Detecting Torsional Modes in Tapered Optical Nanofibers

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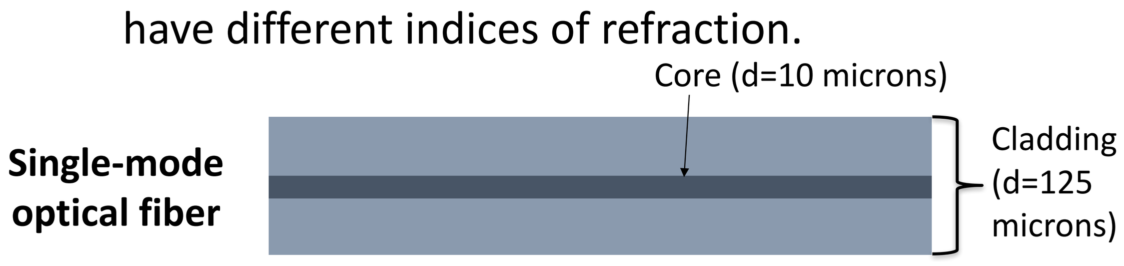
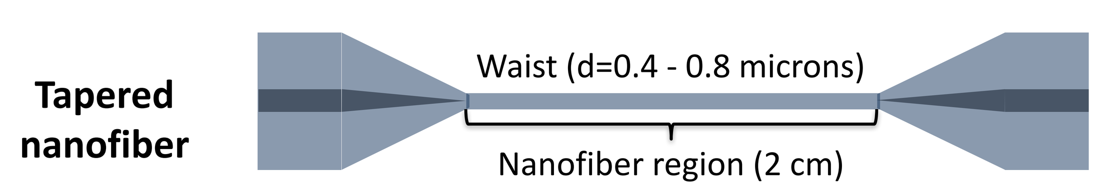
What are nanofibers?

- Nanofibers are created using regular optical fibers (similar to the ones used for optical communications and internet services).
- Optical fibers consist of two concentric cylinders of glass, called the **core** and the **cladding**, which have different indices of refraction.



- A **heating and stretching** process makes a tapered nanofiber out of a regular optical fiber.
- In the nanofiber region, the core disappears; the cladding becomes the core; and the vacuum outside the fiber effectively becomes the cladding.

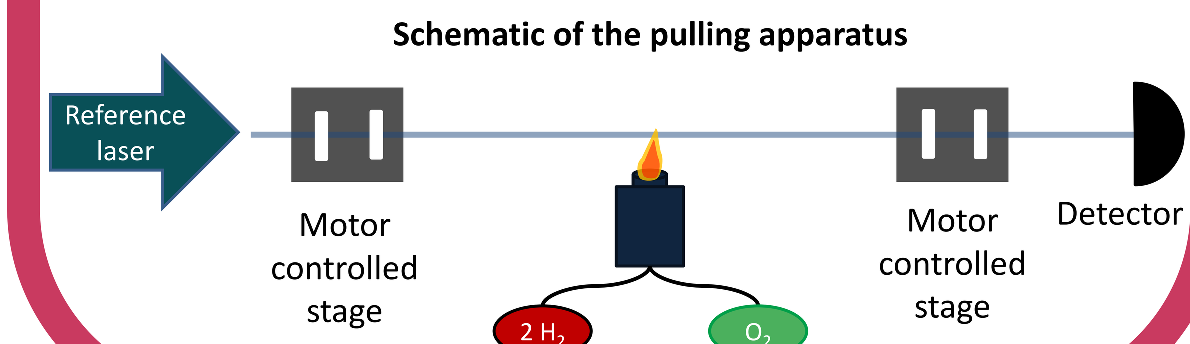


- The nanofiber region is a sub-wavelength diameter, so **some light travels outside the nanofiber** as an evanescent wave and re-enters the fiber at the other end of the region.
- The taper to the nanofiber region includes a linear taper and small exponential taper whose specifications can be important for the presence of torsional modes.

How do we make them?

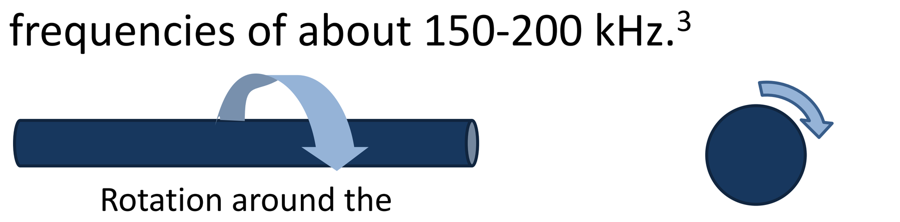
- A pulling apparatus **heats and stretches** a regular optical fiber so it has a tapered nanofiber region.
- A **hydrogen-oxygen flame** whose only byproduct is water heats and softens the fiber without depositing any residue on the fiber. Any residue or small piece of dust can deform or break the fragile nanofiber region.
- **Motor-controlled stages** slowly pull apart the fiber according to preset parameters for fiber size.
- A **reference laser** monitors transmission through the fiber during this process (transmission is usually ~97%, with 3% loss due to the pull).
- ***This summer we helped rebuild this apparatus after it was taken apart and moved. We can now make new nanofibers.***

Schematic of the pulling apparatus



What are torsional modes?

