A Compact Atmospheric Entry Speed Sensor for Mars Missions

Benjamin Wise and Vahid Eghbalifarkoosh

Micro-Sensor Laboratory, Department of Mechanical Engineering

Objective and Motivation

•Miniaturization of laser-based velocimetry system measuring hypersonic space vehicle entry speed

•LIDAR-based system collects Rayleigh back-scattered light and analyzes its Doppler shift to determine the relative speed of the entry vehicle

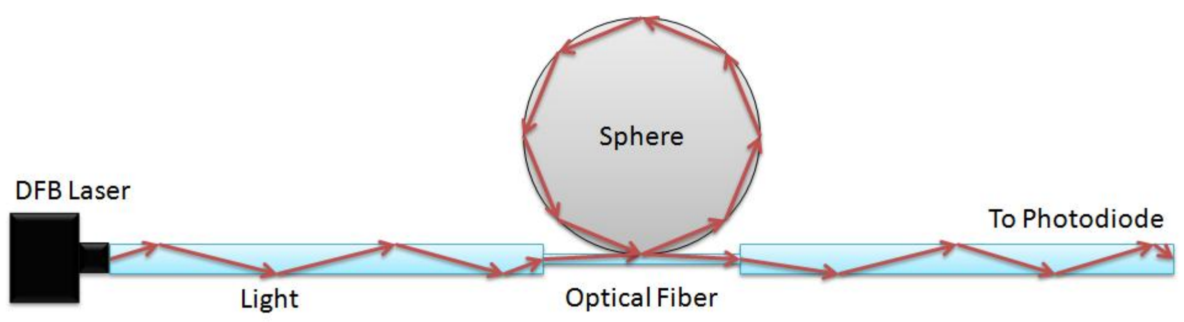
•Doppler shift is determined using whispering gallery modes of spherical microresonators, rather than the typically used Fabry-Perot interferometer, allowing miniaturization

•Rayleigh scattered light is either free-space or fiber coupled (using single mode optical fiber) to the polymer microresonator.

•Resonator diameter is modulated by a scanning Piezo stack allowing shifts in the optical modes to be analyzed, resulting in near real time calculation of atmospheric entry speed

