Transmission Asymmetry in Nano-opto-mechanical Metamaterials at μW Optical Power

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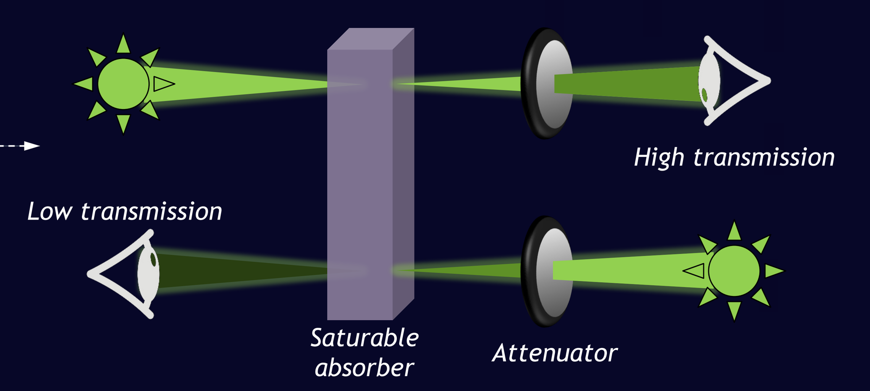
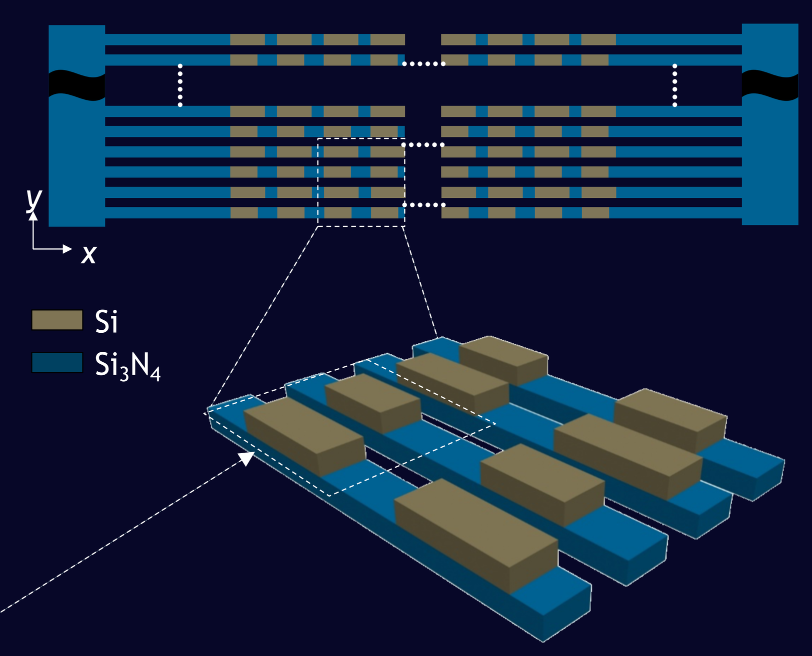
In linear optics, the transmission of absorbers is identical in the forward and backward propagation directions. We demonstrate a nonlinear metamaterial with intensity-dependent transmission asymmetry at 30 μW.

Asymmetric Transmission via Optomechanical Nonlinearity

Conventional approaches to asymmetric transmission

- Magnetic field (esp. the Faraday effect)
- Nonlinearity (@high light intensity)
- Mode/polarization conversion





