Subwavelength plasmonic sources with designed phases and amplitudes

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Why SP sources with tunable phase and amplitude?

Surface plasmon couplers, SP based devices, optronics

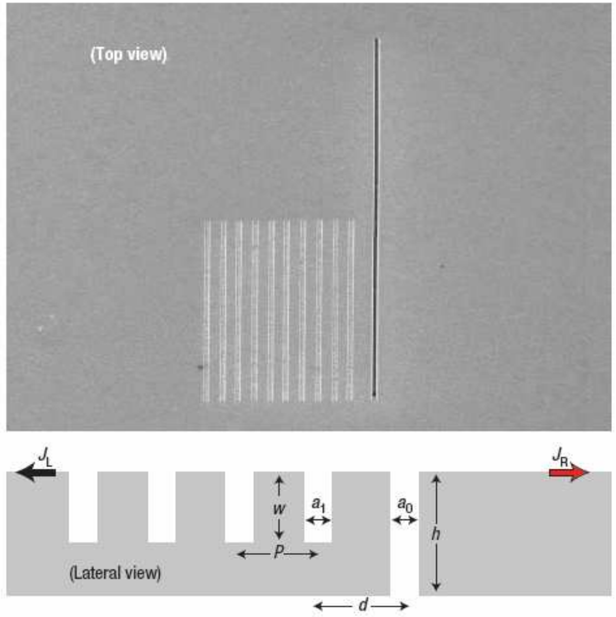


Figure 1 Scanning electron micrographs and schematic diagrams of the structures investigated. The parameters used in the definition of the slit, grooves and metal film are also shown. J_R and J_L are the current energy densities for right- and left-propagating SPPs.

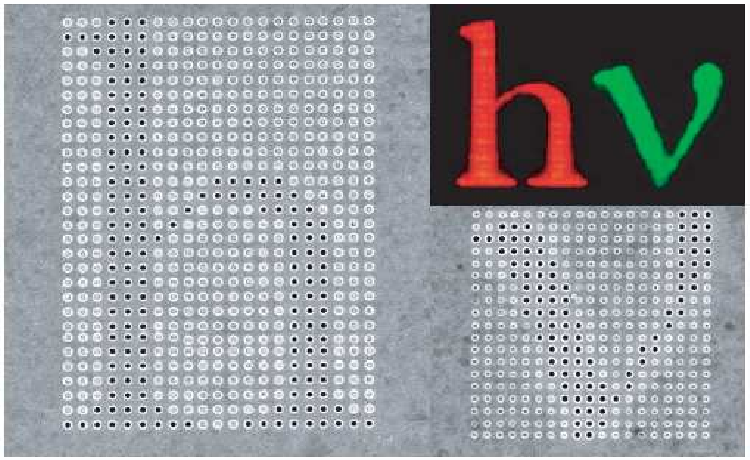
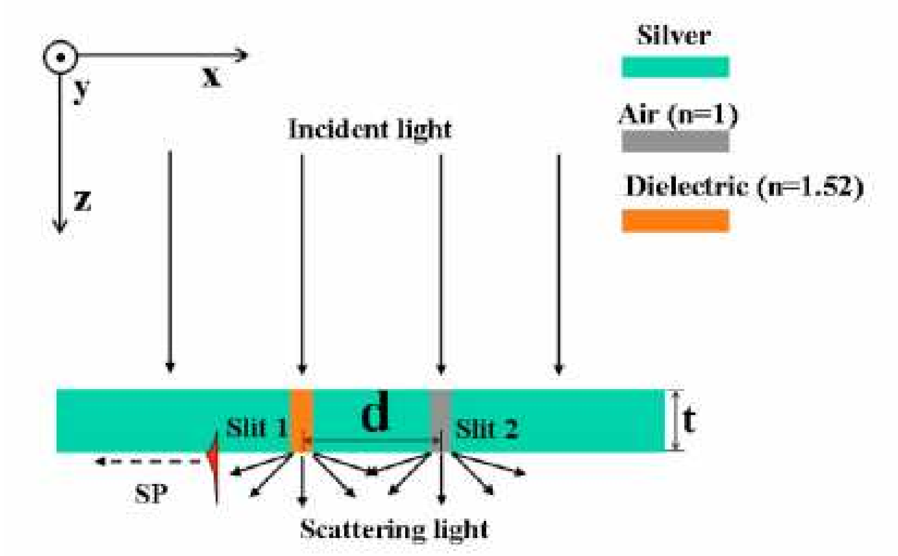


Figure 6 | Holes in a dimple array generating the letters 'hv' in transmission. An array of dimples is prepared by focused-ion-beam milling an Ag film. Some of the dimples are milled through to the other side so that light can be transmitted. When this structure is illuminated with white light, the transmitted colour is determined by the period of the array. In this case the periods were chosen to be 550 and 450 nm respectively to achieve the red and green colours.

Extraordinary transmission of light and related phenomena

Basic idea: fill hole or slits with different dielectrics



- Phase accumulation through propagation in the slits
- Different dielectrics ⇔ relative phase shifts and amplitudes

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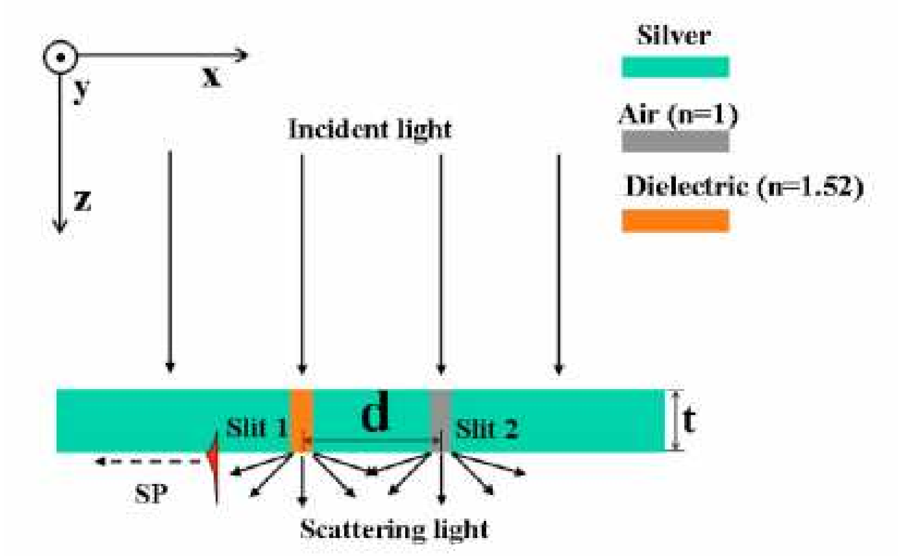

