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Finite Element Method Analysis of Resonant Cavity for Whispering Gallery Acoustic Sensing Microscopy

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Abstract

Whispering Gallery Acoustic Sensing (WGAS) is being developed by Dr. La Rosa's group (PSU-Physics) as a non-invasive method for controlling the probe-sample distance in tuning fork (TF)-based scanning probe microscopy (TF-SPM). The novel idea behind WGAS lies in exploiting the frame of the microscope also as a **resonant acoustic cavity** to sensitively monitor the nanometer-sized amplitude of the nano-probe attached to the TF. To improve the WGAS detection sensitivity, the microscope-frame's frequency response needs to be optimized to match the TF-probe resonance frequency. However, to attain analytical solutions of the eigen-frequencies associated to the current microscope frame is a very complex task due to the cavity's asymmetric geometry. Here we use finite element methods (FEM) as an alternative approach to find out the frequency response of a variety of cavities having different geometries. We specifically study the cavities' response around 32 kHz (the TF-probe resonance frequency).

Introduction

Whispering Galley Acoustic Sensing: Remote acoustic detection of nanometer-sized oscillations of probes used in scanning probe micros-copy.

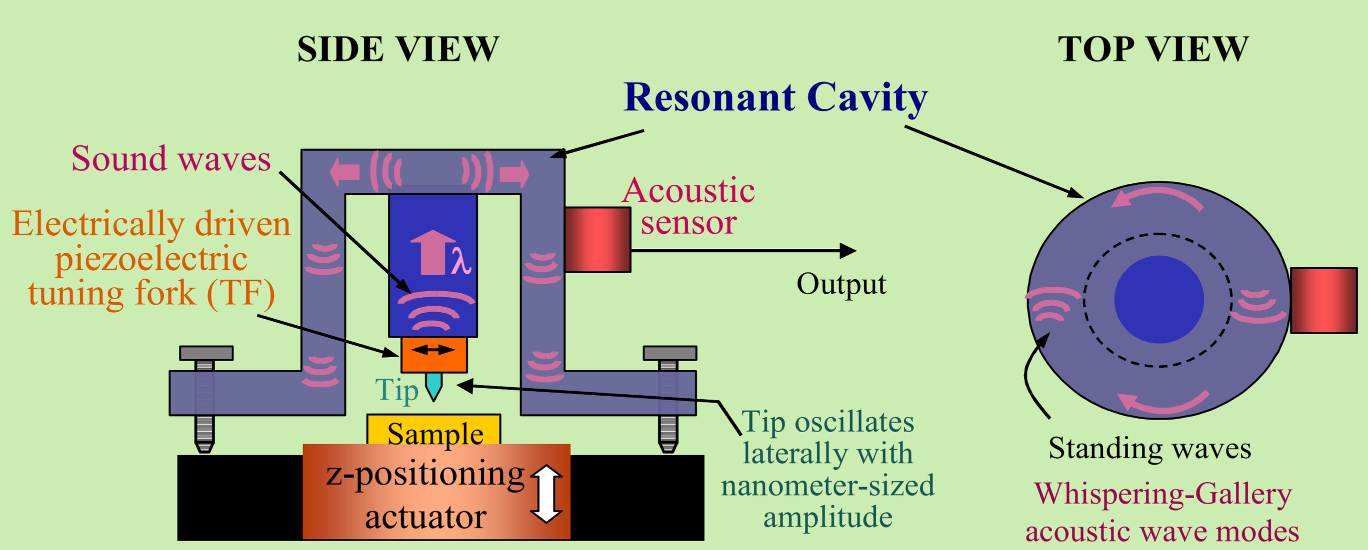


Fig.1 Whispering galley acoustic sensing.

