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Periodically structured plasmonic waveguides

W. M. Saj[a,b], S. Foteinopoulou[b], M. Kafesaki[b], C. M. Soukoulis[b] , E. N. Economou[b]

[a]Faculty of Physics, University of Warsaw Pasteura 7, 02-093 Warsaw, Poland
[b] Institute of Electronic Structure and Laser (IESL), Foundation of Research and Technology-Hellas (FORTH), Heraklion, Crete 71110, Greece

metamorphose

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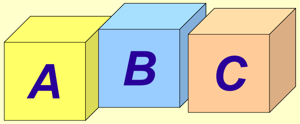
PDF version 13.04.2008 (some slides repeats instead of animations as in orginal file)

Outline

Plasmon-polariton waveguides



Numerical investigations of periodically modulated plasmonic waveguides:

- *band structure*
- *transport of energy and phase*
- *time evolution of field*

Conclusions

Surface plasmons-polaritons (SPP)

Coupled oscillations of electrons and electromagnetic field that may propagate along the conductor-dielectric interface with ampitude exponentially decreasing from the media interface

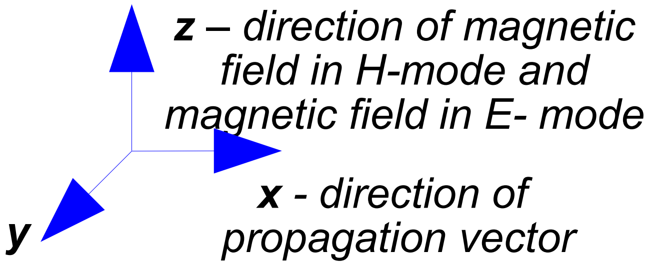
high field confinement (below dielectric diffraction limit)

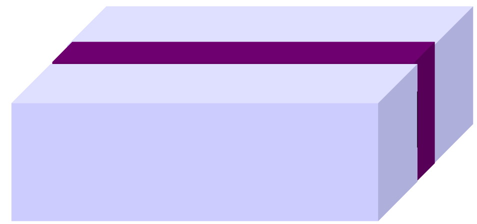
high local field amplitude

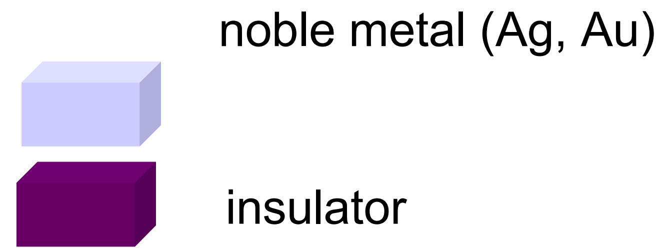
Nanometer size optical devices
Plasmonics

SPP waveguides

MIM (Metal-Insulator – Metal) waveguide



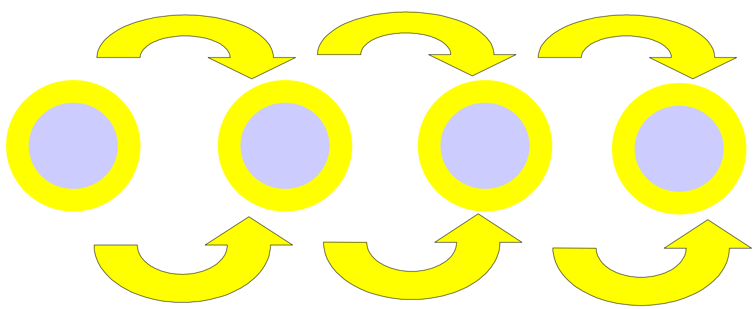




Coupled surface plasmons of metal walls

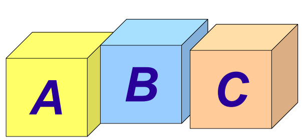
Dionne, J., Sweatlock, L., Polman, A., and Atwater, H., "Plasmon slot waveguides: Towards chipscale propagation with subwavelenth-scale localization," Phys. Rev. B 73, 035407 (2006).

Nanoparticle waveguide



Mie plasmon resonances of metal nanoparticles coupled through free space radiation

Maier, S. A, Kik, P. G., and Atwater, H. A., "Optical pulse propagation in metal nanoparticle chain waveguides," Physical Review B 67, 205402 (2003).