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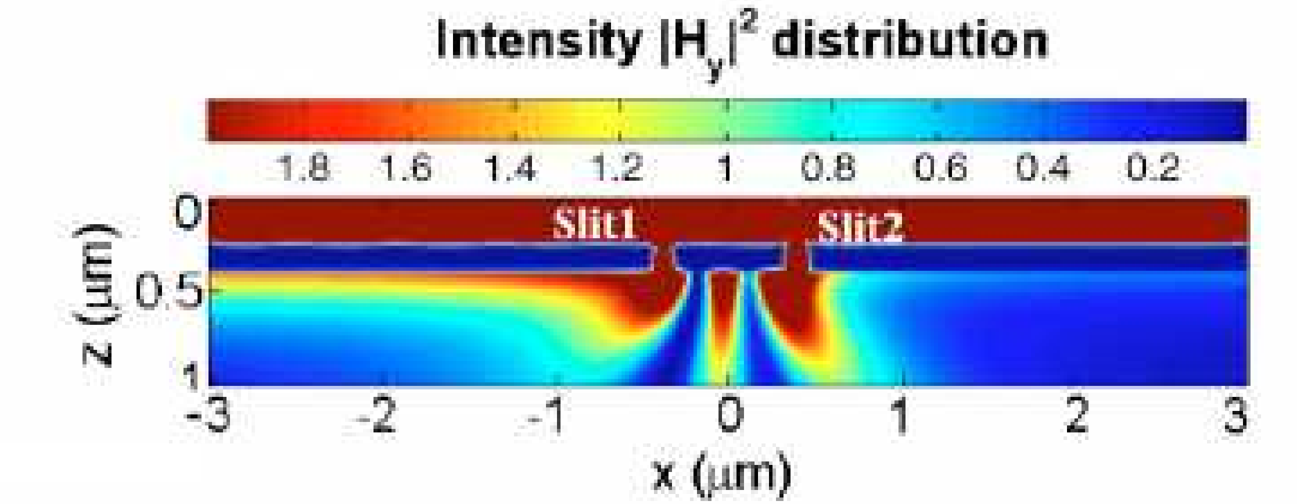
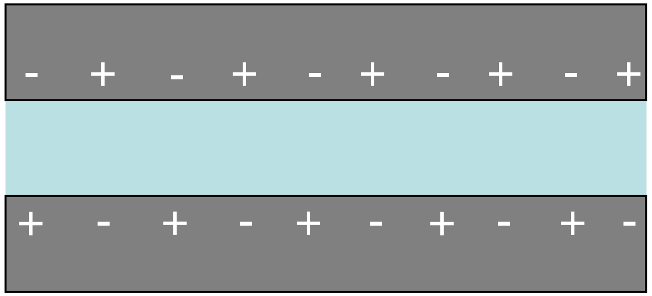
Unidirectional emission of SPs

Not practical with many different cavities



Xu *et al.* Appl. Phys. Lett. **92**, 101501 (2008)

Make use of Gap Plasmons dispersion relation (1)



- SPs in gaps => interaction of electrons on both sides of the gap

- Coupling between SPs

- Symetric and antisymetric modes

- obviously coupling depends on gap size

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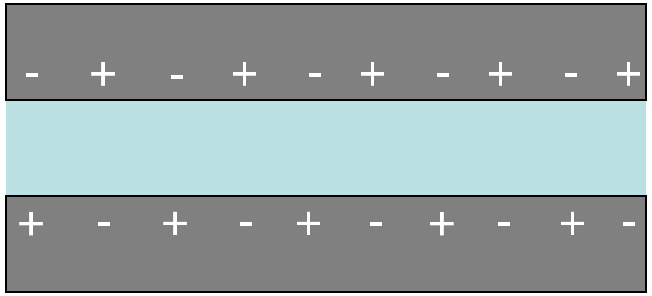

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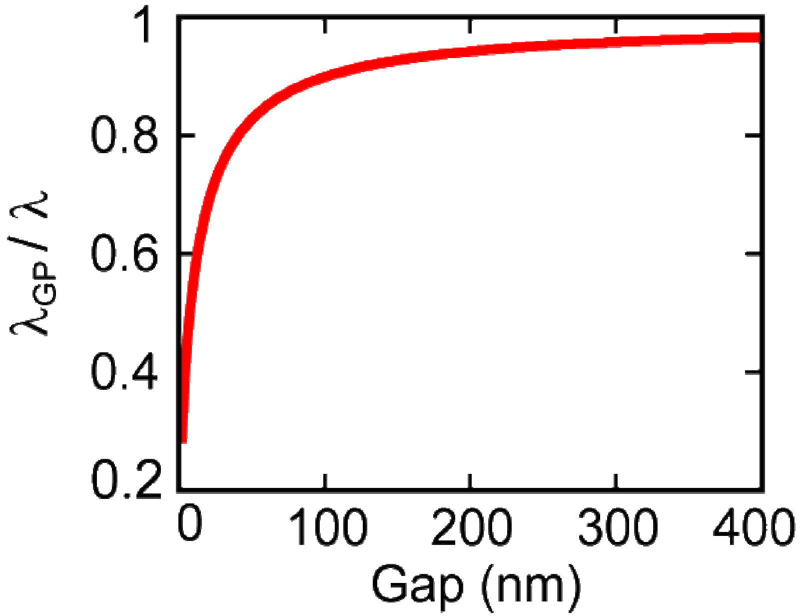
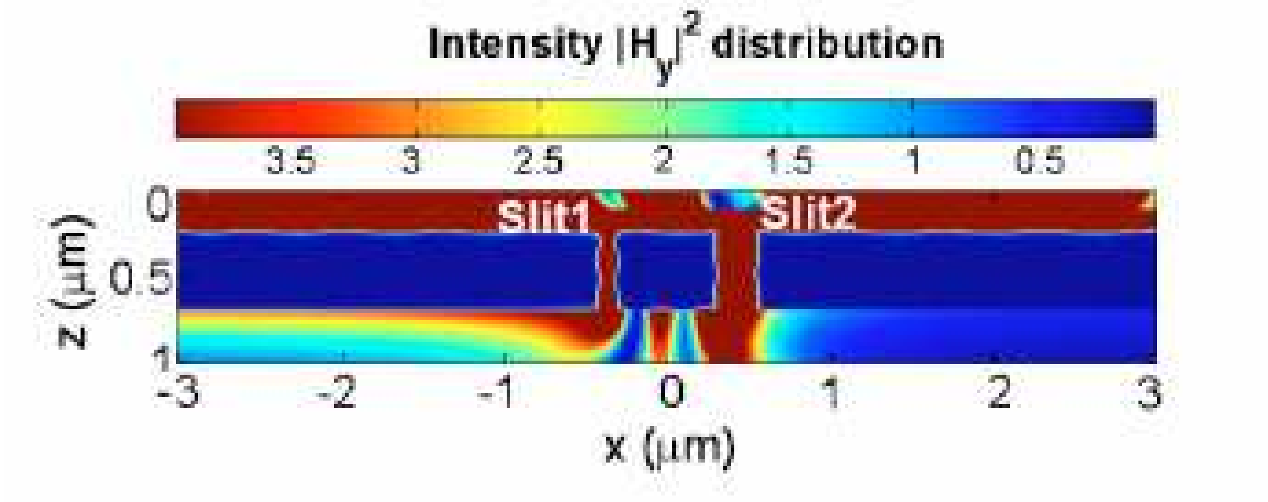


