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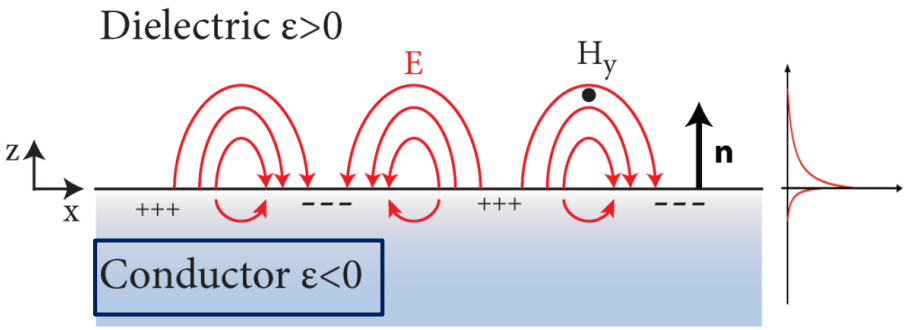
Near-field imaging of resonating hyperbolic polaritons in nanorod antennas made of boron nitride

NanoSpain '17, San Sebastián, España

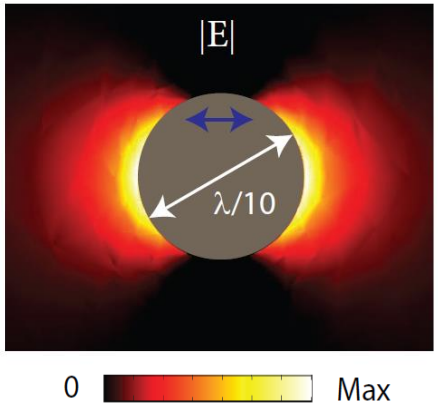
F. J. Alfaro-Mozaz, P. Alonso-González, S. Vélez, I. Dolado, M. Autore, S. Mastel, F. Casanova, L. E. Hueso, P. Li, A. Y. Nikitin and R. Hillenbrand

Plasmons concentrate electromagnetic fields into a nanoscale spot

Surface Plasmon Polaritons

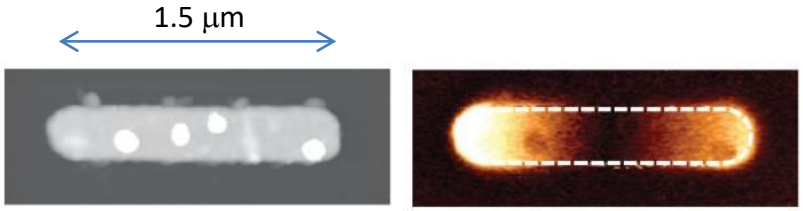


Localized Plasmon Resonances



Gold Nanoparticle

Plasmonic nanorod antenna resonances

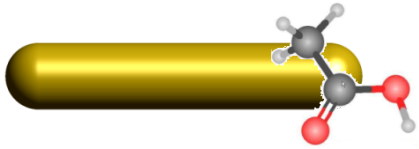


Topography

Near-Field Intensity

Nature Photonics 3, p.287 (2009)

Application of plasmonic nanorod antennas

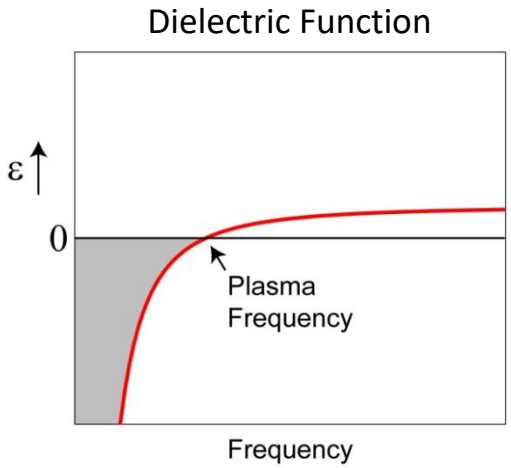


Mid-IR molecular spectroscopy

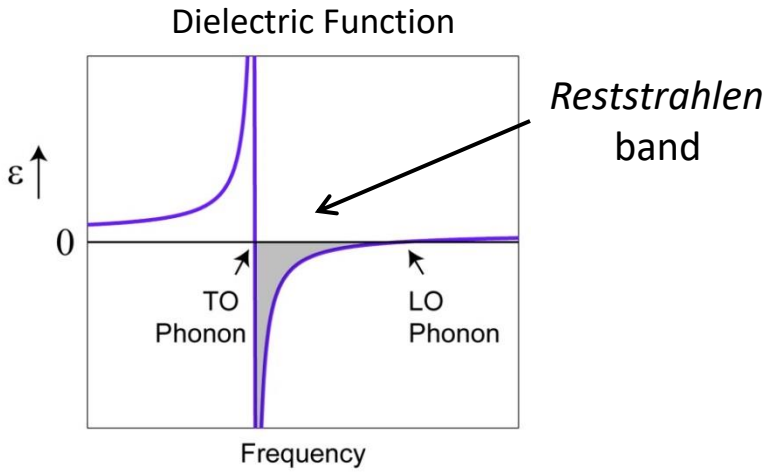
Neubrech PRL 101, 157403 (2008)

Plasmon and Phonon-Polaritons

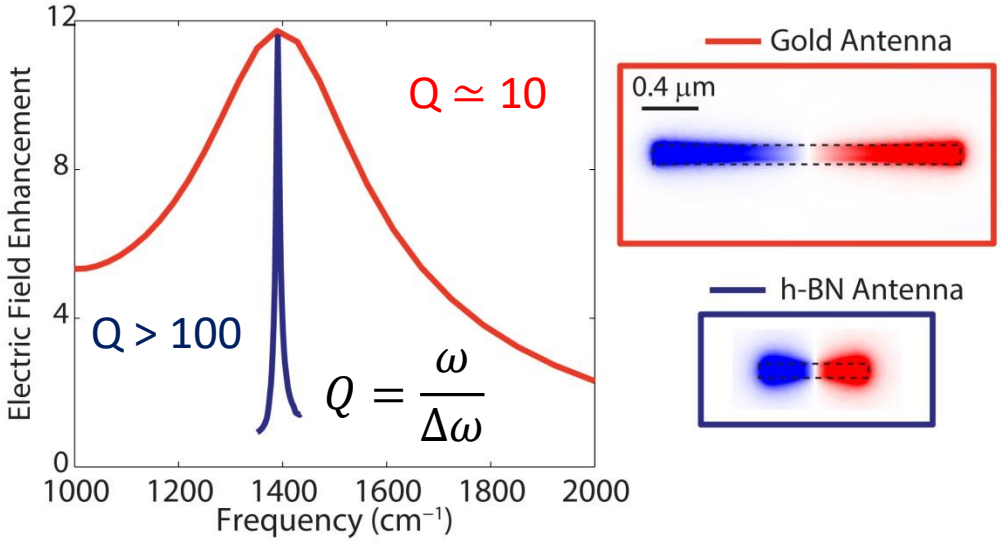
Metals / doped semiconductors
collective free electron oscillations (**plasmons**)



Polar crystals (SiC, h-BN, quartz...)
strong lattice vibrations (**phonons**)



Preliminar Simulation of the Dipolar Resonances of representative Plasmonic and Phononic Antennas

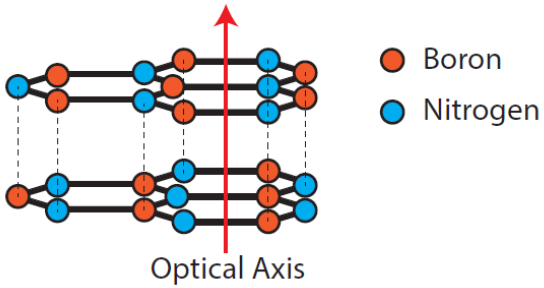


Hillenbrand et al., Nature (2002)

Caldwell et al., Nano Letters (2012)

h-BN is an Anisotropic Phononic Material

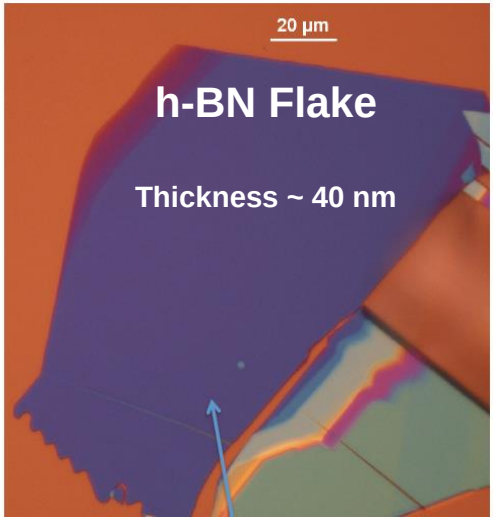
Atomic Structure



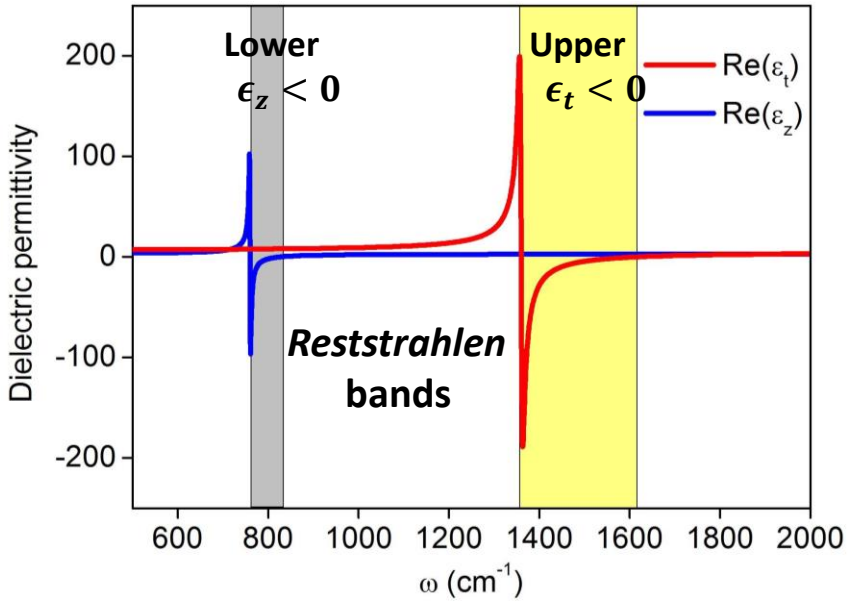
h-BN properties

- 2D **van-der-Waals** (layered) material
- **Easy to prepare** by exfoliation – In contrast with other phononic material such as SiC
- Due to its layered structure, **its permittivity is highly anisotropic**

