Angle-Mediated Control of Hyperbolic Phonon Polariton Propagation in Thin α-MoO_3 Wedges

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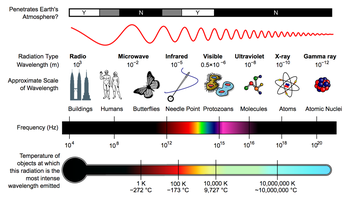
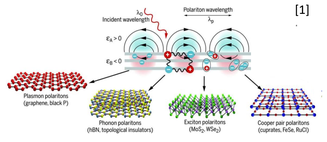
Background

- Infrared (IR) radiation contains many useful properties
- Objects near room temperature emit IR radiation constantly, making it useful for imaging and cooling
- IR spectroscopy is used for atomic vibration characterization
- Unfortunately, long wavelength leads to high diffraction limit, limiting on chip applications

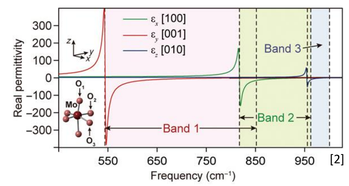


Introduction

- Polaritons are formed by coupling between charge oscillations and light
- Thery are often studies in 2D materials
- Phonon polaritons (PhPs) involve coupling of atomic oscillations (phonons) to IR light
- PhPs have higher less loss than plasmons, making them useful for on chip photonics



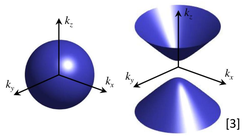
[1]



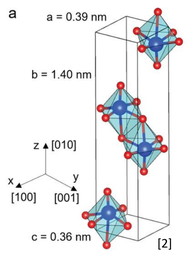
[2]

- α-MoO_3 has three Reststrahlen bands, or areas where phonon polaritons occur
- Our work focuses on Band 2, with measurements presented at 870cm^{-1}.
- In the unit cell below, the unlinked polyhedra indicate the weak vdW bonding enabling exfoliation into 2D structures

$$\frac{k_x^2}{\varepsilon_{xx}} + \frac{k_y^2}{\varepsilon_{yy}} + \frac{k_z^2}{\varepsilon_{zz}}$$


[3]

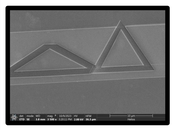
- Hyperbolicity is an extreme form of anisotropy
- Permittivity changes sign in different directions
- This leads to high confinement and control
- α-MoO_3 is orthorhombic, allowing it to be biaxially hyperbolic



[2]

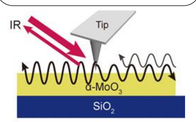
Fabrication & Imaging

SEM image of patterned flakes

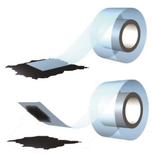


- Mechanical exfoliation using tape and source flake
- Final flake thickness of 127nm
- Focused ion beam etching with Ga^+ ions for micropatterning
- Annealing at 300°C for 90 minutes to eliminate etching damage

Scanning Near Field Microscopy uses a laser and nanoscale tip to image evanescent waves



Mechanical Exfoliation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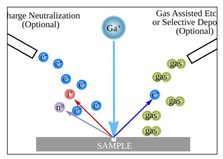
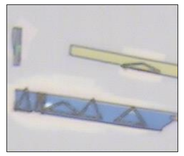
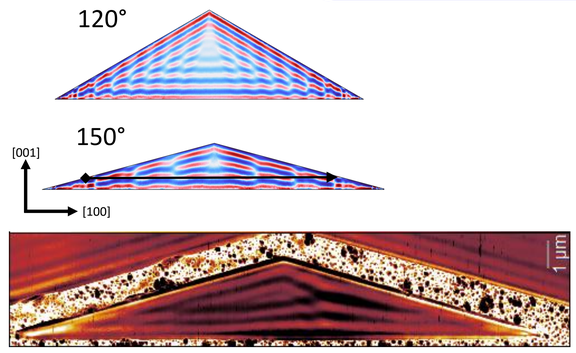
Focused Ion Beam Etching