J. A. Dionne, S.A. Sweatlock, H.A. Atwater and A. Polman, plasmon slots waveguide: towards chip-scale propagation with subwavelength-scale localization, Phys. Rev. B., **73**, 35407 (2006).

Make use of Gap Plasmons dispersion relation (2)

50 and 200 nm wide slits 770 nm apart



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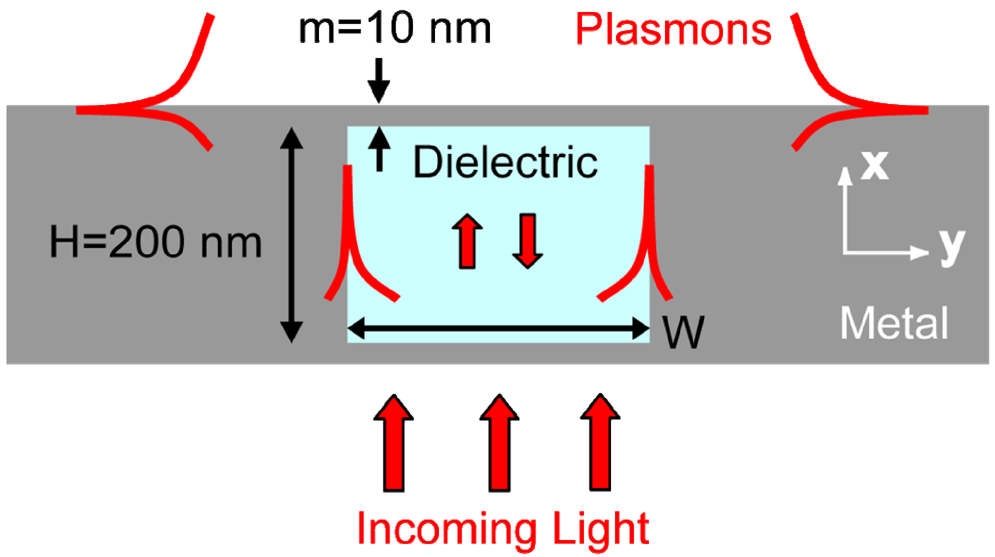
- Steep part of the curve ⇔ very narrow slits
- OR very thick films
- Very high aspect ratios…

Our approach: a Fabry-Perot resonator using GP dispersion relation



- Incoming light is TM polarized
- Gap plasmons generated in the slit
- Fabry-Perot tuned by the thickness of the mirrors
- SPs generated on the upper part of the film

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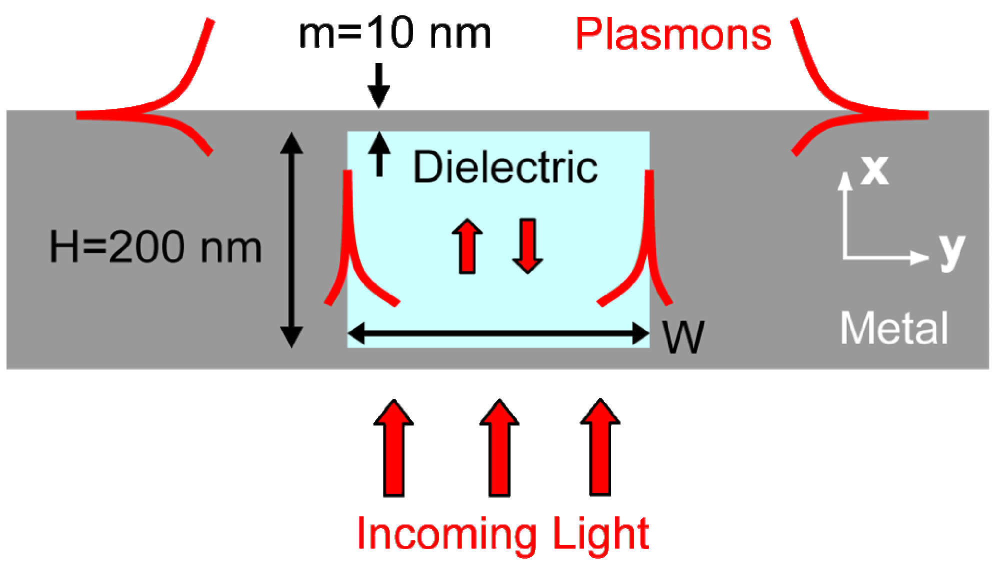

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Simulation: * Fem, Comsol Multiphysics

