The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
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2328-14

Preparatory School to the Winter College on Optics and the Winter College on Optics: Advances in Nano-Optics and Plasmonics

30 January - 17 February, 2012

Experimental techniques for the detection of surface plasmons and Bloch surface waves

F. Michelotti
University Roma La Sapienza
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BLOCH SURFACE WAVES ON PHOTONIC CRYSTALS

APPLICATIONS TO GAS SENSING AND BIOPHOTONICS

SAPIENZA Università di Roma

Department of Basic and Applied Sciences for Engineering

Molecular Photonics Laboratory

Francesco Michelotti

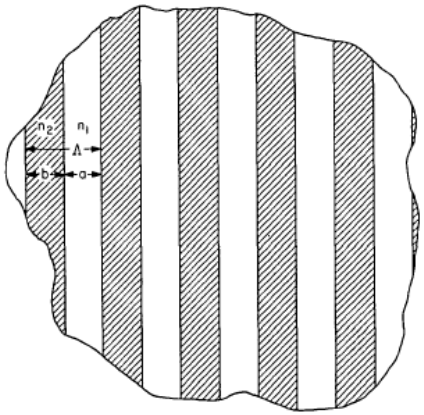
International Centre for Theoretical Physics, Trieste, February 2010

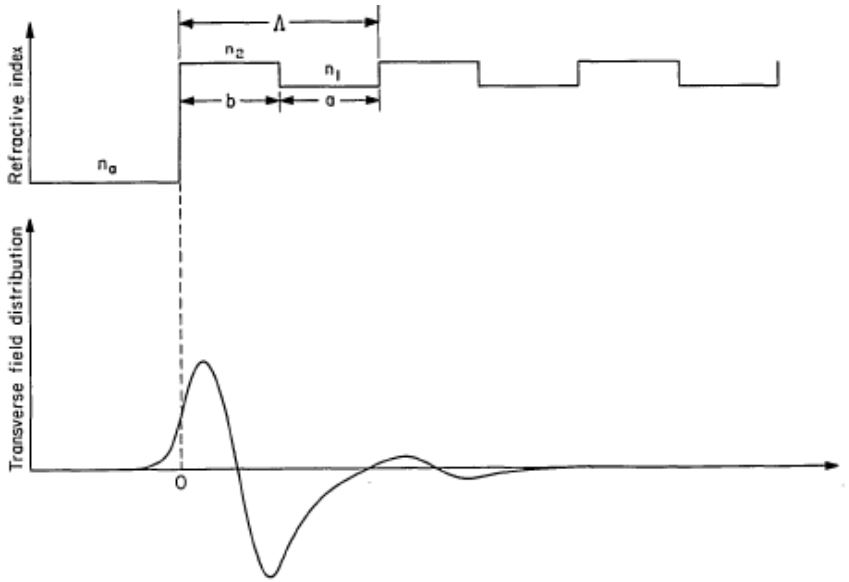
BSW at the truncation interface of 1DPC

Electromagnetic propagation in periodic stratified media. I. General theory*

Pochi Yeh, Amnon Yariv, and Chi-Shain Hong
California Institute of Technology, Pasadena, California 91125
(Received 8 November 1976)

The propagation of electromagnetic radiation in periodically stratified media is considered. Media of finite, semi-infinite, and infinite extent are treated. A diagonalization of the unit cell translation operator is used to obtain exact solutions for the Bloch waves, the dispersion relations, and the band structure of the medium. Some new phenomena with applications to integrated optics and laser technology are presented.





J. Opt. Soc. Am., Vol. 67, No. 4, April 1977

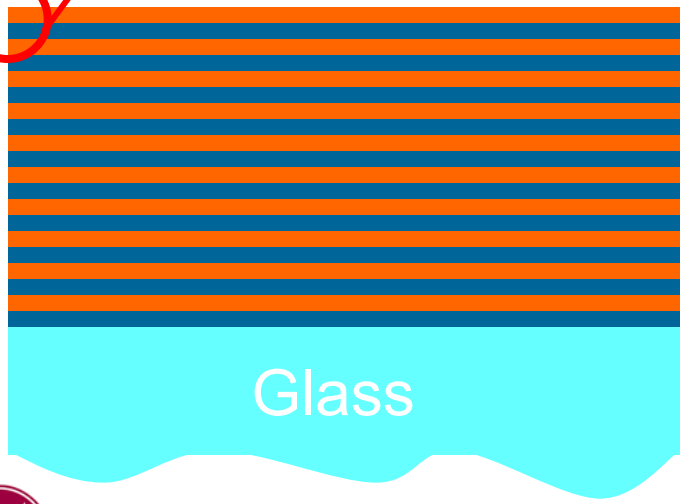
Lecture 2

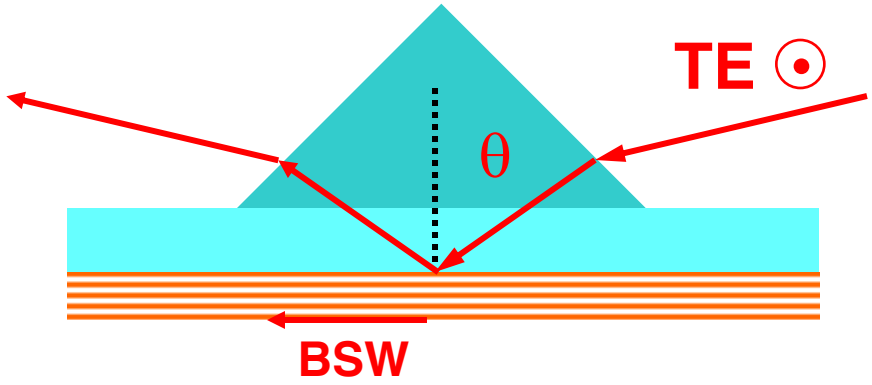
Experimental techniques for the detection of SPP and BSW

a-$Si_{1-x}N_x$:H based 1D Photonic Crystal

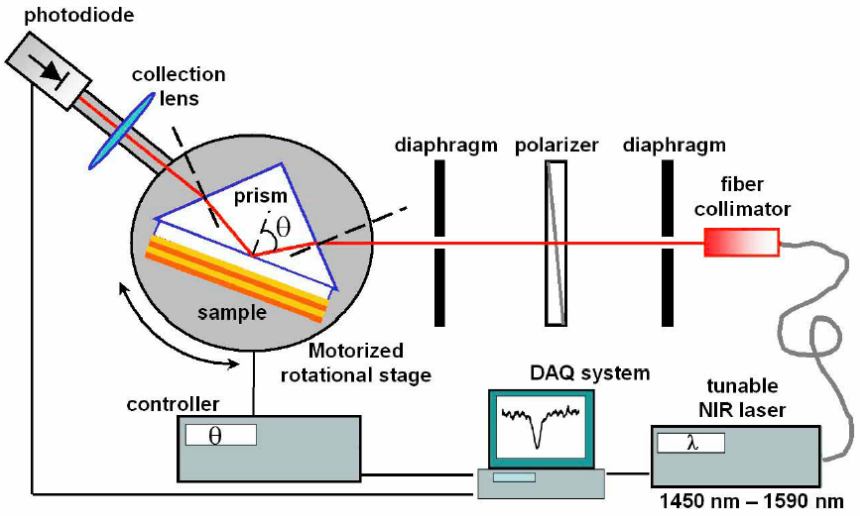
L	t=294nm n=1.75 @ λ=1530nm
H	t=240nm n=2.23 @ λ=1530nm

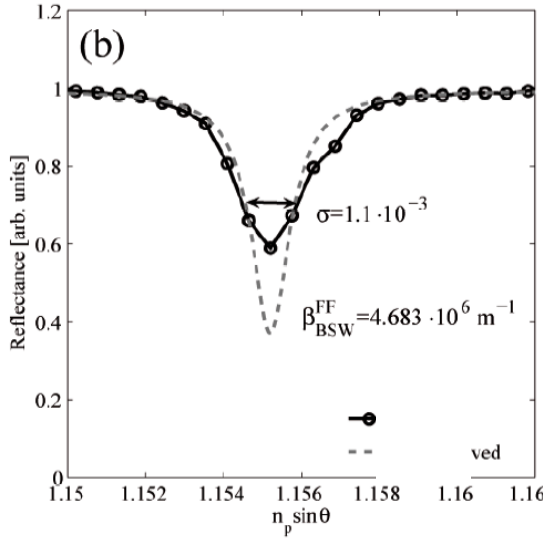
10 periods

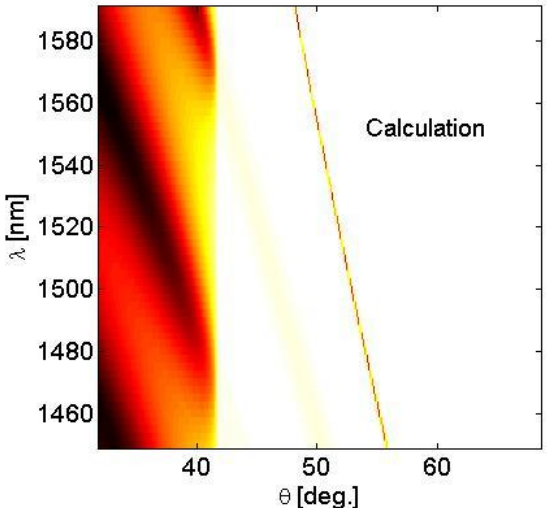




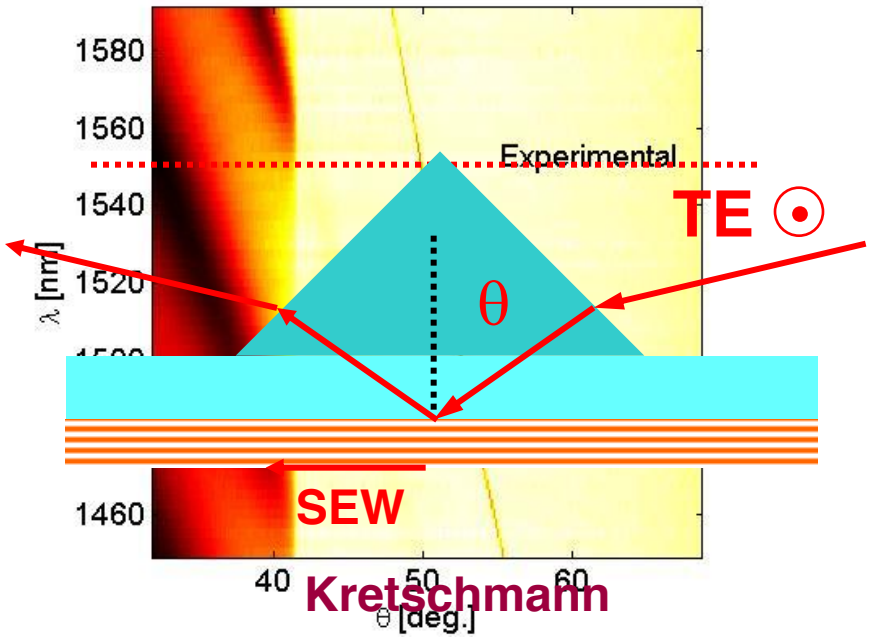
Kretschmann

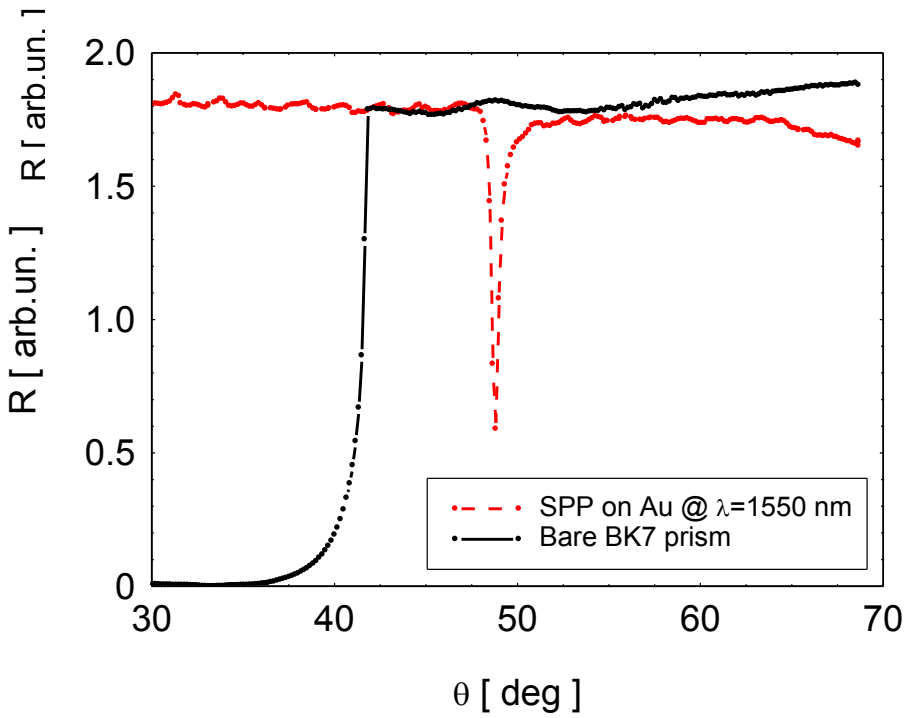






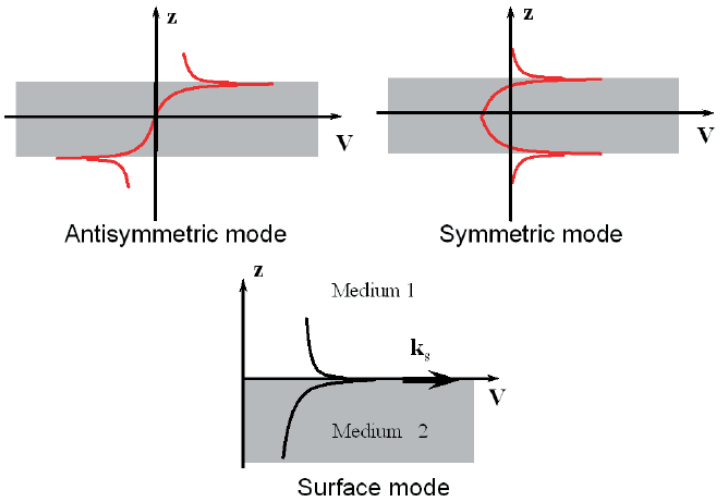
Kretschman Reflectance Map





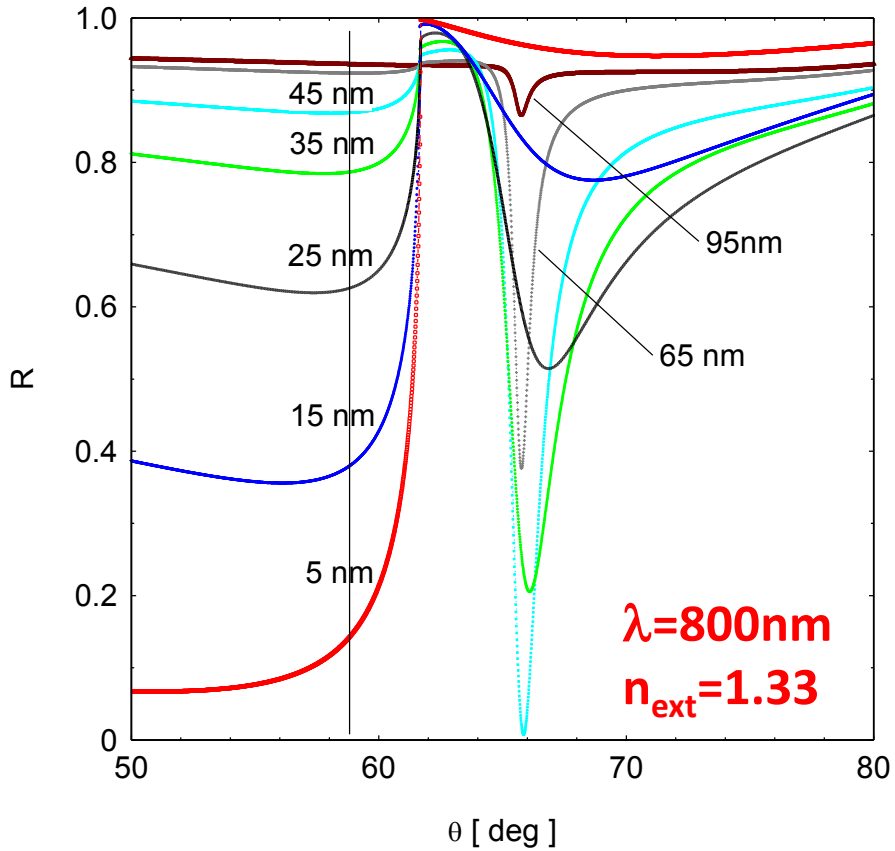
Comment on line-width and coupling efficiency - SPP

Contact

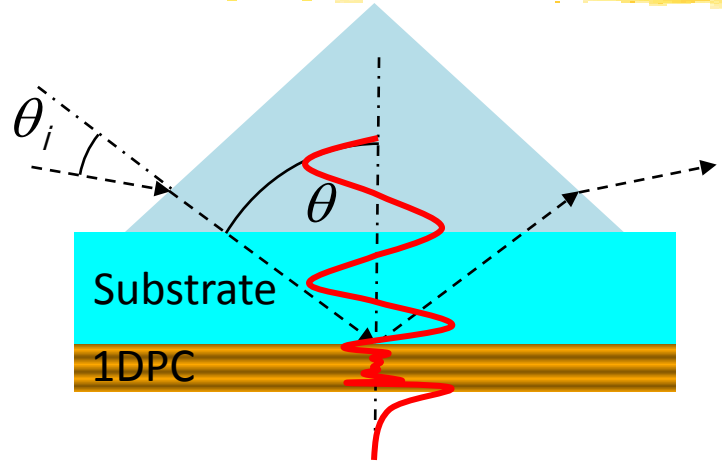


▲ Fig. 4: Diagrams of slab modes. The electrostatic potential V of modes is plotted as a function of the location in the slab. Above: antisymmetric and symmetric modes. Below: pure surface mode, with each interface decoupled from each other.