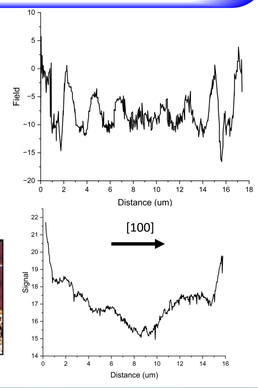


Annealing



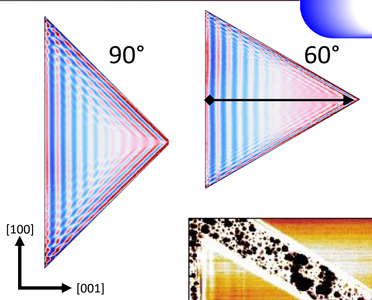
"Forbidden" Propagation

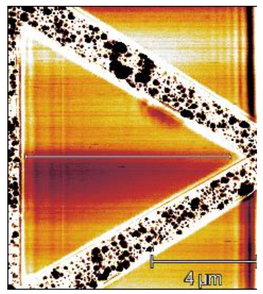


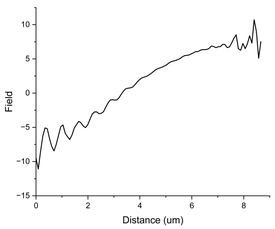


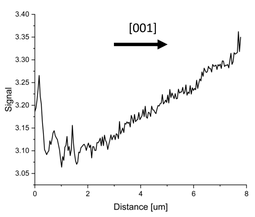
- "Forbidden" Propagation means that the polariton propagation occurs in a normally forbidden direction
- In this case, the [100] direction is forbidden as we are in the RB2 Spectral Band
- Propagation in the [001] is still primary, but our line profiles demonstrate clear [100] propagation
- A key characteristic is the interference pattern, when switching from n to n+1 standing waves

Fine Focusing



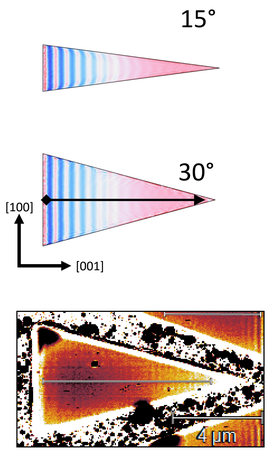


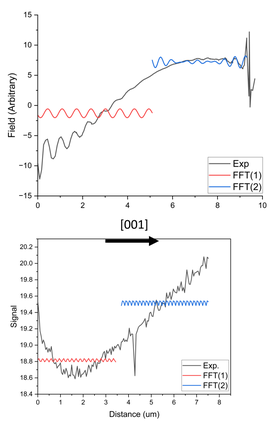




- Fine focusing refers to the increase in field as we approach the tip
- This occurs because we have greater spatial confinement, concentrating energy at the tip
- This is distinct from adiabatic compression because the wavelength of the propagating wave does not change
- The general shape of experimental curve matches well with simulation and has clear indication of increasing field
- Wavelength analysis needs to be performed in experimental results to confirm conservation of wavelength

Adiabatic Compression





$$\frac{\lambda_1}{\lambda_n} = 1.36$$

$$\frac{\lambda_1}{\lambda_n} = 1.23$$

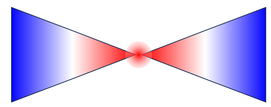
- Adiabatic Compression refers to the compression of both wavelength and field as we approach the tip.
- Similar phenomenon have been demonstrated in plasmonics.
- Furthermore, phonon polaritons have demonstrated this effect in hBN [5]. However, this focusing occurred out of plane due to the uniaxial nature of hBN.
- Because α-MoO_3 has a biaxial nature, compression can occur in plane, which has important implication for chip scale applications
- To quantify compression, FFT and sine wave fitting were performed separately for the front and back half of data
- Fitting was performed separately for the front and back half of data

Conclusions

- Wedge angle is a tunable parameter for achieving high control of propagation within biaxial hyperbolic crystals
- Three distinct regimes are exhibited experimentally: Forbidden Propagation, Fine Focusing, and Reverse Propagation
- High field localization may be achieved with tunable control of wavelength at given frequencies.
- Forbidden propagation has potential application in multidirectional focusing applications

Future Work

- Investigation into nonlinear effects enabled by high fields at tip
- Bow tie like structures for extreme field concentrations between mirrored flakes
- Integration into waveguiding structure
- Experimental investigation of RB1 band
- Substrate and heterostructure effects



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