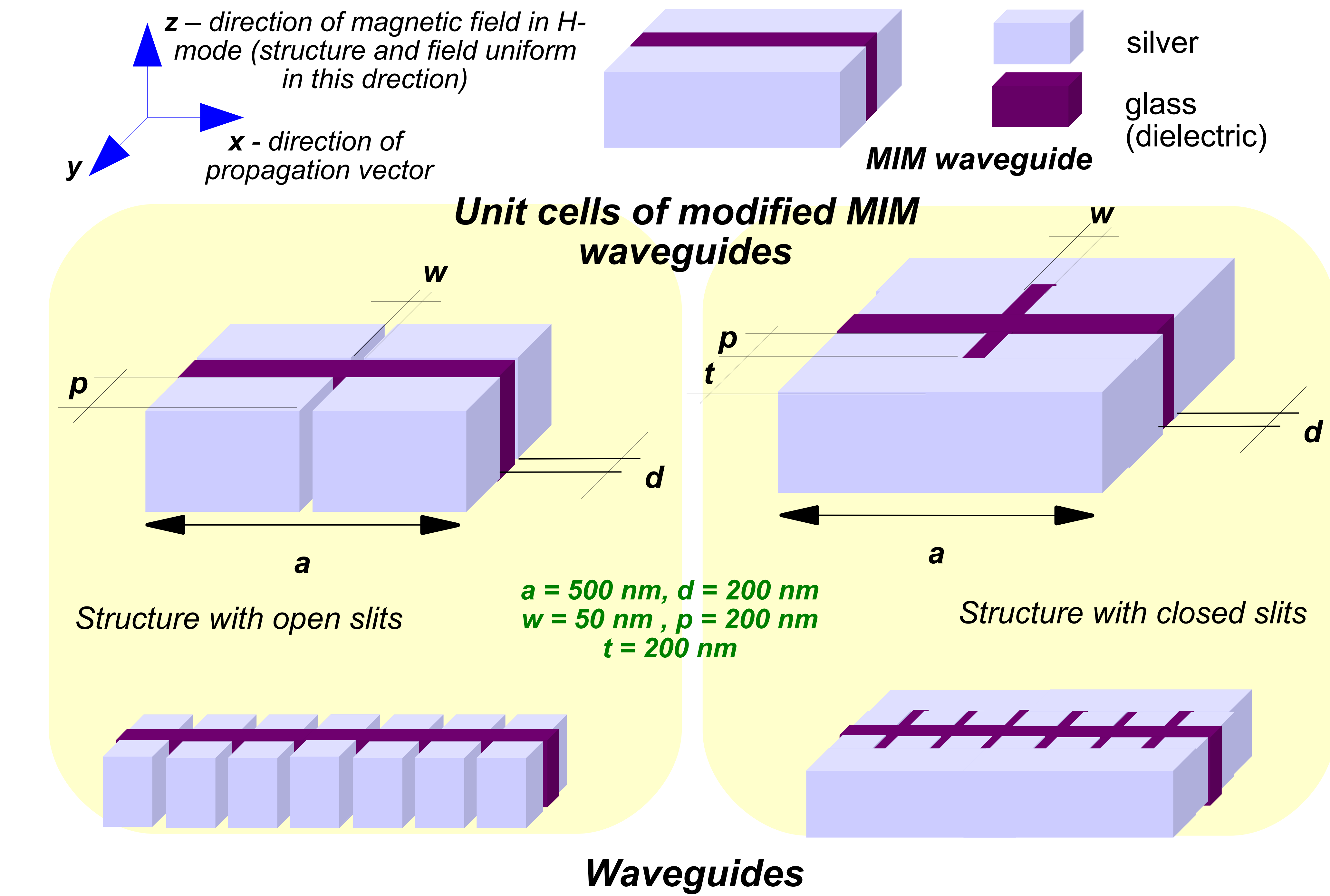


For both of these structures backward waves existence were reported

.....

Both structures are very simple and the number of paramaters that can be adjusted is small

Looking for more design freedom : modified MIM waveguides with introduced periodicity along its lengths



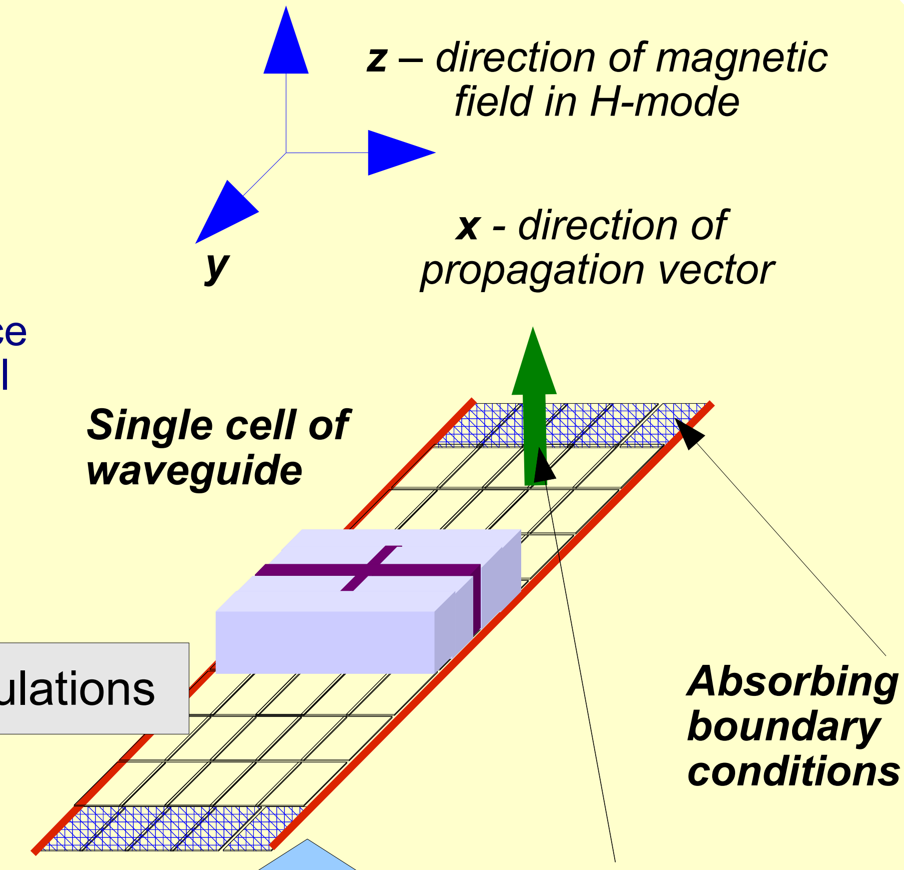
Methodology

Silver is modeled with Drude equation :

$$\varepsilon(\omega) = 1-\omega^2_p/(\omega^2 + i\gamma\omega)$$

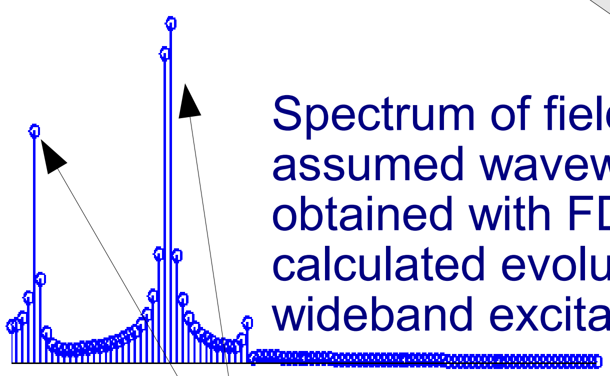
with $\omega_p = 1.29 \times 10^{16}$ Hz and $\gamma = 1.14 \times 10^{14}$ Hz

we investigate H-polarized modes using Finite Differnce Time Domain (FDTD) method on the 2D computational grid with space discretization step 2 nm and time discretization step equal 6.67×10^{-18} s, both for propagation simulation and examination of modal structure



FDTD simulation scheme for mode finding

FDTD calculations



Spectrum of field for assumed wavewector k obtained with FDTD calculated evolution of wideband excitation

Peak frequencies ω relate to modes with assumed wavewector **k**

Band structure of waveguide

Methodology

Silver is mod [redacted]

with ω_p [redacted]

we inv [redacted]
Time [redacted]
grid v [redacted]
discr [redacted]

Convergence tests needed to reasonable trade off between space discretization step and accuracy

[redacted] f magnetic [redacted] ode

Stability of boundary conditions interacting with evanescent waves demands extra computational area

FDTD simulation scheme for mode finding

rel [redacted]
assum [redacted] or [redacted]