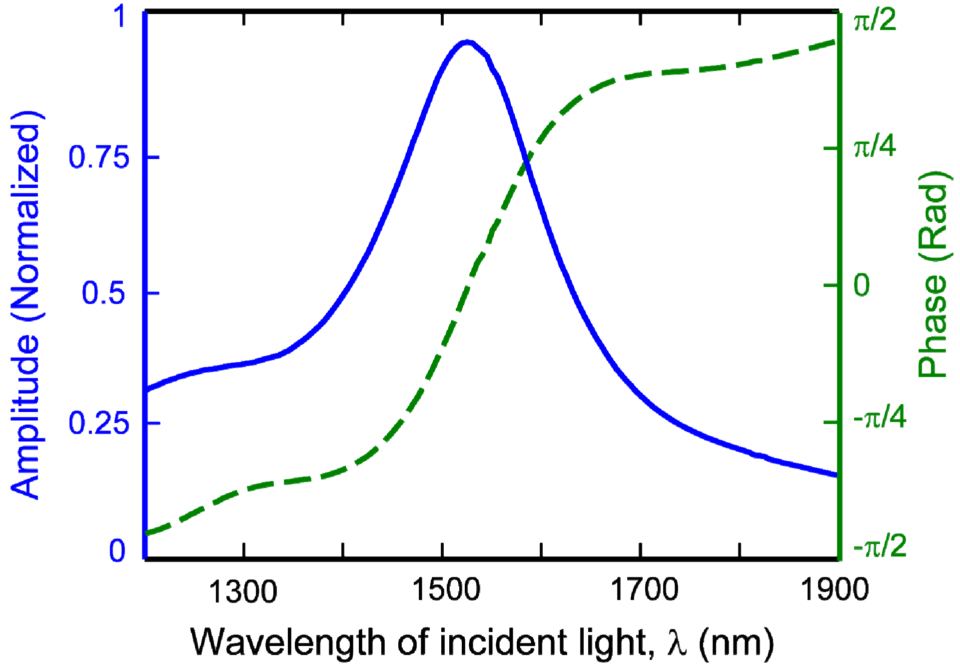
* Metal: Gold
* Dielectric Ta_2O_5, n=2.3
* wavelength of interest: 1.5µm

→ Light impinging on bottom of film

→ Extraction of H field on top of film

→ Evaluation of SP amplitude and phase using overlap integral (Mode Matching)

The “closed” slit: a simple driven harmonic damped oscillator



$$A \approx A_0 \frac{\lambda_0}{\sqrt{\lambda_0{}^2 + Q(\lambda_0 - \lambda)^2}}$$

$$\phi \approx \operatorname{atan}\left(Q \frac{(\lambda - \lambda_0)}{\lambda_0} \right)$$

Q: quality factor
λ_0: resonance wavelength

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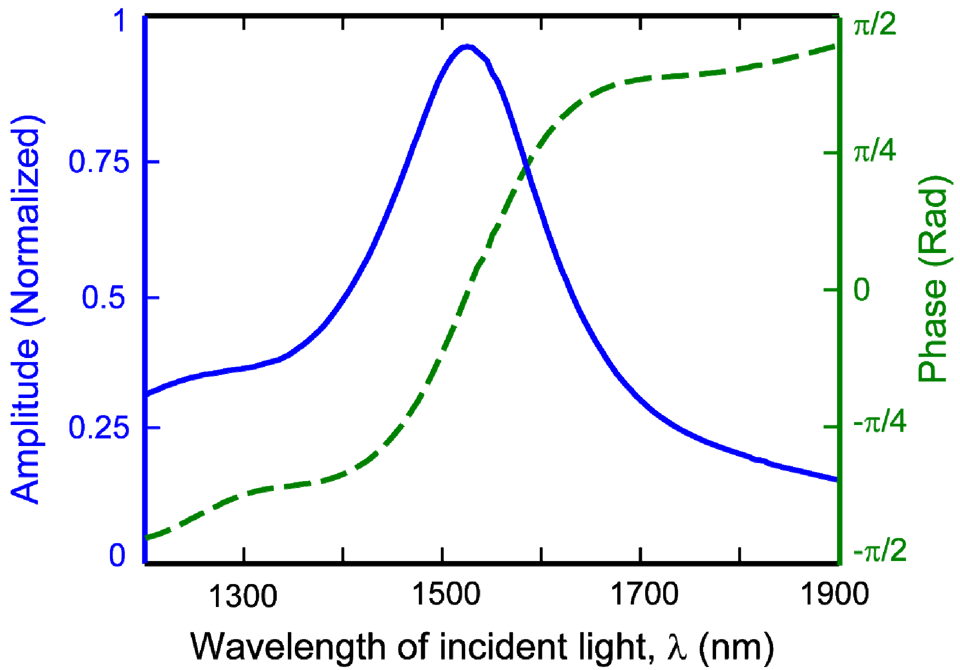

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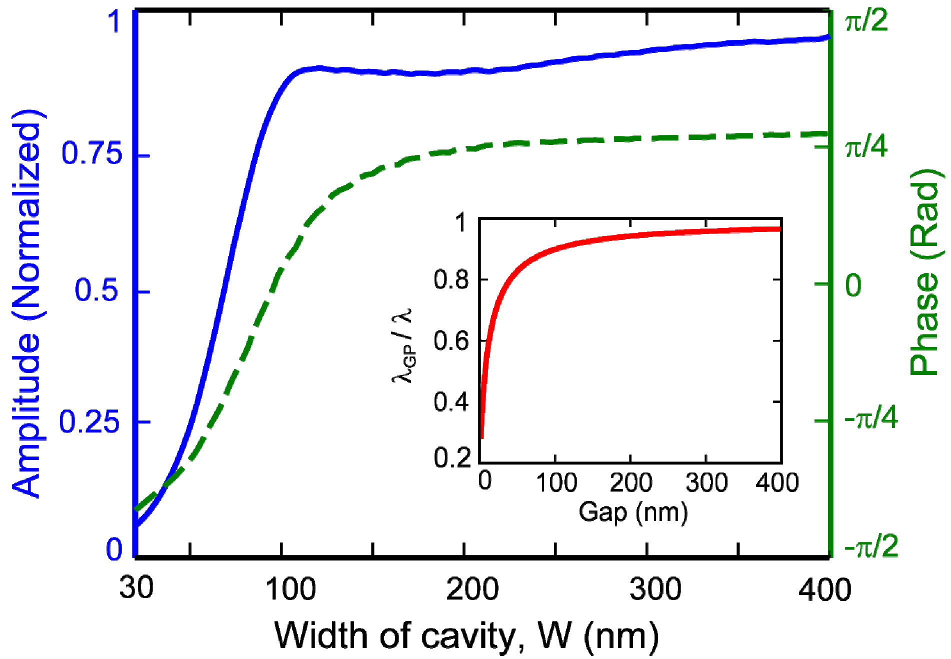
λ_0: resonance wavelength

