Controlling Light Propagation at the Nanoscale in Confined Molybdenum Trioxide (MoO_3) Nanobelts

Northwestern

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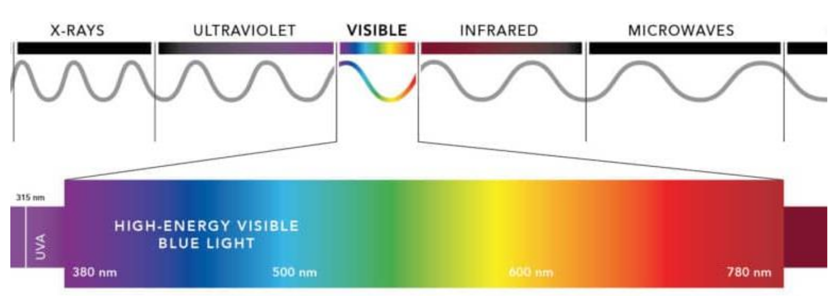
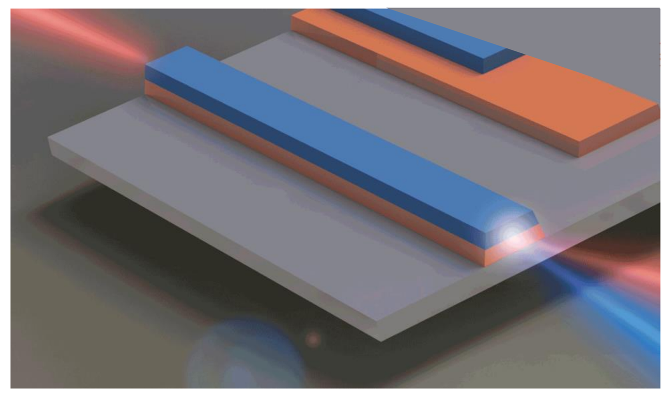
Motivation

- Light is electromagnetic radiation
- Infrared (IR) light is characterized by long free-space wavelengths
- Polaritons can be used to realize much smaller wavelengths in the IR range, thereby enabling flat and sub-diffractional IR optical components

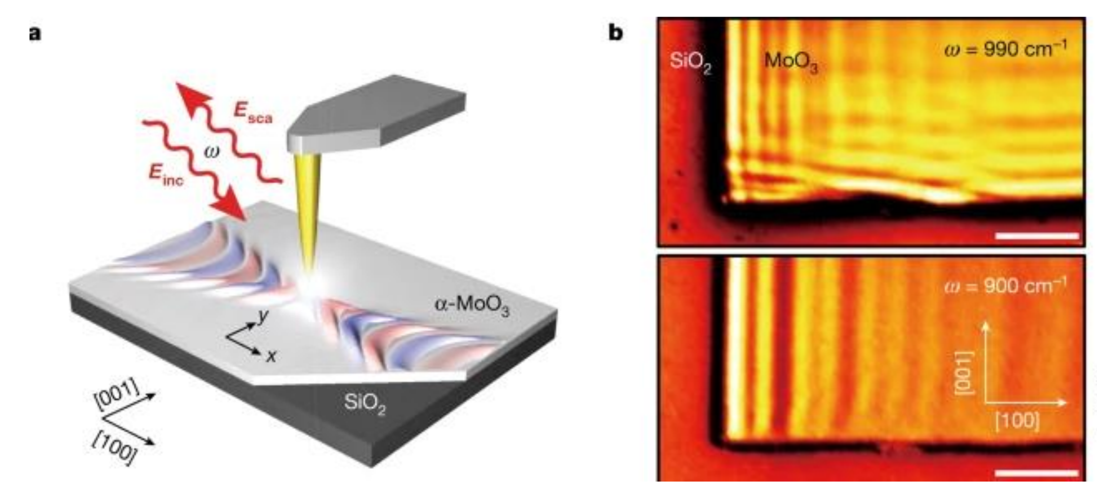
→ *Overview: IR optics is a promising field that relies on polaritons to achieve new advances in imaging, communications, sensing, and light sources*





Technique: s-SNOM

- With an atomic force microscope (AFM), a metallic tip scans across the surface of a material to provide topographical information
- When light is scattered off this tip, we can probe sub-diffractional light-matter interactions and visualize polaritons (this is called scattering-type scanning near-field optical microscopy or s-SNOM)



