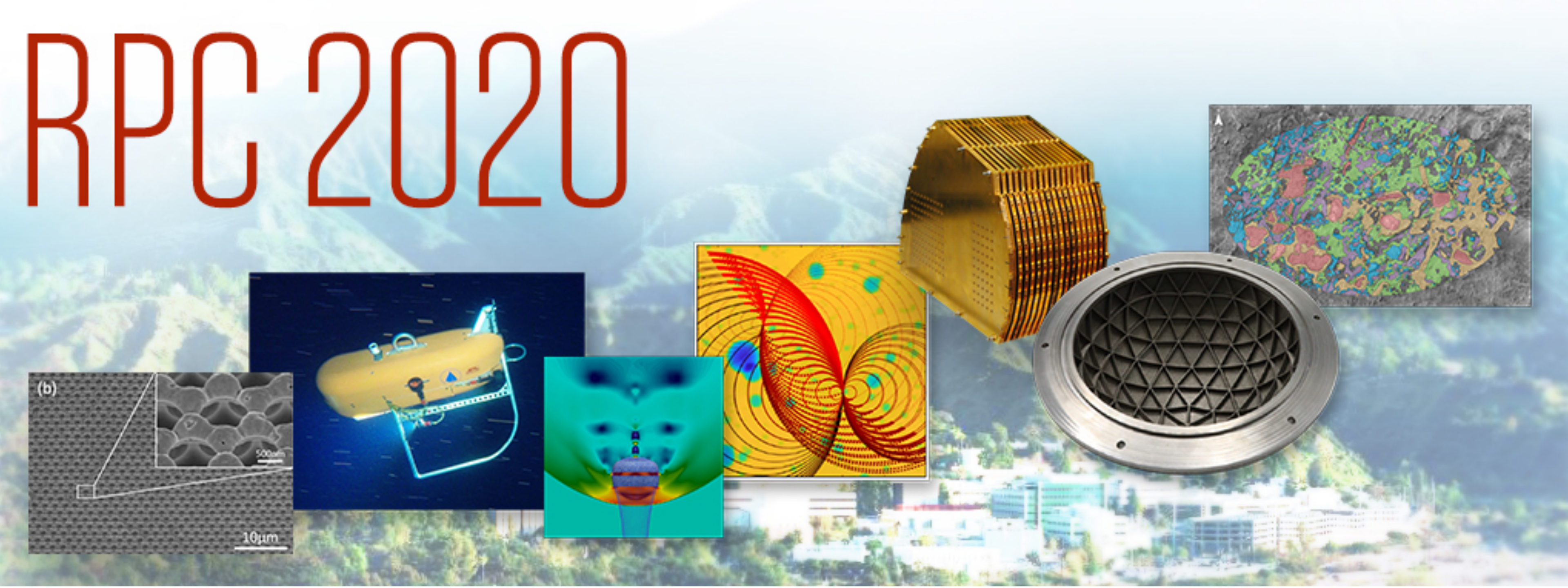

Virtual Research Presentation Conference

A Silicon Circle Involute Flexure Spring Seismometer

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Program: Spontaneous Concept

Assigned Presentation #RPC-210

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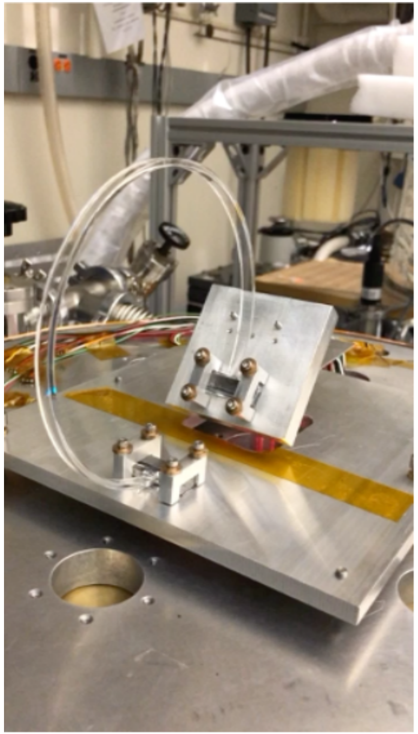
Introduction

Abstract

The sensitivity of any broadband mechanical seismometer design is limited by the unavoidable energy loss occurring during its periodic motion. Therefore, the goal is to first minimize all identifiable dissipation mechanisms, (air damping, tribology of surface contacts, electromagnetic losses, etc...). Then, the ultimate performance of a seismometer design will be set by the thermodynamic laws of physics in the material, known as the Fluctuation-Dissipation theorem. This theorem relates thermal fluctuations at a given temperature to dissipation of energy.