Band structure of waveguide

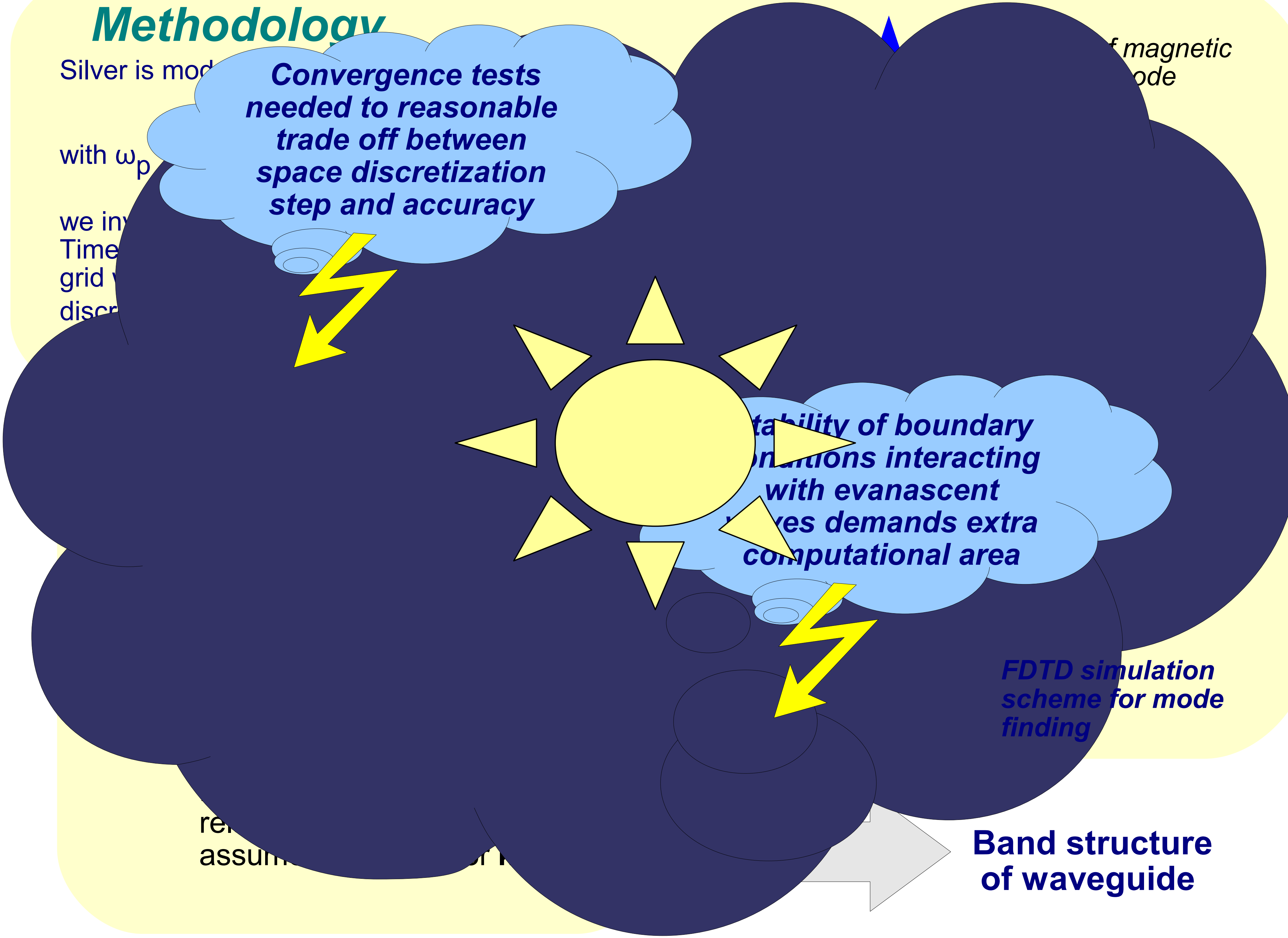
Methodology

Silver is mod

with ω_p

we inv
Time
grid w
discr

f magnetic
ode

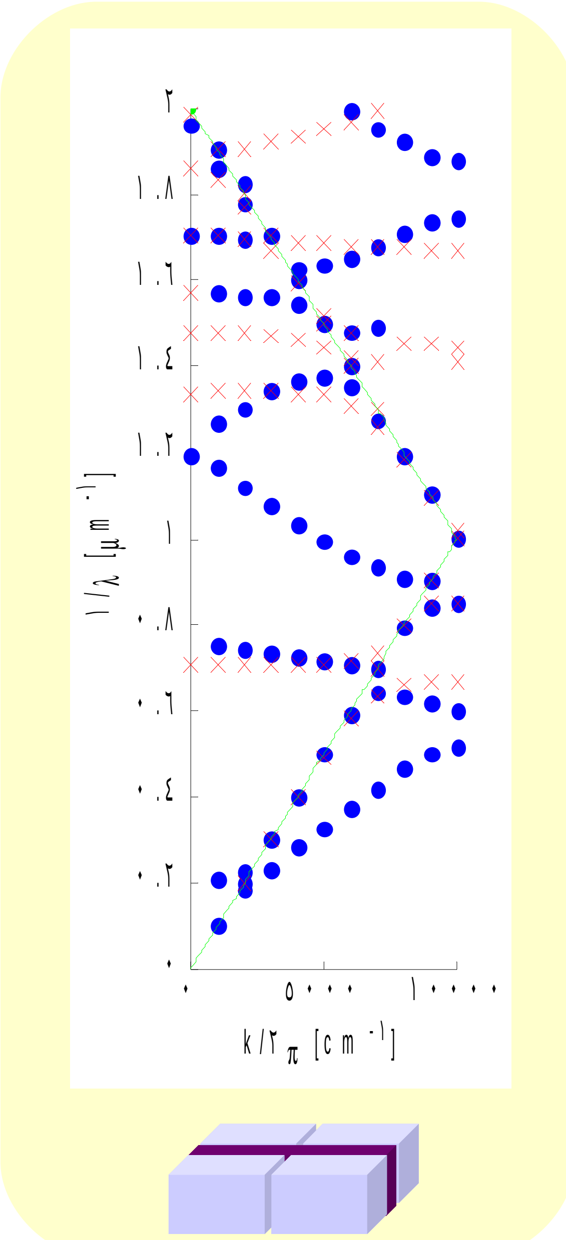


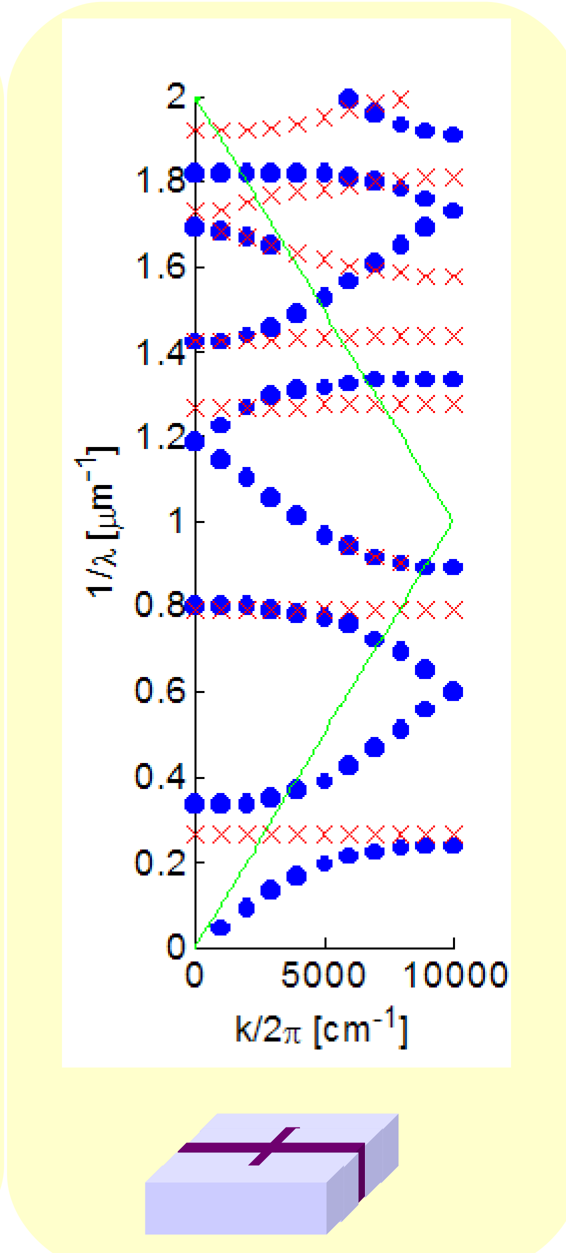
FDTD simulation scheme for mode finding

re
assum r