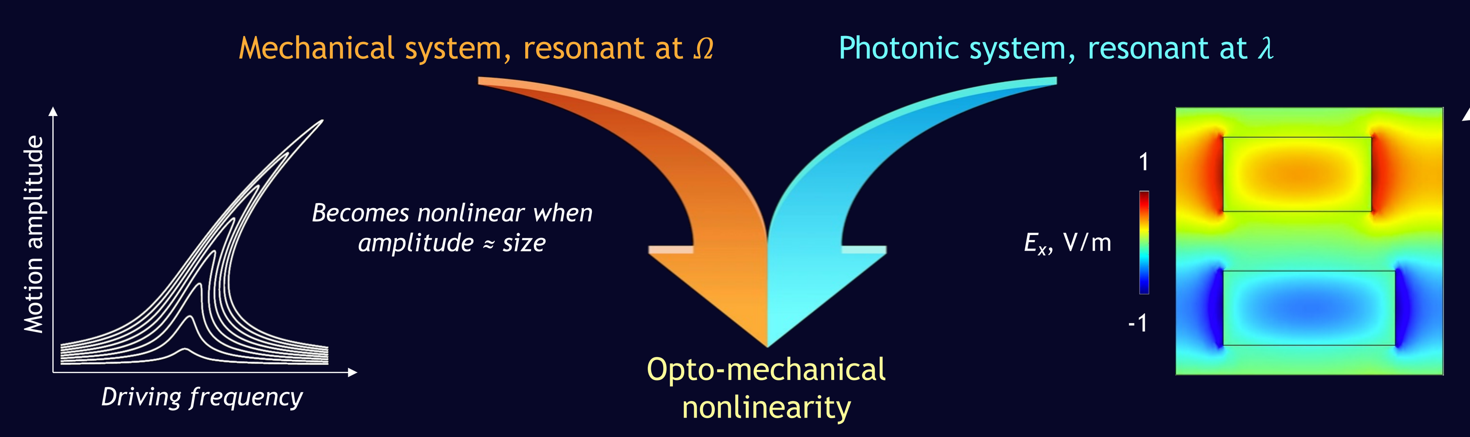
- Metamaterial of Si nano-bricks on flexible, free-standing Si_3N_4 beams
- Optical forces induce nanometric relative displacements of beams *differently for FWD and BWD illumination directions*