Measurement Principle

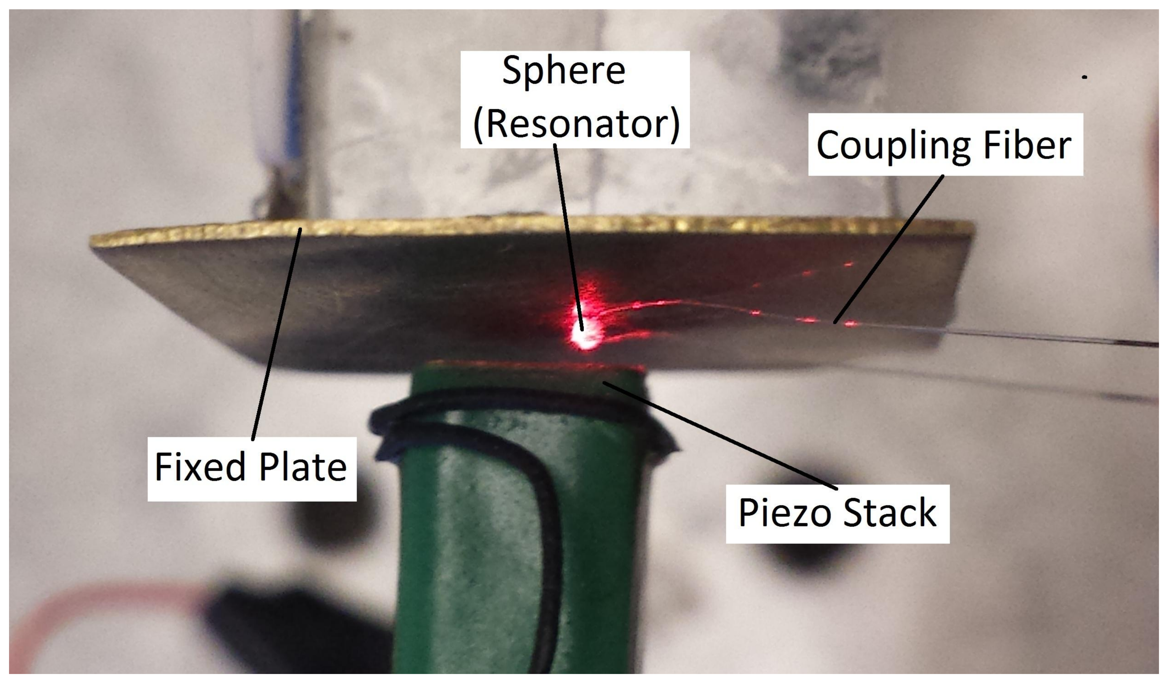
Whispering Gallery Mode Phenomena

- Demonstrated by Lord Raleigh in 1910, it is the phenomena that occurs when sound waves propagate along the surface of a dome, allowing a whisper to be heard a great distance away.
- Similar phenomenon can occur in circular optical cavities; light from tunable laser is coupled tangentially via optical fiber into dielectric microsphere (silica, PDMS, PMMA, etc.)
- The light experiences total internal reflection and travels circumferentially.
- 

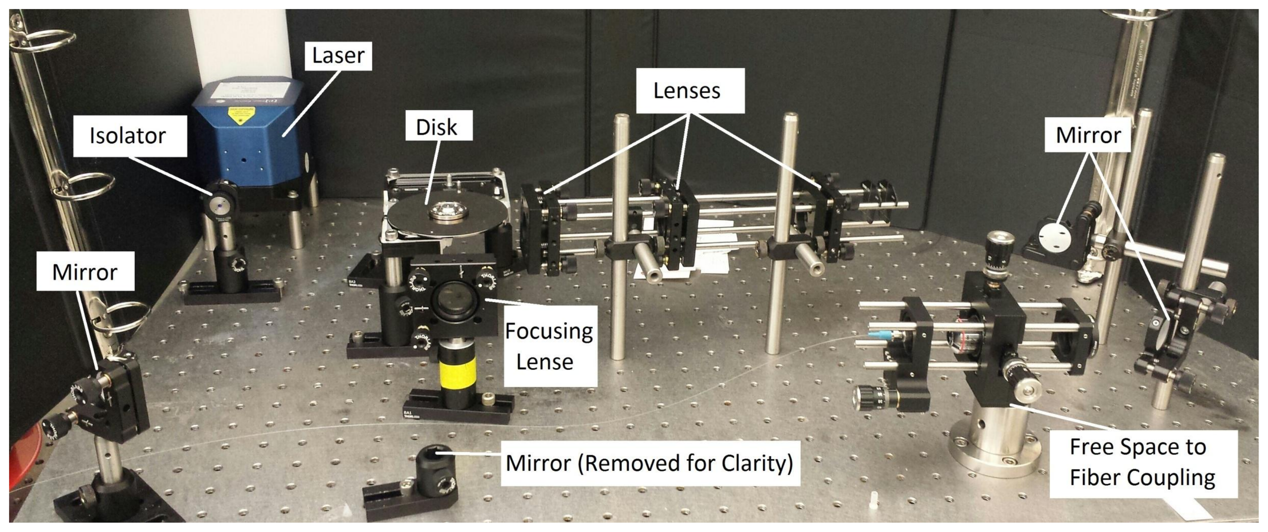
refraction) and the wavelength at which resonance occurs, allowing us to determine any change in wavelength (caused by Doppler Shift) by varying the radius of the sphere in a predictable way:

$$\frac{\Delta n}{n_0} + \frac{\Delta r}{r} = \frac{\Delta \lambda}{\lambda}$$

Current Research



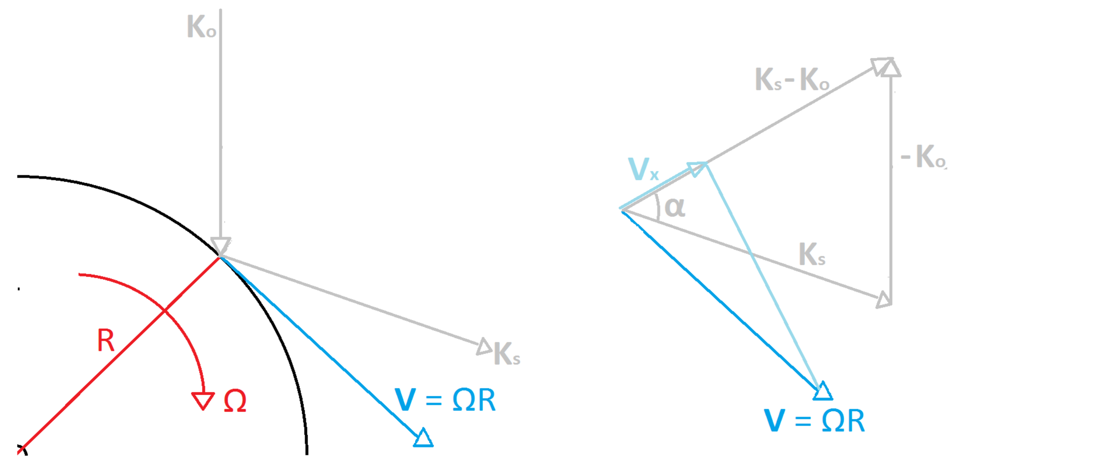
•By modulating the radius of our polymer microsphere with a regular waveform using the Piezo stack, we are able to determine baseline wavelengths at which resonance occurs, then as the light is Doppler shifted, we are able to determine Δλ to calculate the speed of the atmospheric entry vehicle. (Above: During operation, the resonator is in contact with both the fixed plate and Piezo stack.)



