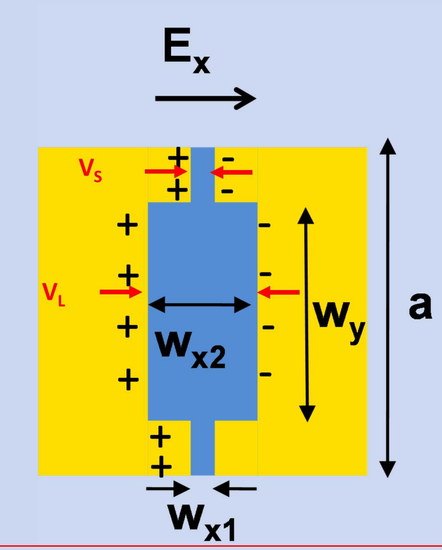


Surprisingly, nearly 30% of the transmitted power is channeled through an area ~ $(\lambda/250)^2$ that is 1/60th of the unit cell area.

Operational principle : The design exploits quasi-static or the near-instantaneous response of the metal electrons to the incoming electromagnetic field (light)

- The two sides are electrically disconnected resulting in charge accumulation.
- High conductivity of metal ensures potential difference at the small gap and large gap are the same i.e., $V_S = V_L$.
- Electric field in the small gap is considerably larger than in the large gap. In fact, the ratio of the electric field obeys a simple relation

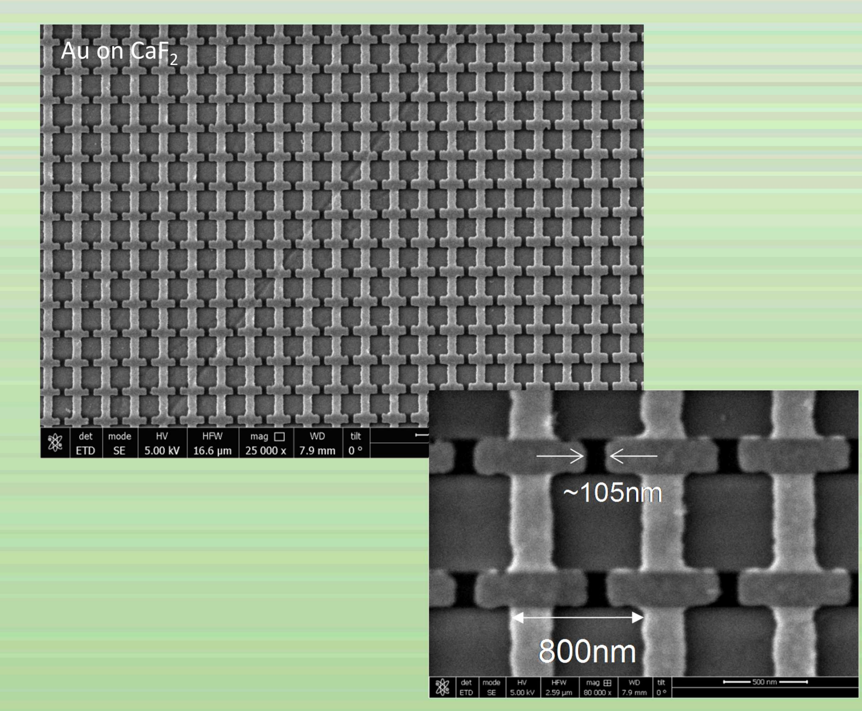
$$\frac{E_S}{E_L} \cong \frac{w_{x2}}{w_{x1}}$$



The quasi-static behavior of this structure is non-resonant thus enabling a broadband optical response.

Summary

- **Structure can be fabricated using nanolithography**
- **Transmission and field enhancement can be controlled through the geometric parameters (a, w_{x1}, w_{x2}, w_{xy}) of the double-groove structure.**
- **Will enable many applications: Mid IR sensing and detection, Mid IR sources, non-linearity enhancement, higher harmonic generation.**



Reference:

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

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