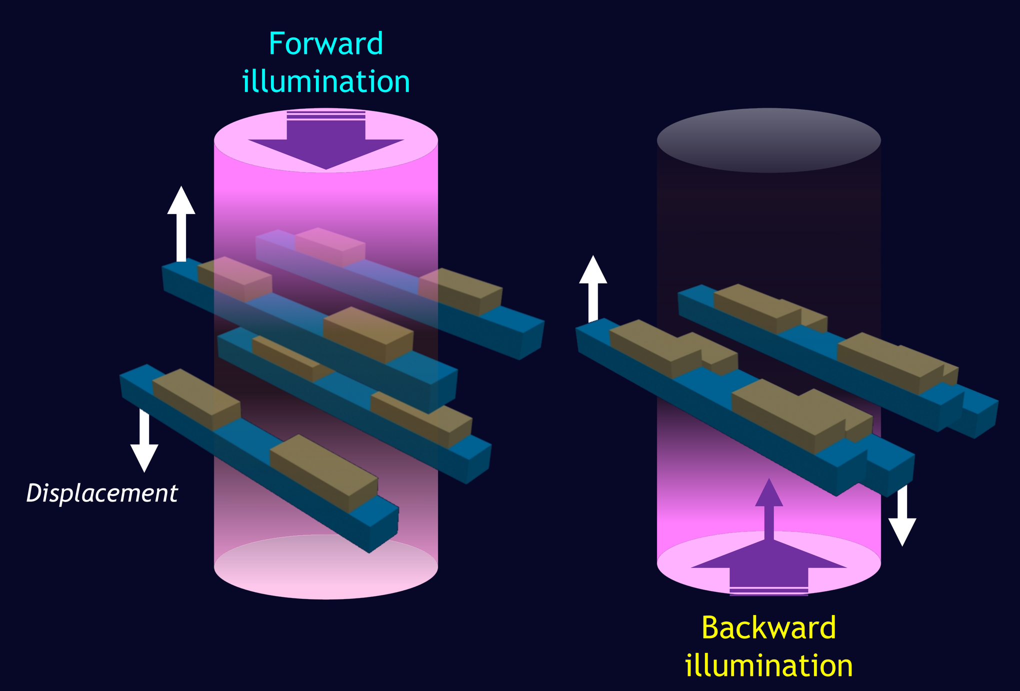
→ Strong differential mode conversion

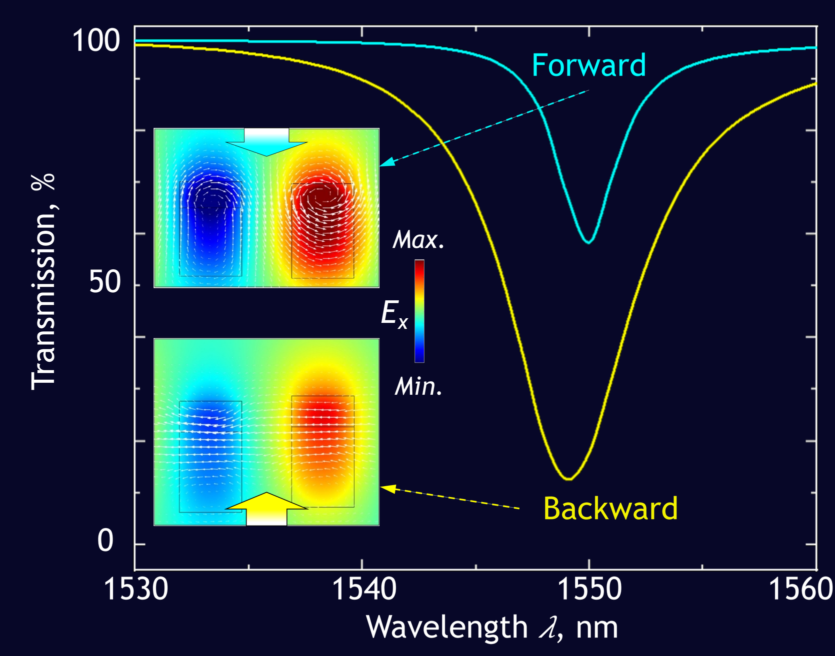
→ Spectral dispersion of transmission different for FWD/BWD directions

✸ We utilize opto-mechanical nonlinearity:

- Strong nonlinearity at low intensity via coupling of optical and mechanical resonances in an all-dielectric metamaterial



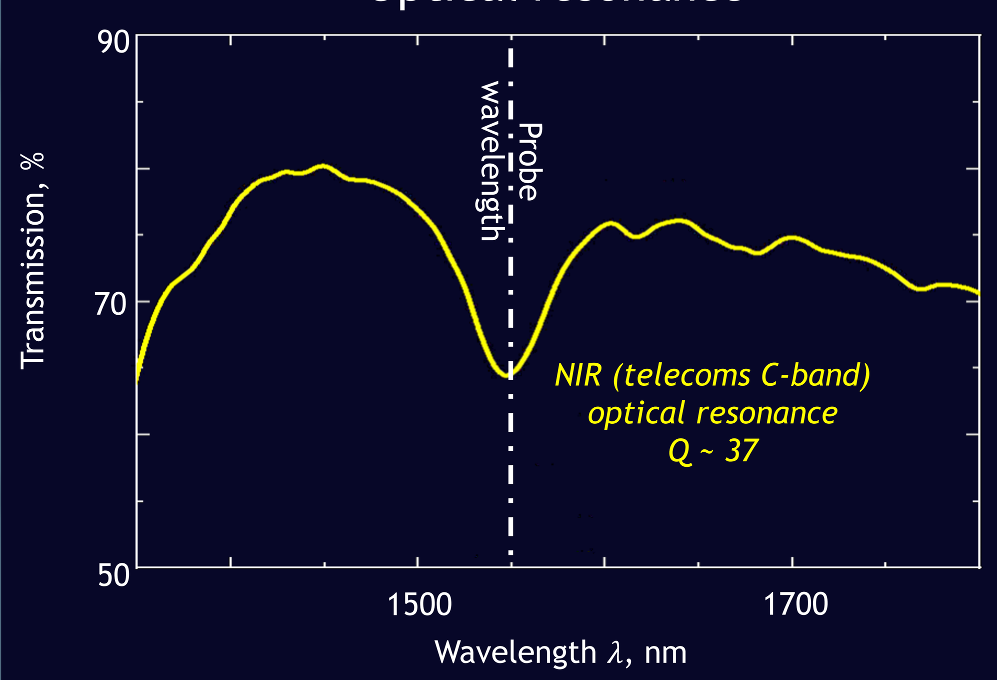


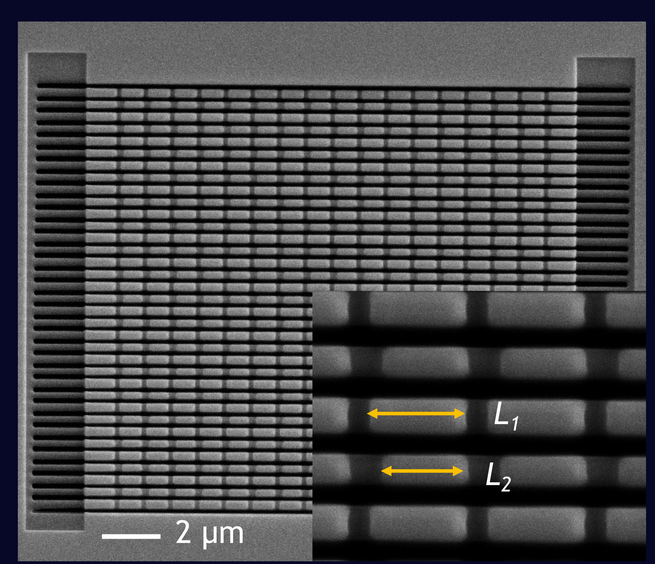


- Nanoscale structural reconfiguration driven by optical forces
  → directionally asymmetric change in optical properties
- Theory: Zhang, *et al.*, Light Sci. Appl. 2, e96 (2013)