•In order to provide a more robust proof of concept during this phase of research, we are attempting to measure the Doppler shift produced by the rotational motion of a HDD Disk, which is able to attain tangential speeds of >60 m/s (at 12,000 RPM), greater than our conservatively estimated measurement precision of 20 m/s with polymer and 2 m/s with silica microresonators. (Above: Free space optical system for measuring Doppler shift from a rotating HDD Disk.)

•Ultra-small line-width laser (Above: blue cube) allows us to theoretically measure Doppler shifts associated with velocities of less than 0.1 m/s. At this point, our sensing element becomes limiting, however, improved manufacturing methods, such as micro-fabrication of resonator and waveguides should allow increased sensitivity.

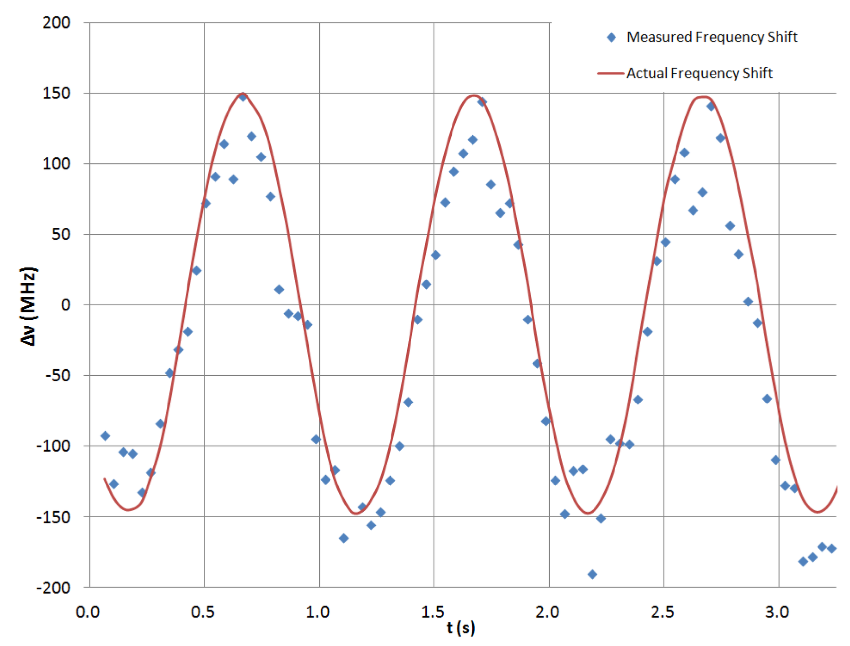
Current Research (continued)



•A vector representation of measuring the Doppler shift of light scattered from a rotating object, where Ko is incident and Ks scattered light. Doppler shift, $\Delta f = (2\ V_x\ /\ \lambda)\ \sin\ (\alpha/2)$, can be measured from scattered light Ks incident on a photo detector.

•See Ötügen, et. Al, *"A new laser-based method for strain rate and vorticity measurements,"* for more details.

Real-Time Sensing



•Initial data from tests in the IR spectrum, simulating a Doppler shift by varying the laser frequency, (Above: Red Curve) show that our sensing system is able to detect changes in frequency of laser light (simulated Doppler shifts) at a rate of at least 25Hz providing near real time sensing of Doppler shifts.

Future Steps

Future iterations of this project will include micro-fabrication of resonators and waveguides to increase measurement precision, as well as direct measurement of Rayleigh scattered Doppler shifted light.

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· Micro-Sensor Laboratory, Lyle School of Engineering, Southern Methodist University, Dallas, TX 75205 ·

· +1-214-768-3255 ·