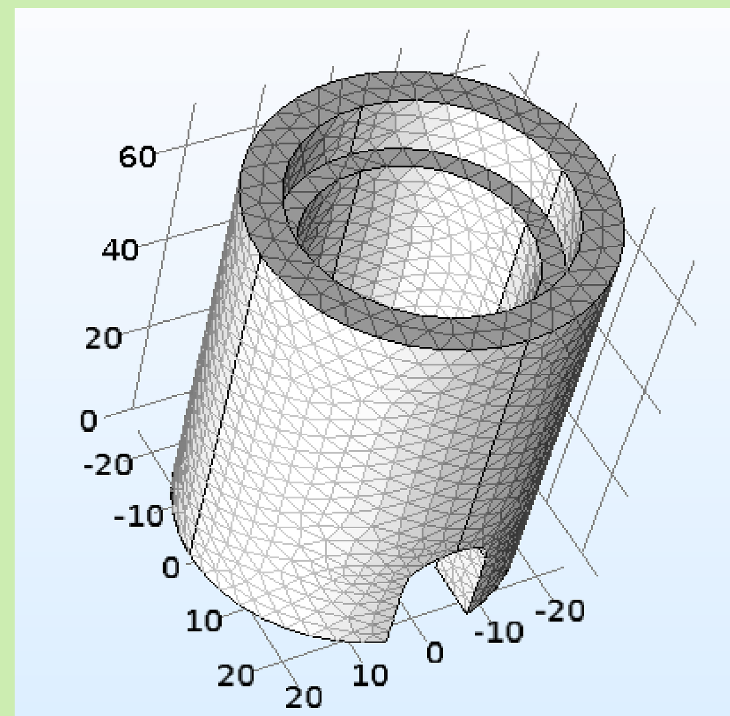
♦As the tip oscillates laterally, acoustic waves are engendered into its TF holder, travel upwards, and then settles standing waves on the periphery of the cavity. An acoustic sensor is placed at a proper position to maximize the detected signal.

♦For maximum detection sensitivity the acoustic cavity's resonance should match the resonant frequency of the tuning fork.

♦In this poster session, we focus our studies on the acoustic response of different cavities, using FEM, aiming at optimizing the WGAS acoustic detection sensitivity.

Setup

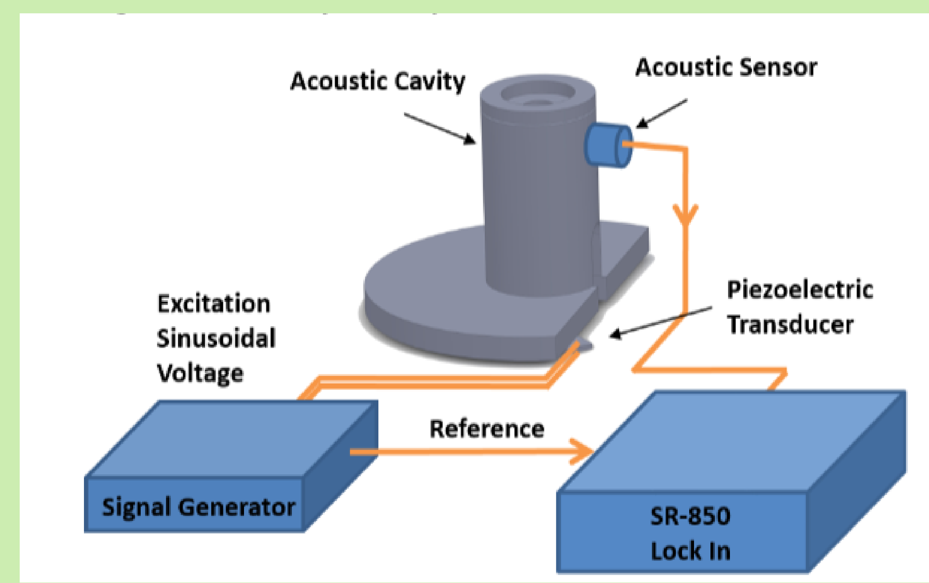
Fig.2 Simulation Setup:



♦Simulations with COMSOL Multiphysics are used to map the amplitude of mode-vibrations across a replica of cavity used in the experiments.

♦The size of the mesh is refined until further call reduction doe not produce any significant change in the mode mapping.

Fig.3 Experimental Setup:



♦A small piezo plate (placed at the bottom of the cavity) is used to excite a mode of frequency ω.