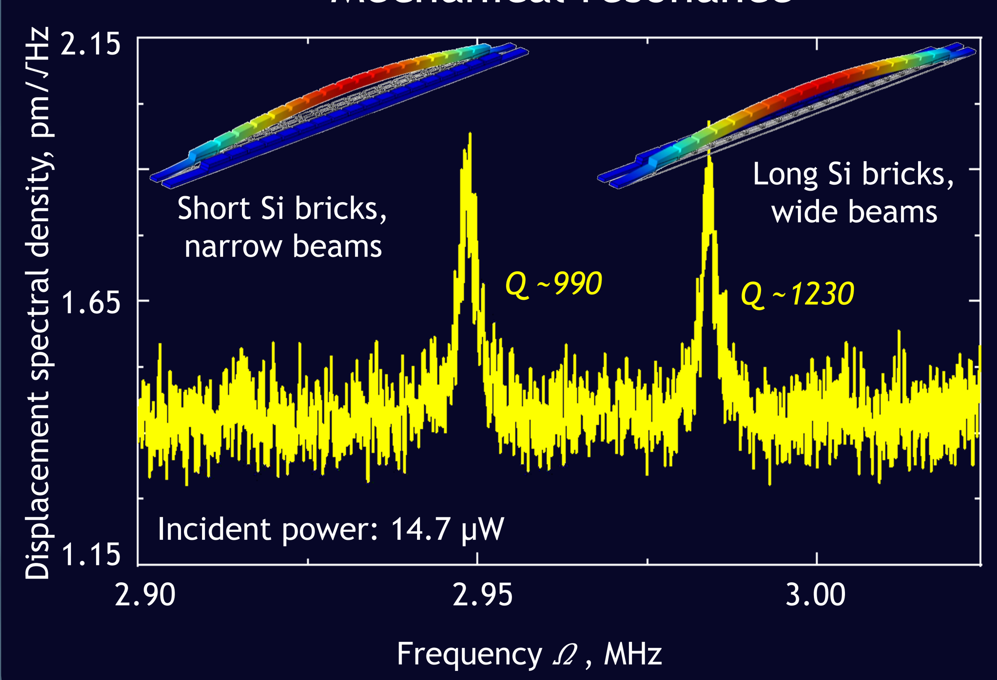
Metamaterial Optical & Mechanical Resonances