Optical microscope image



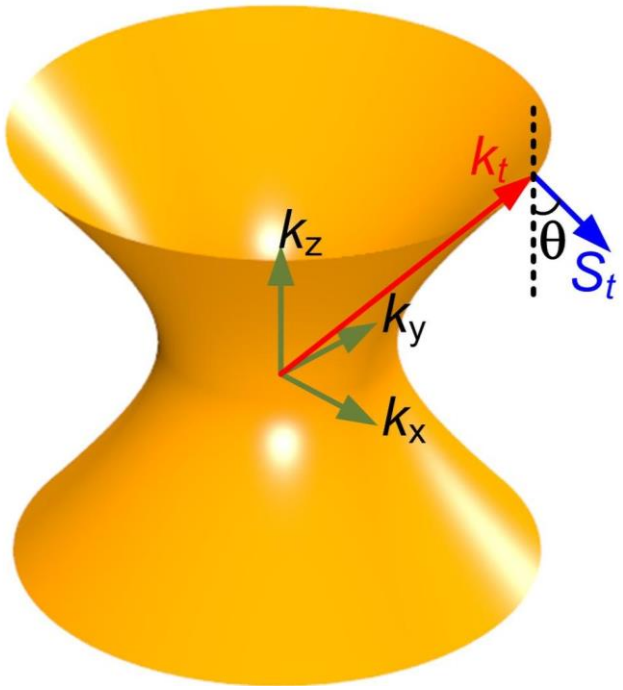
Dielectric Function



J. D. Caldwell et al., Nat. Comm. **5**, 5221 (2014)

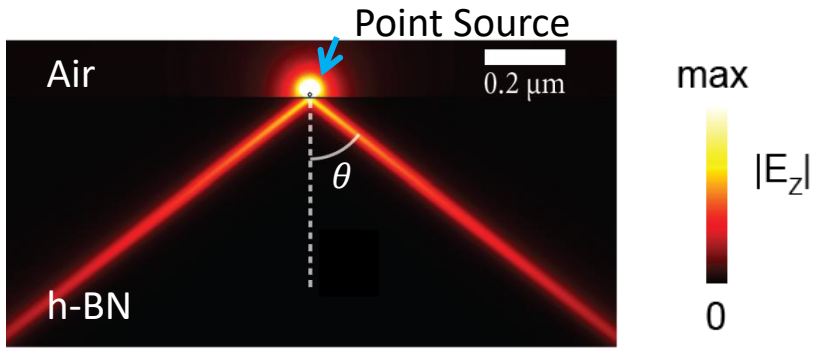
Hyperbolic Volume Polaritons in h-BN

Isofrequency Surface of h-BN in momentum space

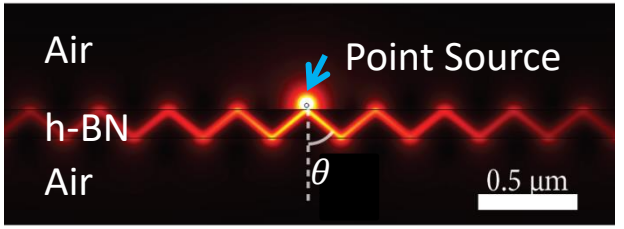


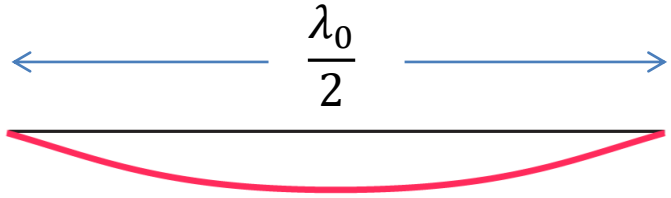
$\omega = \text{const}$

Simulation: Point source over h-BN

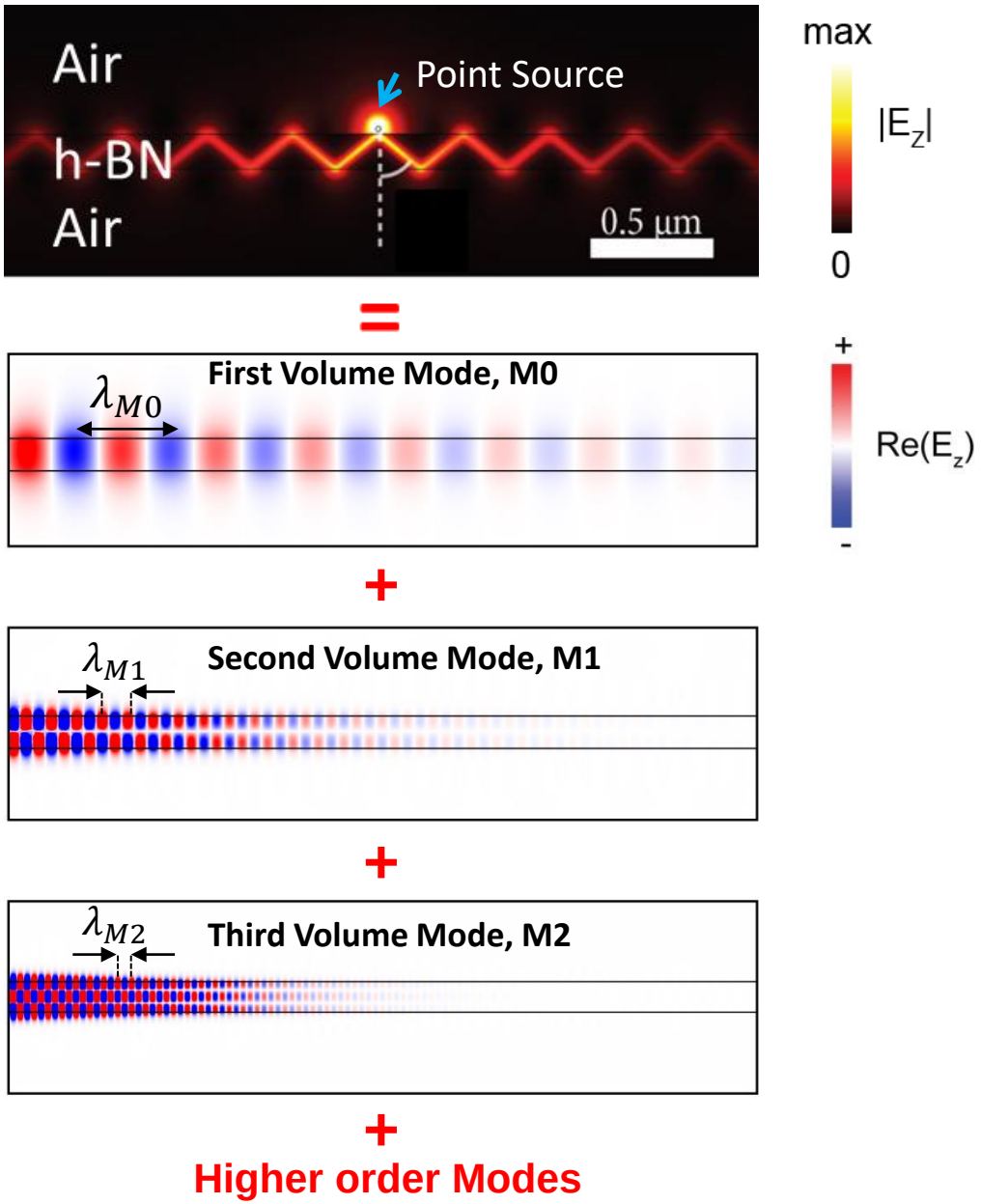


Simulation: Point Source over h-BN slab





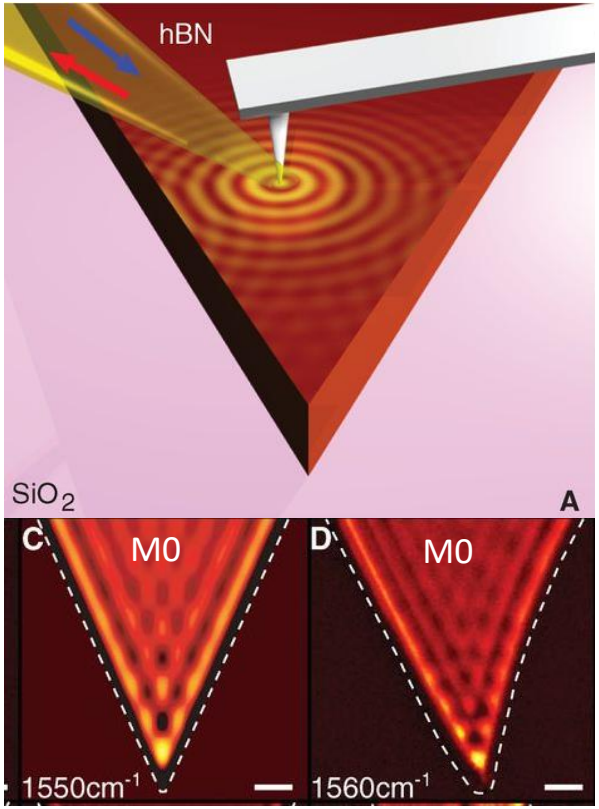
Hyperbolic Volume Polaritons in an h-BN Slab



Higher order Modes

Imaging of Hyperbolic Phonon Polaritons in h-BN

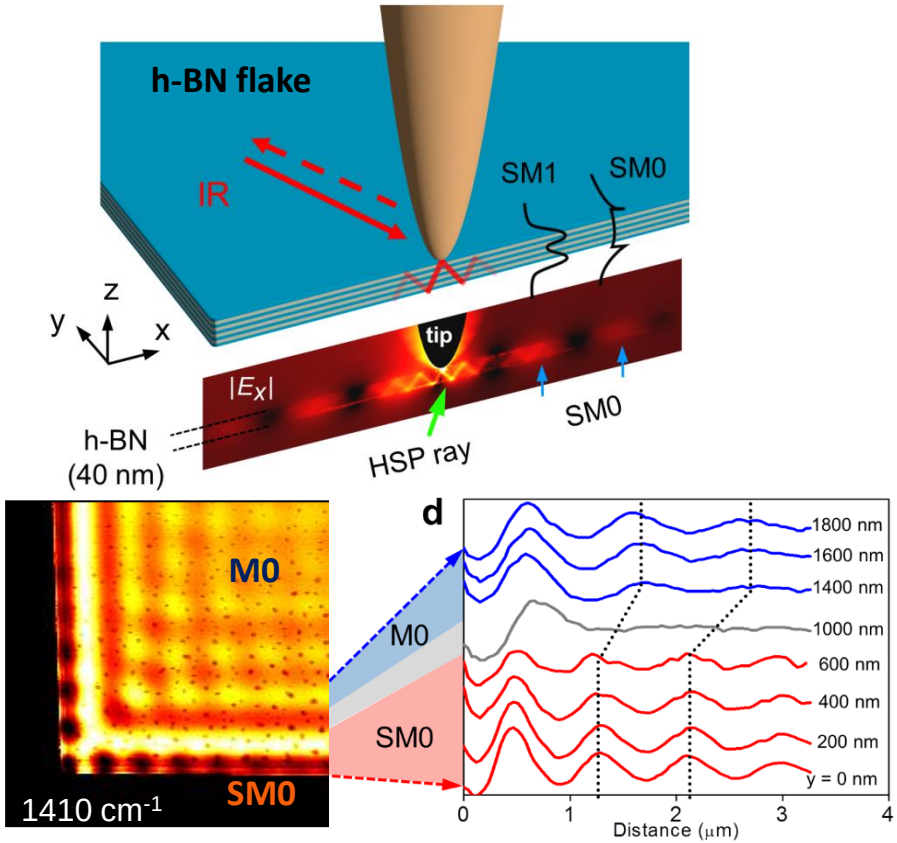
Imaging of Hyperbolic Volume Polaritons in h-BN Flakes