Coupling is controlled by the thickness of the gold layer

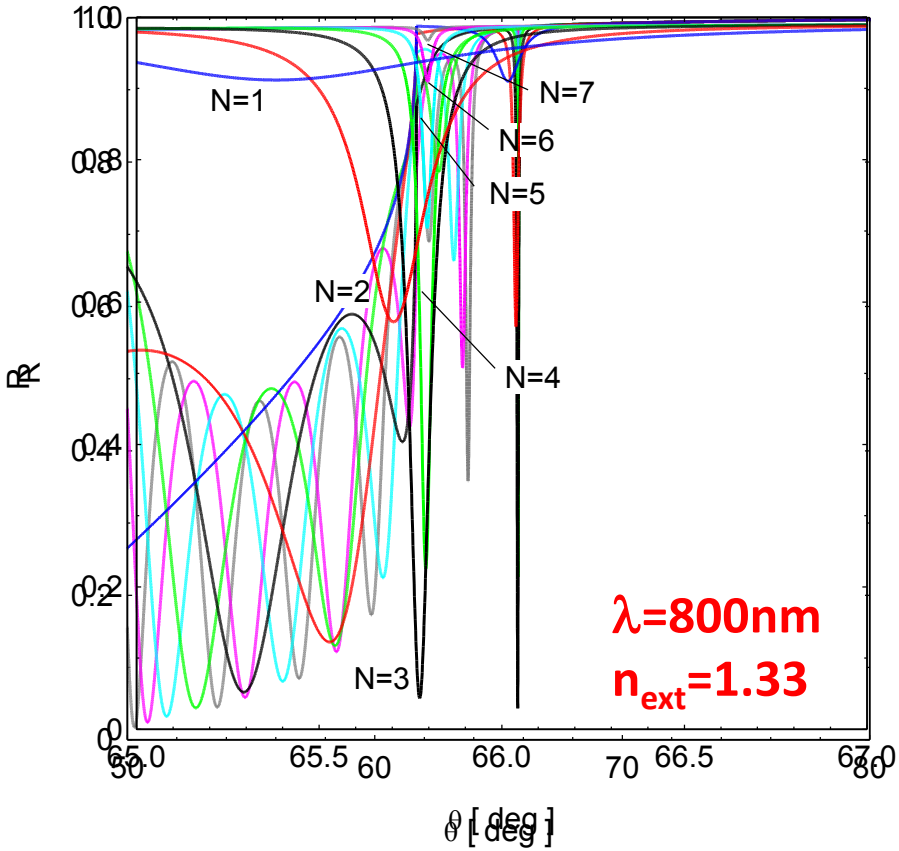


Comment on line-width and coupling efficiency - BSW



PMA, Kretschmann

Coupling is controlled by the number of periods of the 1DPC

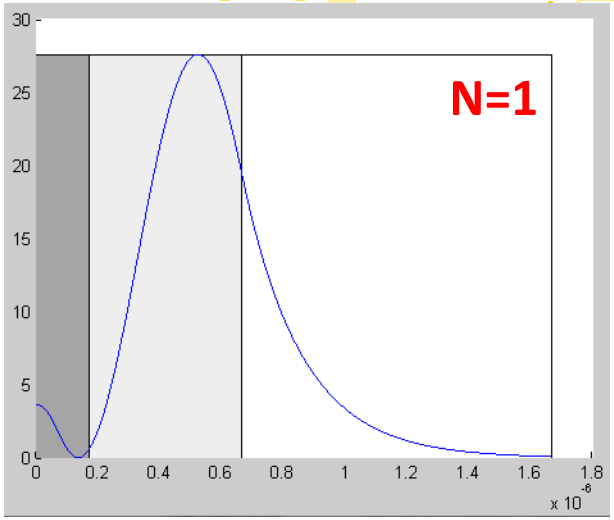


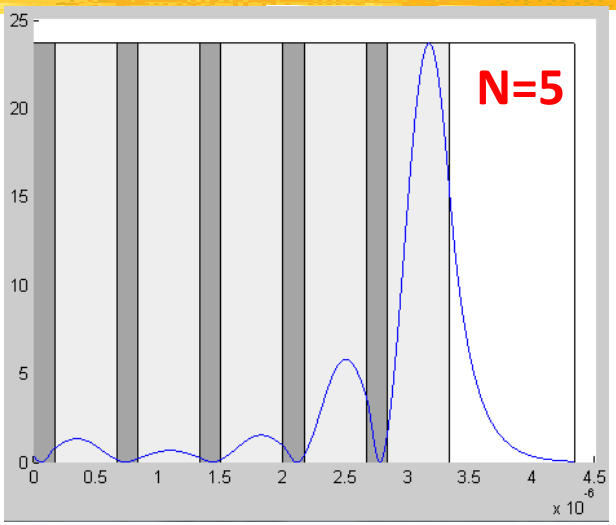
1DPC - Glass / $(HL)^N$ / water

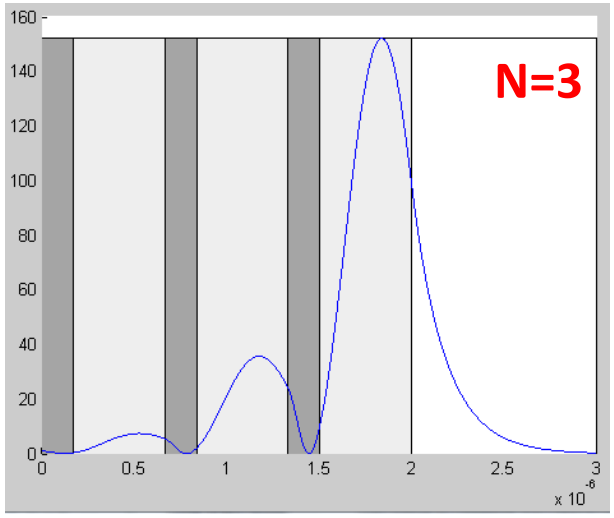
H (Ta_2O_5) n_H=1.99 t_H=170 nm

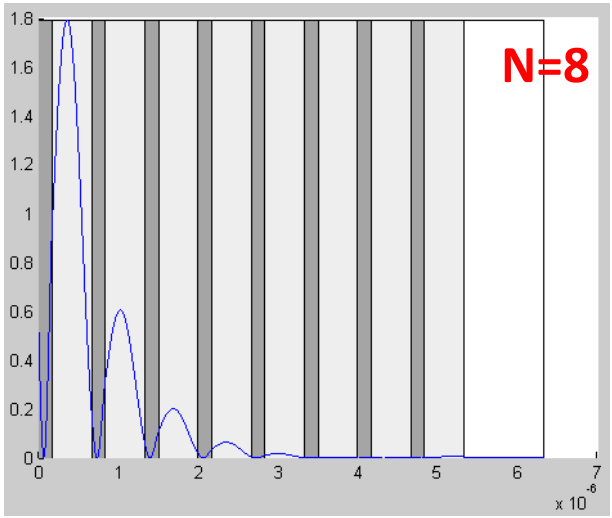
L (SiO_2) n_L=1.48 t_L=495 nm

Comment on line-width and coupling efficiency - BSW

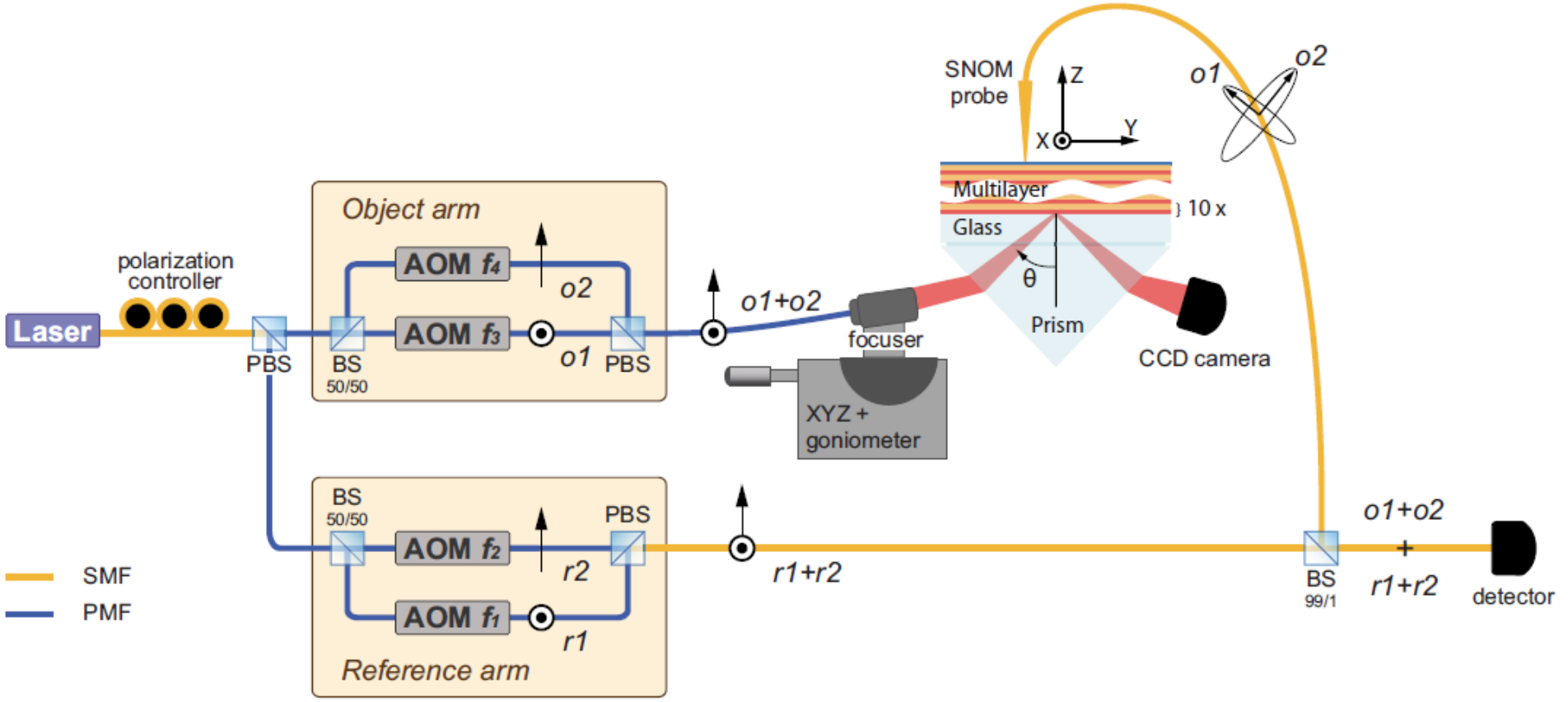








a-$Si_{1-x}N_x$:H based 1D and 2D PC– SNOM Investigations



a-$Si_{1-x}N_x$:H based 1D and 2D PC– SNOM Investigations

L	t=294nm n=1.75 @ λ=1530nm
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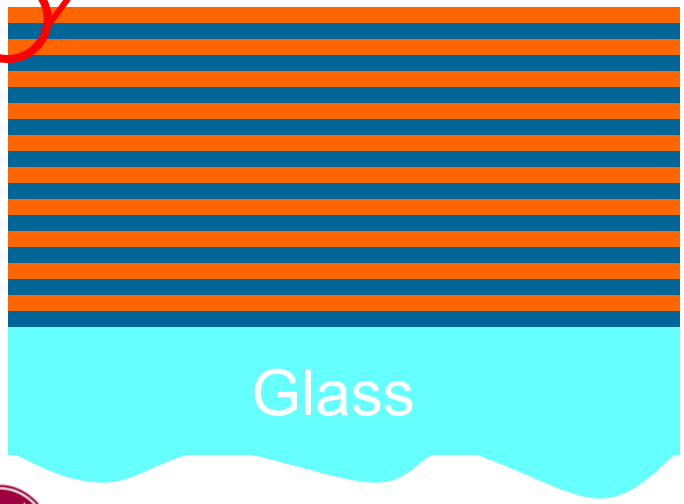
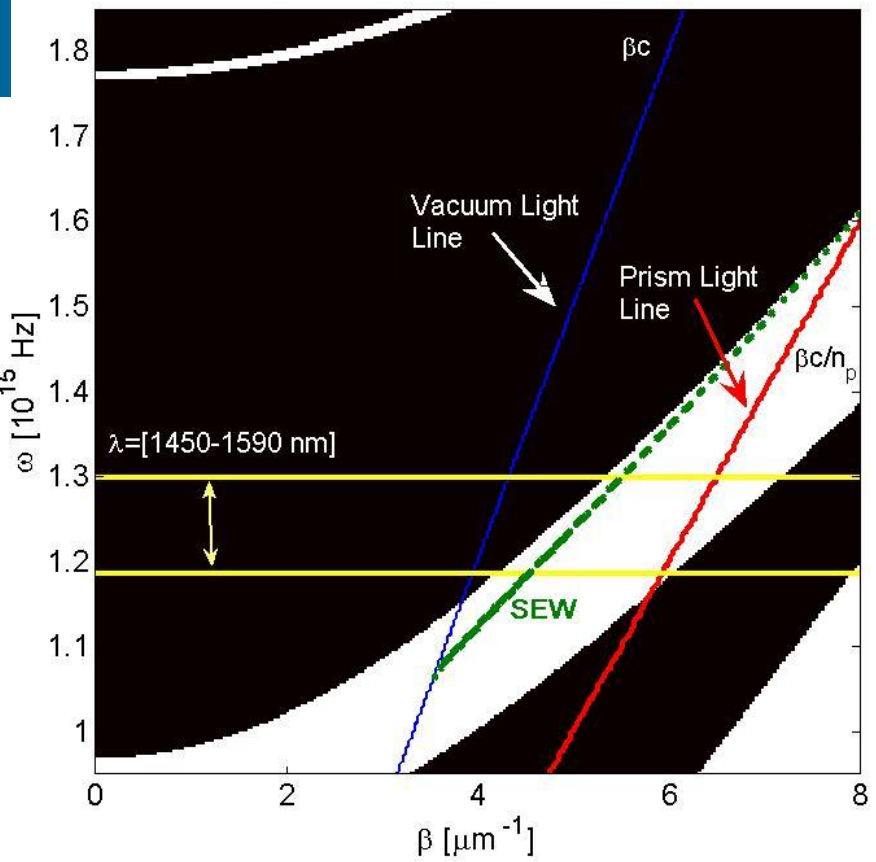
10 periods