Results

Experimental

- In the spectral range ~855 to 960 cm^{-1}, polariton propagation should be restricted to the [100] crystal axis
- However, for narrow samples, the propagation occurs in the forbidden [001] direction in a subset of that range: ~878 to 897 cm^{-1} (A-C)
- The propagation returns to the expected [100] direction with decreased polariton wavelengths

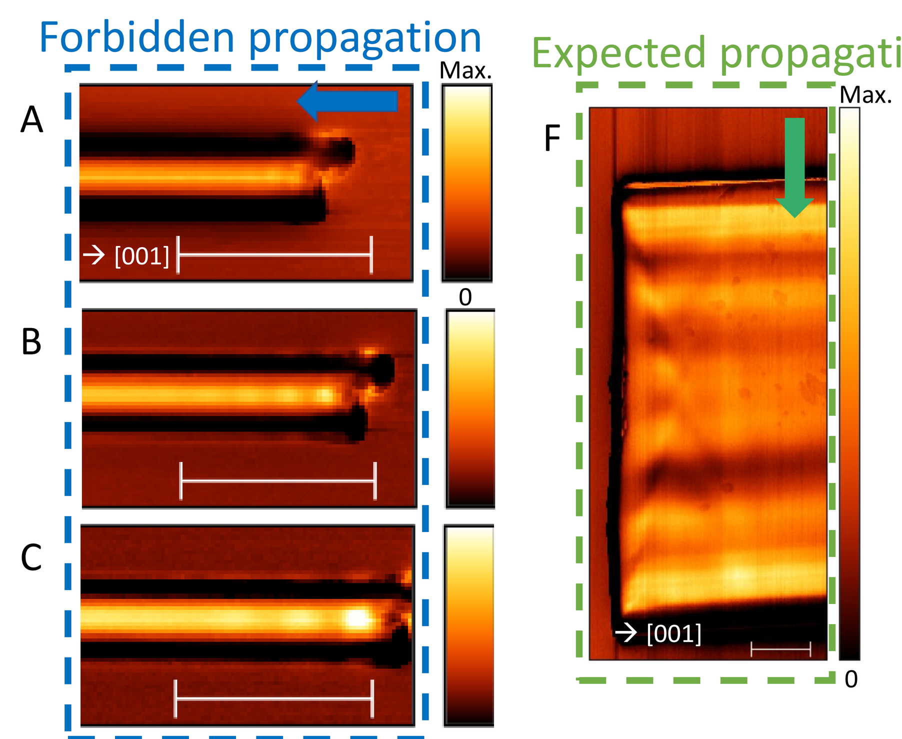
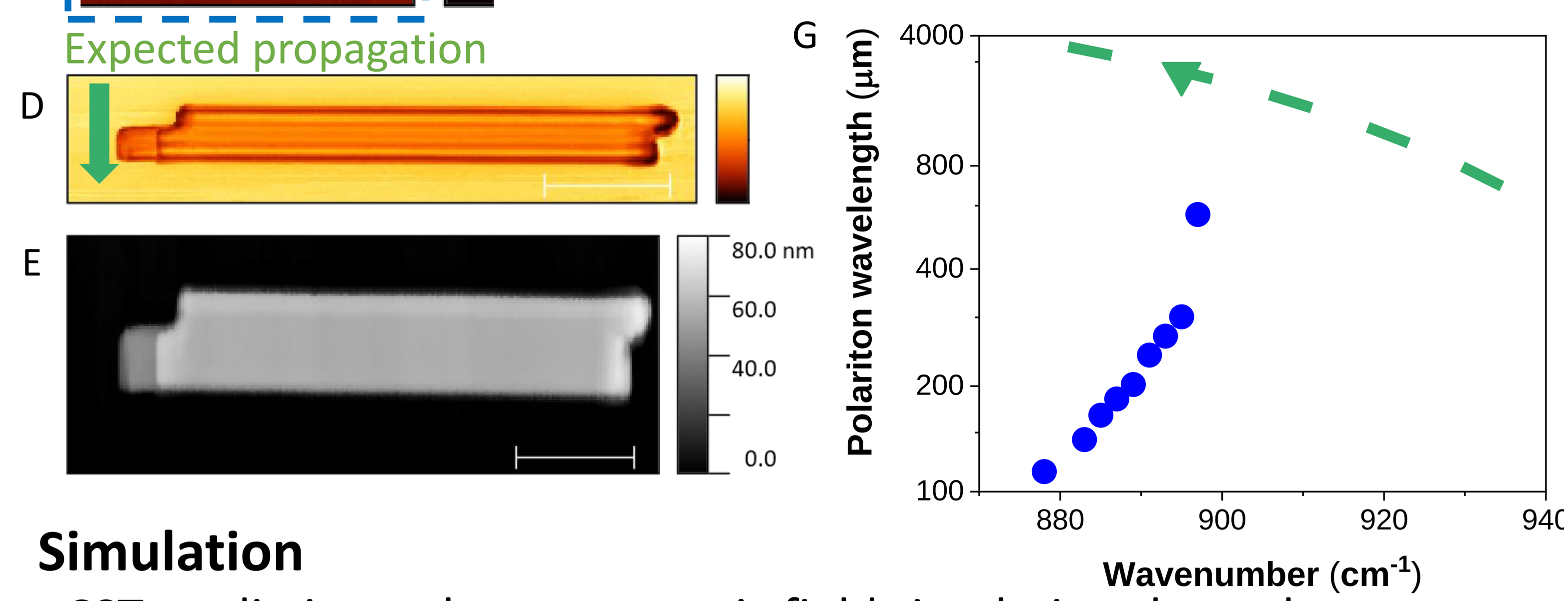