Visualization of the M0 Mode

S. Dai **(D. Basov Laboratory)** , Science (2014)

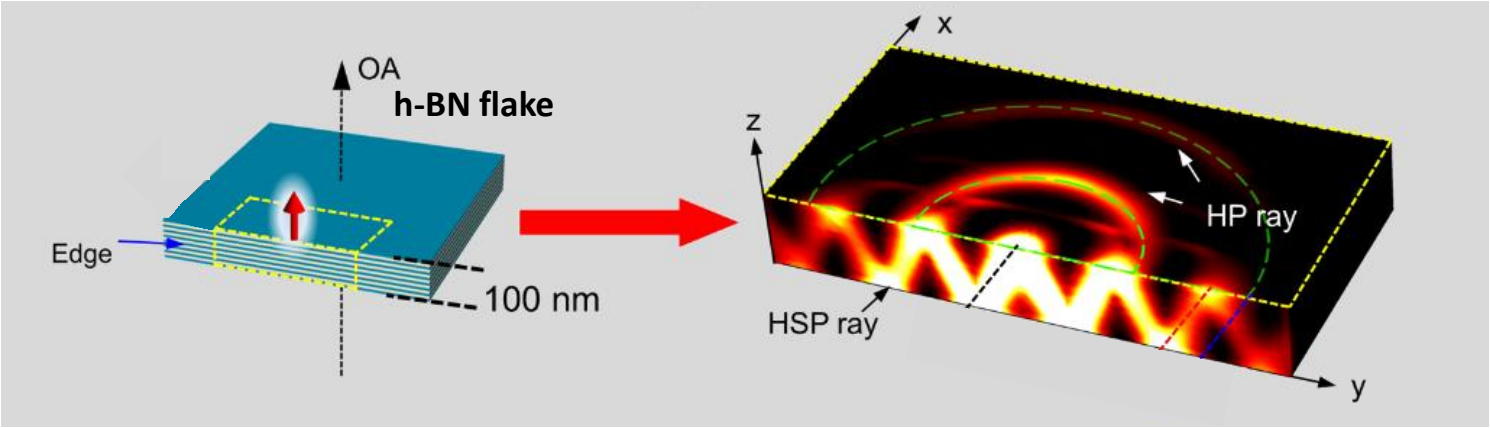
Imaging of Hyperbolic Volume and Surface Polaritons in h-BN Flakes



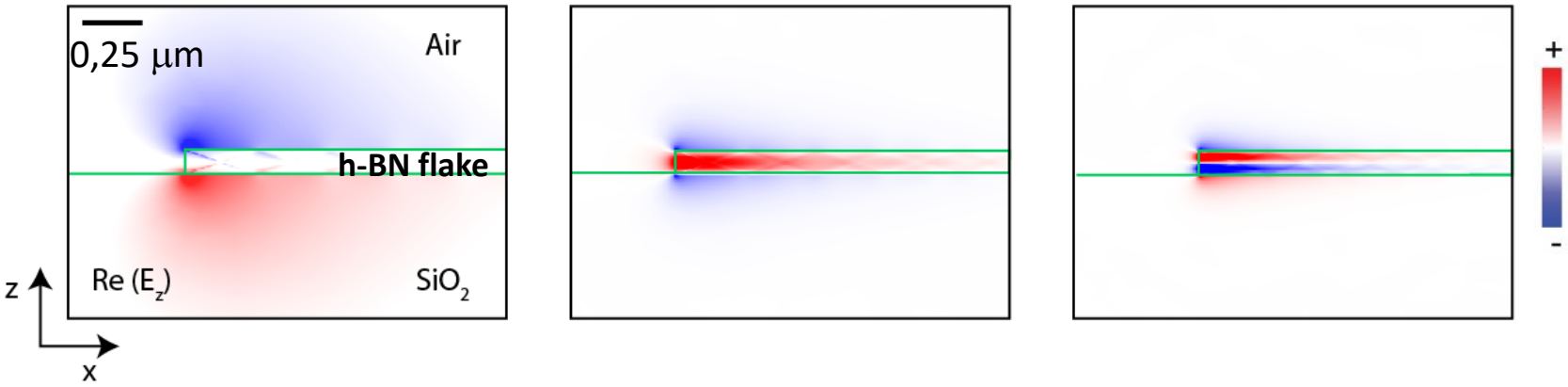
Visualization of the M0 Mode and the SM0 Mode

P. Li, I. Dolado, Nano Letters (2016)

Hyperbolic Surface Polaritons (Dyakonov Polaritons) at the edges of h-BN flakes

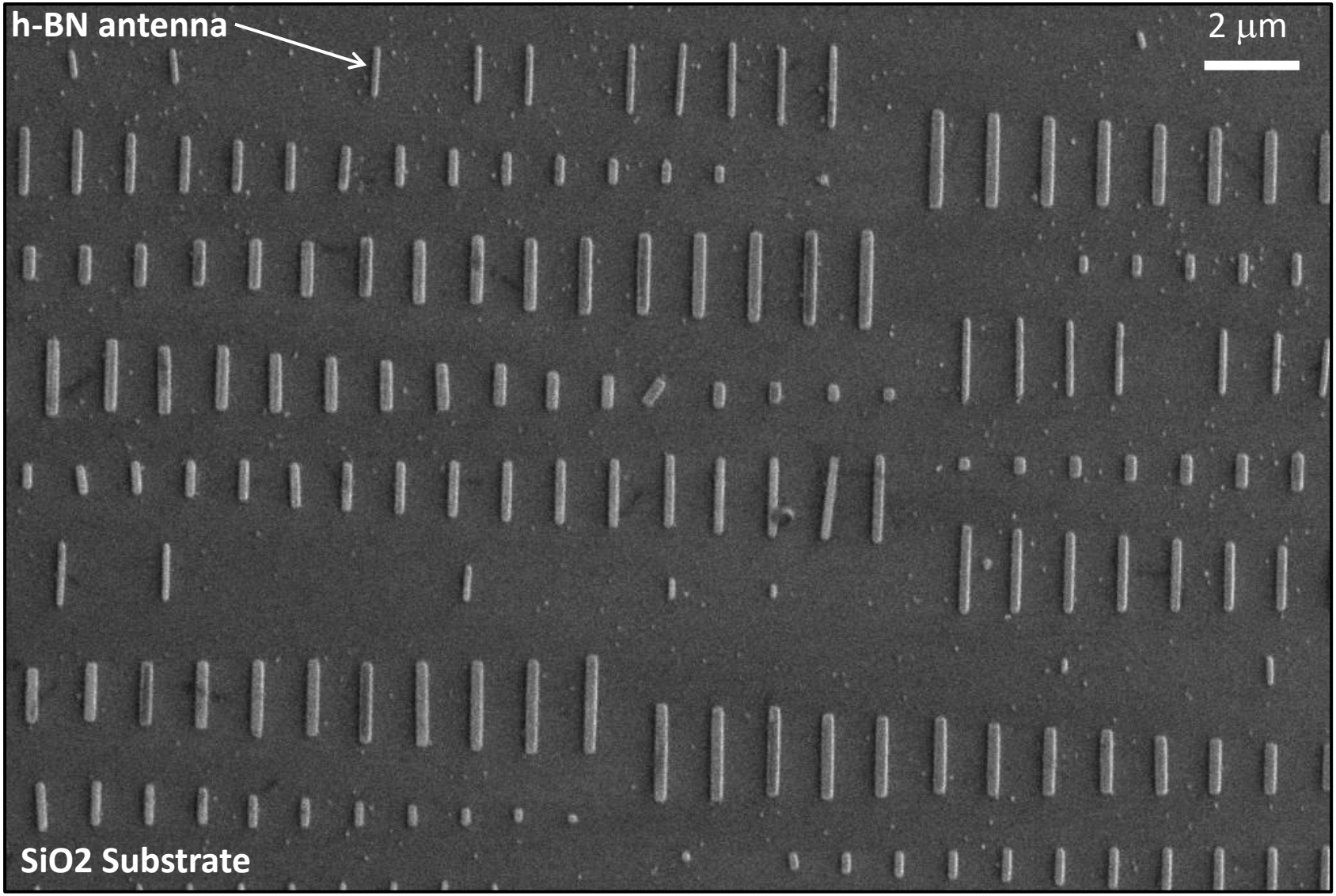


First Surface Mode, SM0 **Second Surface Mode, SM1** **Third Surface Mode, SM2**



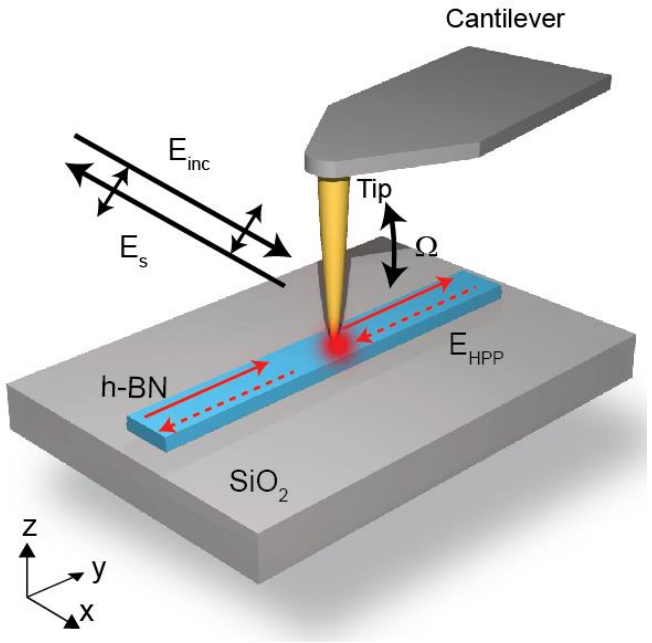
P. Li, I. Dolado, Nano Letters (2016)