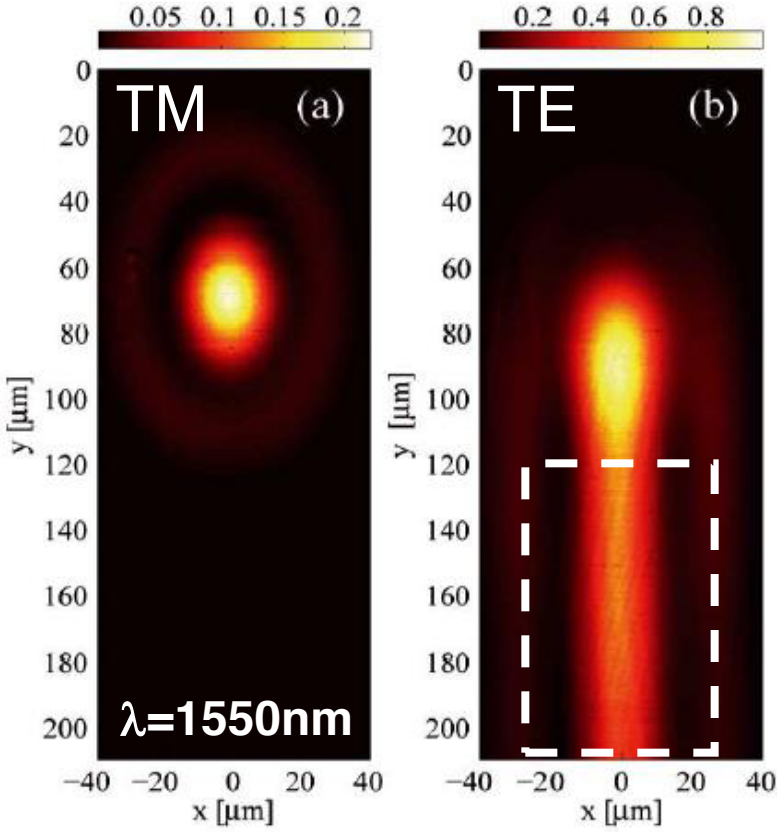


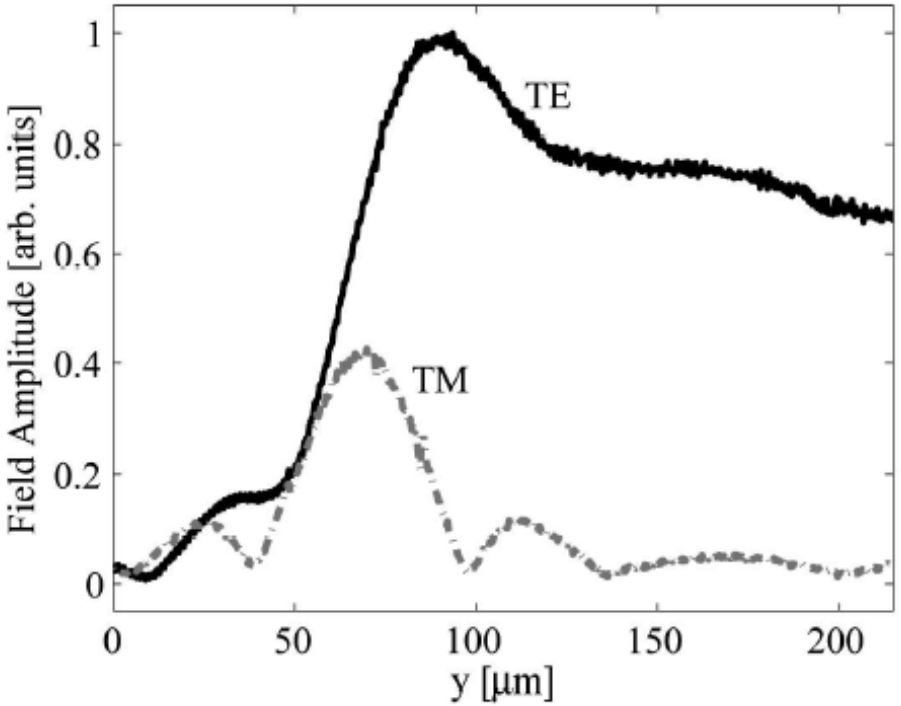
Band Diagram



Multi-heterodyne SNOM Investigations

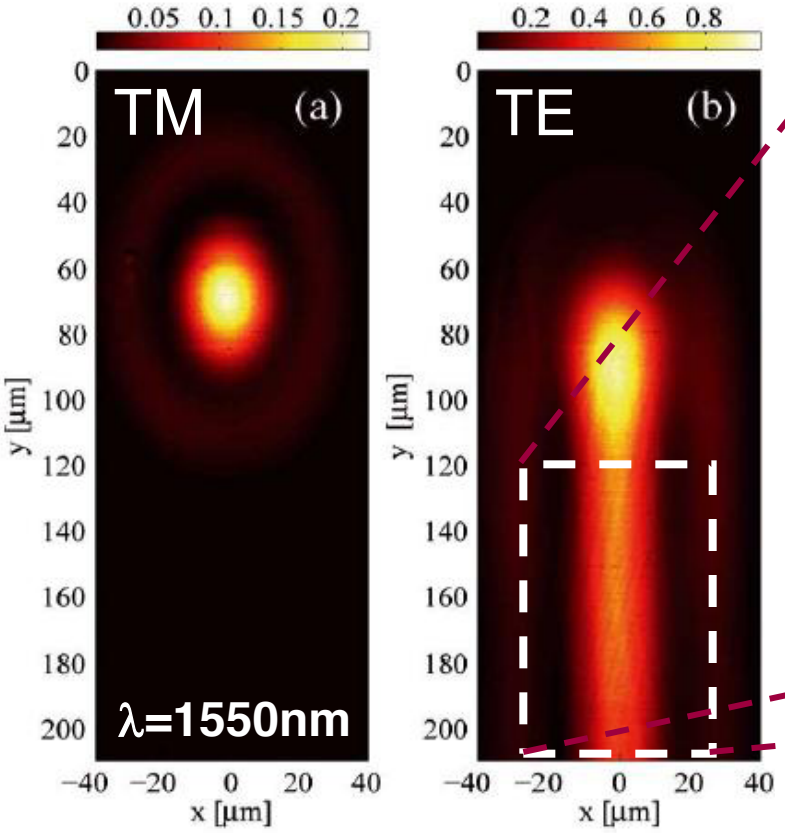
Optics Express **16**, 5453 (2008)

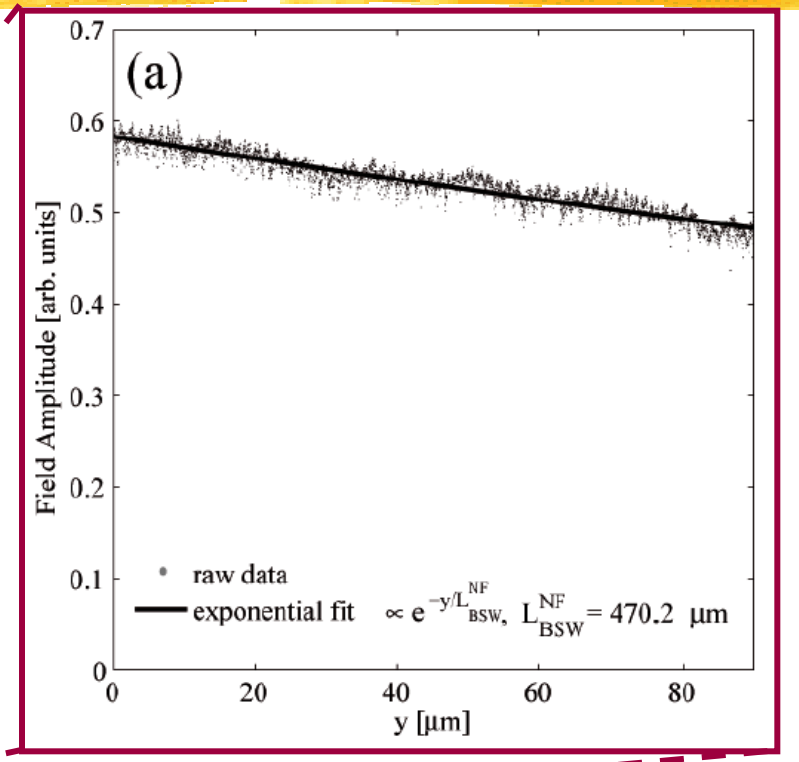




Multi-heterodyne SNOM Investigations

Optics Express **16**, 5453 (2008)

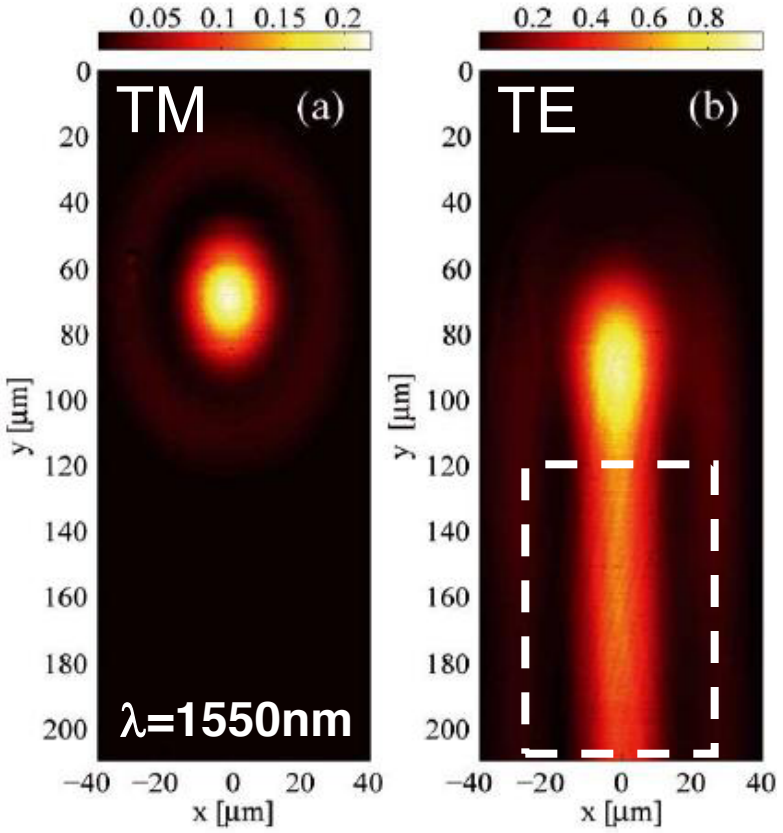


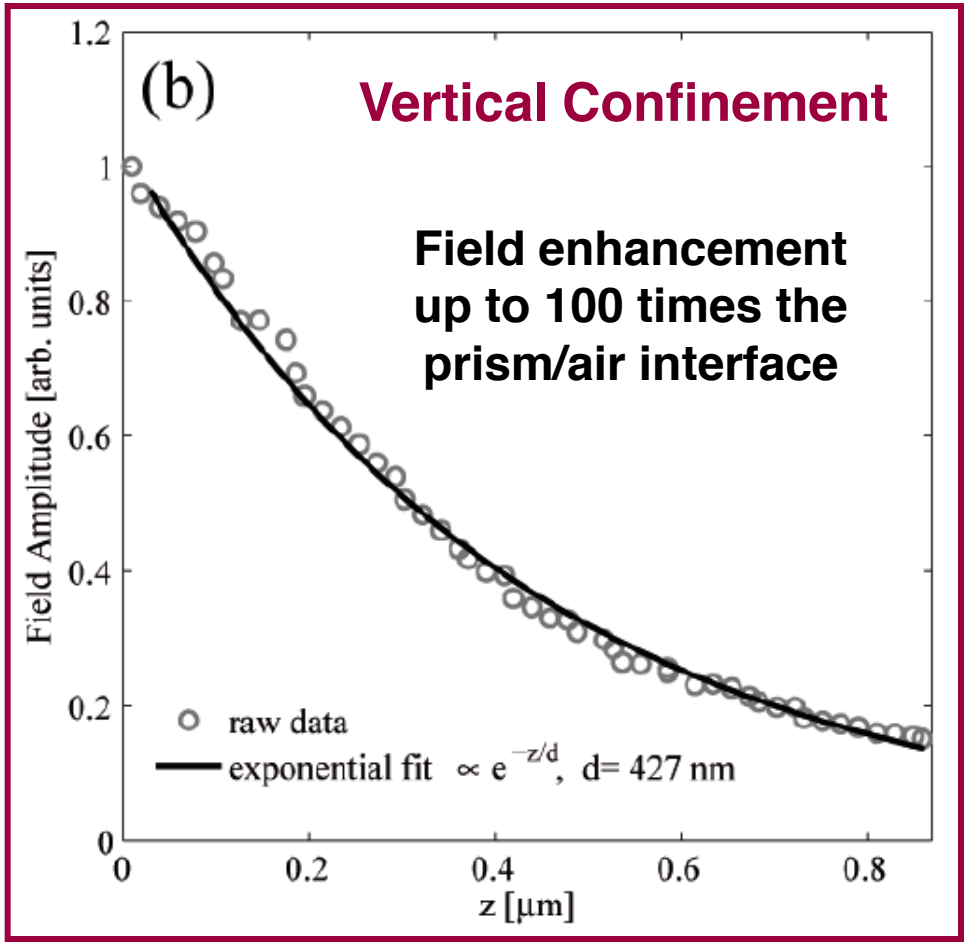


The observed decay length (~470µm) is consistent with the observed line width of the far field measurements

Multi-heterodyne SNOM Investigations

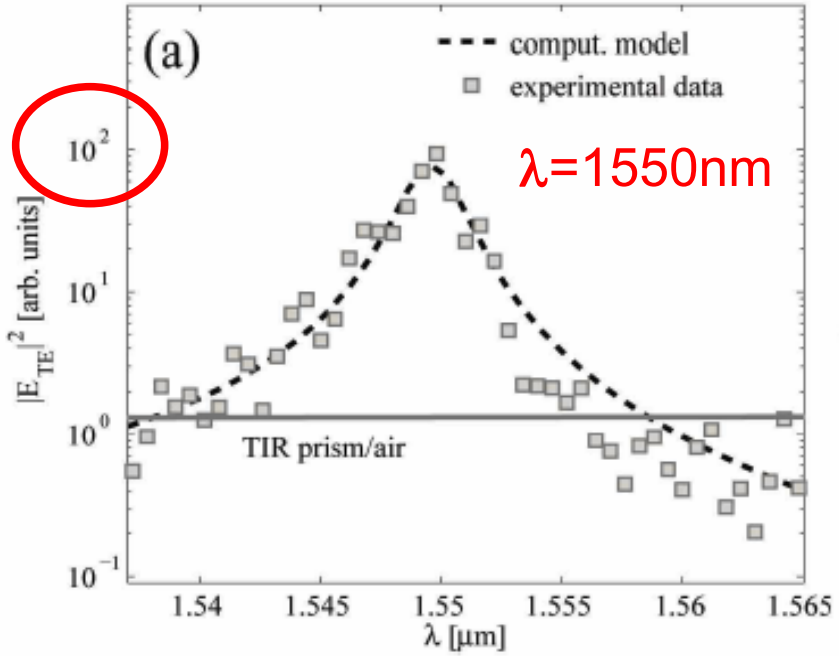
Optics Express **16**, 5453 (2008)