- **Below λ_0 => the resonator lags, and the output amplitude is small (depends on Q)**

- **At λ_0 => resonantor in phase and output amplitude close to unity (depends on losses)**

- **Above λ_0 : resonator leads and amplitude drops (depends on Q)**

Using both the GP and the driven oscillator concept @ 1.5µm



- Change width ⇔ change of the GP wavelength
- Modification of λ_0, resonance wavelength of the caviy
- At a fixed wavelength, amplitude and phase vary as a function of W

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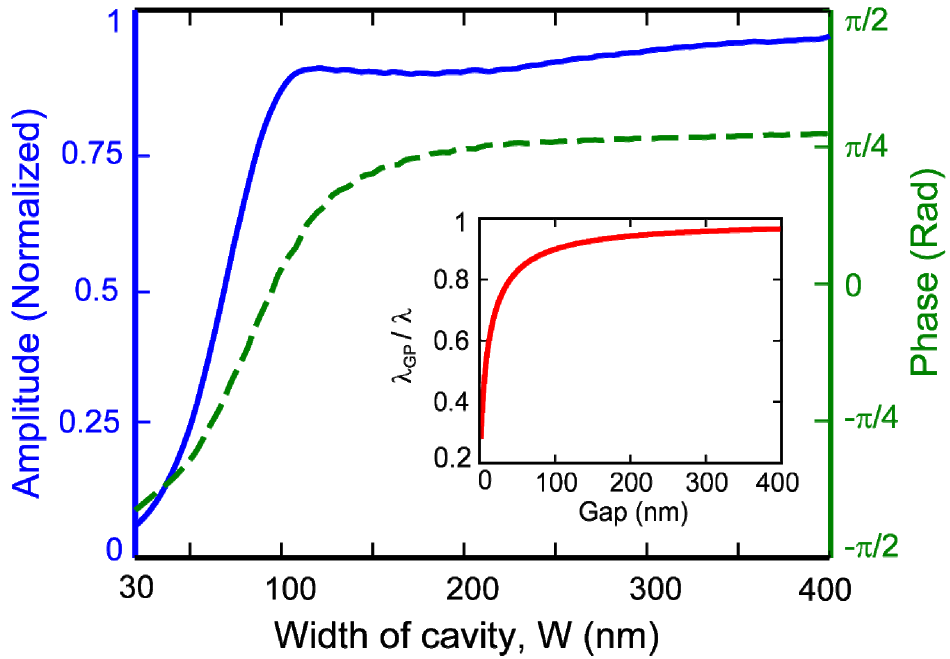

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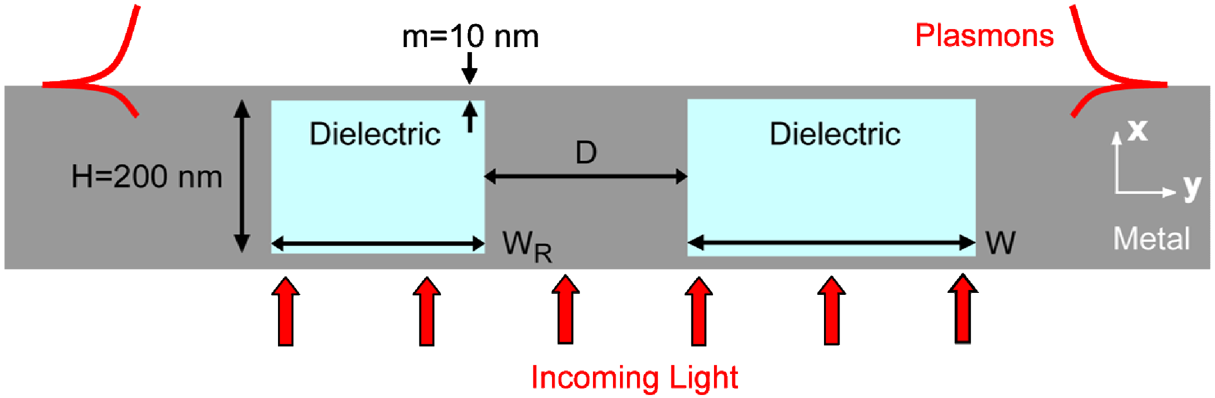
- Even in the flat part of the DR, the phase shift goes from 0 to π/4 (resonance…)
- Here the phase shift is limited to π/4, because Q is small
- Thicker mirrors induce larger phase shift, up to π/2, but smaller output amplitudes => tunable upon application…

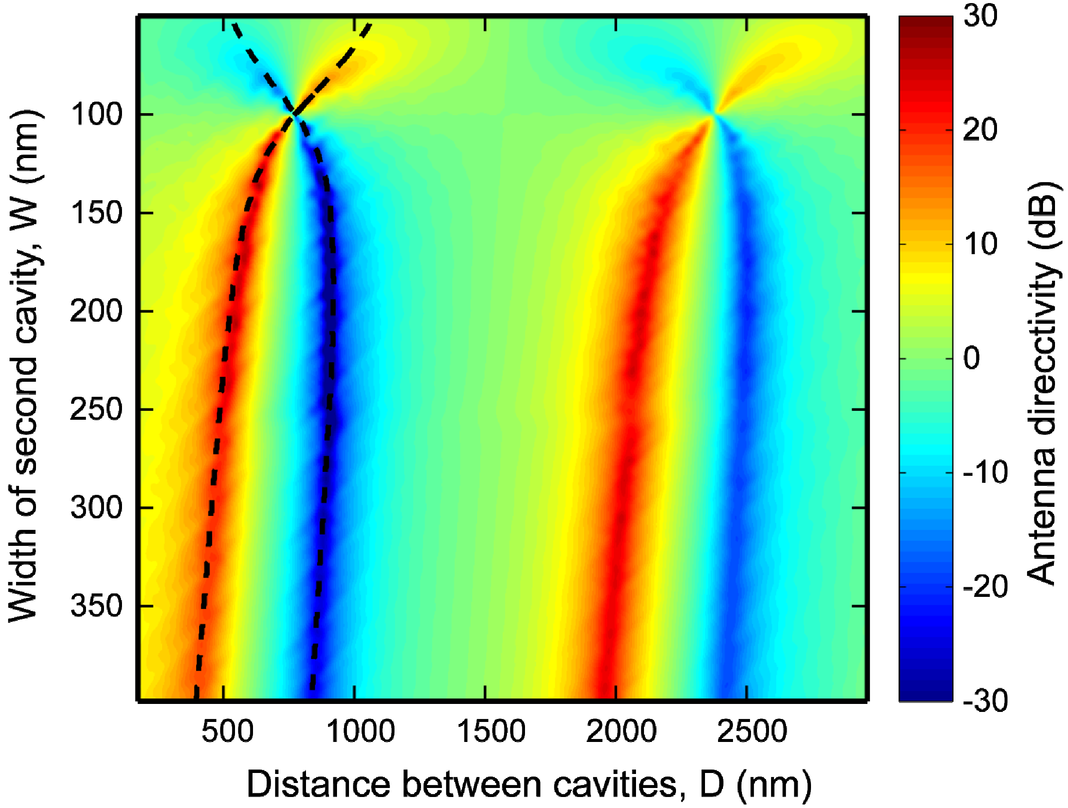
Example: unidirectional SP launcher using 2 cavities @ 1.5µm