♦The acoustic signal is synchronously detected with a lock-in amplifier (referenced to the frequency ω).

♦A frequency sweep (while keeping the sensor at a fixed position) allows to identify localized spectral response.)

Result and Discussion

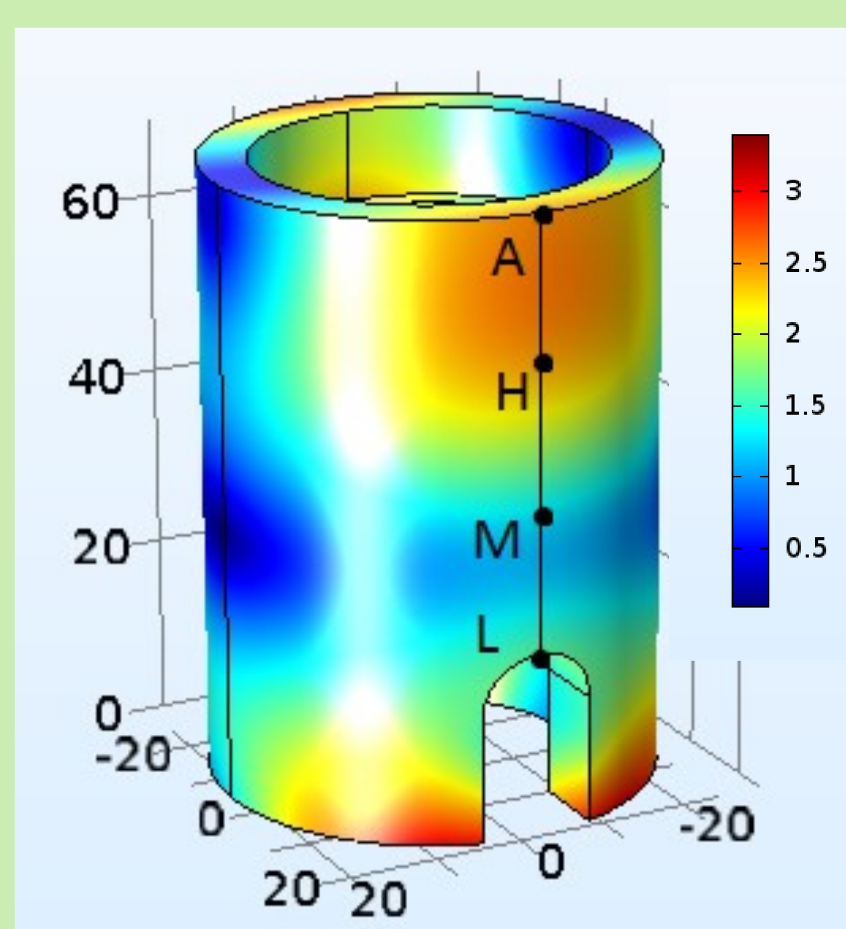


Fig.4 Mapping of a particular acoustic mode w/2pi = 28 kHz

Discussion 1:

- Mesh quality highly effects the simulation.

- Acoustic signal is high at edge point of the cavity. This show potential of using a pentagon instead of cylinder cavity.