Scanning Electron Microscope Image of a batch of h-BN Antennas

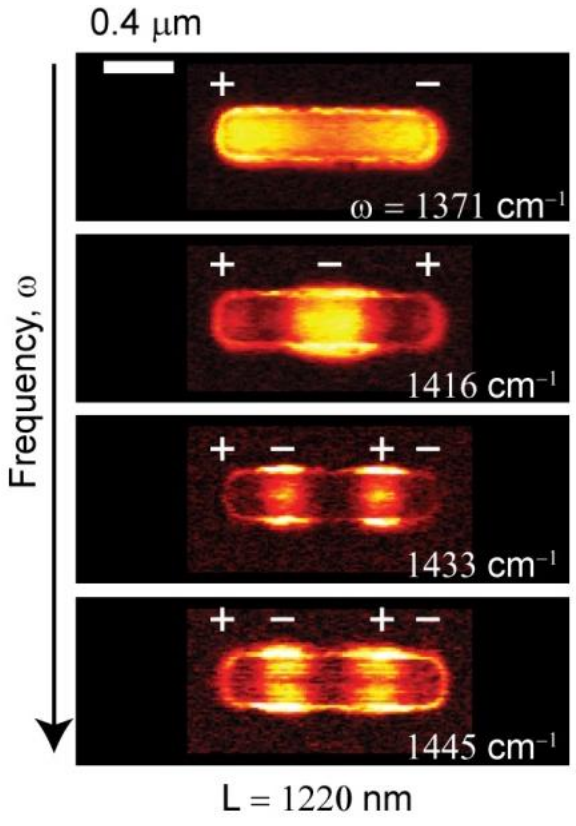


Nanoimaging of h-BN Nanorod Antennas: Longitudinal modes as a function of Length and Frequency