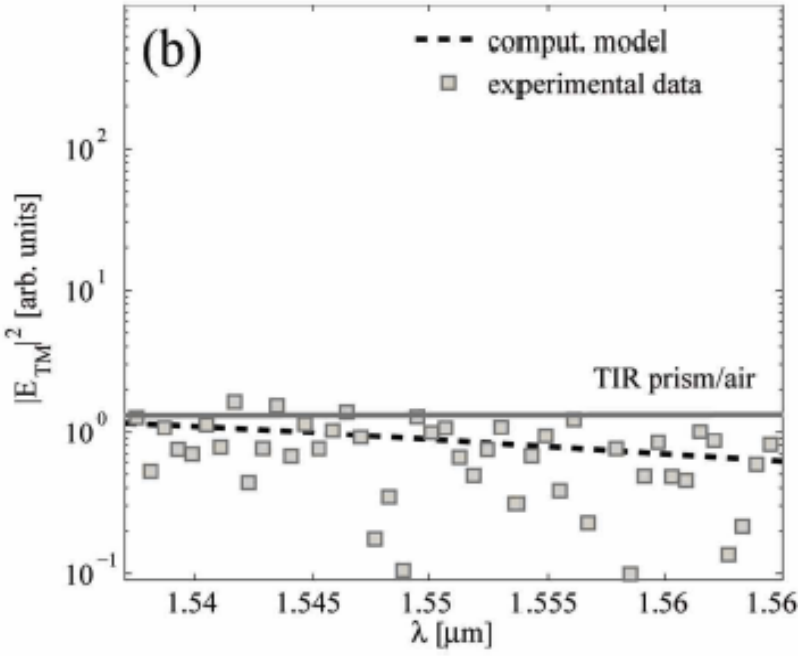


Multi-heterodyne SNOM Investigations

Coupling of BSW is associated to a near-field intensity enhancement at the multilayer top surface



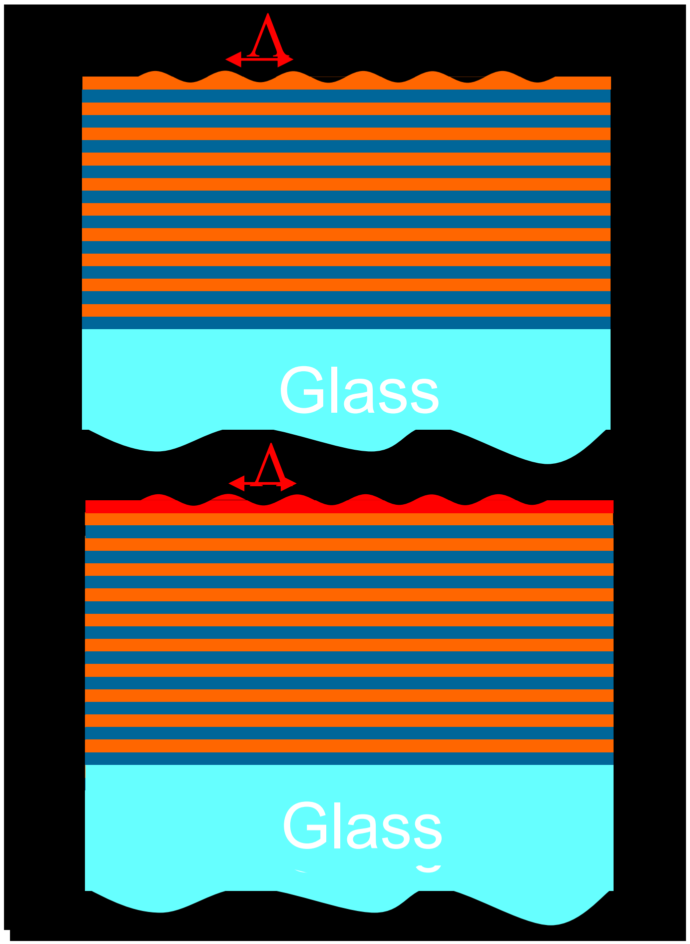
BSW (TE pol.)

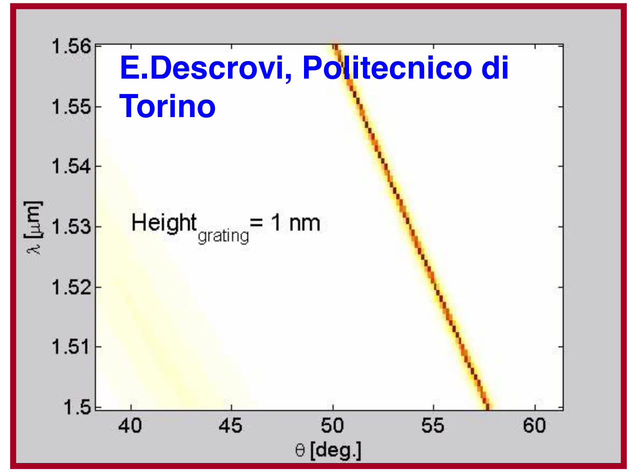


NO BSW (TM pol.)

Opt. Express 16, 5453 (2008)

Holographic lithography in hybrid polymer-silicon nitride 2D PC for SEW dispersion engineering and application in biophotonics





Spin coating of a DR1-PMMA (60%) thin polymer layer

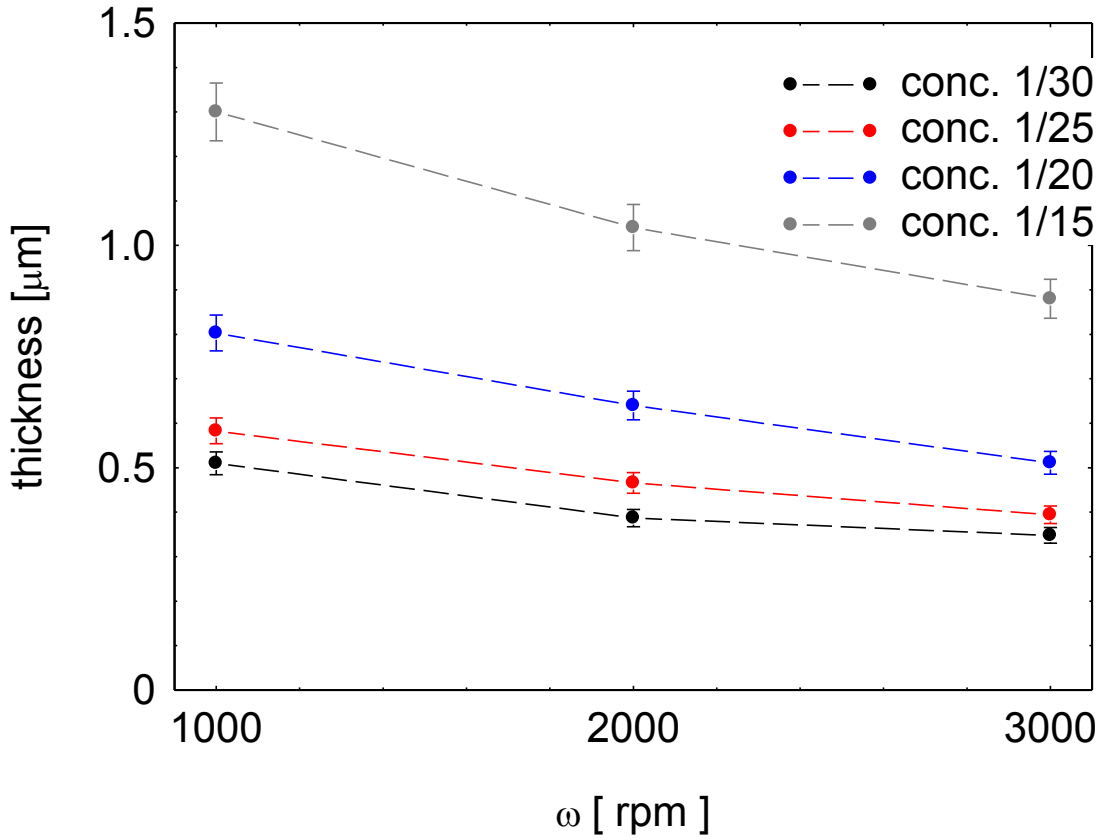
Writing of a holographic surface grating on top of the polymer layer

In order to open a gap at λ the period Λ must be such that:

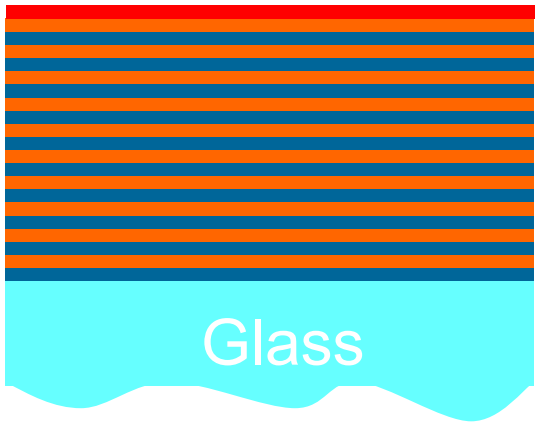
$$\frac{2\pi}{\Lambda} = 2 \cdot \beta_{BSW}^{eff}(\lambda) = \frac{4\pi}{\lambda} \cdot n_p \cdot \sin\theta_{BSW}^{(\lambda)}$$

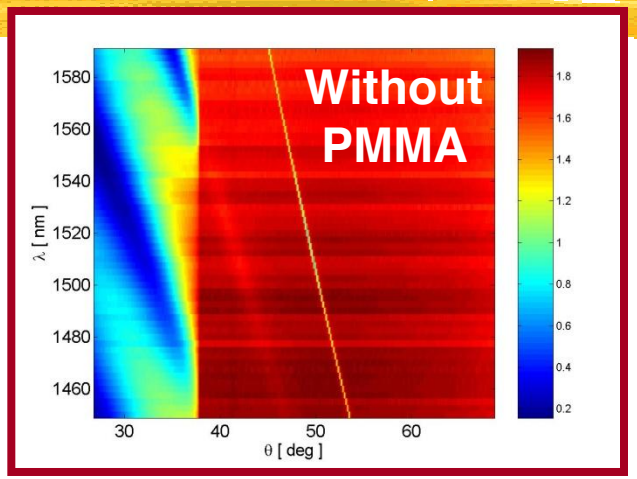
$Si_{1-x}N_x$:H / Polimer 2D PC - Grating fabrication

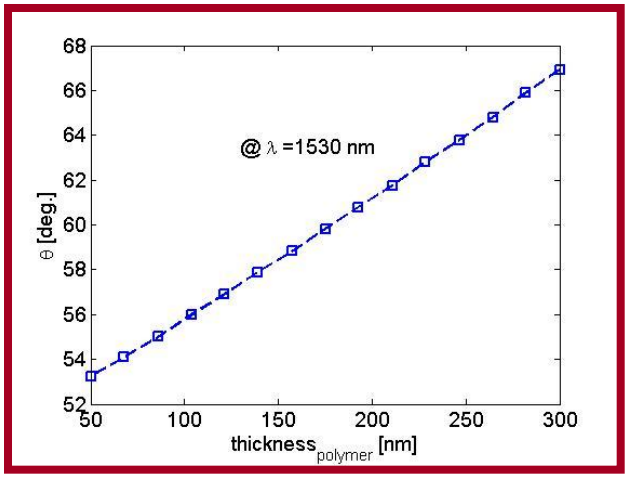
PMMA vs Speed for different concentrations in 1,1,2 Trichloroethane

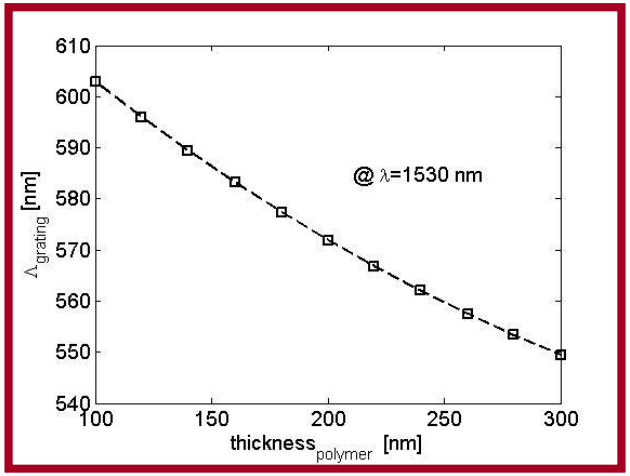


$Si_{1-x}N_x$:H / Polimer 2D PC - Grating fabrication





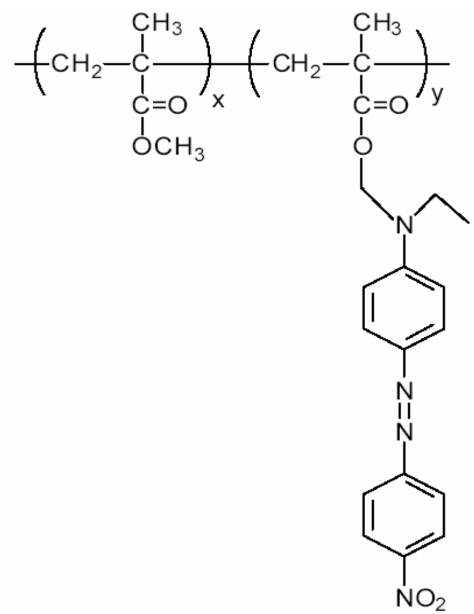


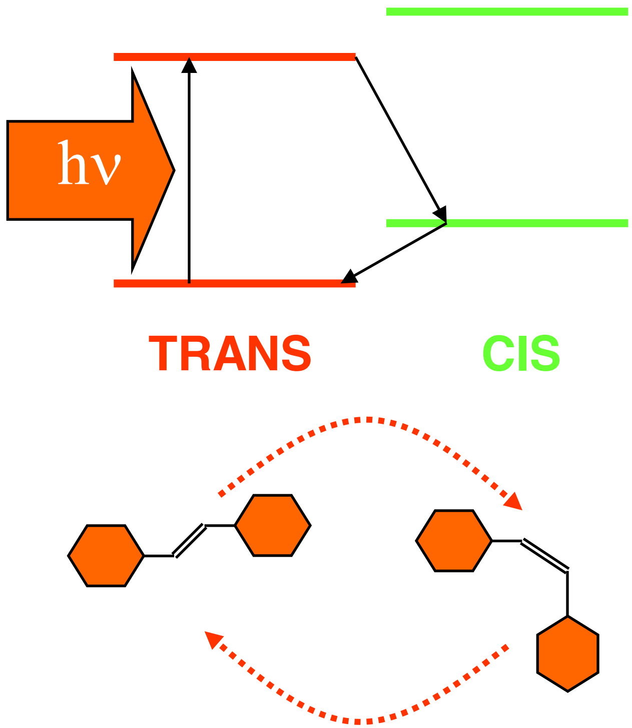


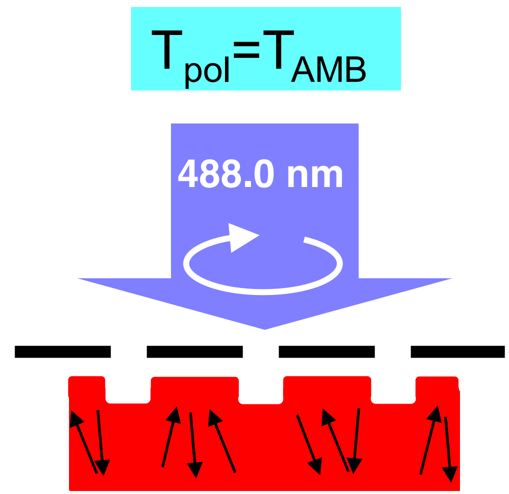
a-$Si_{1-x}N_x$:H / Polimer 2D PC - Grating fabrication