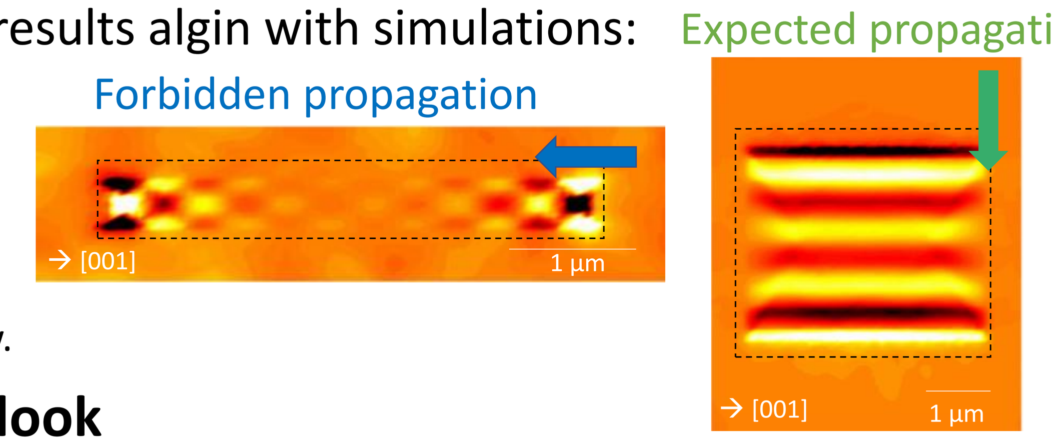
Figure 2: s-SNOM data at (A) 878 cm^{-1}, (B) 889 cm^{-1}, (C) 895 cm^{-1}, and (D) 930 cm^{-1} for narrow sample. (E) AFM height profile of same narrow sample. (F) s-SNOM data at 895 cm^{-1} of wider slab. (G) Wavelength dispersion of induced polaritons. All scale bars are 1 µm.



Simulation

- CST studio is an electromagnetic field simulation that solves Maxwell's equations over 3D spaces, including nanostructure designs
- The experimental results algin with simulations:

Figure 3: CST simulations of MoO_3 showing propagation along the forbidden axis when the slab is sufficiently narrow.