- Use two cavities with different width - left one fixed at 100 nm (resonance)
- Create phase shift between the SPs generated by both cavities
- Use interference between SPs two launch them in one direction only

Simulation: Fem, Comsol Multiphysics

Directivity of the antenna as a function of second cavity distance and width



$$F^{L} = \left(1 + e^{i\left(k_{sp}D - \phi\right)}\right)$$

$$F^{R} = \left(1 + e^{i\left(k_{sp}D + \phi\right)}\right)$$

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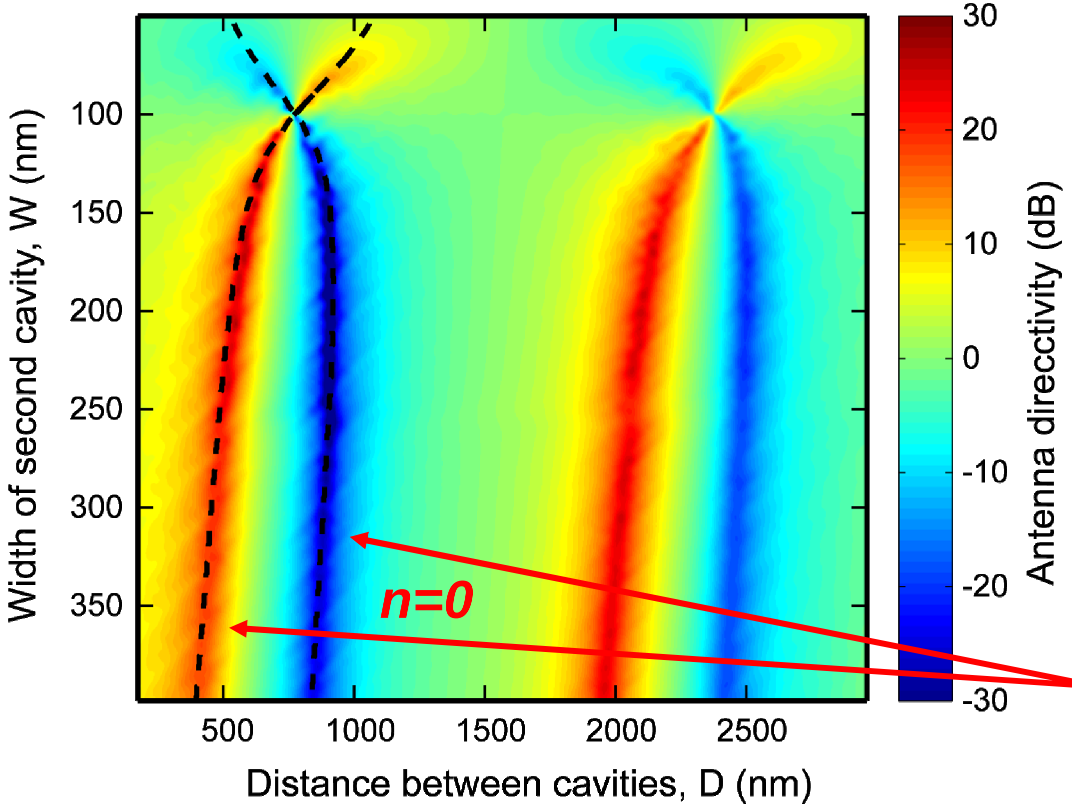