Optically induced surface gratings on azoaromatic polymer films

136 Appl. Phys. Lett. 66 (2), 9 January 1995 0003-6951/95/66(2)/136/3/$6.00



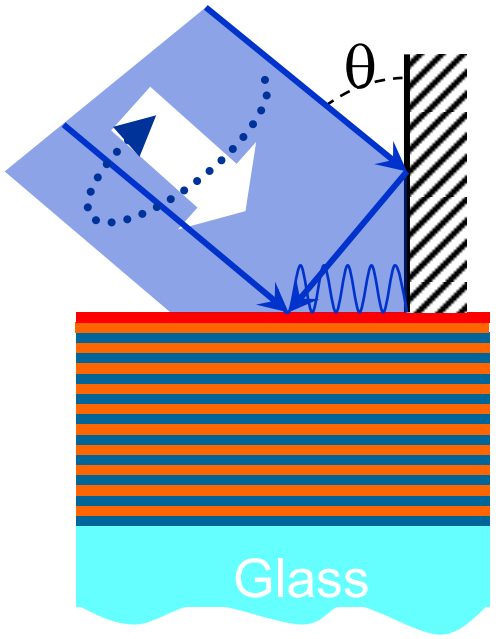




Induction of axial

Drift of the polymer out of the bright regions

a-$Si_{1-x}N_x$:H / Polimer 2D PC - Grating fabrication

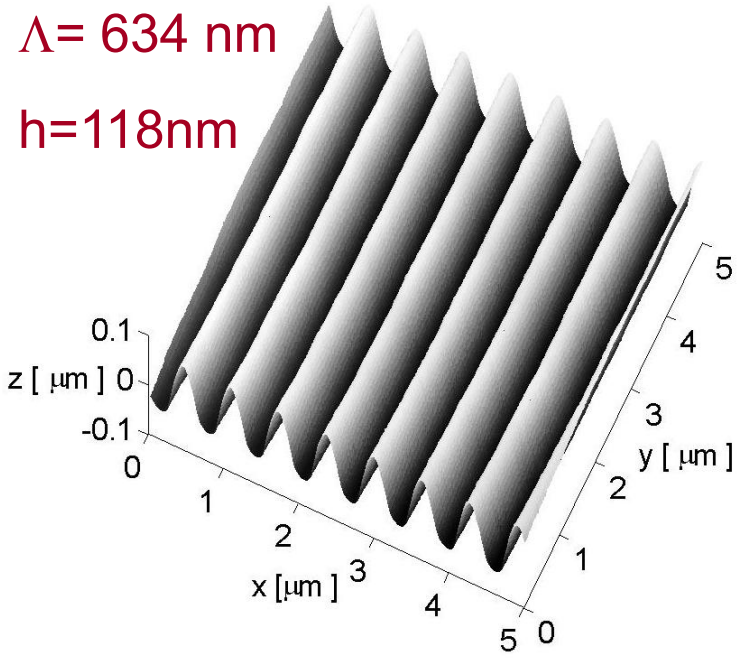


Lloyd mirror configuration

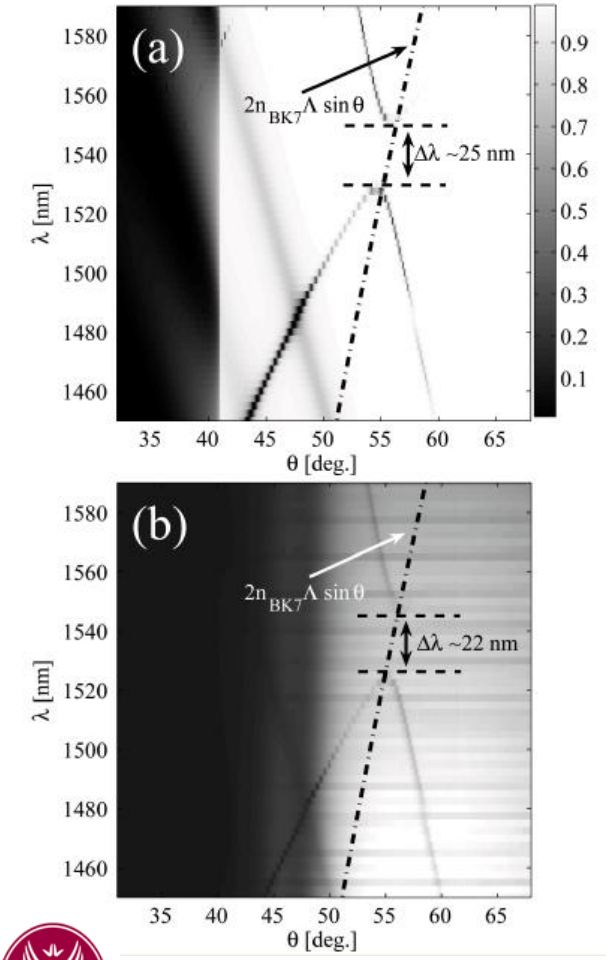
λ = 488.0 nm

I = 60 mW/cm^2

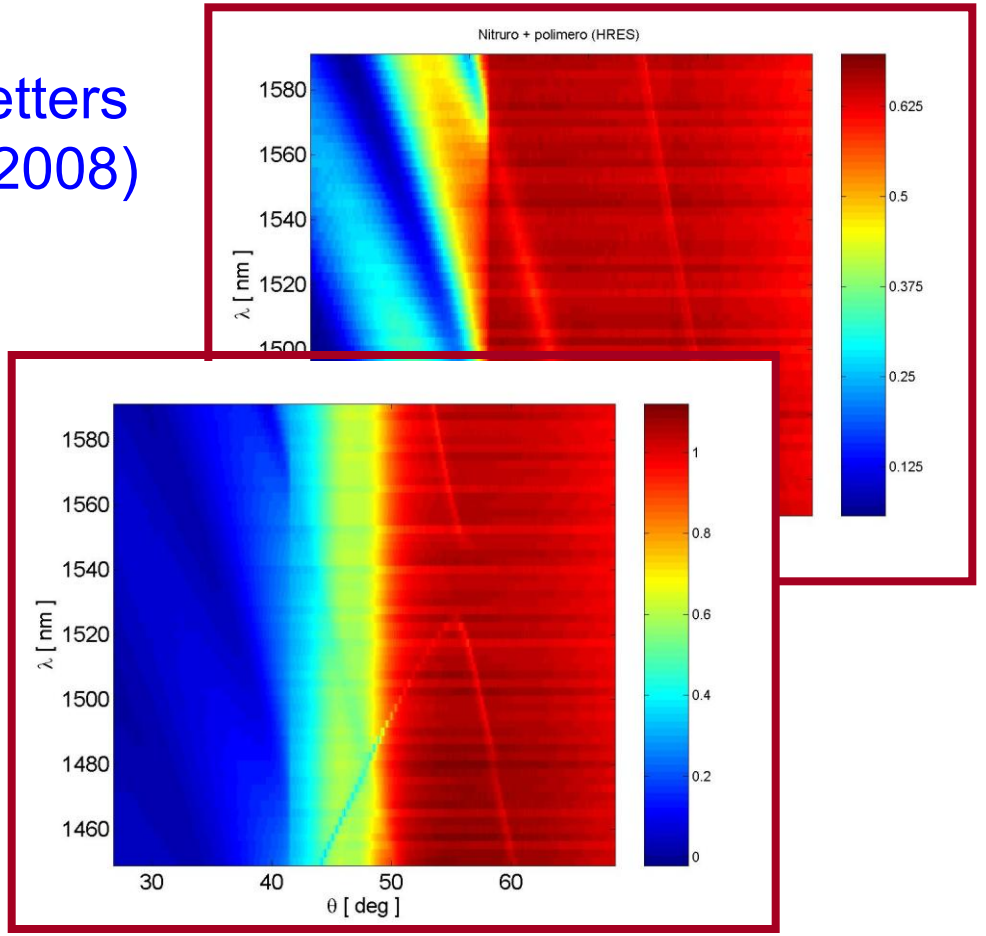
Δt = 90 min



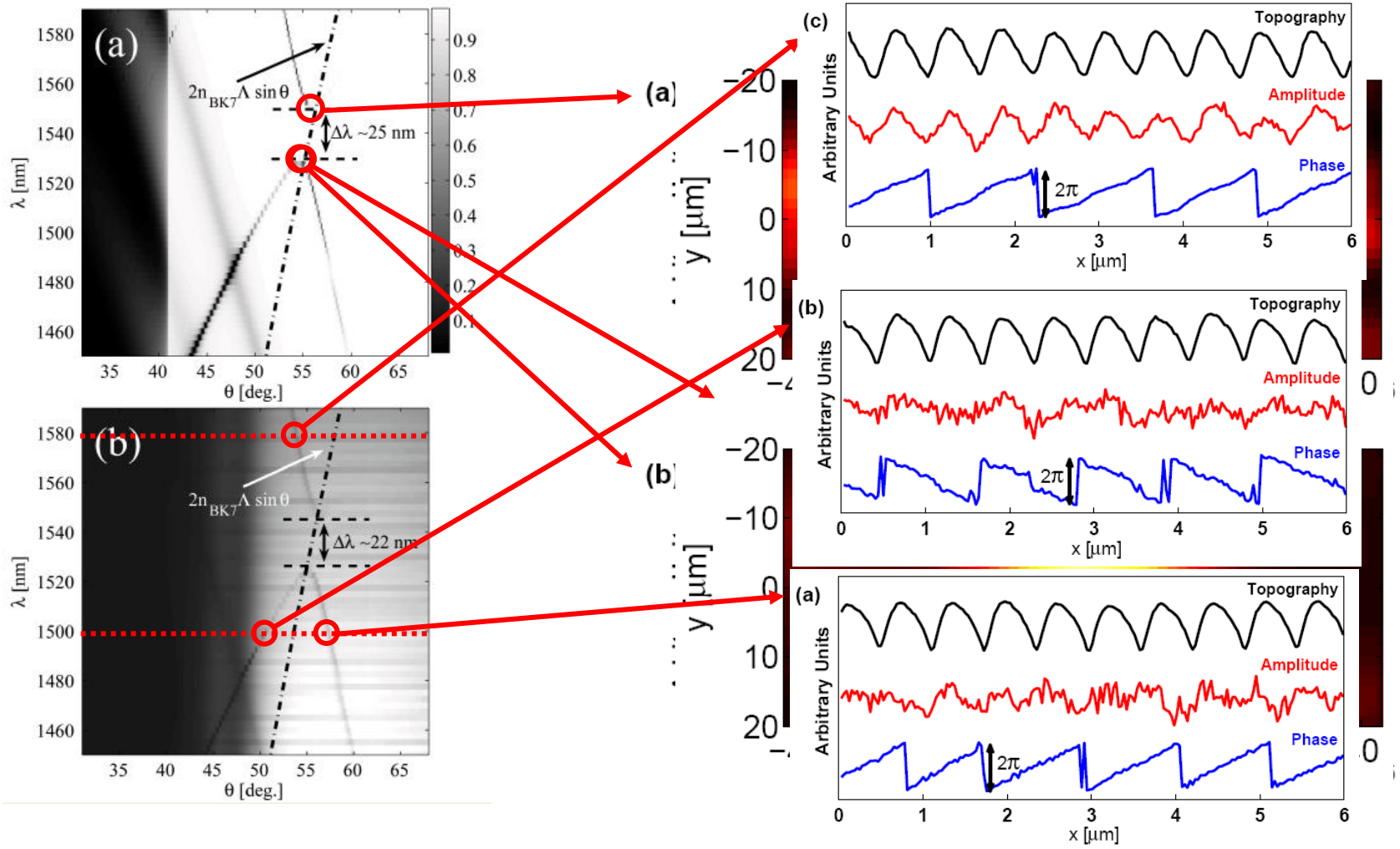
a-$Si_{1-x}N_x$:H / Polymer 2D PC - Dispersion and gap opening



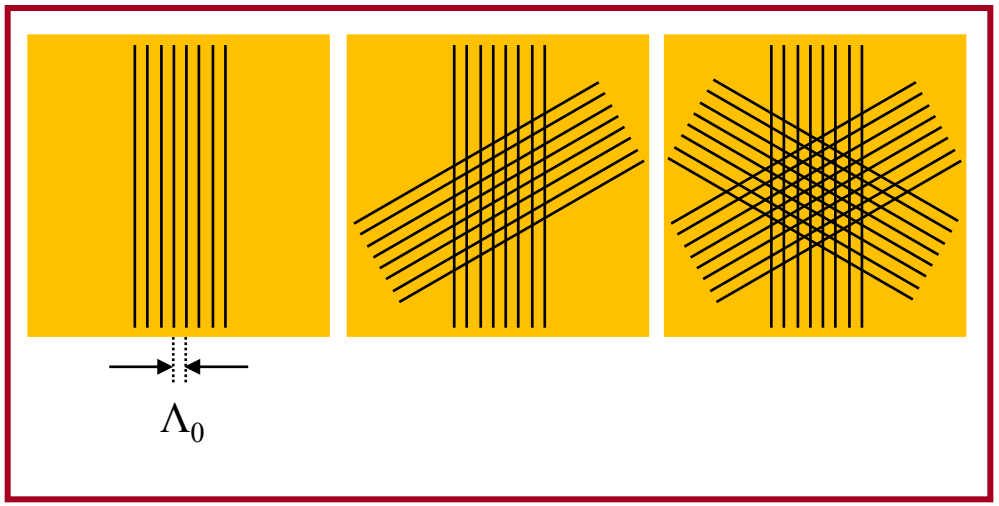
Optics Letters
33, 243 (2008)



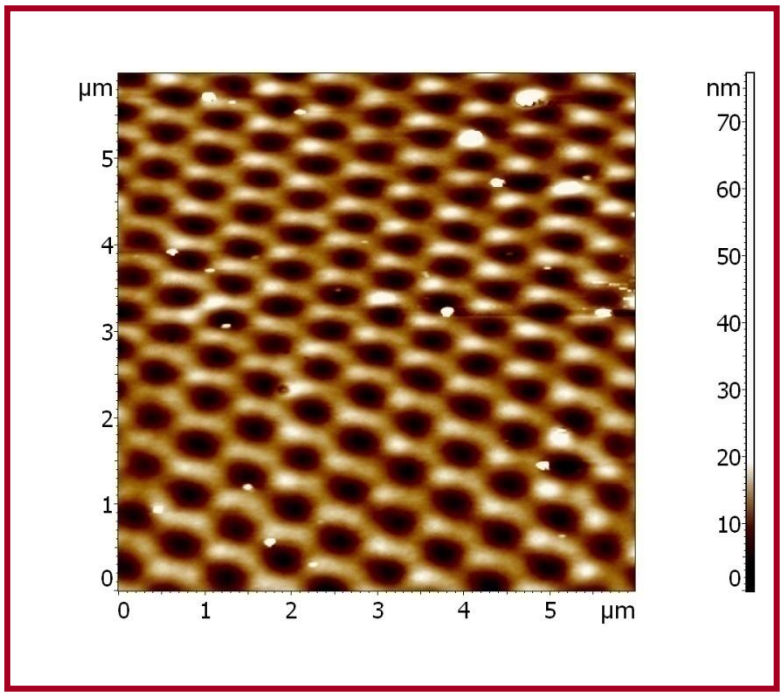
Multi-heterodyne SNOM Investigations



a-Si1-xNx :H / Polimer 1+2D PC – Hexagonal grating fabrication



Periodic 2D gratings can be fabricated by several successive holographic lithographic steps