- Torsional modes are the **twisting mechanical modes** of the nanofiber. They are expected to be at frequencies of about 150-200 kHz.[3]



Aim

To excite and observe torsional modes in a tapered optical nanofiber

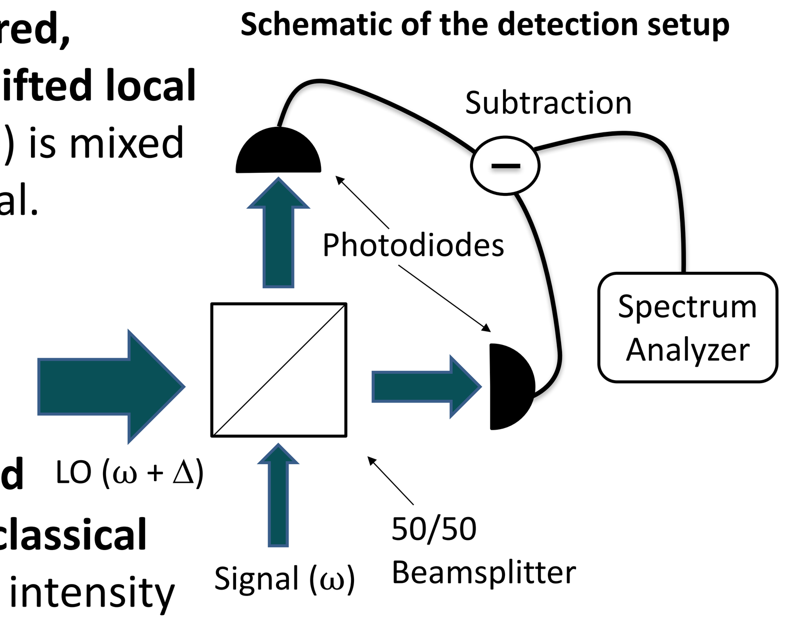
Motivation

- The **mechanical modes** of the nanofiber have been shown to impart frequency kicks to transmitted light.[1] We wish to systematically study these opto-mechanical interactions with the intent to generate **correlated frequency sidebands**, which can be useful in **quantum metrology** and **optical communication**.
- Nanofibers can be used to probe single trapped atoms with applications in **quantum memory**.[2] Therefore, we want as complete as possible an understanding of the behavior of a nanofiber as a **waveguide**.

How do we detect torsional modes?

- We use a technique called **heterodyne detection** to observe the torsional modes.
- A **high-powered, frequency-shifted local oscillator** (LO) is mixed with the signal.
- The currents from the photodiodes are **subtracted to eliminate classical noise** such as intensity fluctuations of the laser.

Schematic of the detection setup



- The presence of the local oscillator **amplifies** the signal and thus raises the signal above the electronic noise floor. This amplification allows us to see weak signals that would otherwise be obscured by electronic noise. Heterodyne detection shifts the frequency noise on the signal up and away from the low-frequency noise of the environment.
- A **beat note** will be visible on the spectrum analyzer at the frequency difference.
- ***Our work this summer involved building a heterodyne detection setup and coupling light through the nanofiber to the setup.***