Band structure of waveguide

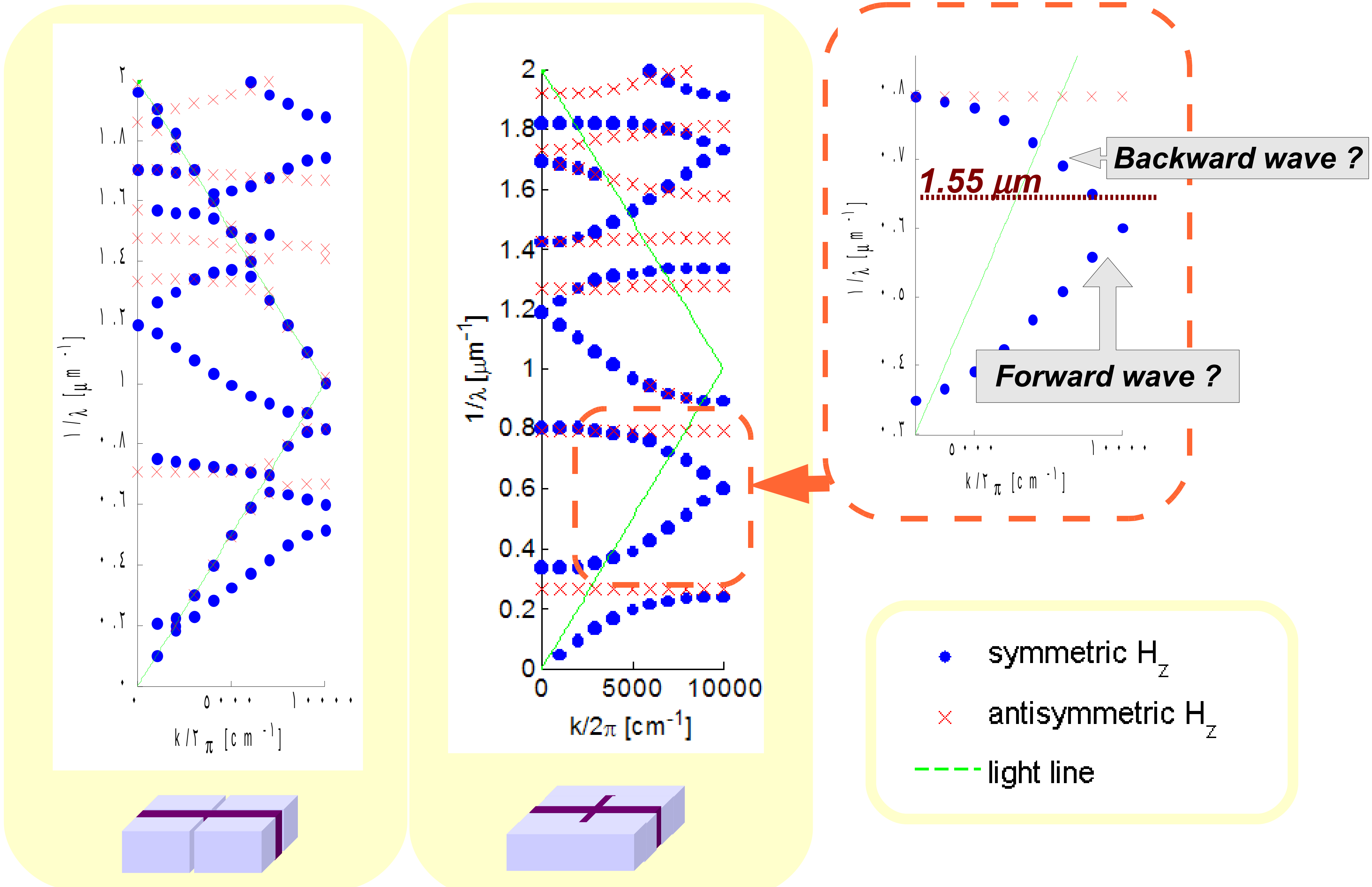
Band structures of modified MIM waveguides *(part 1)*



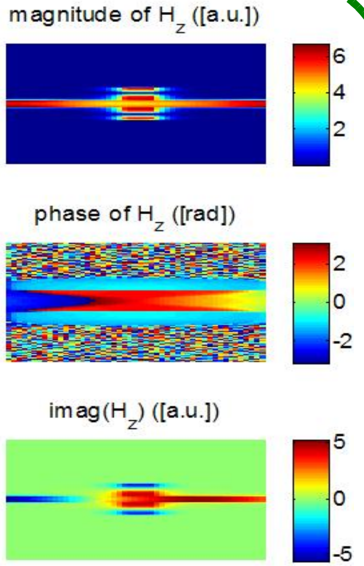


- symmetric H_z
- antisymmetric H_z
- light line

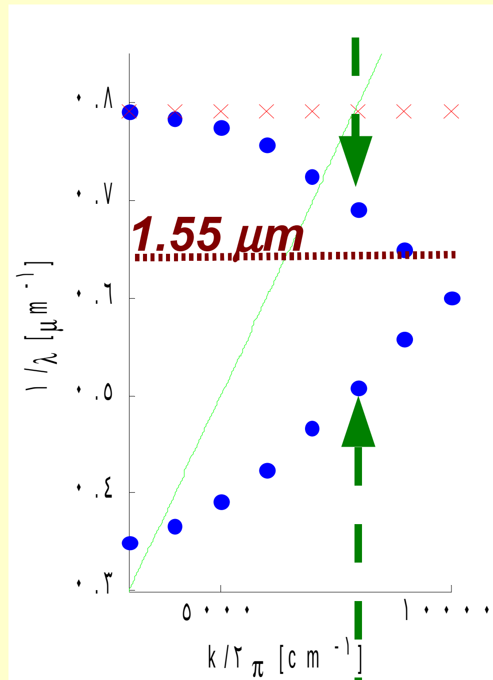
Band structures of modified MIM waveguides *(part 1)*