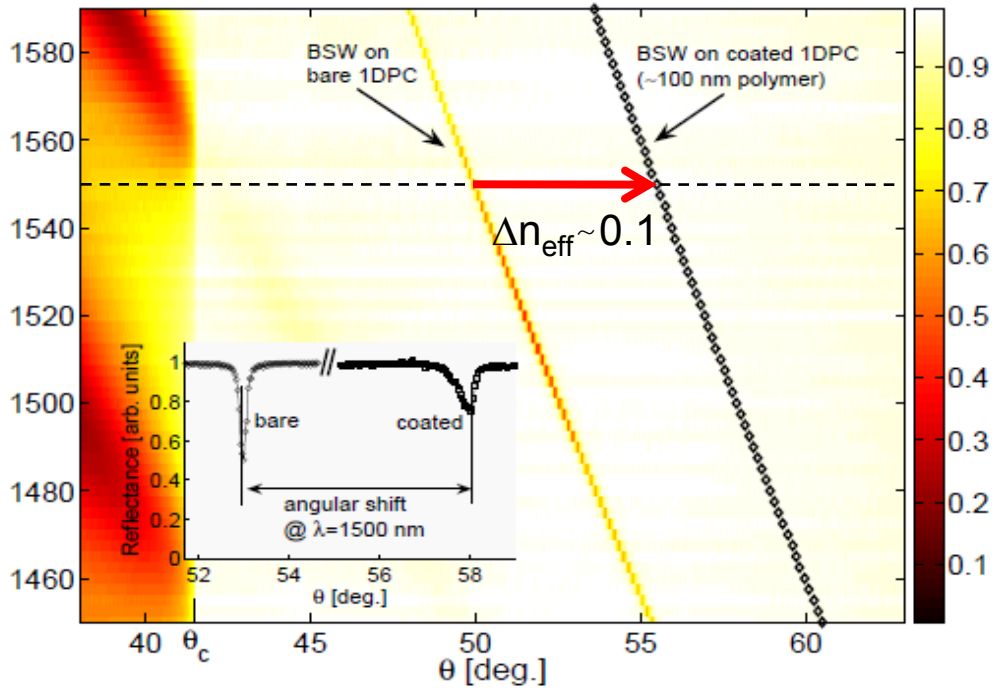


Still preliminary results

Structuring the 1DPC top surface: a thin ridge for waveguiding

Very thin layers can shift the BSW resonance in such a way that they are completely separated

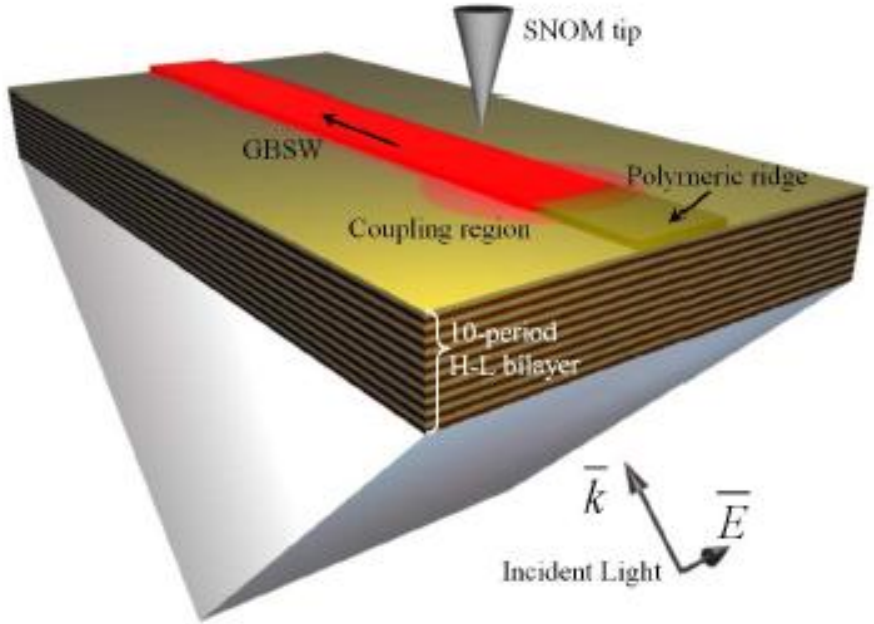
This is possible because of the narrowness of dips



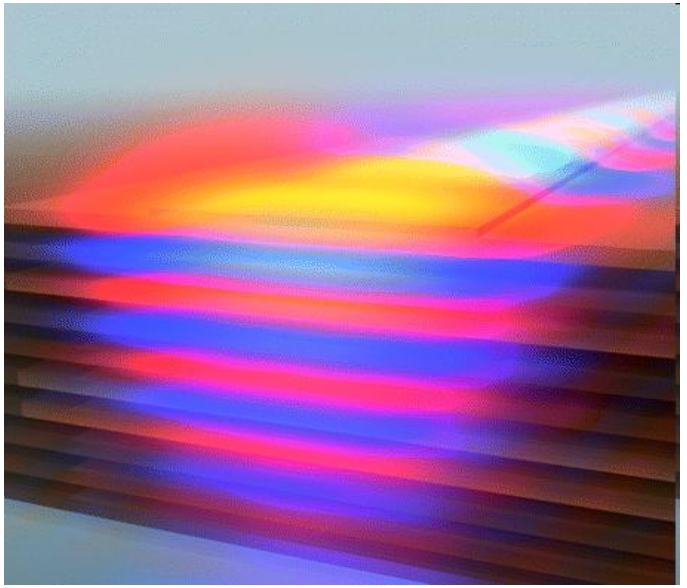
BSW dispersion shift after spinning a 110 nm thick photoresist layer

Structuring the 1DPC top surface: a thin ridge for waveguiding

If the thin layer is patterned, BSW can be selectively coupled in space/wavelength and guided



Polymeric ridge (n=1.625 NIR)
Thickness: 110 nm
Width: 3.5 μm

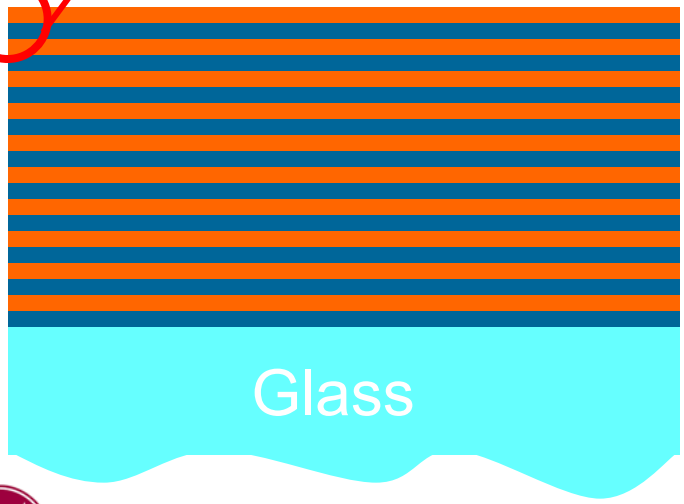


Pictorial view of the fundamental GBSW mode

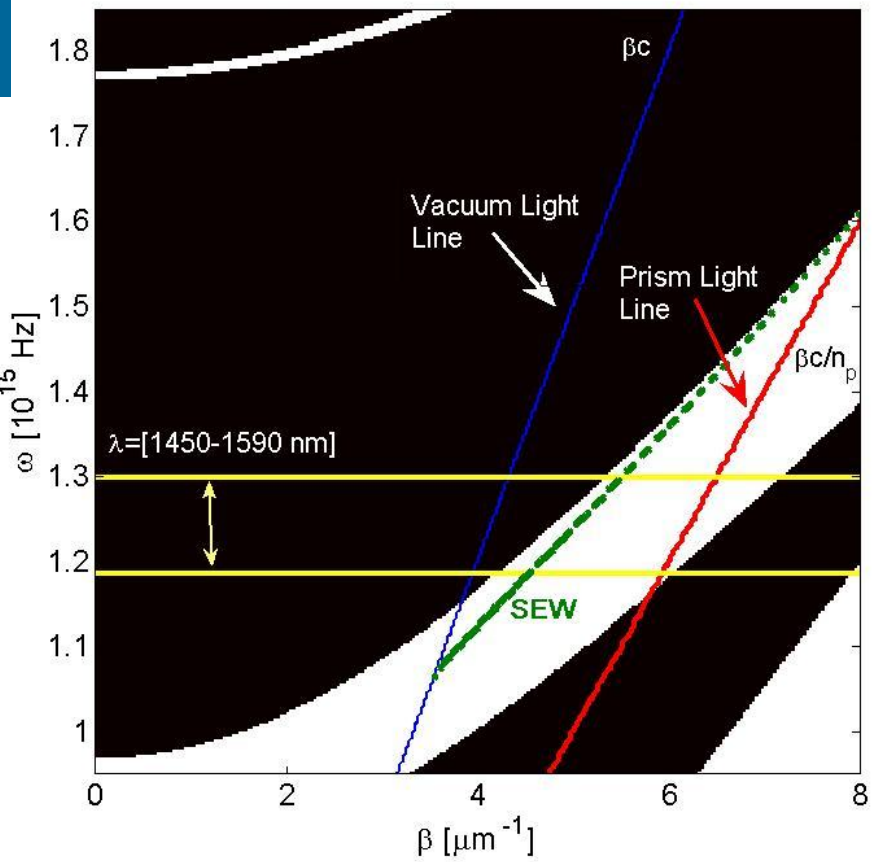
Structuring the 1DPC top surface: a thin ridge for waveguiding

L	t=294nm n=1.75 @ λ=1530nm
H	t=240nm n=2.23 @ λ=1530nm

10 periods

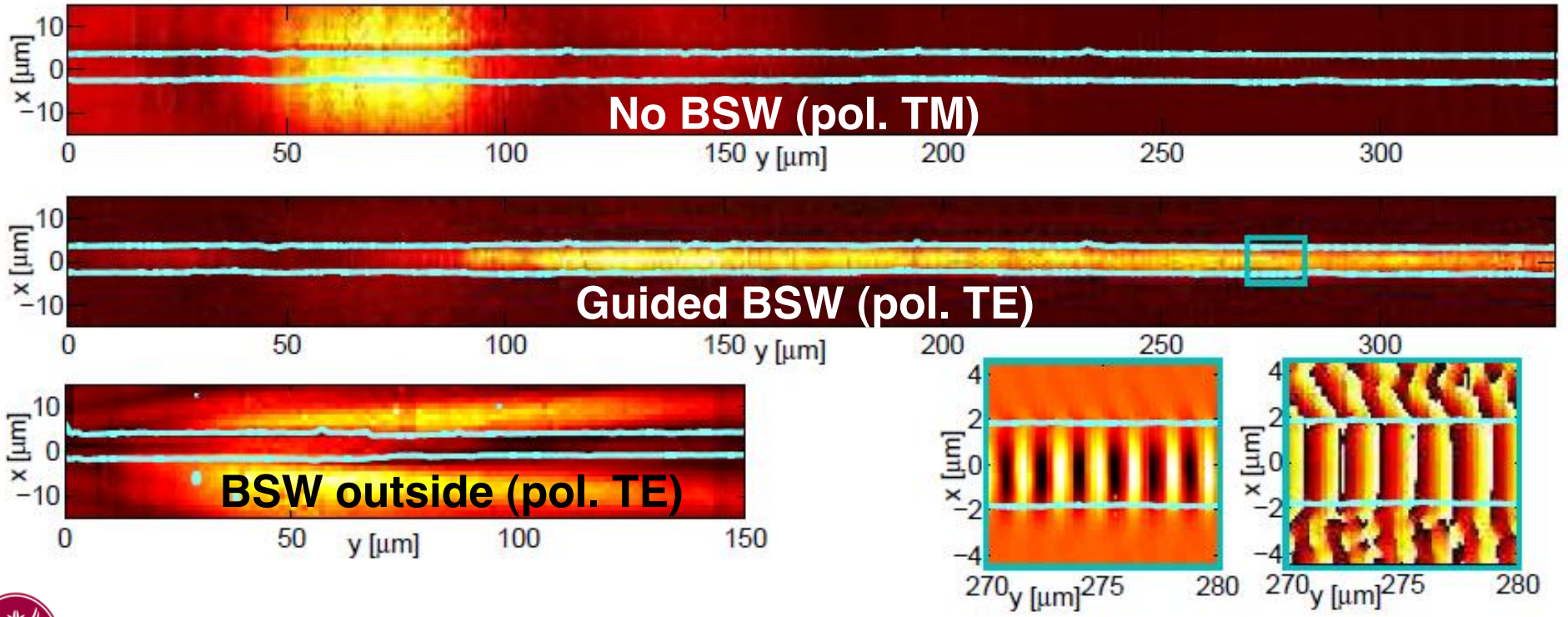


Band Diagram



Structuring the 1DPC top surface: a thin ridge for waveguiding

SNOM imaging of guided BSW



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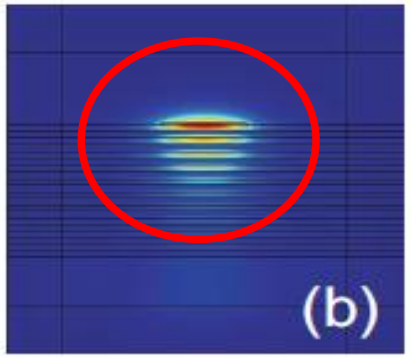
Re{E(x,y)} Φ(x,y)

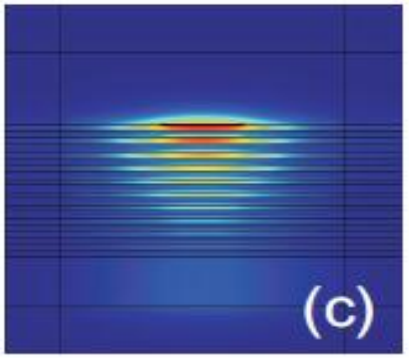
Structuring the 1DPC top surface: a thin ridge for waveguiding

A computational analysis of modes sustained by the structure suggests that the fundamental guided BSW mode has been imaged

t=110 nm

w=3.5 μm



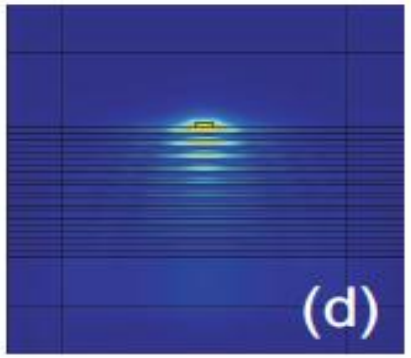


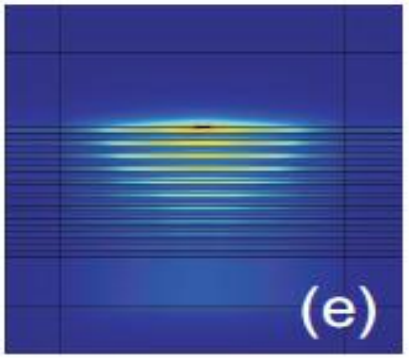
t=20 nm

w=3.5 μm

t=110 nm

w=600 nm





t=20 nm

w=600 nm

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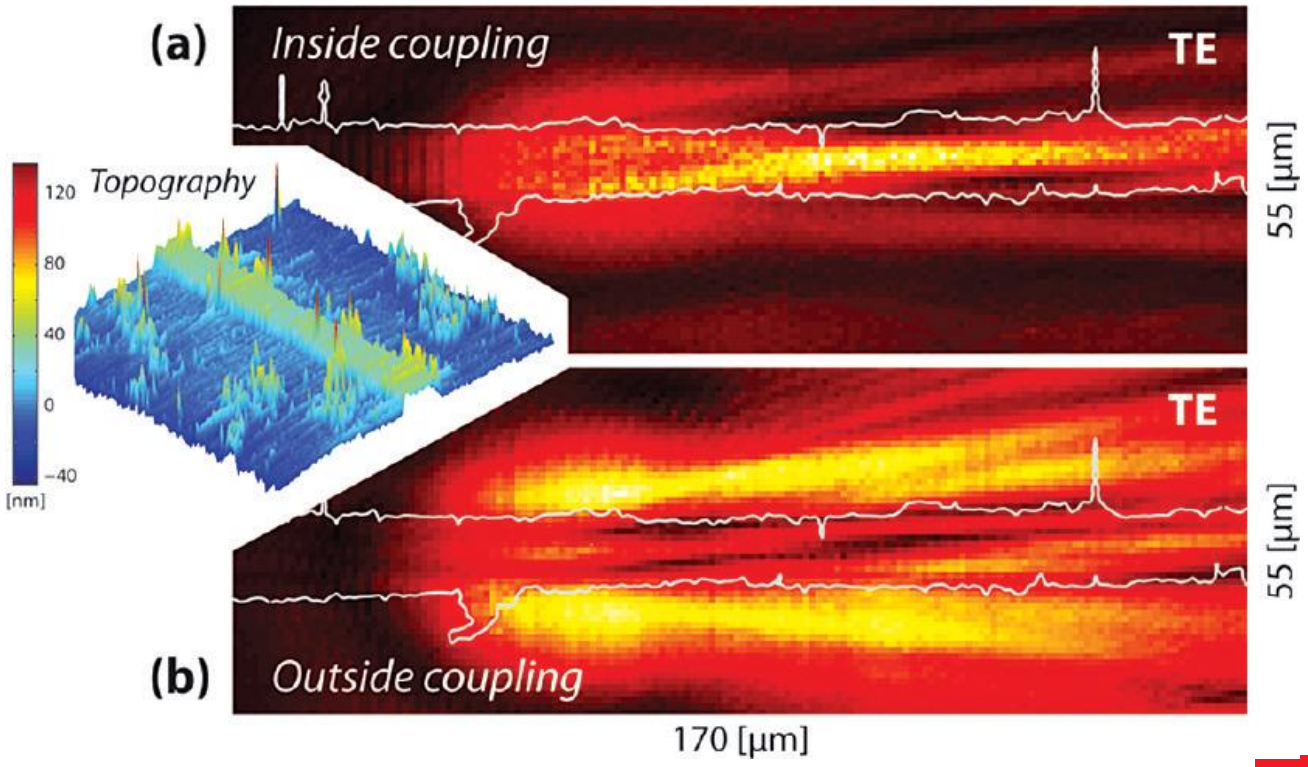
Structuring the 1DPC top surface: an ultra-thin ridge for waveguiding