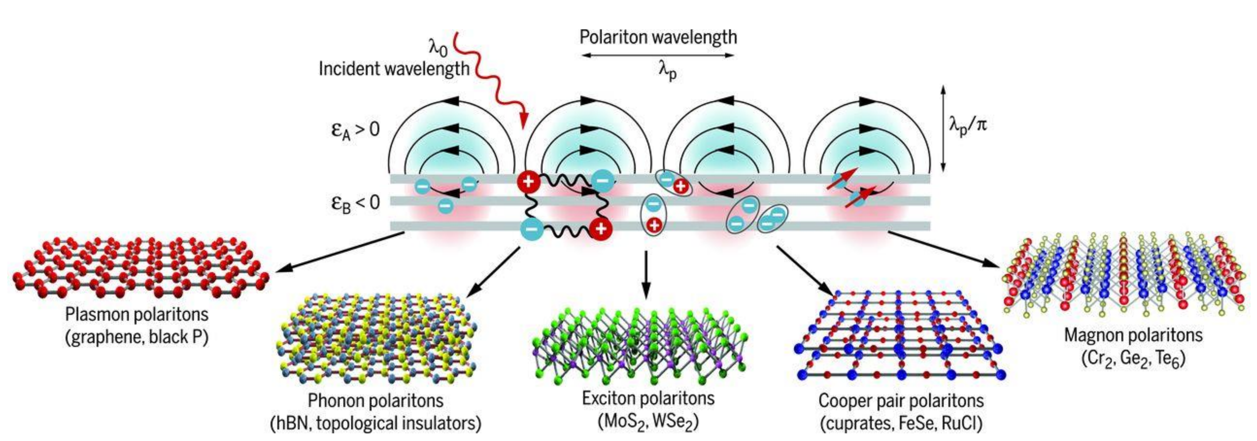


Summary and outlook

- Propagation direction appears to be inverted when the width of the nanobelt is smaller than the polariton wavelength
- The direction of energy flow is rotated by 90˚ with this inversion, and the energy flow can potentially be enabled in other directions
- We can leverage this as a new strategy for optical nano-resonators
- Future work includes more quantitative work and better understanding the criteria for this propagation inversion

Background

- Polaritons are excitations between light and coherently oscillating charges in materials
- Of the many types of polaritons, hyperbolic polaritons exist in highly anisotropic materials



- Hyperbolic materials have opposite signs of the permittivity tensors along different crystal directions
- MoO_3 is the first natural in-plane anisotropic material identified
- MoO_3 exhibits spectral ranges where polariton propagation is restricted along specific directions
- Sub-diffractional Fabry-perot (standing wave) modes can be induced in nanoscale ribbons where propagation is allowed along the "forbidden" direction

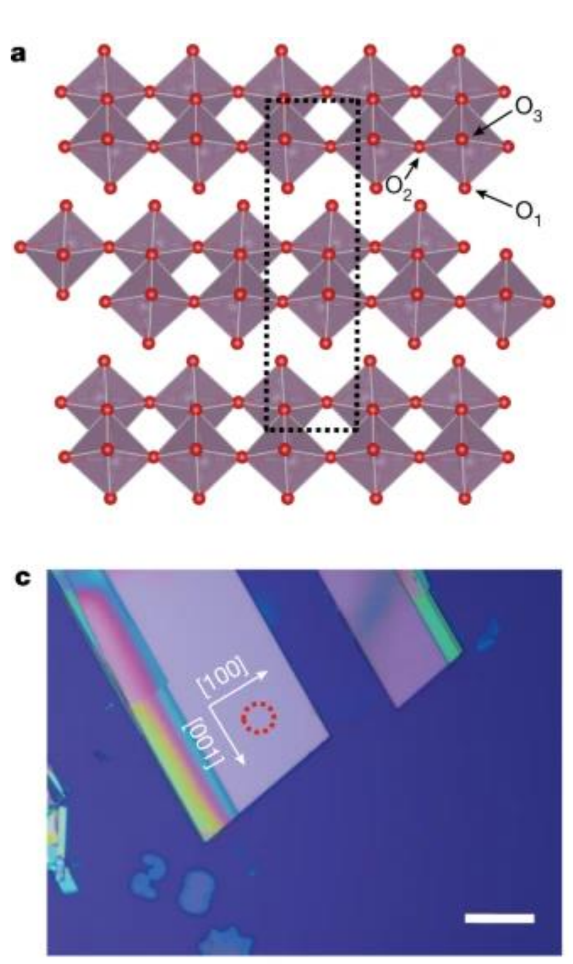
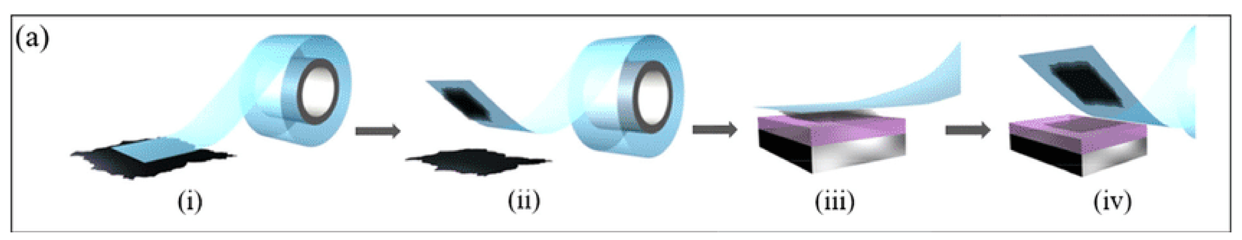