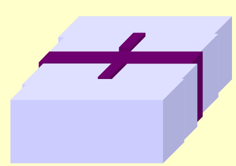


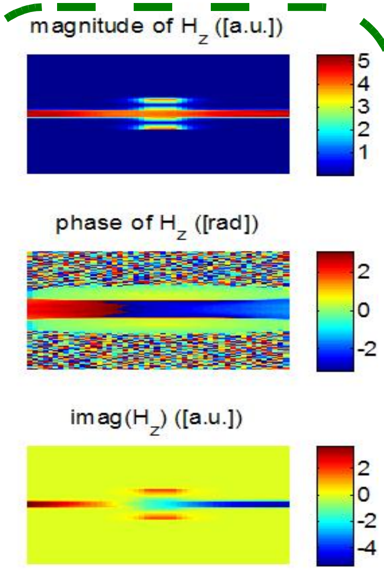
Band structure of modified MIM waveguide *(part 2)*



Negative band slope mode at 1445 nm

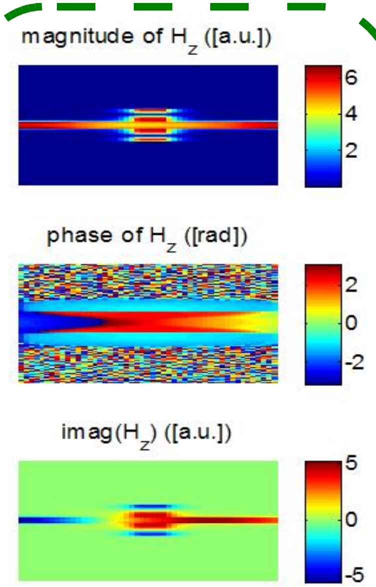






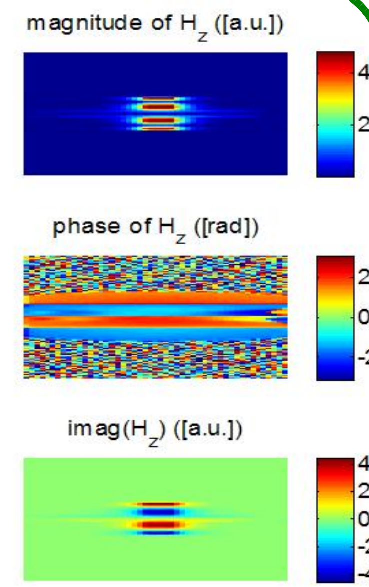
Positive band slope mode at 1966 nm

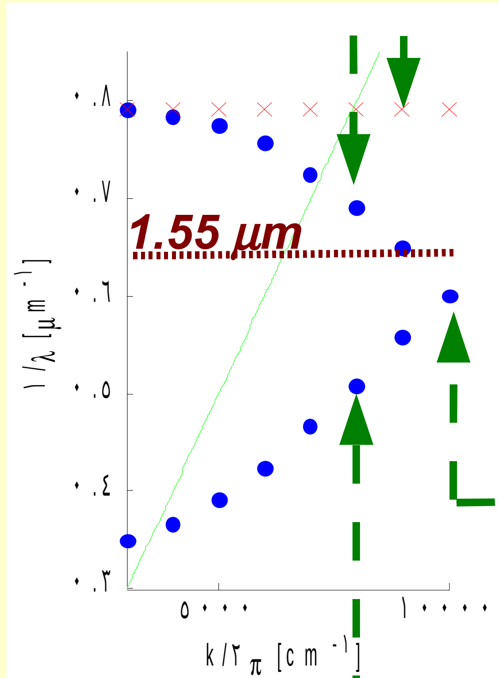
Band structure of modified MIM waveguide *(part 2)*

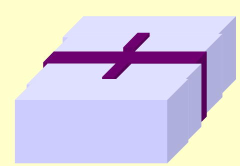


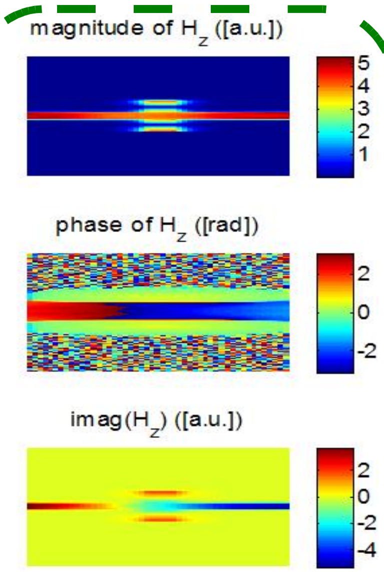
Negative band slope mode at 1445 nm

Stationary mode at 1262 nm (antisymmetric H_z)