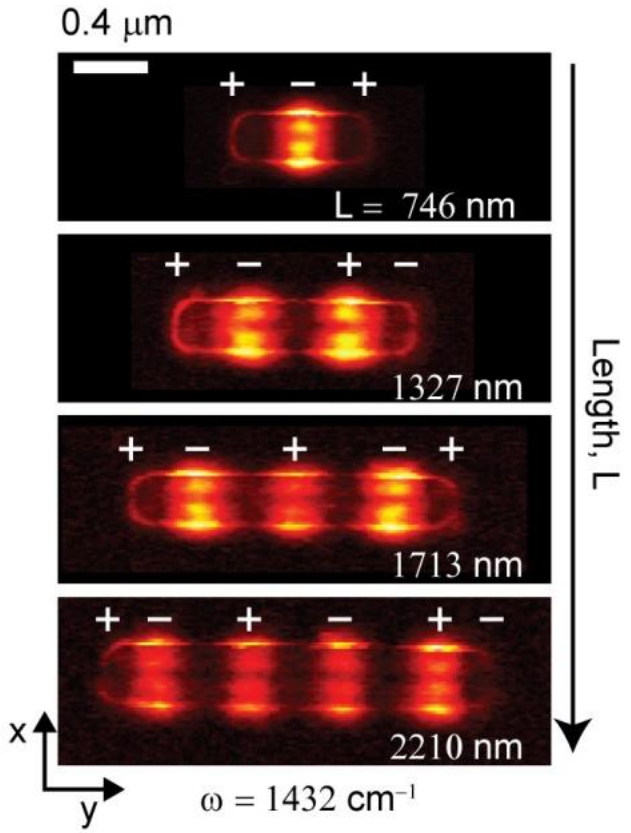
Schematics of the experiment



Near-field images
as a function of frequency ω

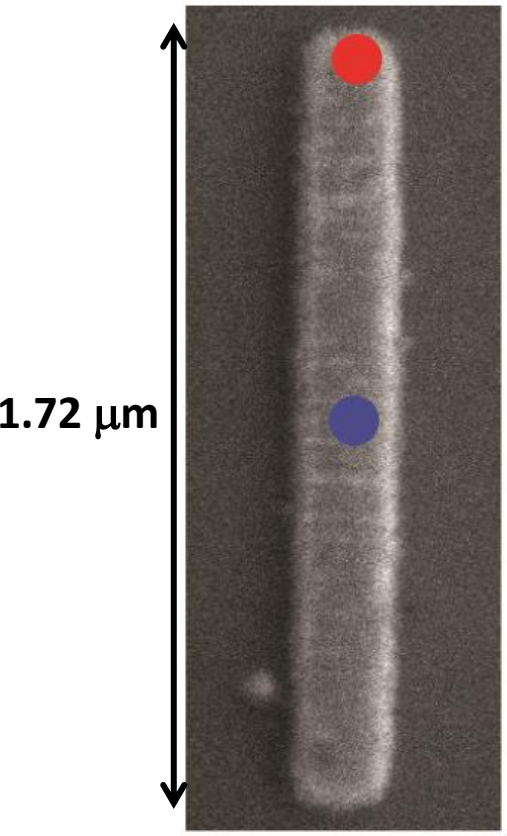


Near-field images
as a function of length L

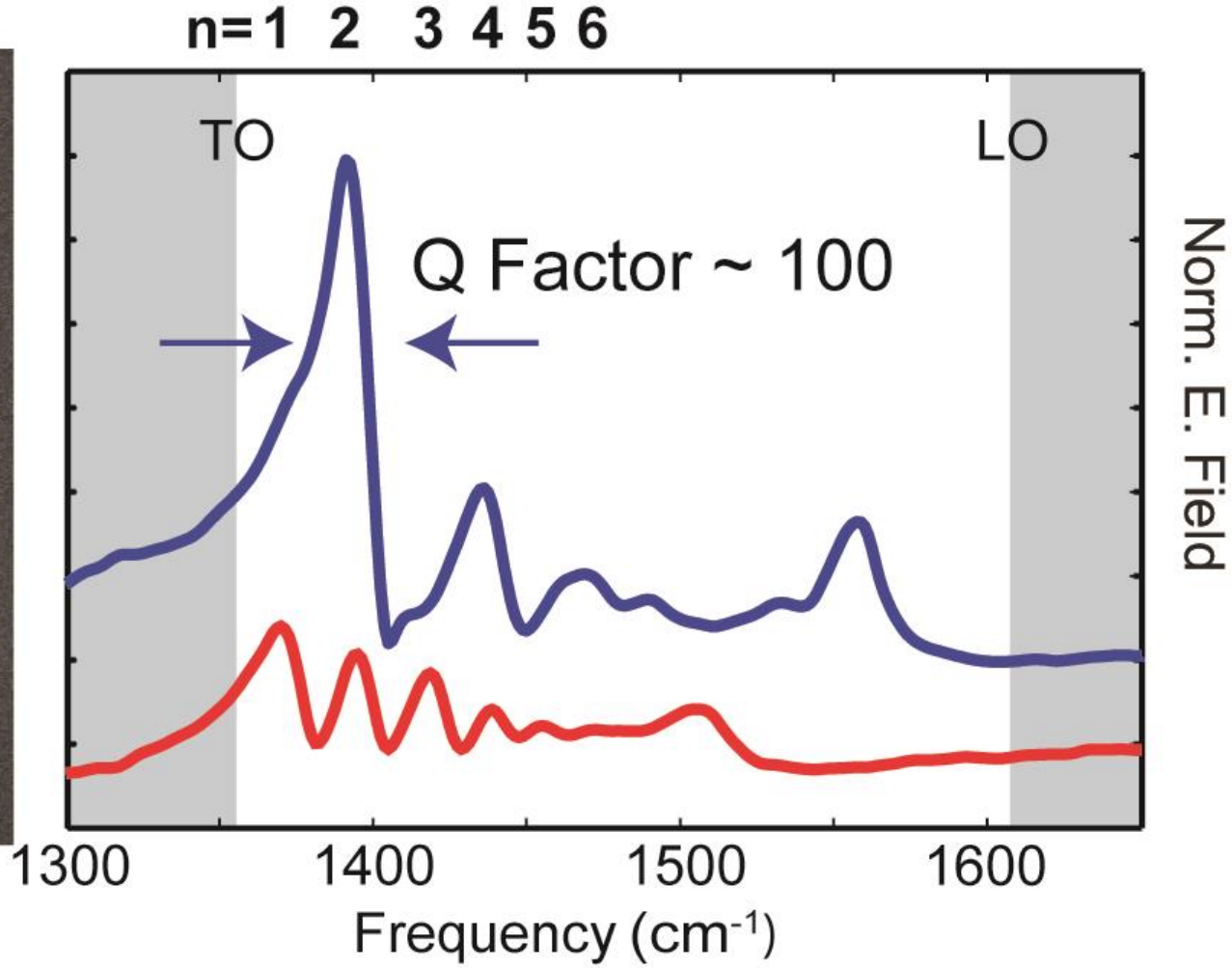


Point Spectra reveal resonances with high Q Factors

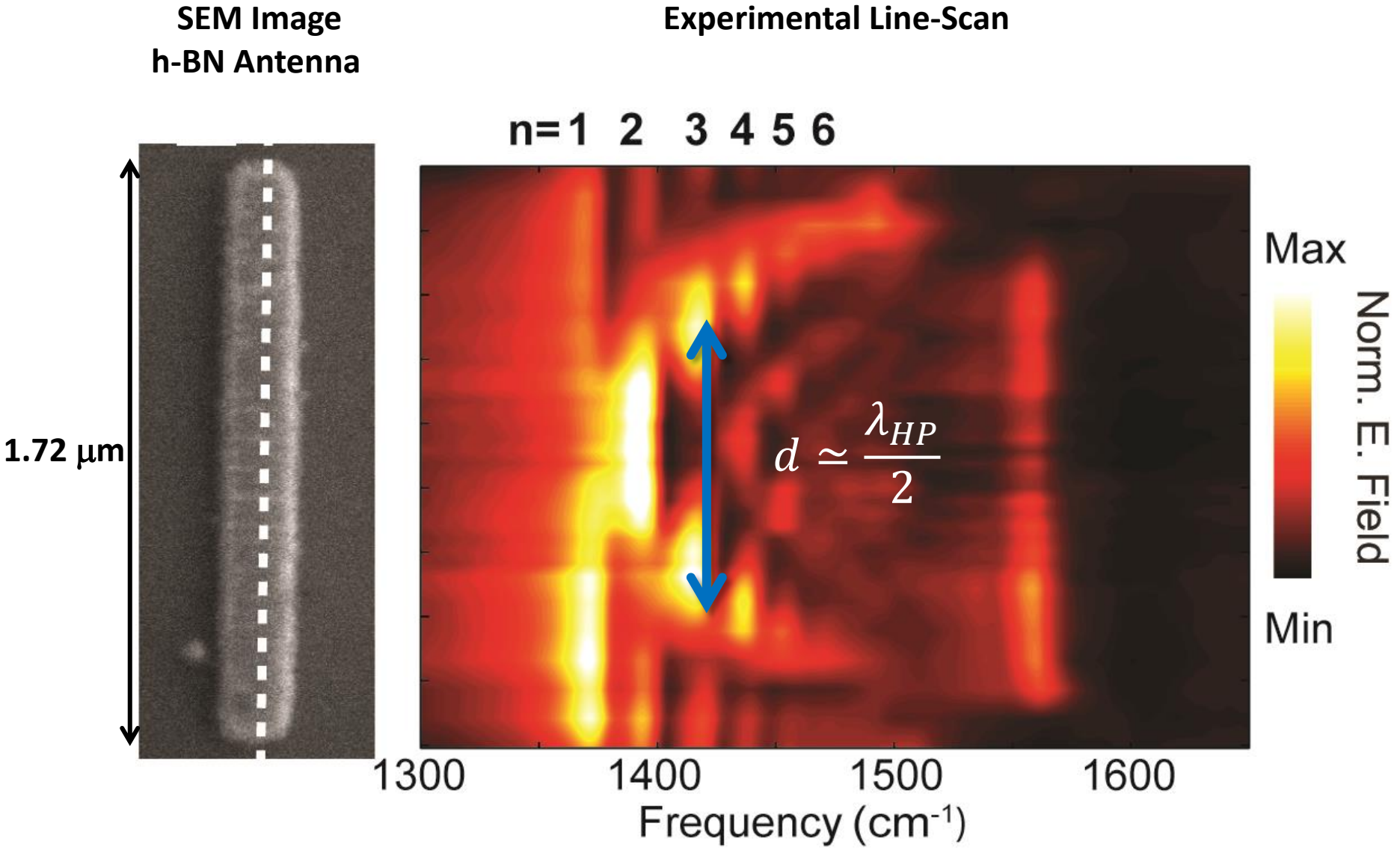
SEM Image
h-BN Antenna



Experimental Point Spectra

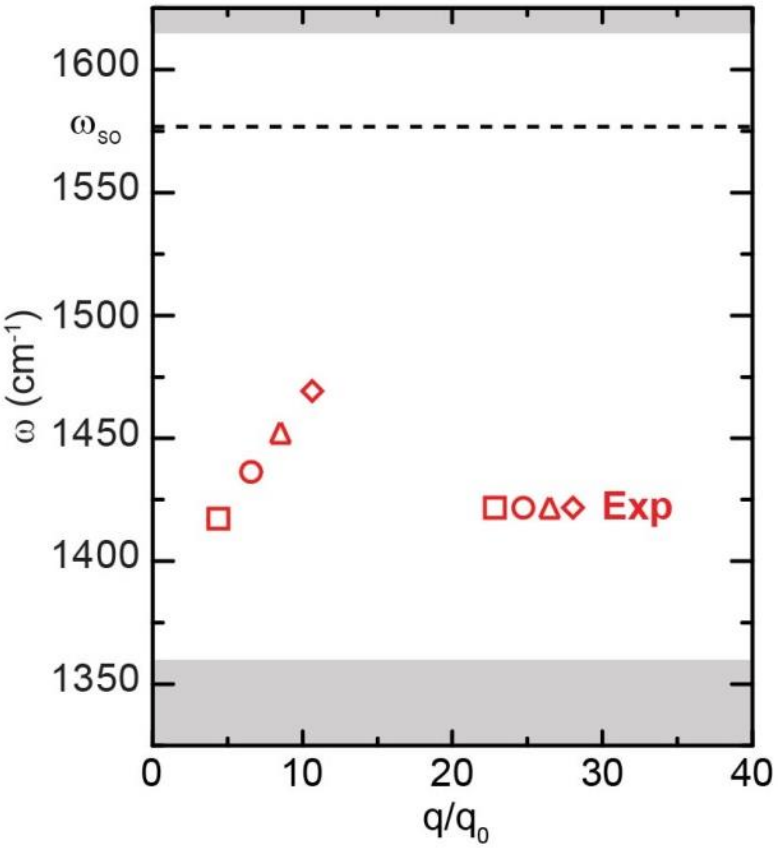


Spectral line-scan allows to connect peak position with resonant wavelength.



Hybridized Hyperbolic Surface Modes gives rise to the Fabry-Perot resonances

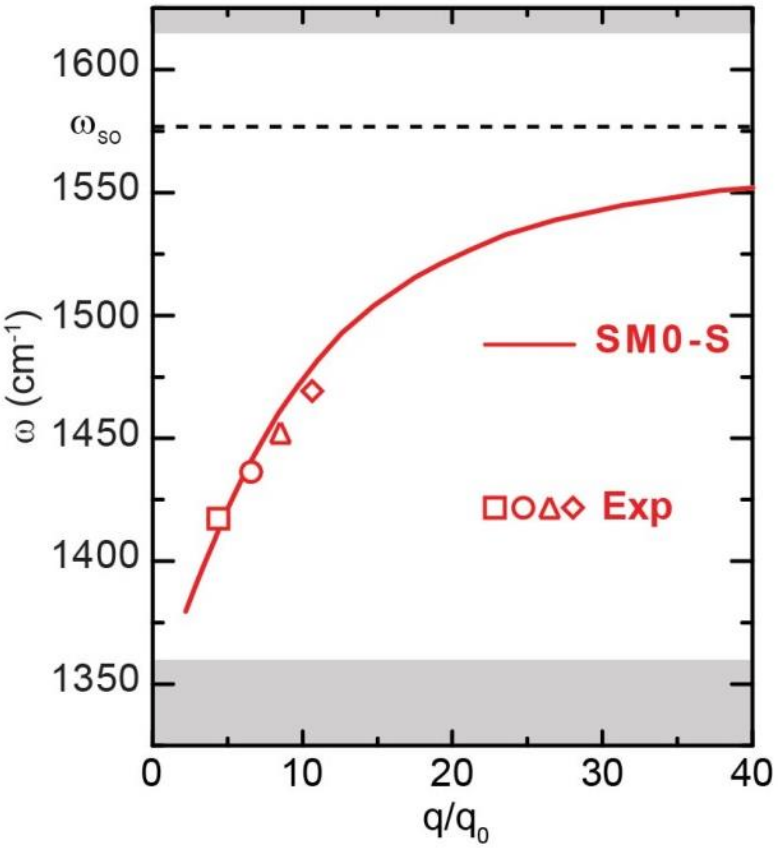
Dispersion of the Modes



q_0: Momentum of light in free space

Hybridized Hyperbolic Surface Modes gives rise to the Fabry-Perot resonances

Dispersion of the Modes



q_0: Momentum of light in free space

Hybridized Hyperbolic Surface Modes gives rise to the Fabry-Perot resonances

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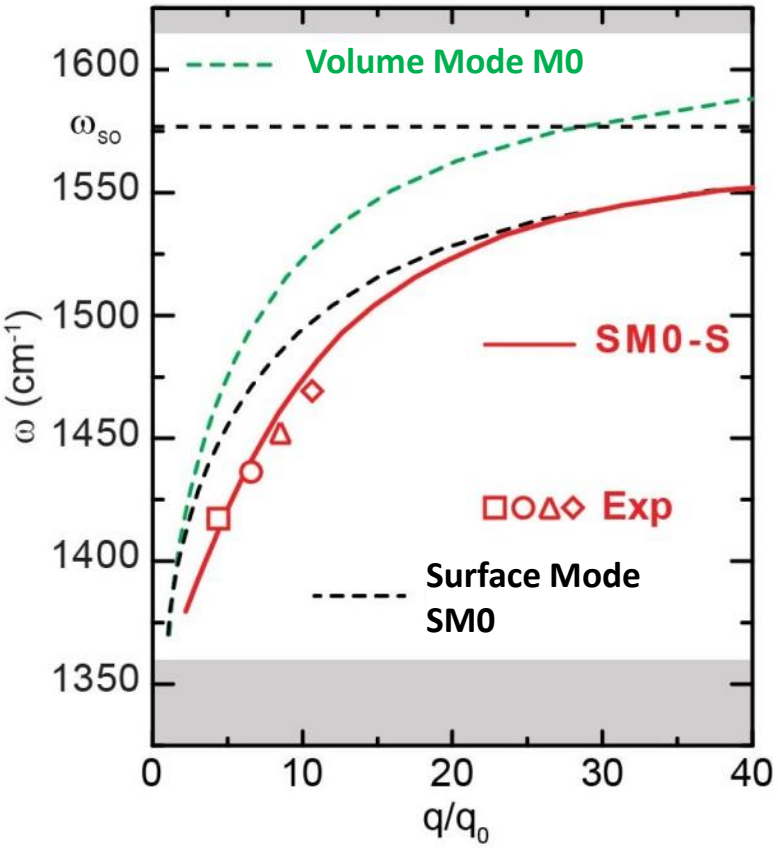
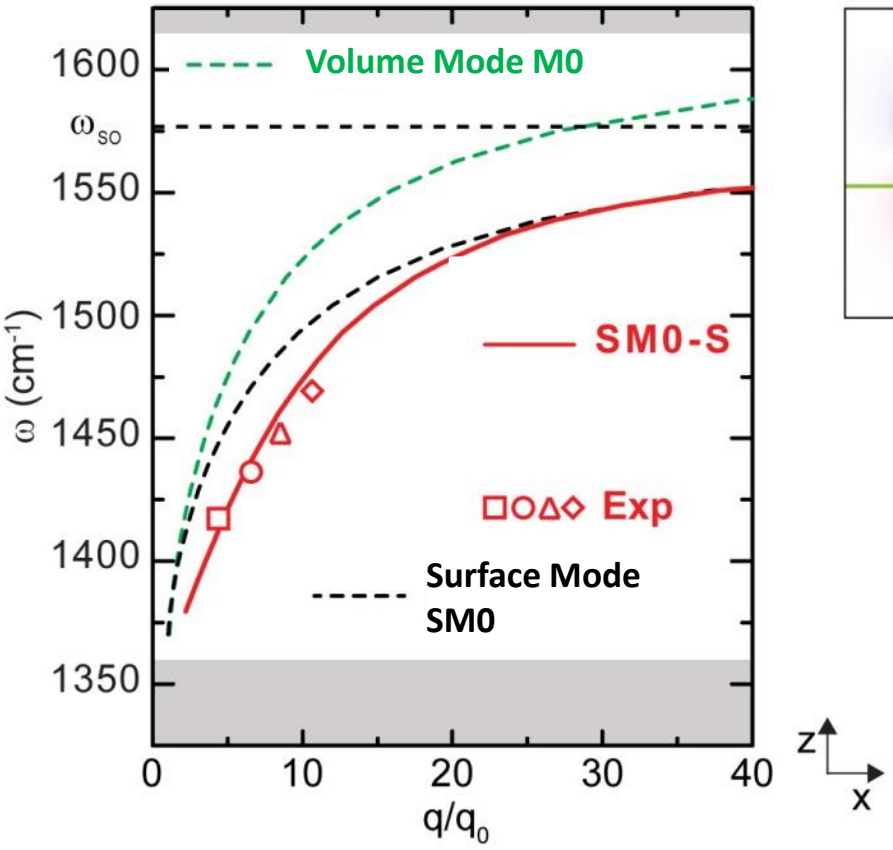