A 30 nm polymer ridge in enough thick to confine the BSW



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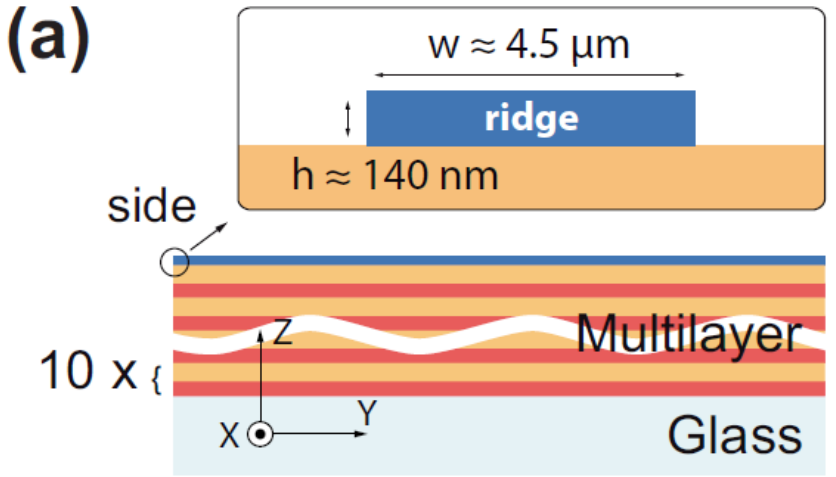
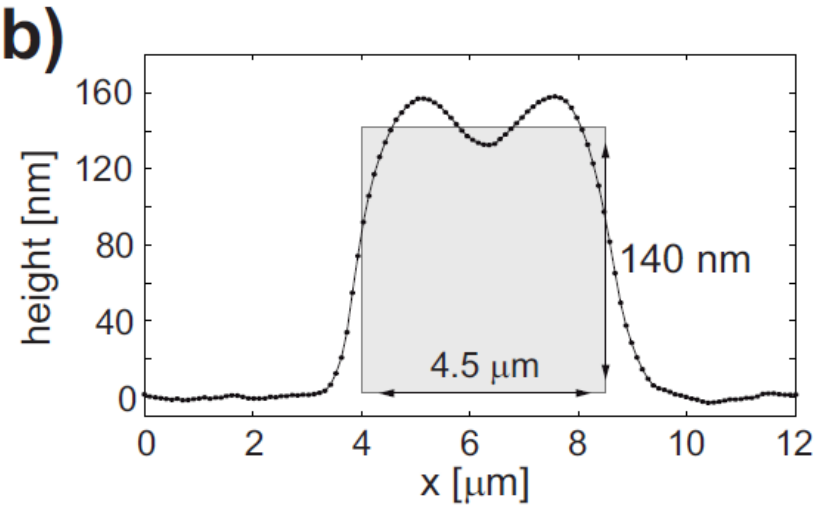
L	t=294nm n=1.75 @ λ=1530nm
H	t=240nm n=2.23 @ λ=1530nm

10 periods





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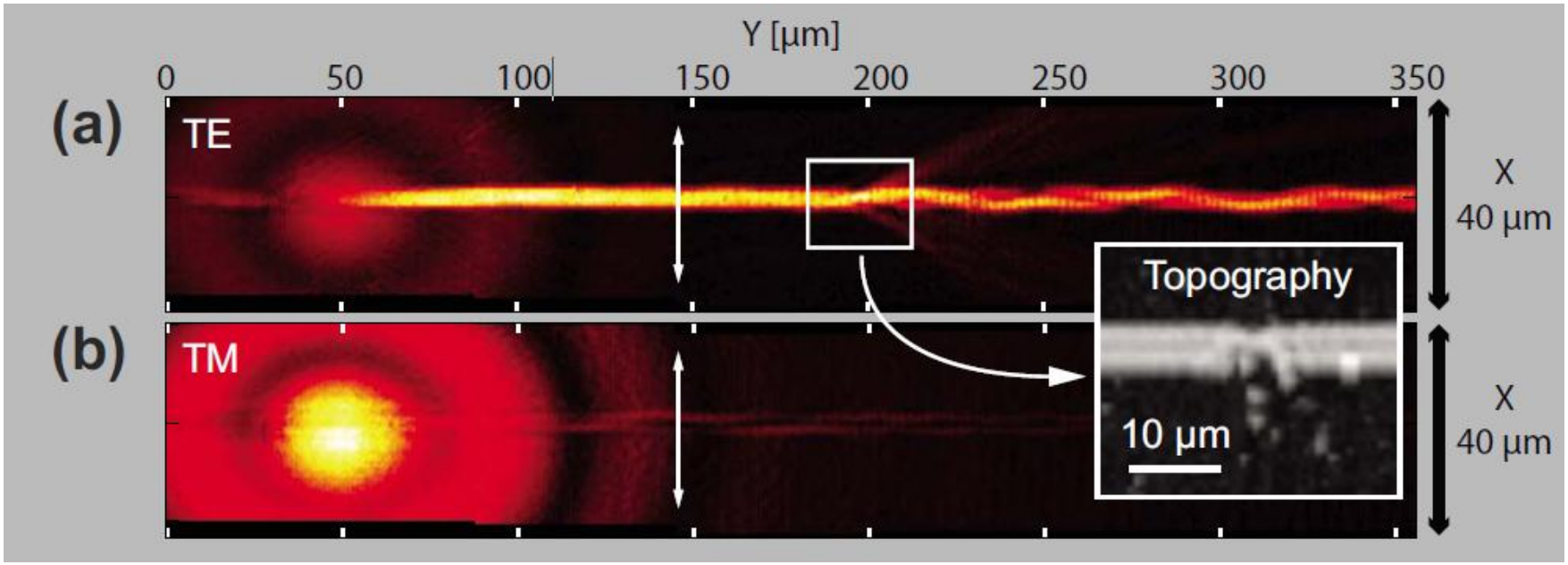
Structuring the 1DPC top surface: a thin ridge for waveguiding



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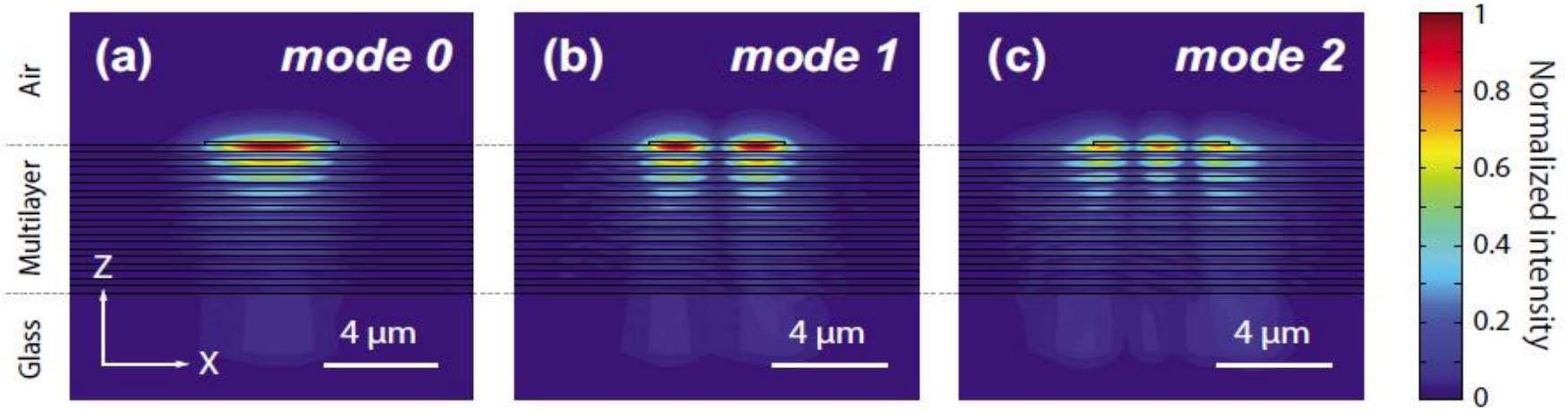
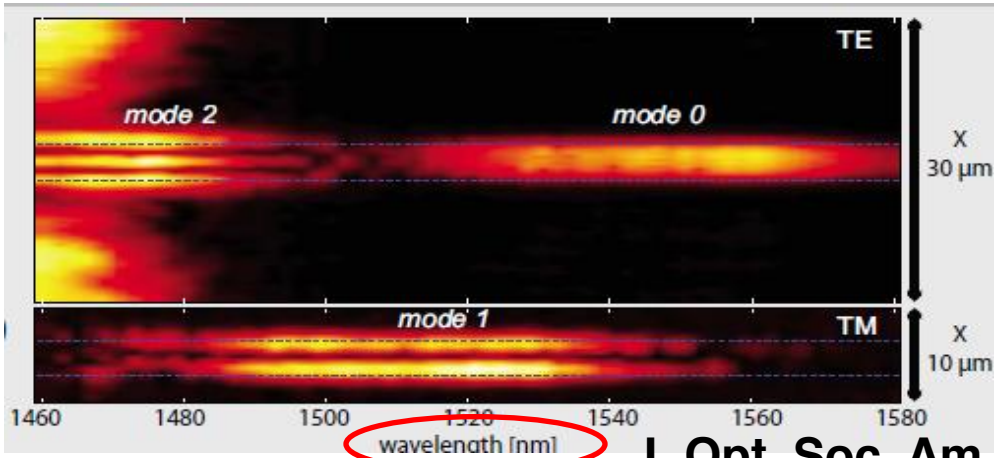
Structuring the 1DPC top surface: a thin ridge for waveguiding

Higher order order modes can be excited…..





At fixed angle, a wavelength tuning can allow the selective coupling of different modes

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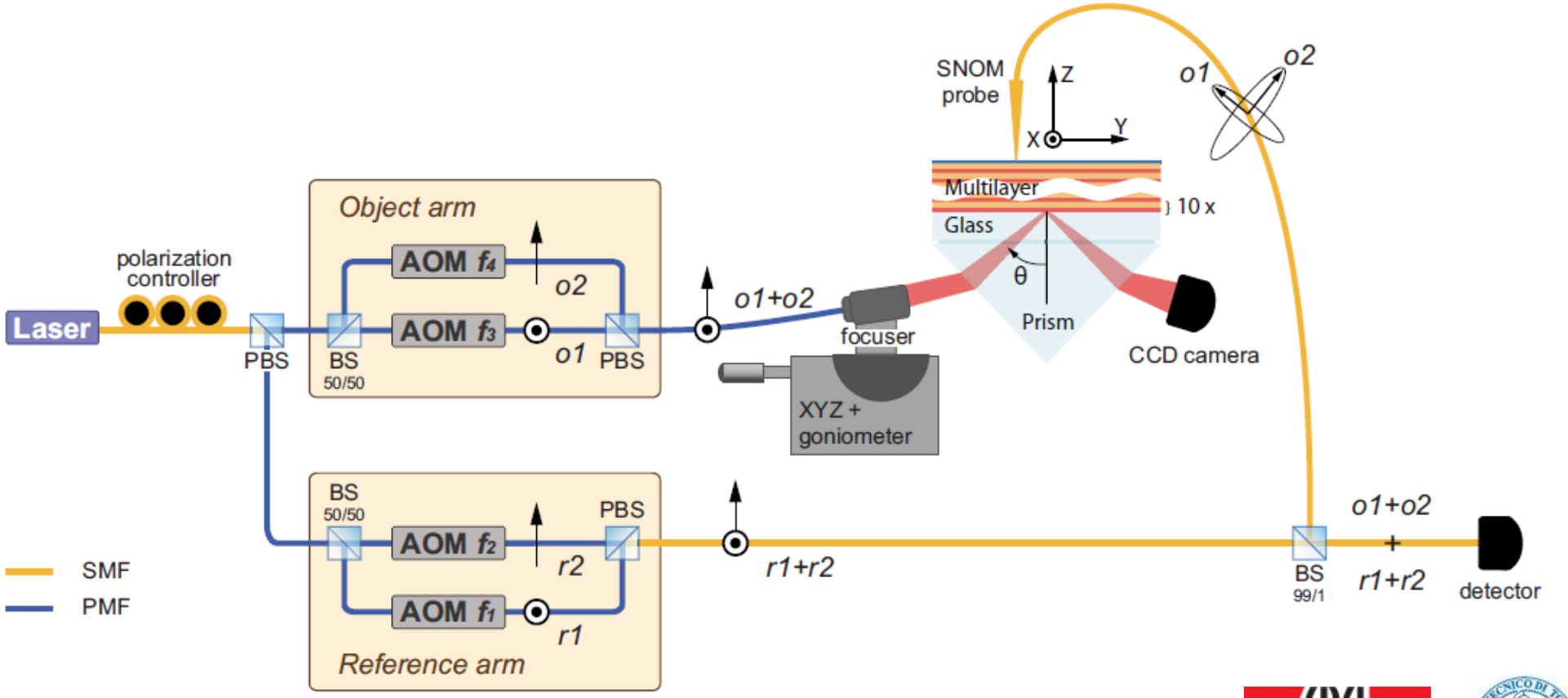
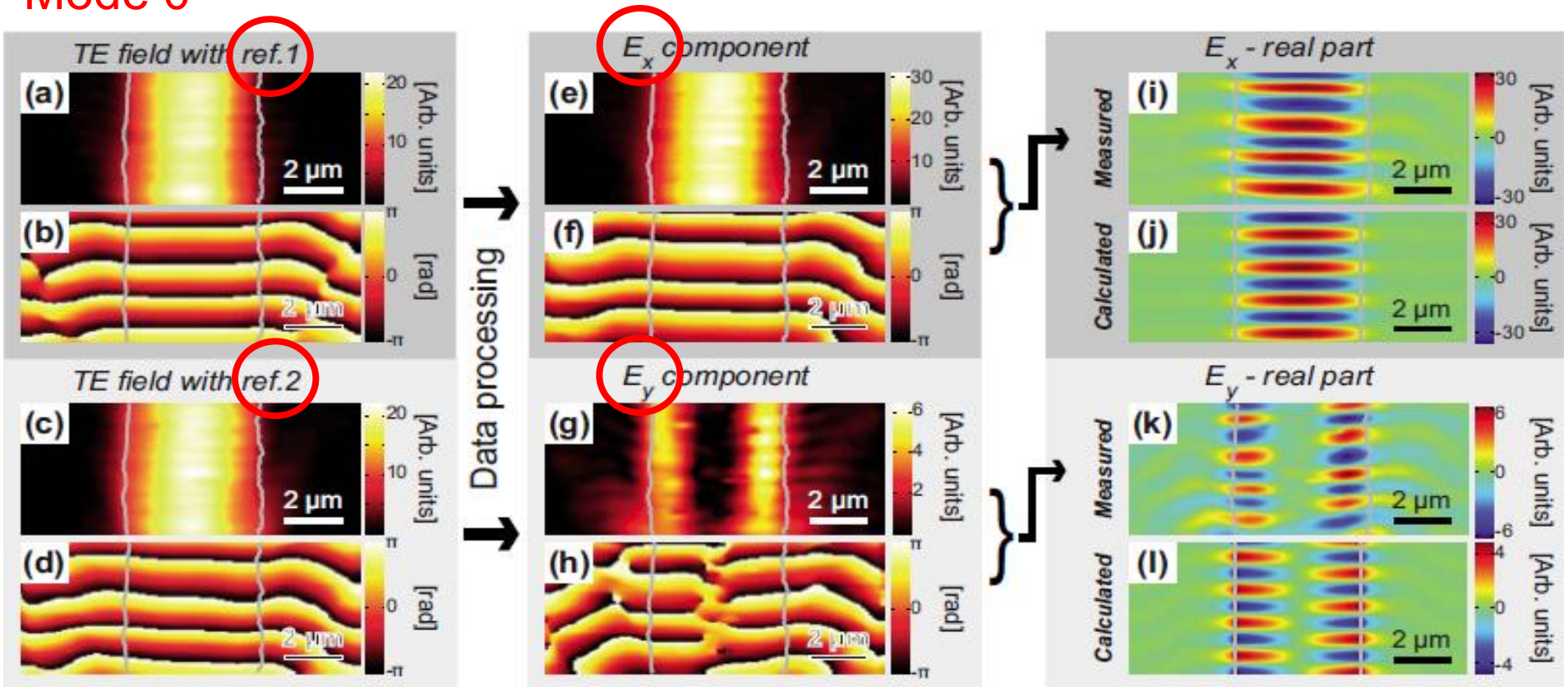
Structuring the 1DPC top surface: a thin ridge for waveguiding