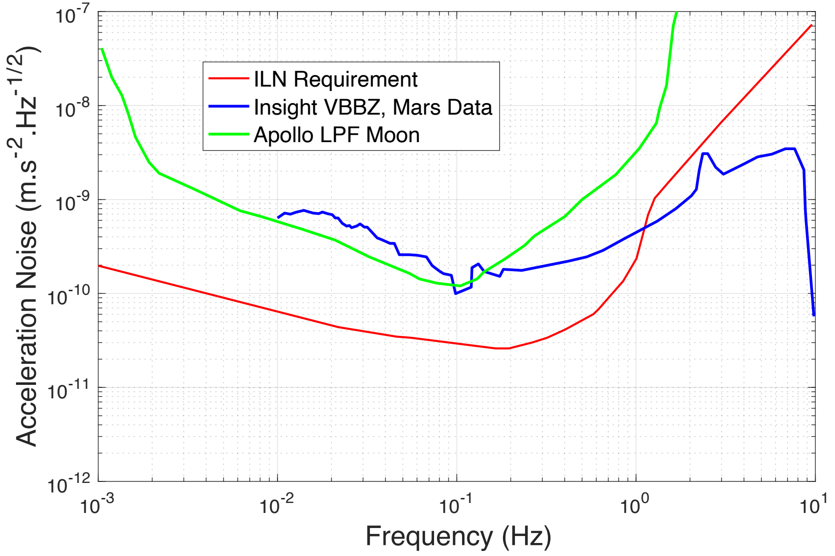
In a mechanical system, the motion noise depends on the temperature and loss angle (dissipation) property of the spring material. In the real world, where temperature is finite, the only way to minimize this thermally-induced dissipation mechanism is to choose a material with the lowest loss angle.

We propose to incorporate a single-crystal Silicon spring into a seismometer design for a lower thermal noise limit than any other broadband seismometer.

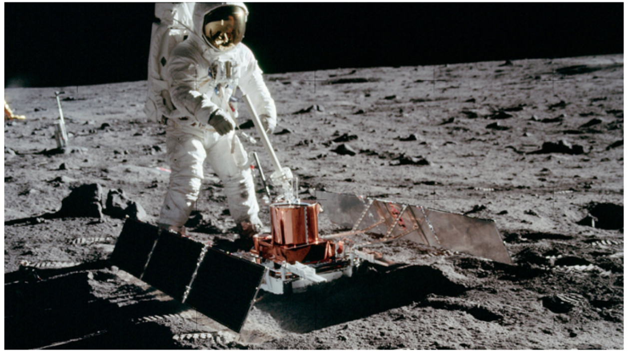


Planetary Seismometer

The state-of-the-art broadband planetary seismometers were deployed on Moon and Mars, and their sensitivity do not to meet the International Lunar Network requirements for the next generation Moon seismology; $2x10^{-10}m/s^2/sqrtHz$ at 0.001Hz.



Moon (Apollo11)

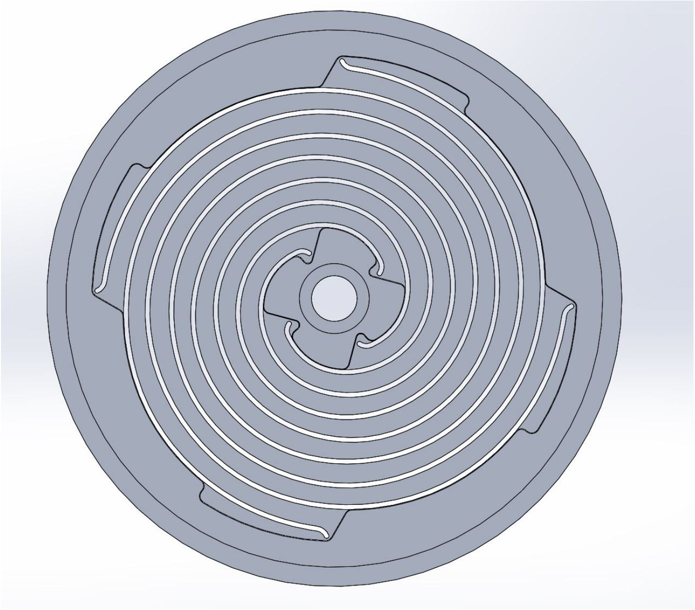


Mars (Insight)