Result and Discussion

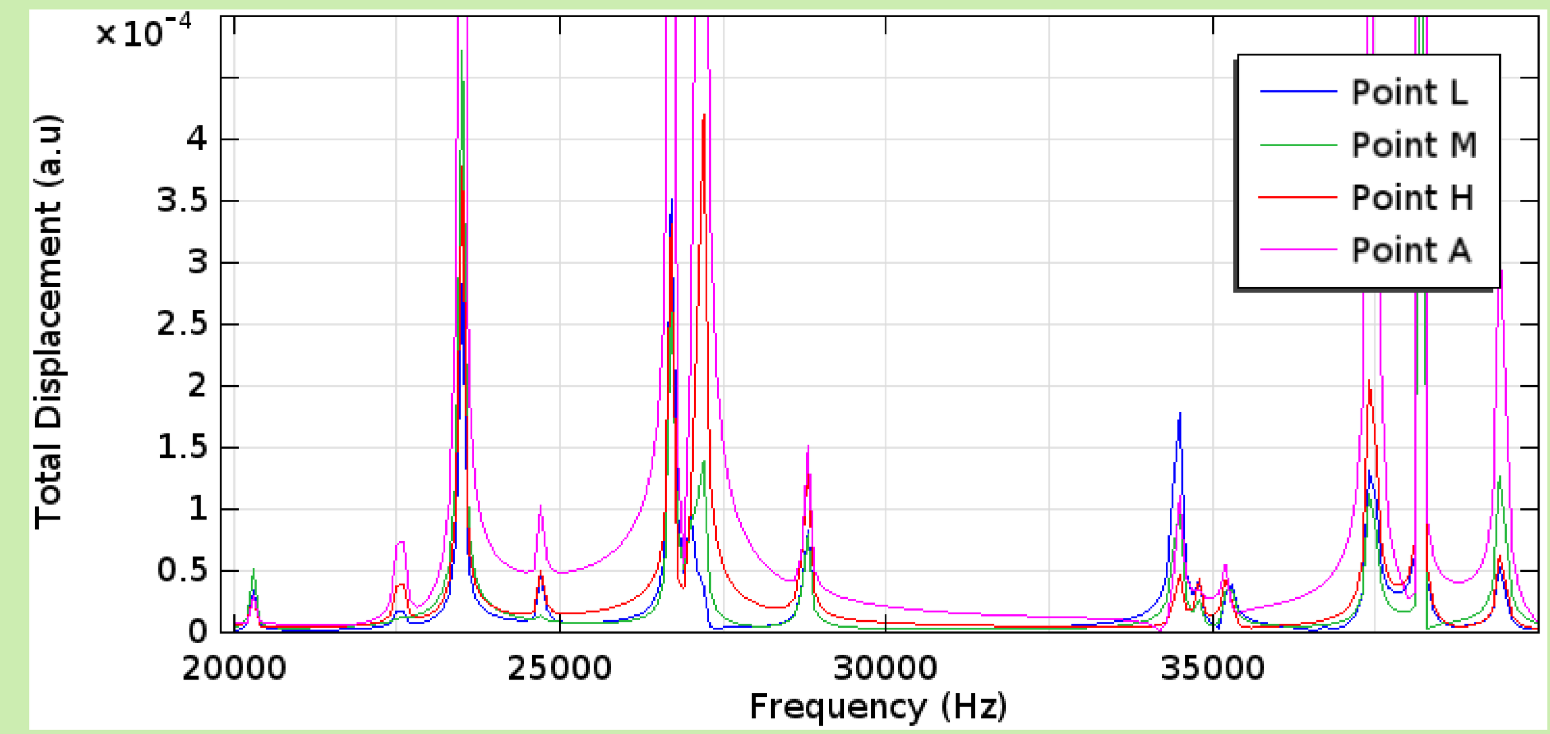


Fig. 5 Frequency Response: Total displacement of the acoustic mode at different locations of the cavity vs frequency.

Discussion 2:

- The frequency response agrees with the theory eigen-frequencies.

- The spectral position of the peaks do not change as the sensor is placed at different locations around the periphery of the cavity.

Future Work

For further investigation:

♦Change the diameters and other dimensions of cylinders to find the relations between cylinder geometry and frequency response.

♦Verify the measurement result with the simulation results.

♦Simulate and measure the complex setup with the base under the cylinder to get closer to the WGAS Microscopy setup.

References

♦La Rosa, R. Nordstrom and S. K. Padigi, Whispering Gallery Mode Ultrasonically Coupled Scanning Probe Microscopy, US Patent No 8,037,762 B2 issued on 10/18/2011.

♦La Rosa, N. Li, R. Fernandez, X. Wang, R. Nordstrom, and S. K. Padigi, Whispering-gallery acoustic sensing: Characterization of mesoscopic films and scanning probe microscopy applications, *Rev. Sci. Instrum.* **82**, 093704 (2011).