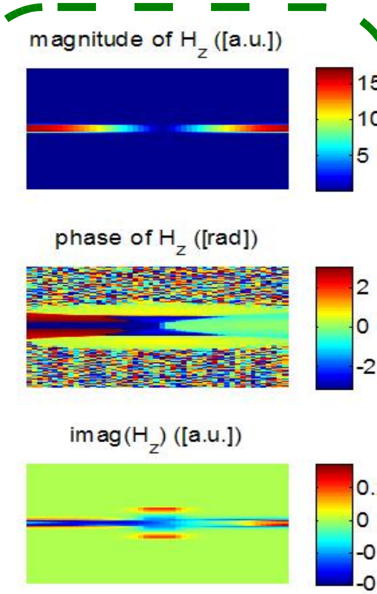




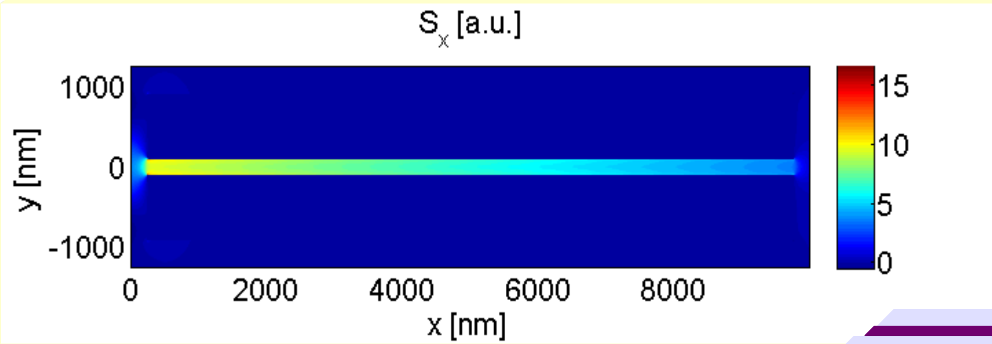


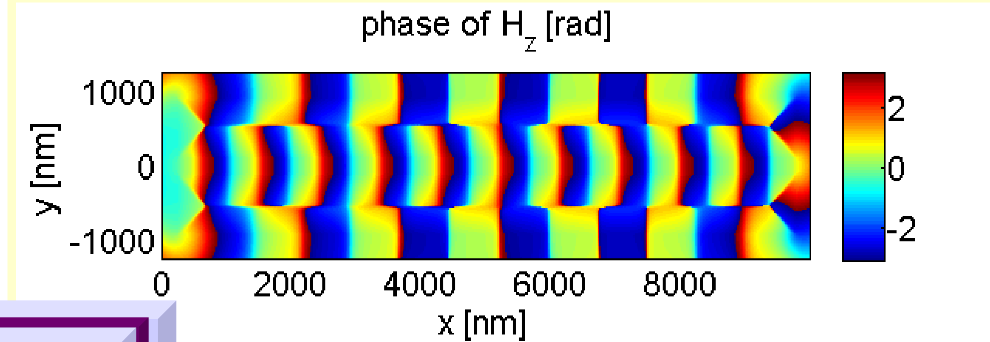
Positive band slope mode at 1966 nm

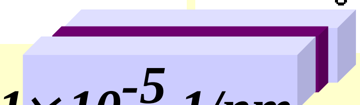
BZ edge mode at 1665 nm



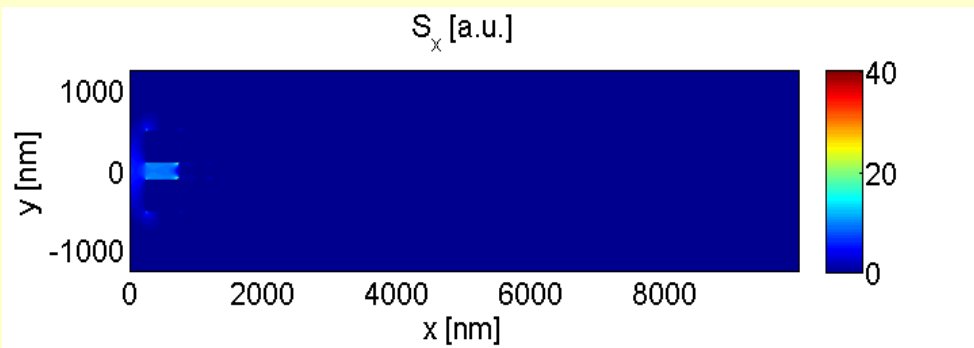
Propagation results : gaussian beam CW back shot excitation, wavelength 1550 nm , steady state values of Poynting vector in x – direction and phase of magnetic field component

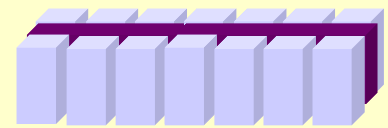




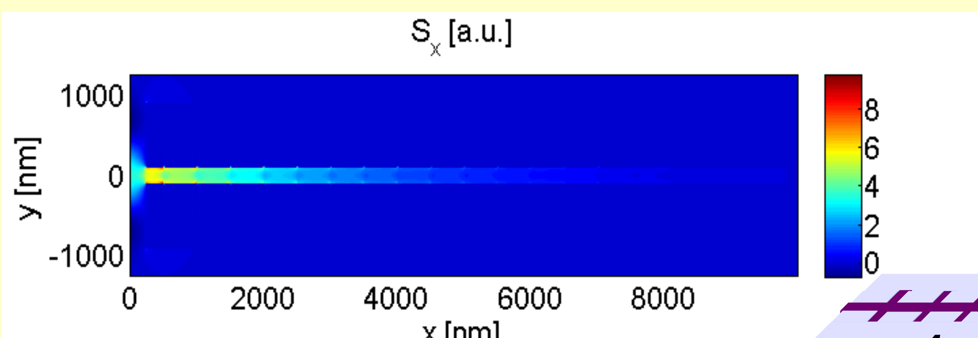


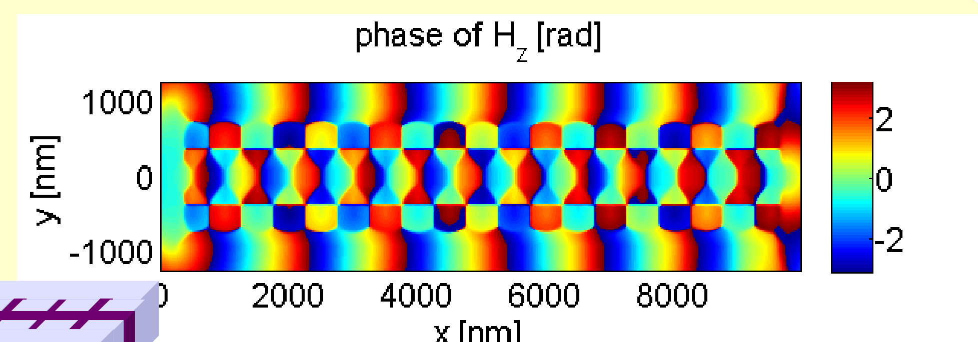
Energy attenuation ratio |a|=9.51×10^{-5} 1/nm

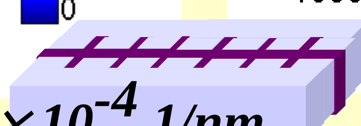




Energy loss much higher than in other structures... other excitation method needed ?