Acknowledgements

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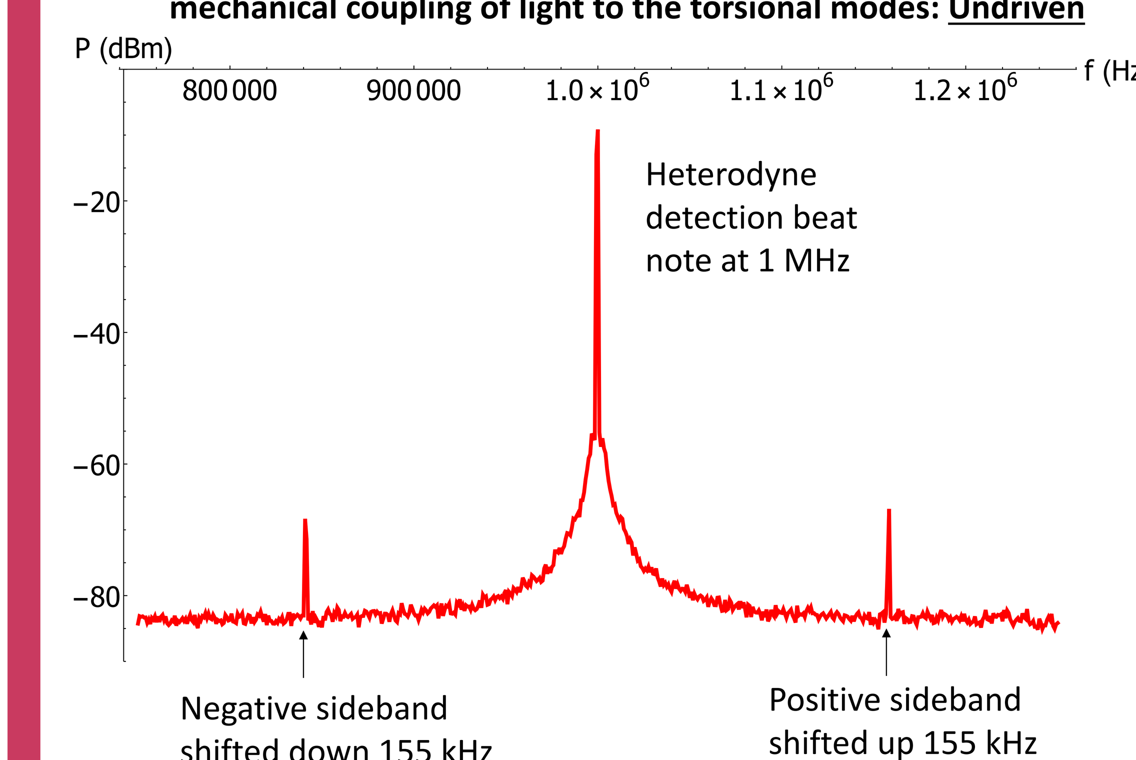
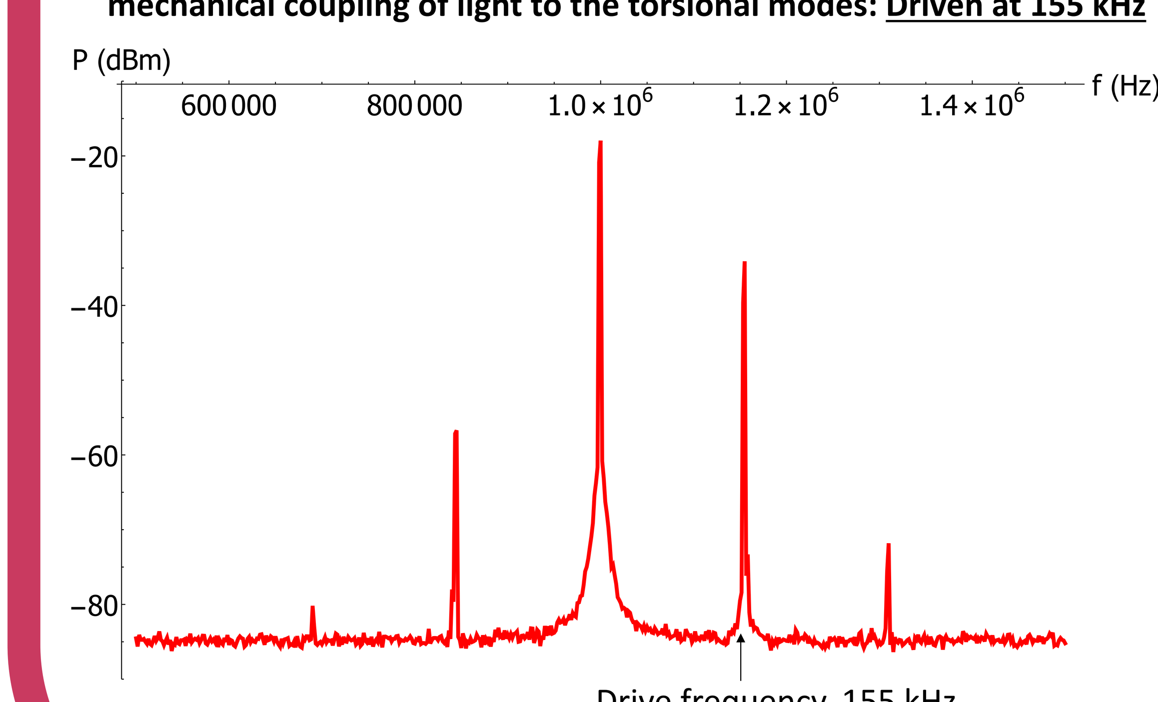
What is the signature of a torsional mode?

- The torsional modes couple with the light transmitted through the fiber. This is an **opto-mechanical effect:** interactions between light and the mechanical vibrations of macroscopic objects.
- We see this effect as **sidebands** to our main peak at ±155 kHz, which is within the 150-200 kHz range we expected to see based on previous studies.[1]
- The light can couple to random thermal excitations, or the torsional modes can be driven by modulating the signal at the frequency of the torsional modes.
- The sidebands were largest when we sent **circularly polarized light** into the fiber, which again confirms the findings of previous studies.[3]

Noise power vs. frequency plot with sidebands caused by opto-mechanical coupling of light to the torsional modes: Undriven



Noise power vs. frequency plot with sidebands caused by opto-mechanical coupling of light to the torsional modes: Driven at 155 kHz



Both the first and second harmonics are excited

Where do we go from here?

- We can now pull nanofibers with the parameters of our choosing (diameter, length, shape of taper).
- We have a setup for exciting and detecting the torsional modes of the nanofiber.
- **Future goals include**:
  - Testing whether the positive and negative sidebands are correlated and if so, using these torsional modes to generate classically squeezed light (light with modified noise properties).
  - Exploring the effects of the parameters we can control (diameter, length, shape of taper) on the expression of the torsional modes across different fibers.

References

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