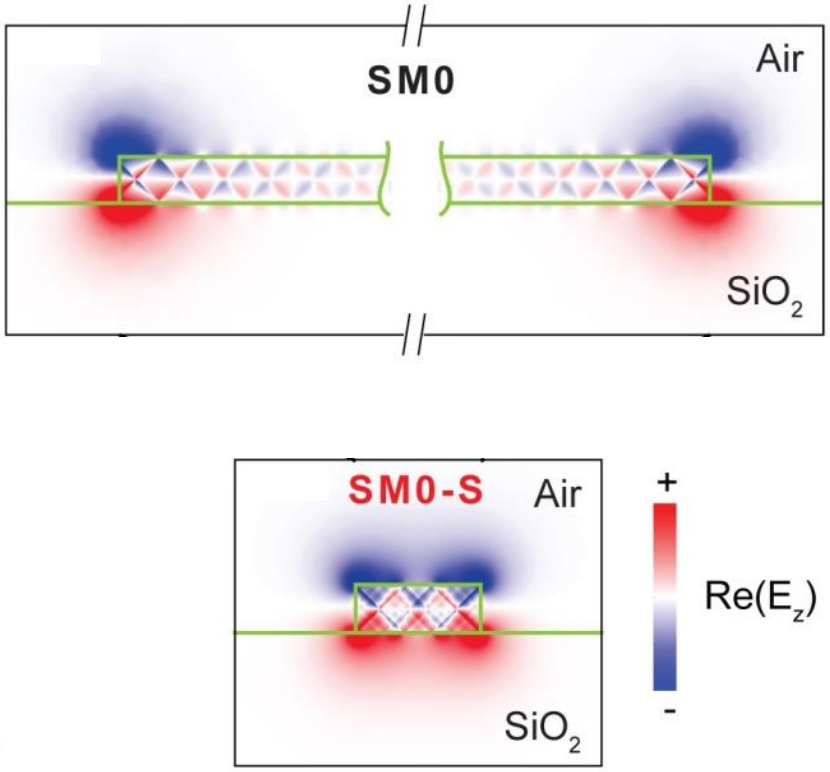
q_0: Momentum of light in free space

Hybridized Hyperbolic Surface Modes gives rise to the Fabry-Perot resonances

Dispersion of the Modes



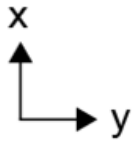
Field Distribution of the Surface Modes



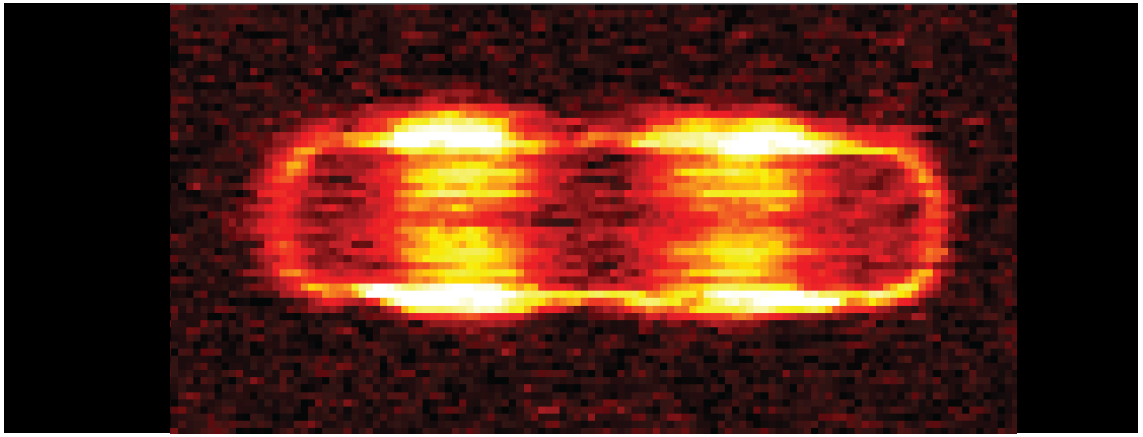
q_0: Momentum of light in free space

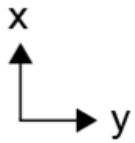
Anomalous transverse Structure of the Hyperbolic Modes

Plasmonic Antenna – Third Order Resonance



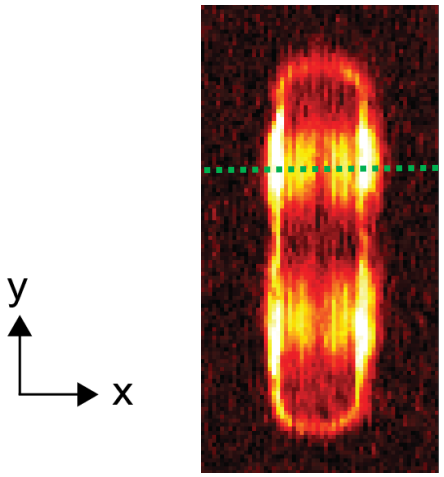
h-BN Antenna – Third Order Resonance

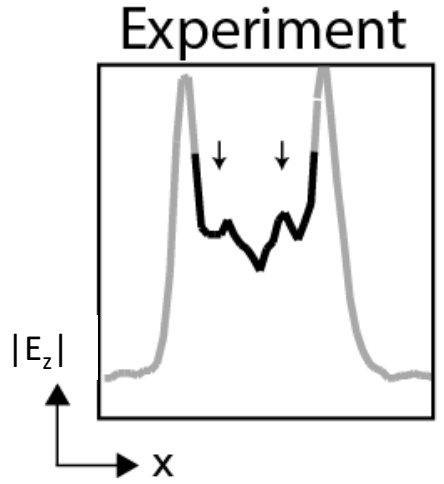




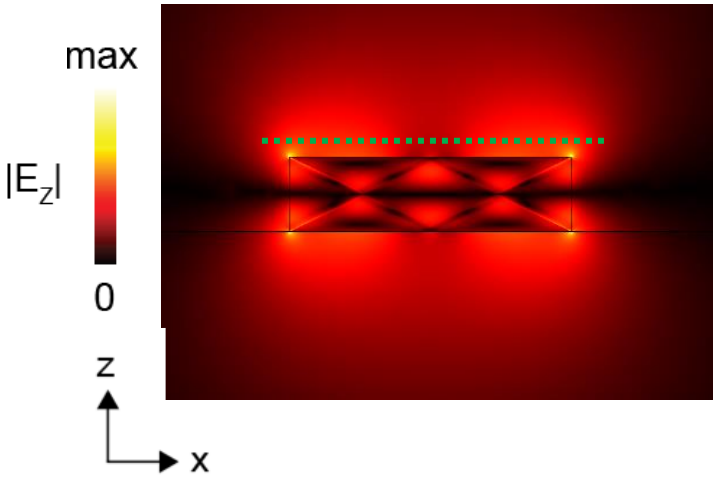
Anomalous transverse Structure of the Hyperbolic Modes

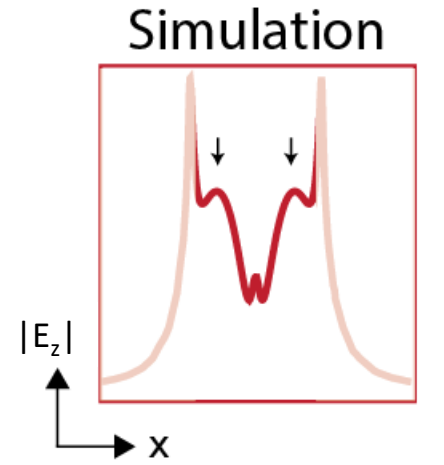
h-BN Antenna – Third Order Resonance



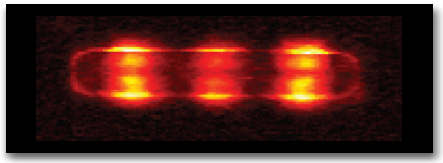


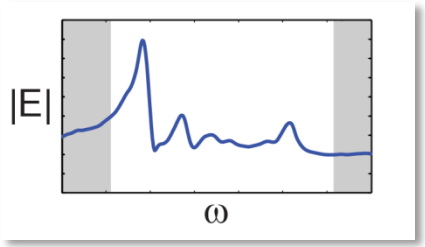
h-BN Antenna – Cross Section of the Mode Profile

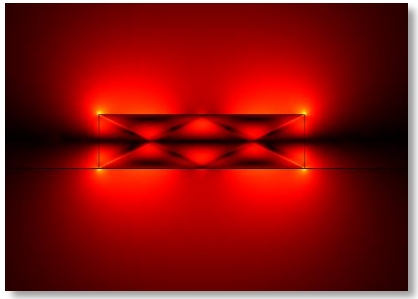




Summary & Outlook







- We have fabricated and studied nanorod antennas made of h-BN
- Through real-space imaging and nanospectroscopy we demonstrated antenna resonances with very large Q factors (Q ~ 100) and deeply subdiffractional confinement.
- We showed that the resonances are due to a hybridized Hyperbolic Surface Mode (SM0-S)
- We expect that these antennas can be used as a building block for metasurfaces and for ultrasensitive molecule detection in the mid-IR

- P. Alonso-González
- S. Vélez, I. Dolado, F. Casanova, L. E. Hueso,
- M. Autore, S. Mastel
- P. Li, A. Y. Nikitin and R. Hillenbrand