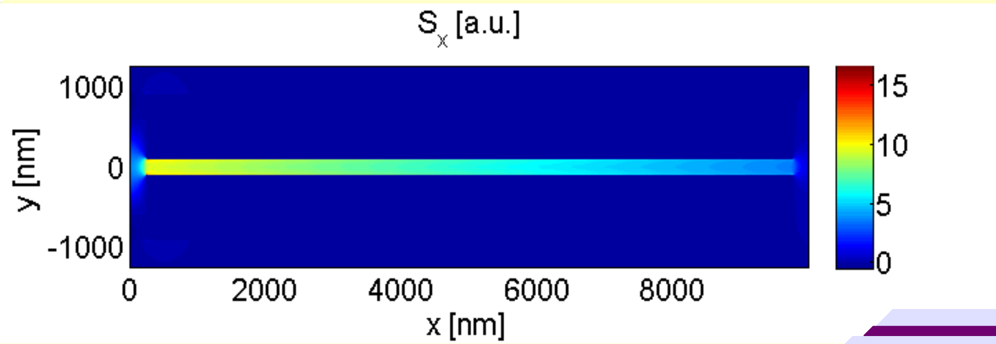


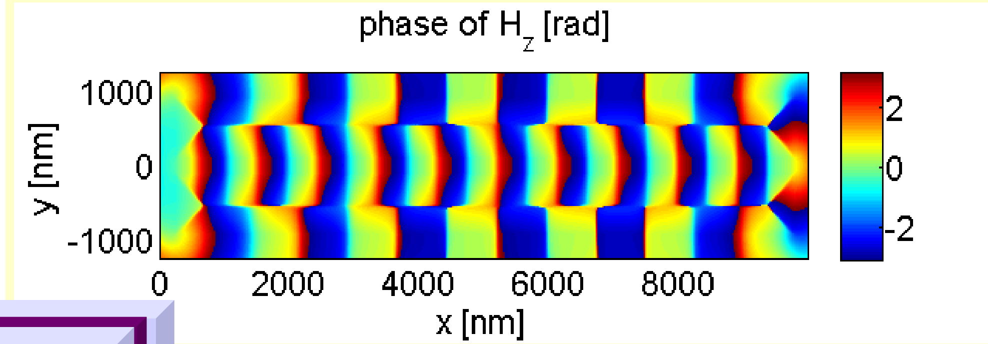


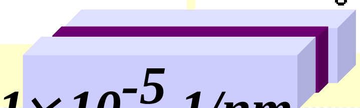


Energy attenuation ratio |a|=4.24×10^{-4} 1/nm

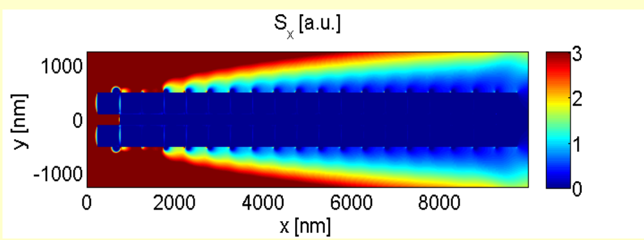
Propagation results : gaussian beam CW back shot excitation, wavelength 1550 nm , steady state values of Poynting vector in x – direction and phase of magnetic field component

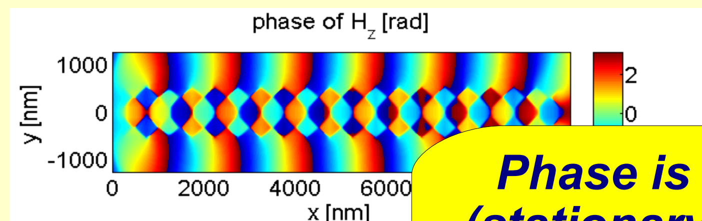






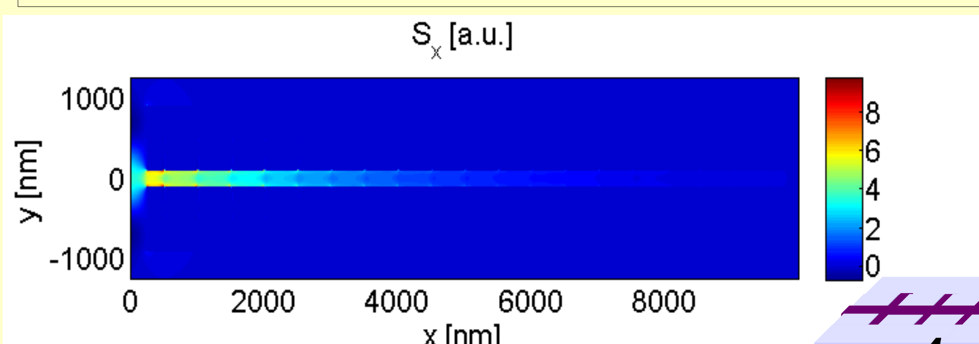
Energy attenuation ratio |a|=9.51×10⁻⁵ 1/nm

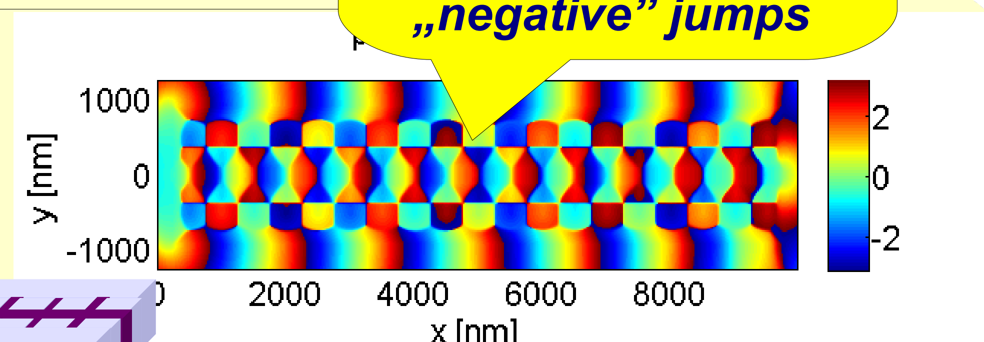


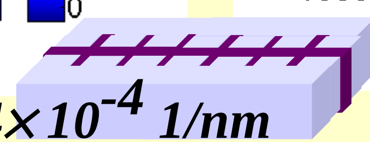


Plane Wave illumination results

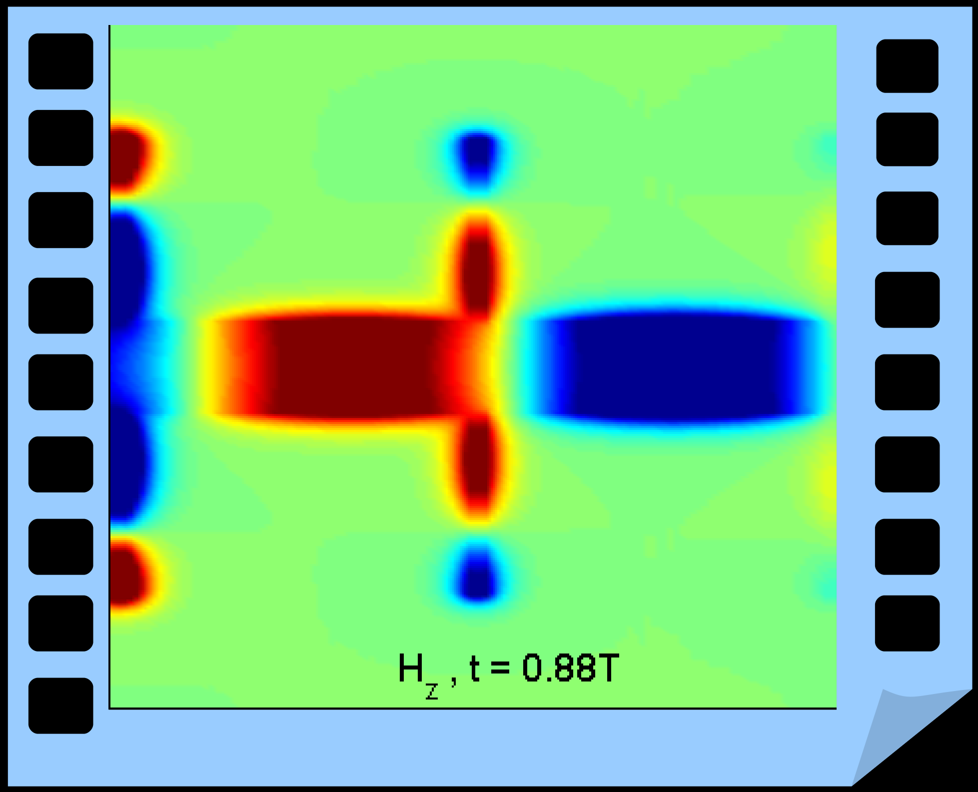
Phase is discrete (stationary plasmon coupling ?) and make locally „negative" jumps