Optical resonance



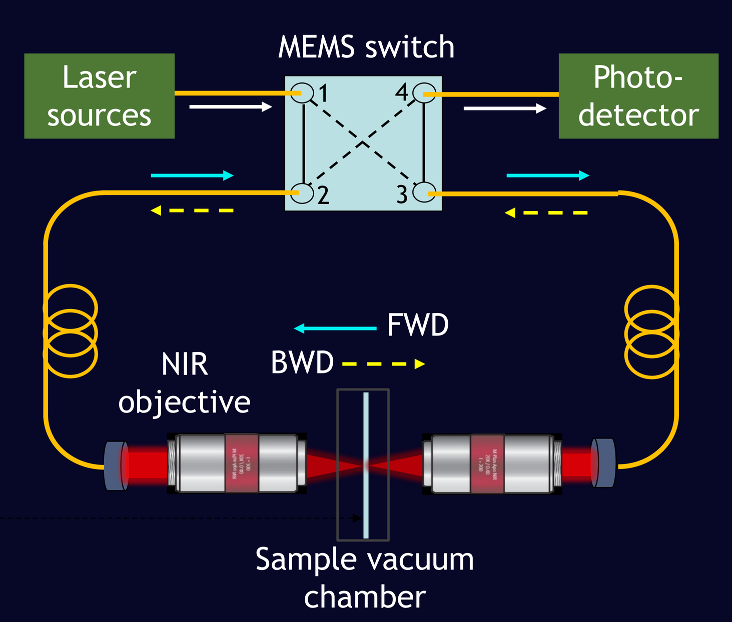


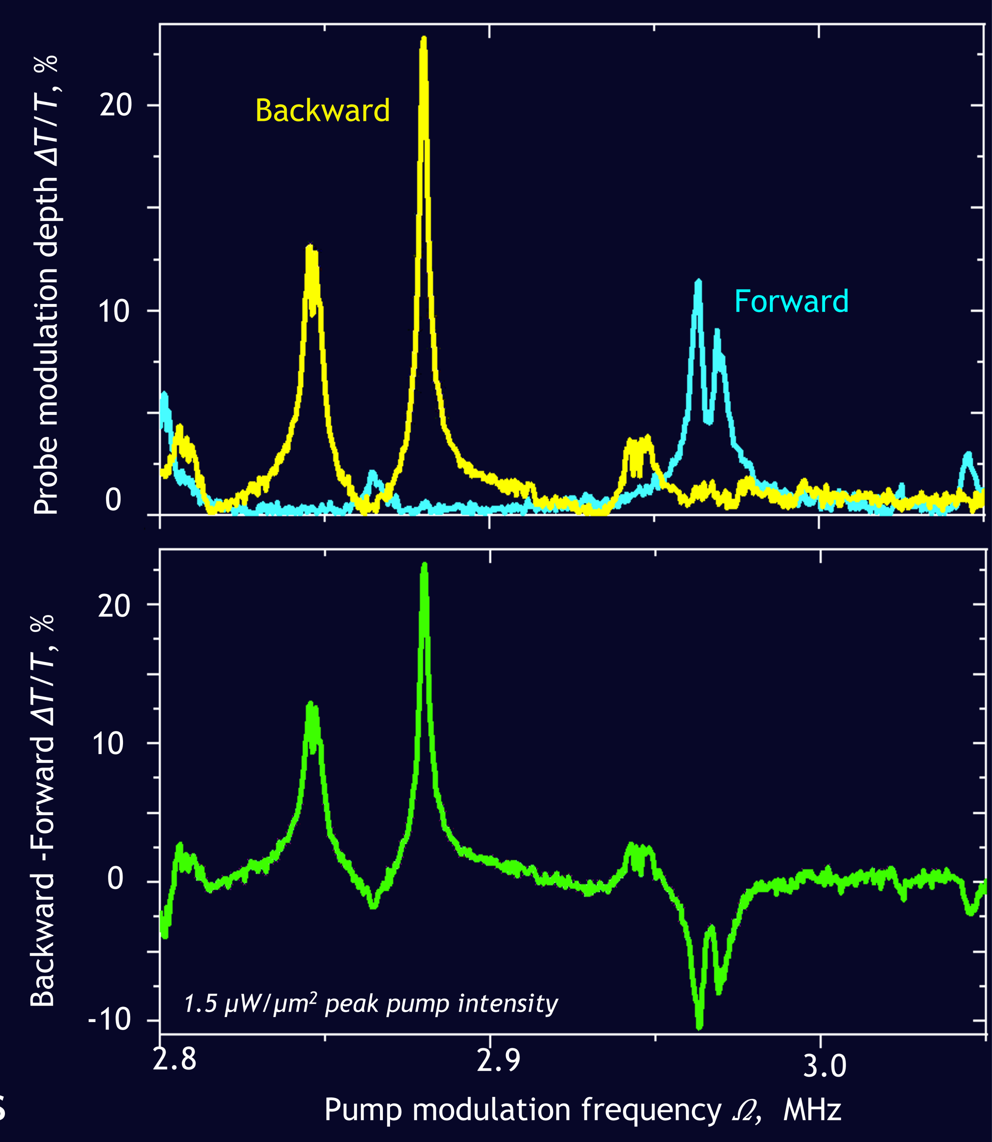
Mechanical resonance



- Si/Si_3N_4 bilayer structured by focused ion beam milling
- Thermal (Brownian) motion detected at beams' fundamental resonant frequencies
- RMS displacements of ~250 pm

Optically-induced Transmission Asymmetry





- Experiment requires identical FWD/BWD paths & illumination conditions, i.e. power, spot size, polarization.
- Pulsed 1550 nm, 30 μW pump beams drives motion at beams' mechanical resonance frequencies

→ Transmission change for CW 1540 nm probe.

- Complex pattern of frequency- and pump power-dependent oscillatory modes
- Backward-Forward difference up to ~23% at μW pump powers

Summary

- Nanoscale displacements of meta-molecules lead to strong changes in metamaterial optical properties
- Mechanical nonlinearity coupled to optical resonance provides giant optical nonlinearity

→ Nonlinear asymmetric transmission at μW/μm²

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