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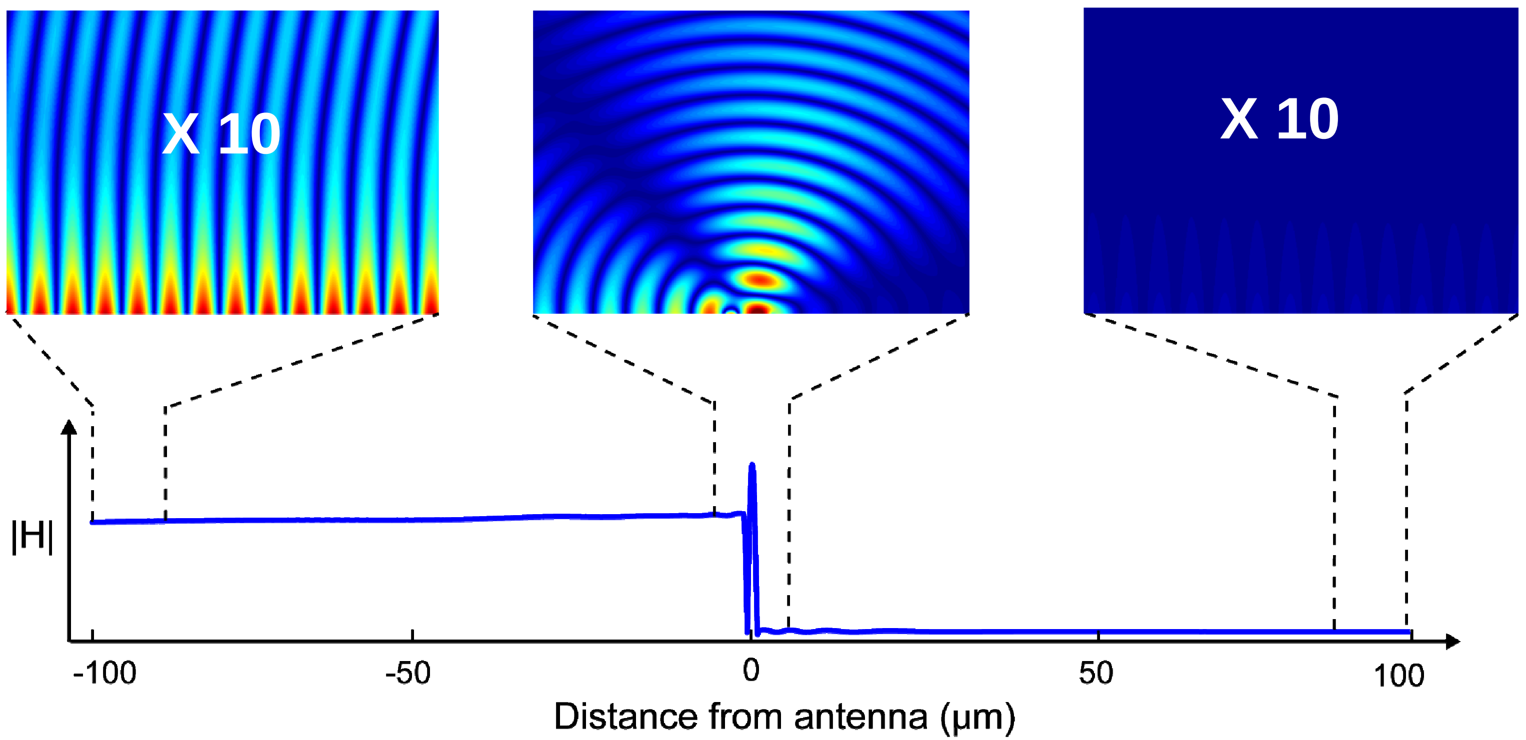
$$k_{sp}D \pm \phi = \pi + 2n\pi$$

- **For narrow slits, correct phase shift, but low outuput amplitude => low directivity**
- **Directivity of 30 dB can be achieved with a decent output amplitude ($\phi=\pi/4$ => $I^+=1/2$)**
- **Aspect ratios smaller than 2…**

Snapshot of generated H field for W_R=300nm and D=340nm



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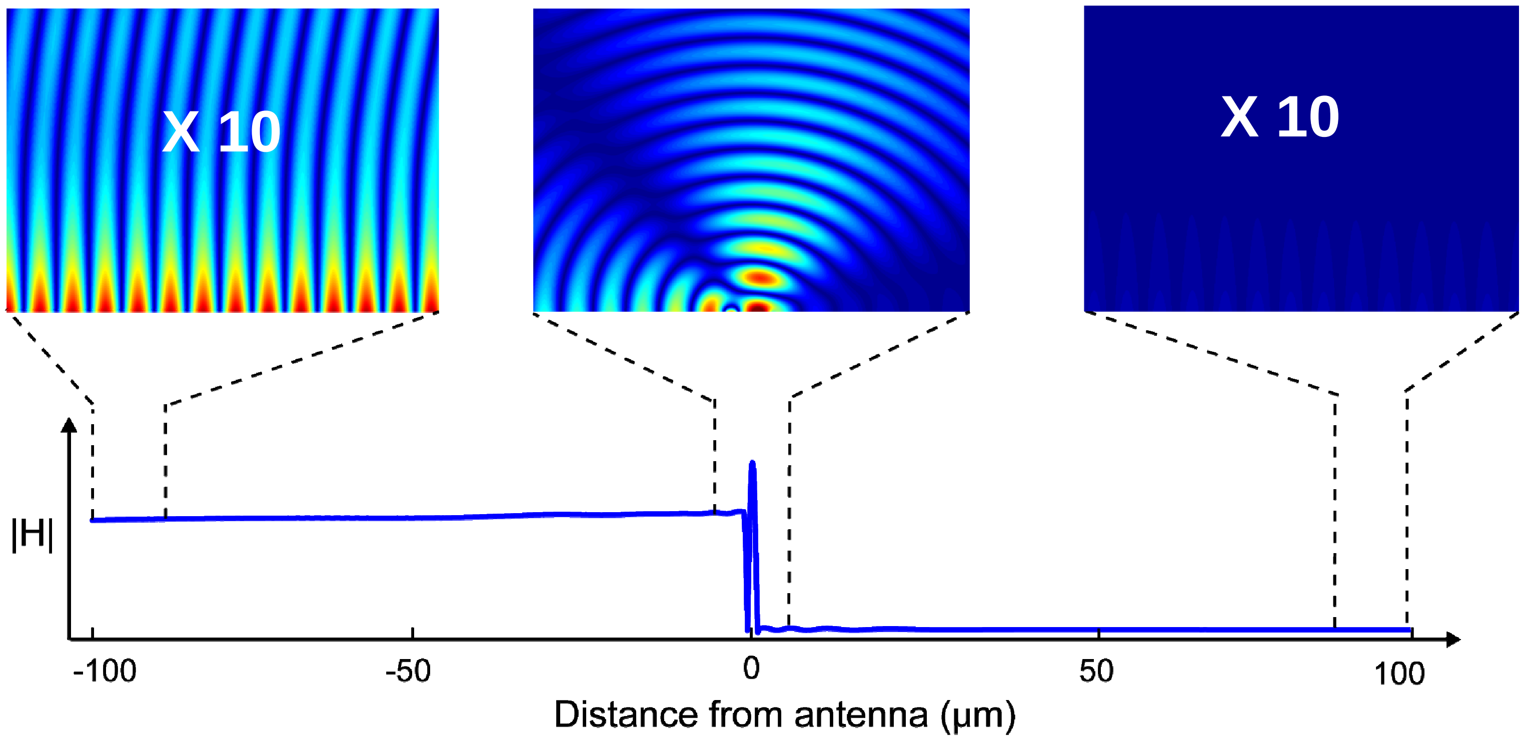


Total antenna size of 740 nm i.e. half wavelength

Of course, directional emission of bulk waves also, λ_{sp} very close to λ @ 1.5µm

Perspectives

Theo.:

Theoretical study of more complex structures made of N cavities with tuned amplitudes and phases for optronics and SP-based devices

Periodic large scale assembly of cavities with designed phase and amplitudes => new applications of ETL and related phenomena using different sources

Exp.:

Fabrication and measurement of a single cavity

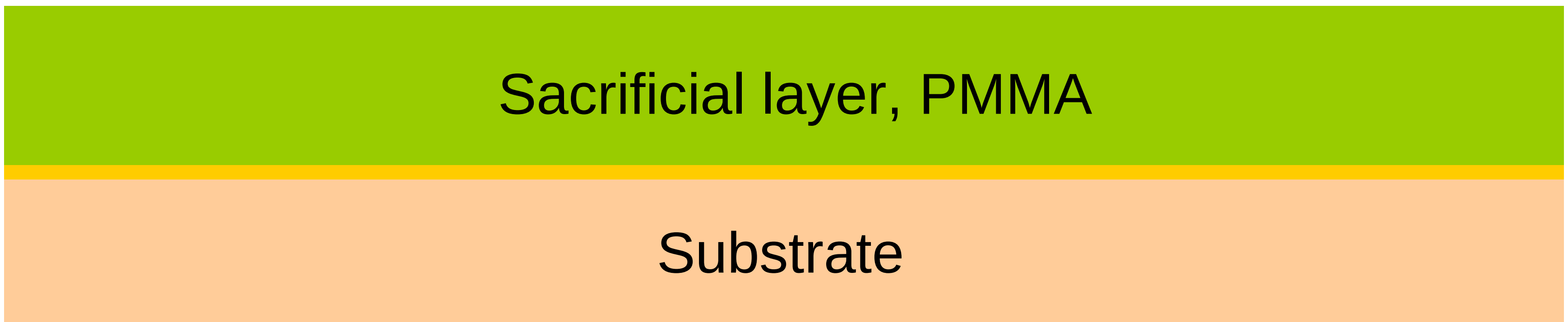
Experimental study if the unidirectionnal SP launcher

Paper: G. Lerosey et *al*. Controlling the phase and amplitude of plasmon sources at a subwavelength scale, ***Nano Letters,*** February 2009

Fabrication ideas…

- **Core problem is the dielectric embedded in the metal fim**
- **E-beam lithography has been tried alongside Focused Ion Beam and dielectric deposition => too complicated**
- **Next try: EBL for dielectric deposition and electroelectroless plating**

EBL



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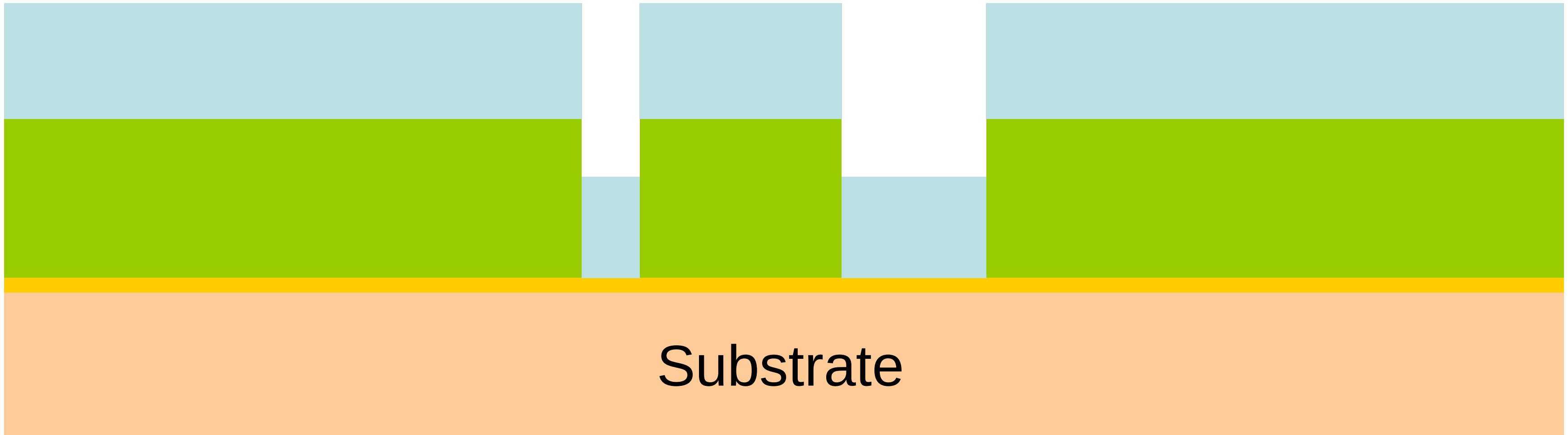
Dielectric deposition (evaporation)



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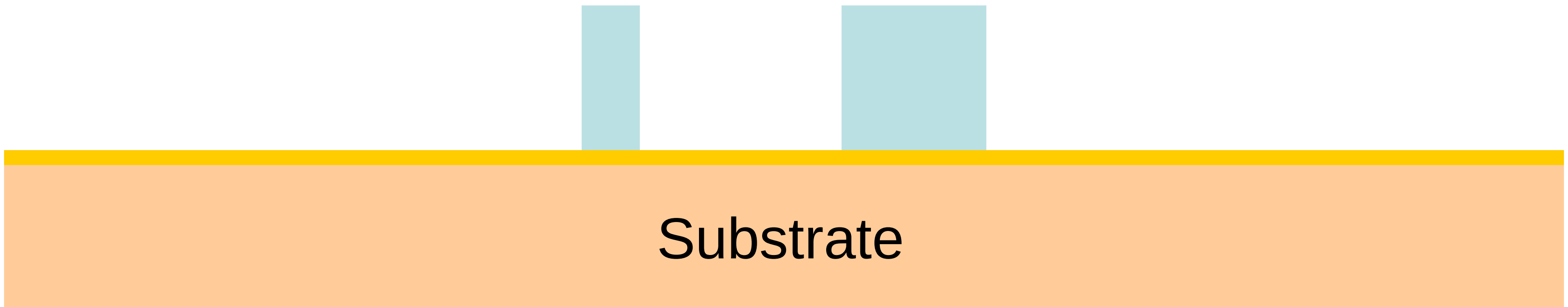
Lift Off



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Electroless deposition + Gold thin film on top