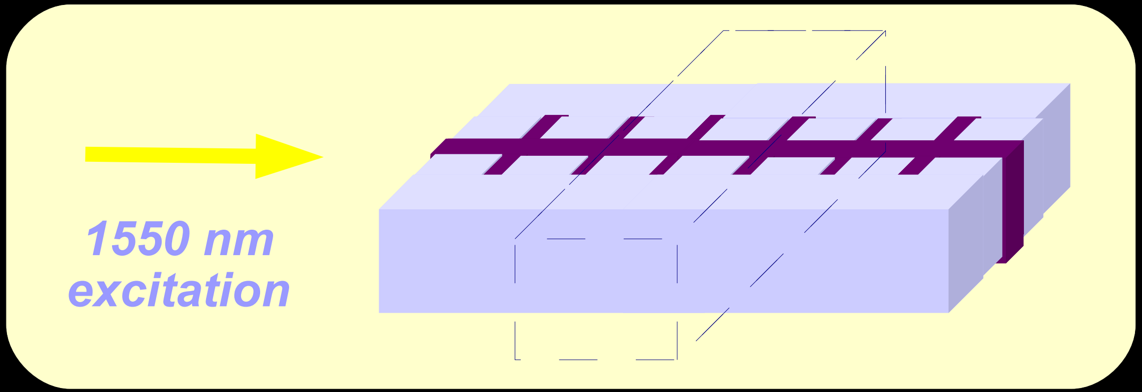




Energy attenuation ratio |a|=4.24×10⁻⁴ 1/nm



Time evolution of magnetic field in modified MIM waveguide during one period of wave



Tuning the band structure

Waveguiding mechanism could be aproximately described as transfer of energy between coupled stationary slit plasmons

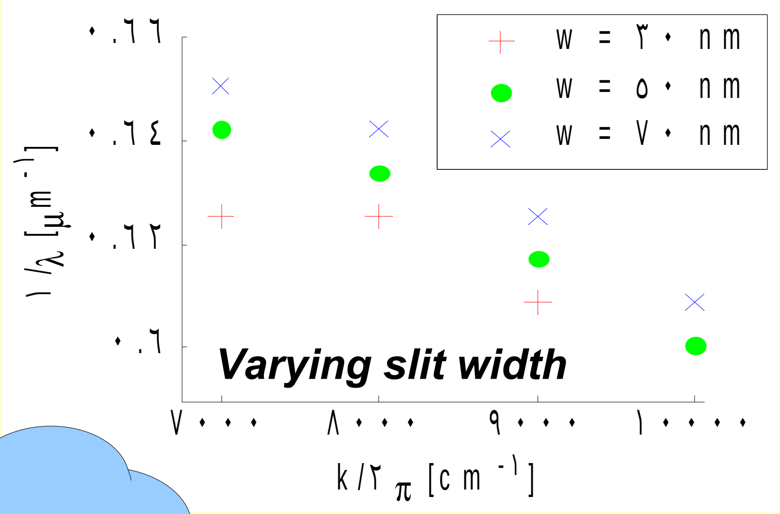
so...

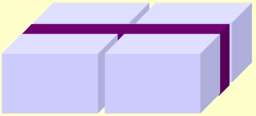
Design hints:

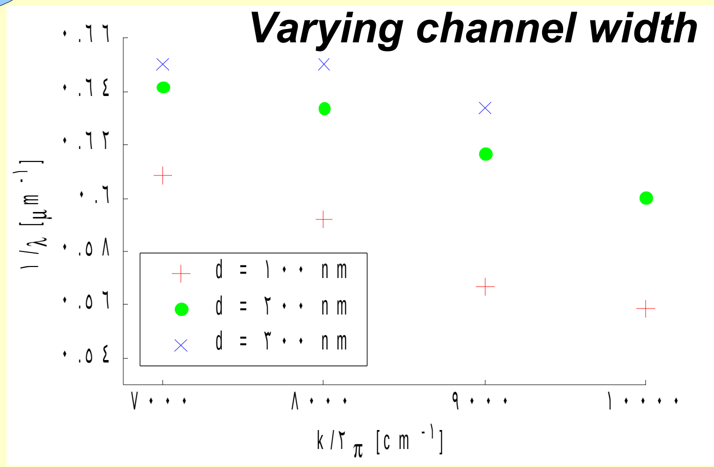
resonance frequency of slit should position the band (range of work frequncues)

the channel parametres should influence the coupling (so the band slope etc.)

It is only an approximation....







Comparison with other designs

	Present work	***Maier et al 2003****	***Dionne et al. 2006*****
Structure	MIM waveguide with periodic structuring: a) periodic indentations in silver claddings (open slit structure) b) periodic enlargements of spacer dielectric core (closed slit structure)	metal nanoparticles	Metal-insulator-metal layers (MIM)
Waveguiding mechanism	Coupling between nano-slits (closed or open)	Coupling between Mie-plasmons	Propagation of the coupled SPP from the two silver cladding layers
Work frequencies	set by geometry	close to nanoparticle Mie-plasmon resonances	close to SPP frequency of metal plane-insulator interface

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****Maier, S. A, Kik, P. G., and Atwater, H. A., “Optical pulse propagation in metal nanoparticle chain waveguides,” Physical Review B 67, 205402 (2003).***

***Dionne, J., Sweatlock, L., Polman, A., and Atwater, H., “Plasmon slot waveguides: Towards chipscale propagation with subwavelenth-scale localization,” Phys. Rev. B 73, 035407 (2006).*

Conclusions

- Bands with both negative and positive dispersion slope exists in MIMs waveguide with periodic modulation (*forward and backward waves ?*)
- Plasmonic resonators coupled with guided wave may be a promising solution for optical range metamaterial

Acknowledgments

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meta morphose

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