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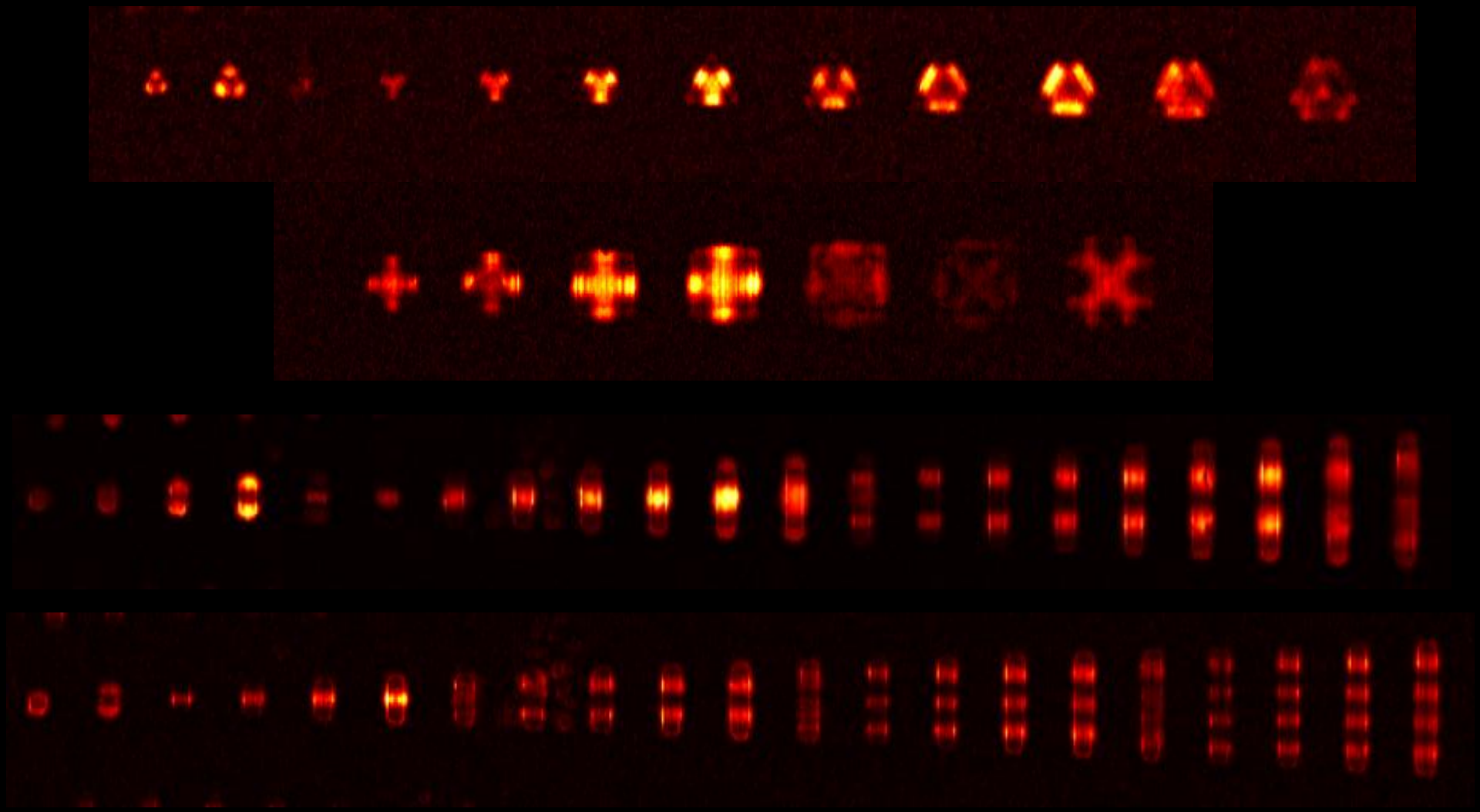
GRAPHENE FLAGSHIP

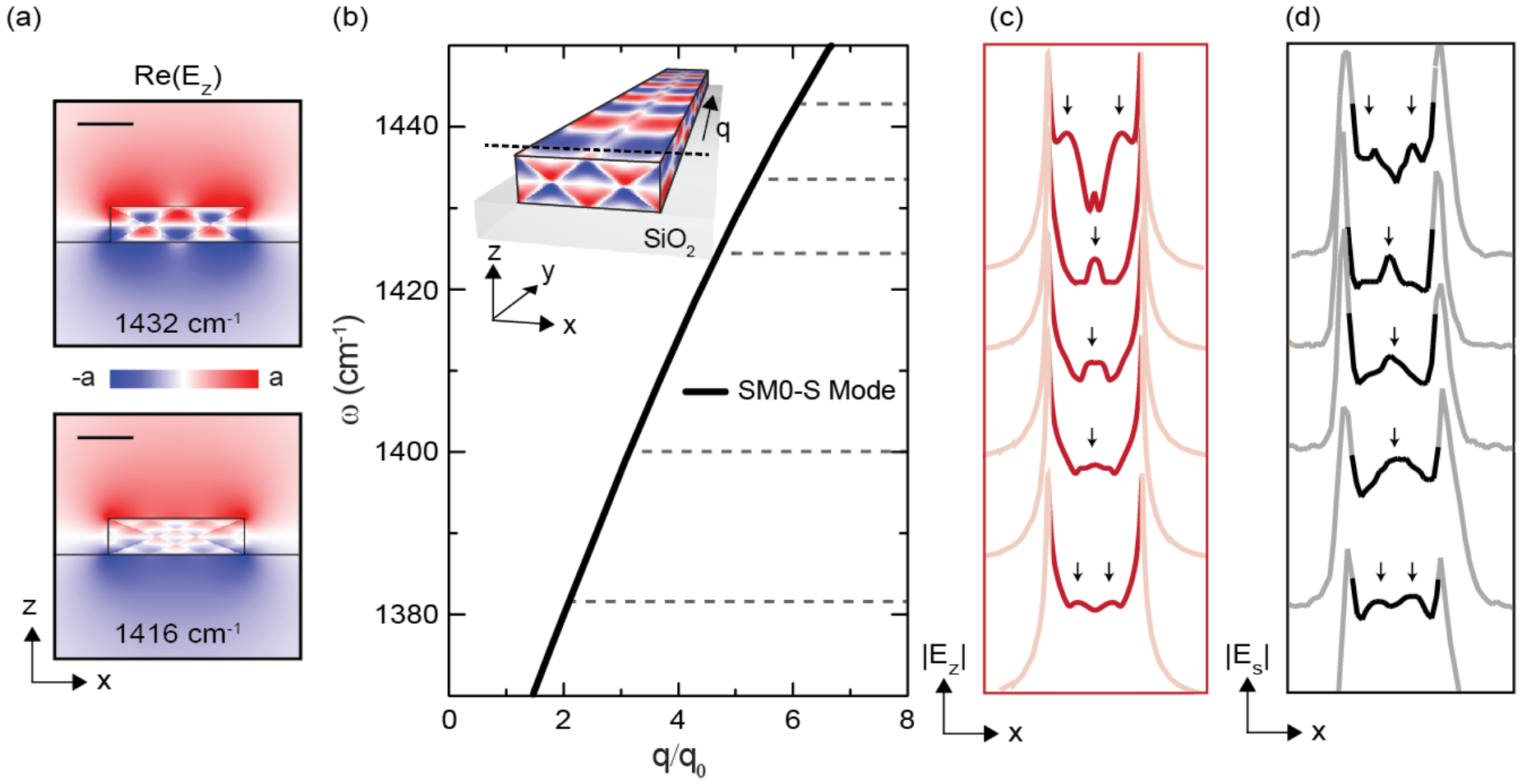
Thanks for your attention!



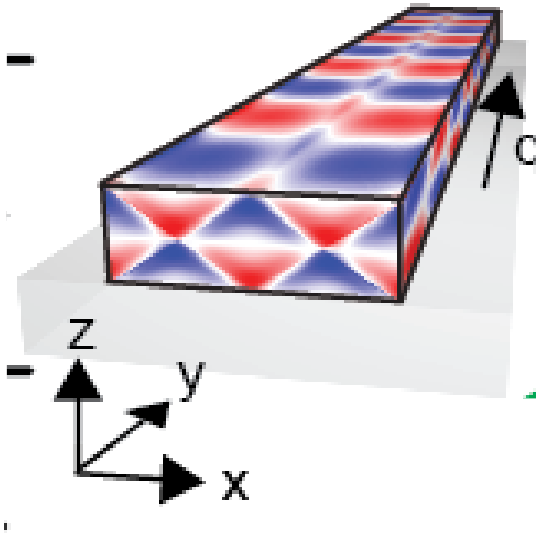
Images by Pablo Alonso, Nanogune (2015)