Structuring the 1DPC top surface: a thin ridge for waveguiding

Mode 0



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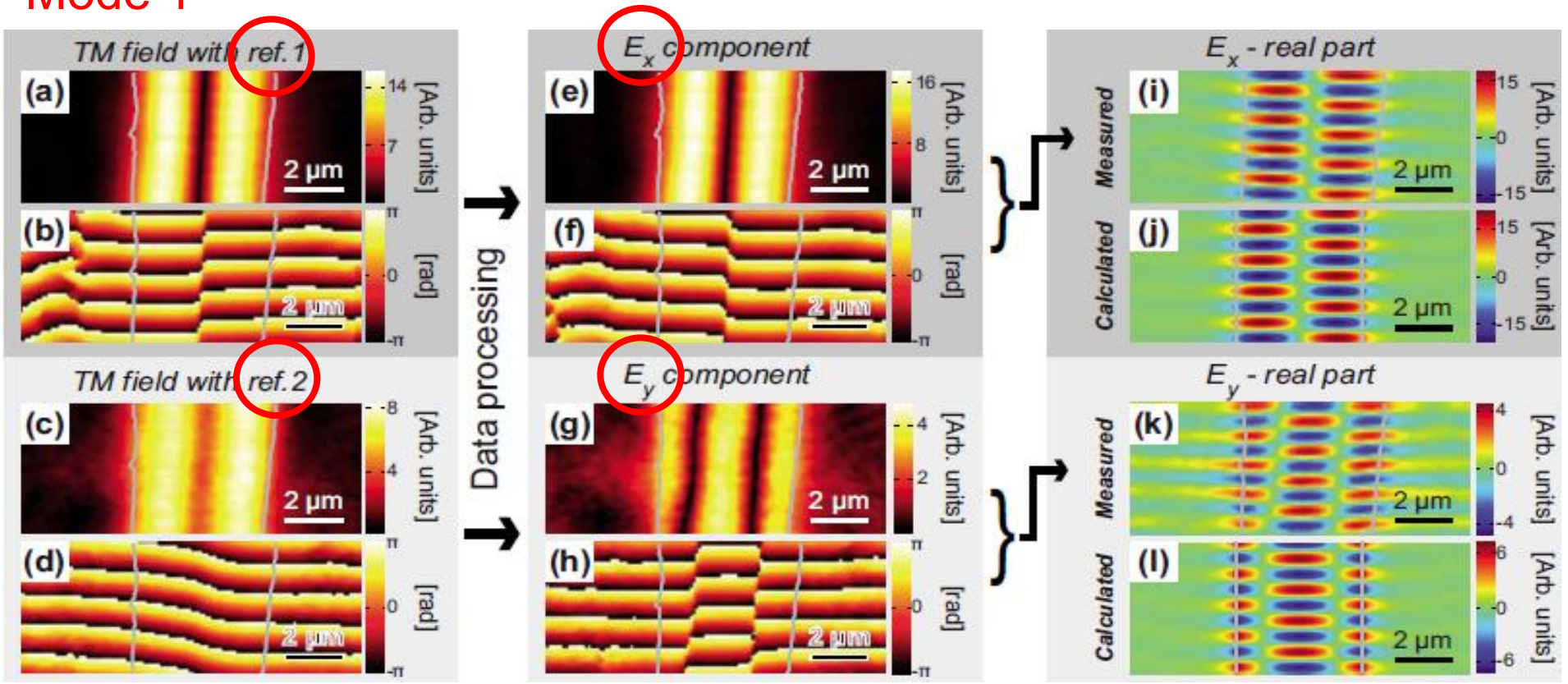
Structuring the 1DPC top surface: a thin ridge for waveguiding

Mode 1



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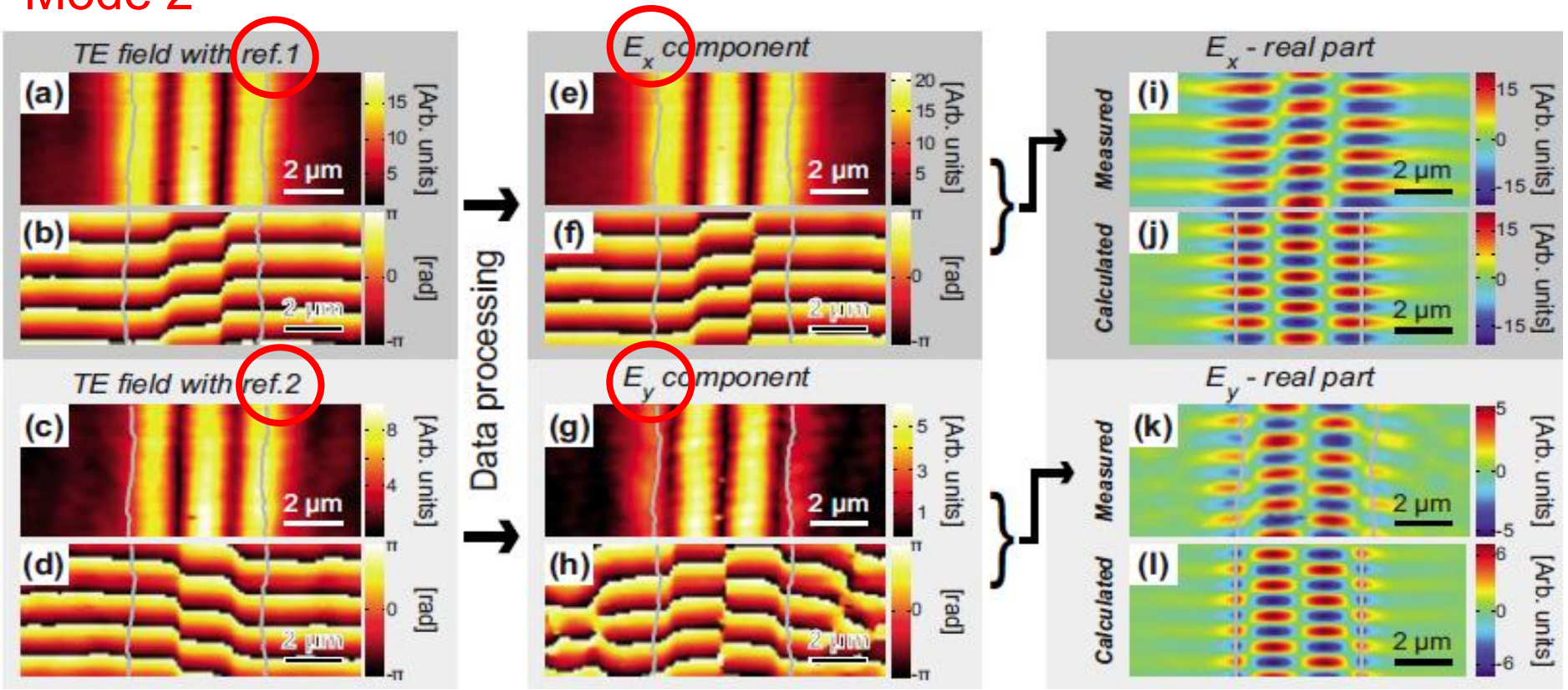
Structuring the 1DPC top surface: a thin ridge for waveguiding

Mode 2



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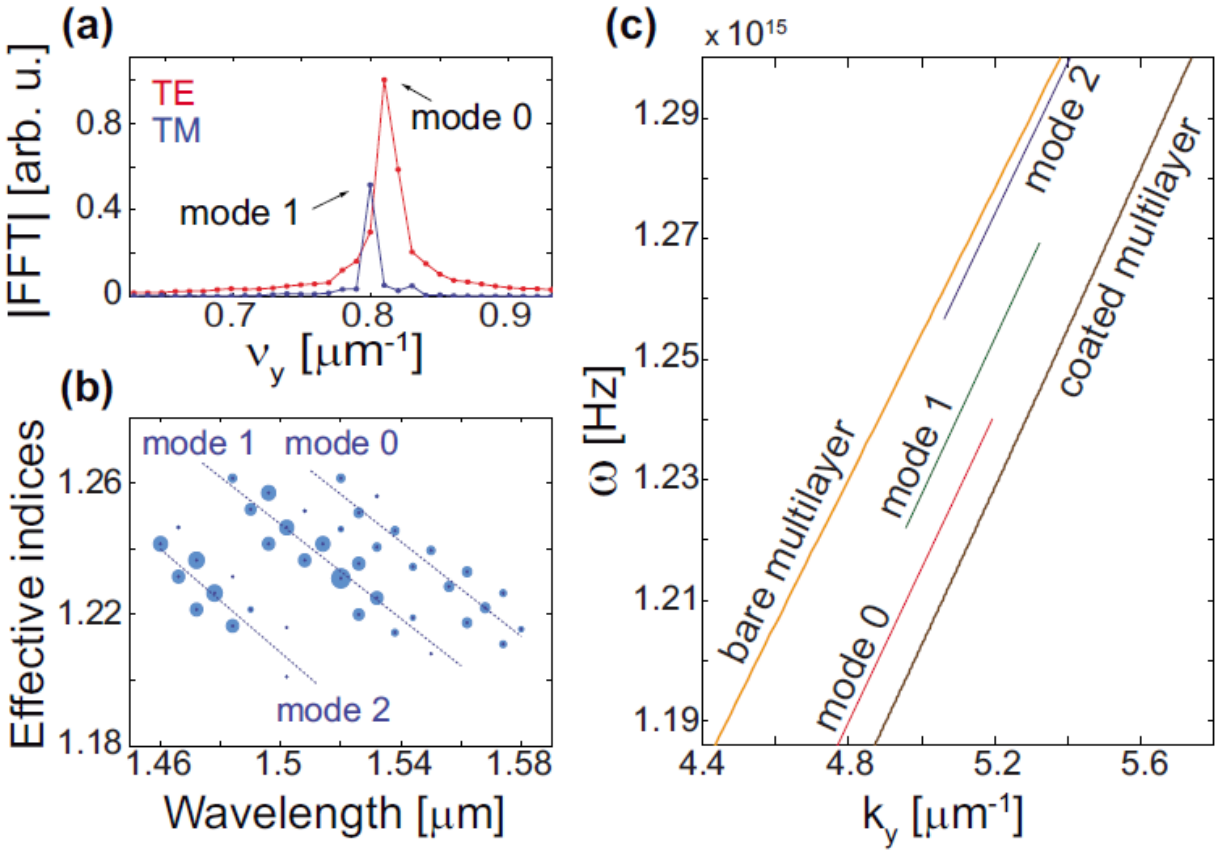
Structuring the 1DPC top surface: a thin ridge for waveguiding

Higher order modes dispersion diagram



Different degrees of confinement have a counterpart within the dispersion diagram

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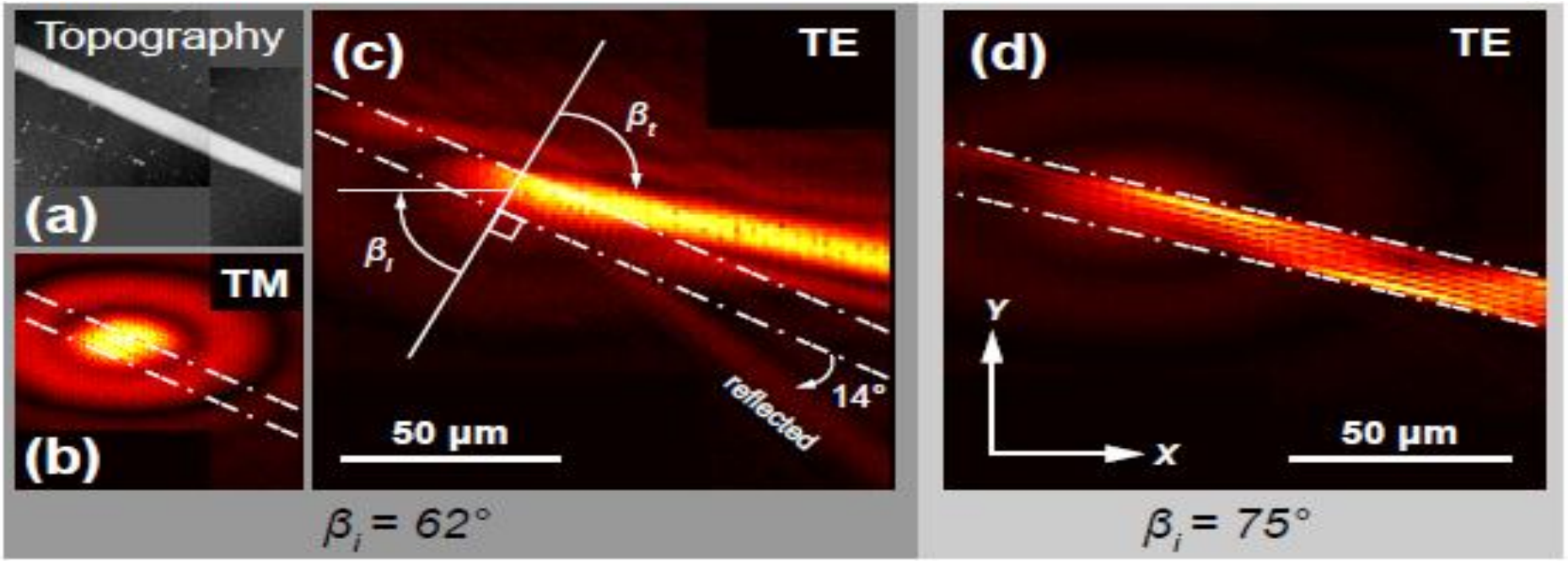
Structuring the 1DPC top surface: a thin ridge for waveguiding

When a tilt is introduced between the coupling direction and the ridge, BSW might not be guided: refraction/reflection take place



Refraction rules in accordance to BSW dispersion

Appl. Phys. Lett. 96, 151101 (2010)

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Summary of general properties of Bloch surface waves

- The degrees of freedom permitted by the 1DPC design (materials and geometry) allow to obtain propagation of BSW in any spectral range
- The absence of losses in dielectrics gives rise to very narrow resonances and possibly long propagation distances
- The absence of metals makes that quenching is absent in fluorescence applications
- Strip loading permit to obtain transverse confinement and guided BSW
- Any type of surface integrated optical device can be in principle designed