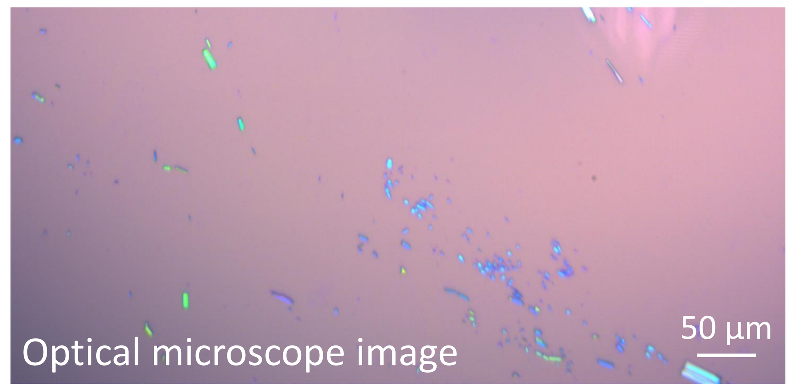
Figure 1: MoO_3 orthorhombic crystal lattice and optical image of exfoliated flake.

Methods: Sample Fabrication

1. Material exfoliation was performed with scotch tape to peel apart the MoO_3 material layers and then transfer flakes to a Si or SiO_2 wafer



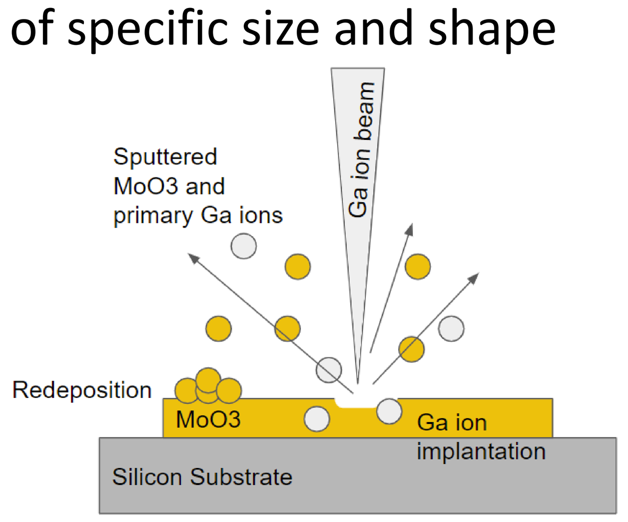
Results in flakes of random sizes and shapes



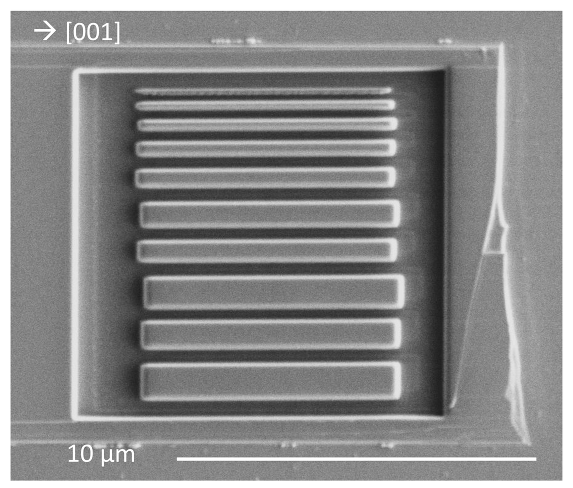
2. Focused ion beam (FIB) uses heavy gallium ions to mill through material, so we can fabricate samples of specific size and shape

Challenges with FIB:

- Gallium implantation and poisoning
- Redeposition
- Obtaining clean and sharp edges



Possible solutions: annealing sample after fabrication, lowering the milling rate, and using a chrome (Cr) mask



References and Acknowledgements

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