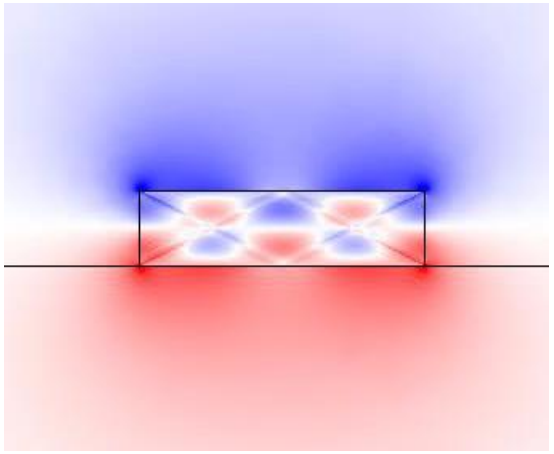
J. Alfaro et al, in progress

Near-Field profile of the Waveguide Mode (SM0-S) changes with frequency

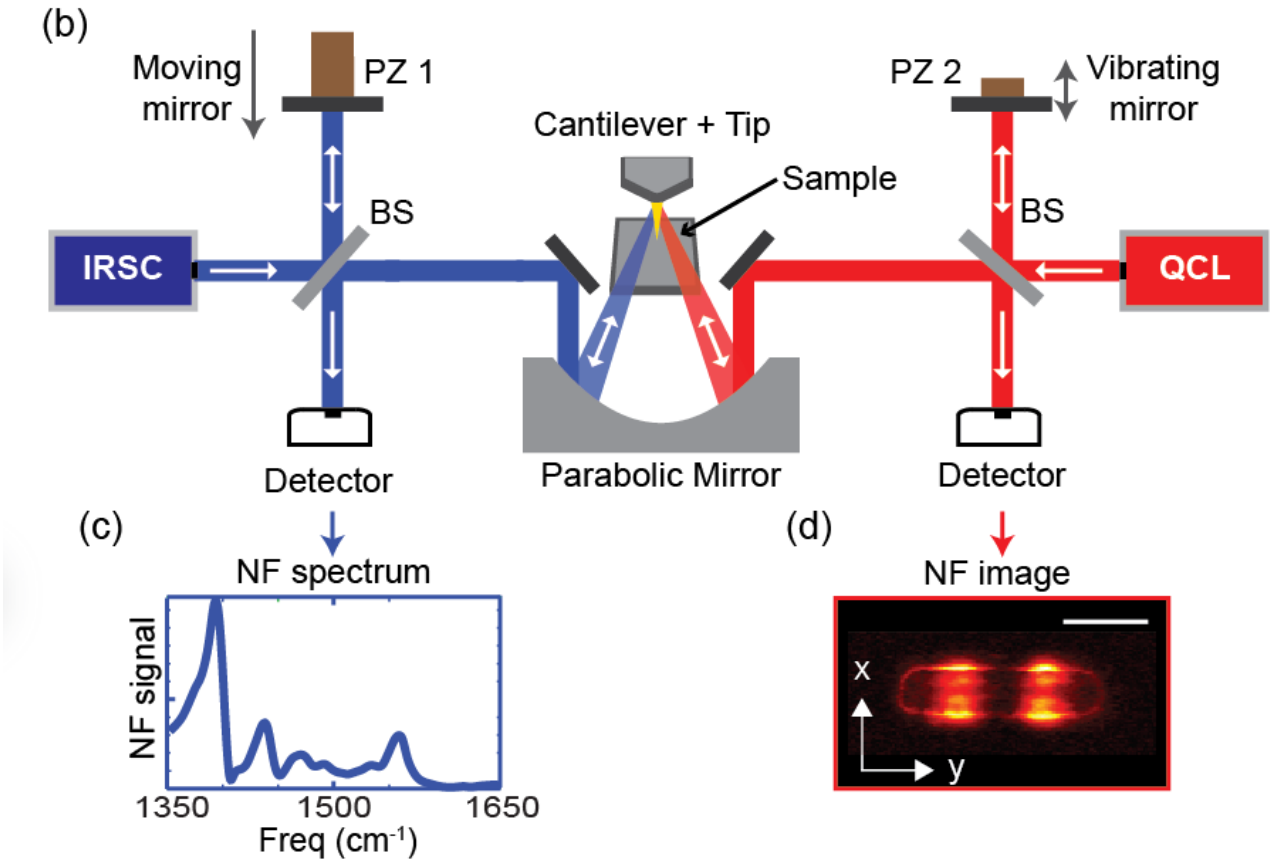


Propagation of the SM0-S mode





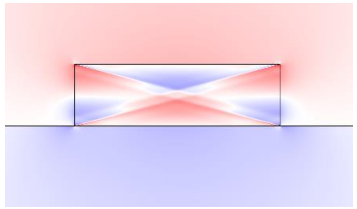
Experimental Setup



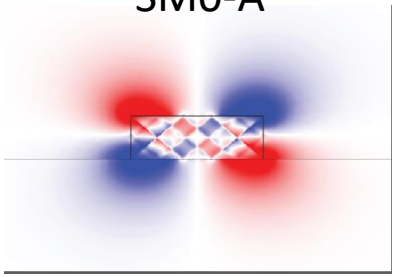
Profiles of Modes

Surface Modes

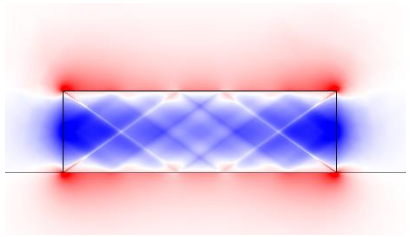
SM0-S



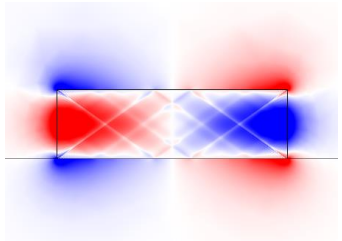
SM0-A



SM1-S

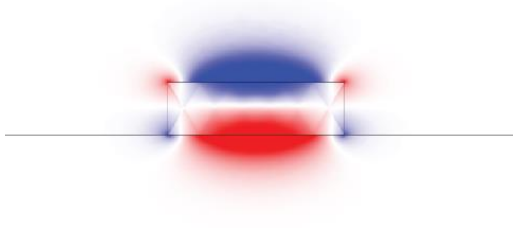


SM1-A

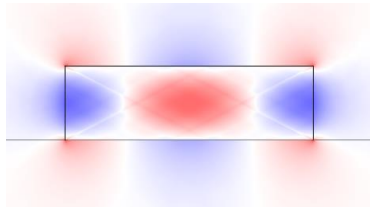


Volume Modes

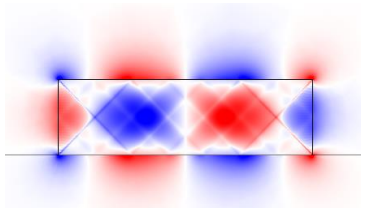
M0-W



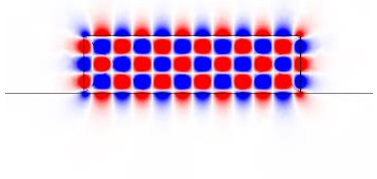
M1-2



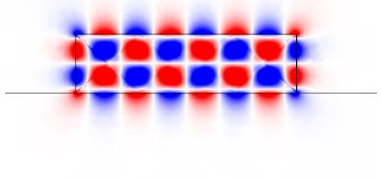
M1-3



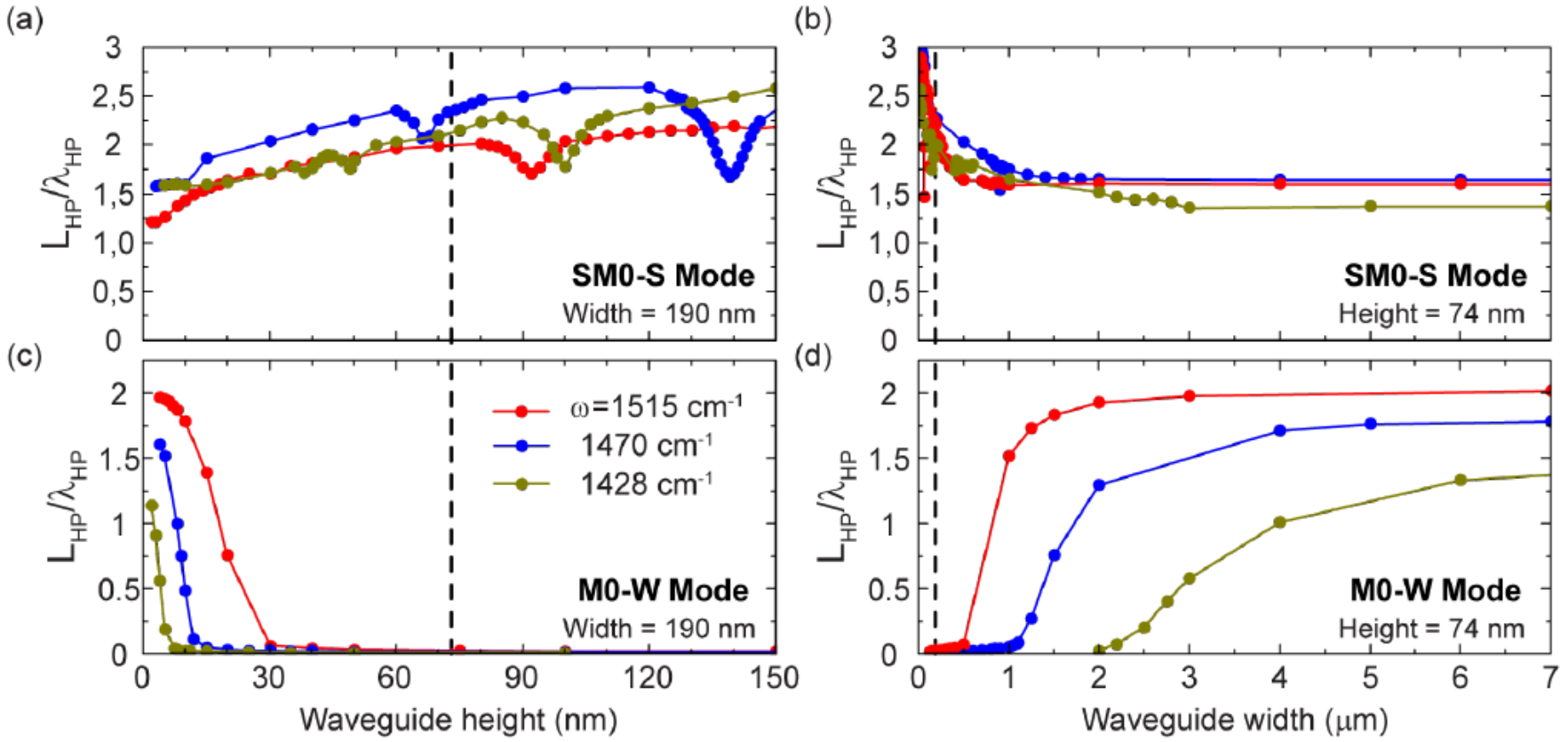
M4-11



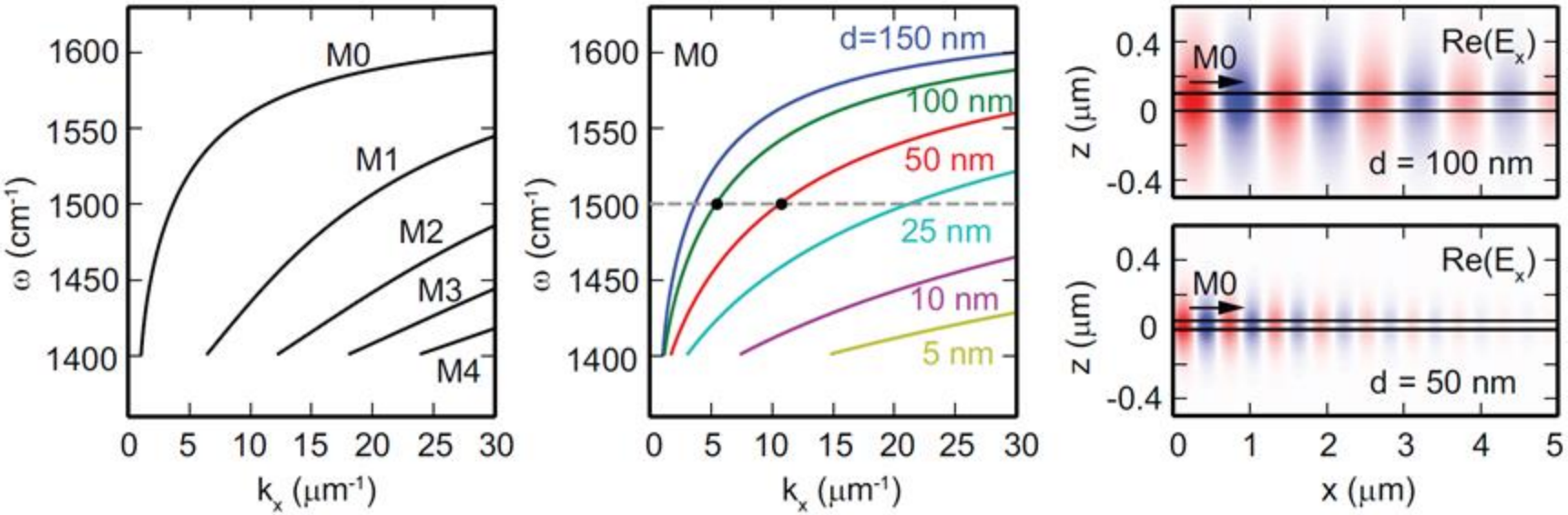
M3-8



SM0-S Mode propagates even for very small antenna cross-sections



Dispersion of the Volume Modes Mn. Dispersion of the M0 mode as a function of Frequency



Alexey Nikitin et al.