Images credit: NASA

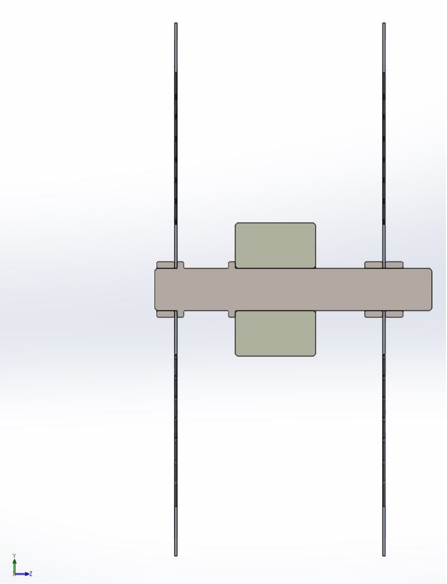
Spring Design Concept

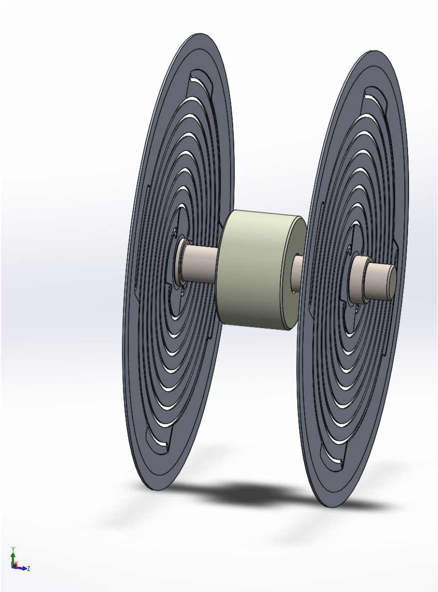
- Single crystal silicon
  - 120 mm OD, inner and outer rims ~0.55mm thick, spring leaves 0.300mm thick
  - Best specific strength, which is key parameter for springs of this type. Also, no residual stress.
  - Thicker rims for less hysteretic loss from spring motion under stress.
  - minimum strength of 1 GPa
- Four leaves, with extra half-loop
  - Much more linear than version than three leaves
  - Four leaves is best to use with Silicon, since it is orthotropic with 90 degree rotational symmetry
  - Leaf flapping modes start at 40 Hz



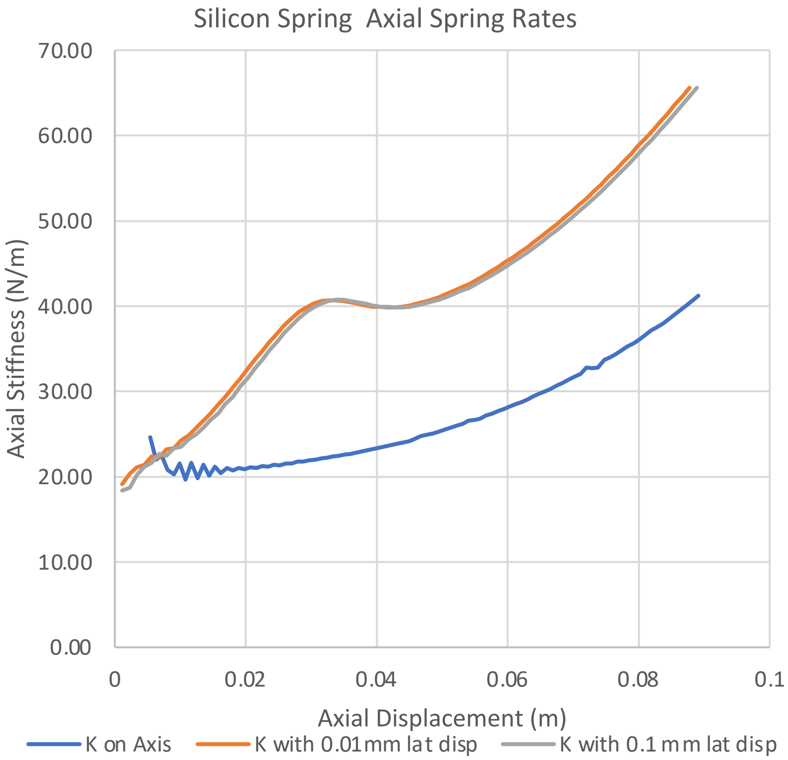
Seismometer Core Design

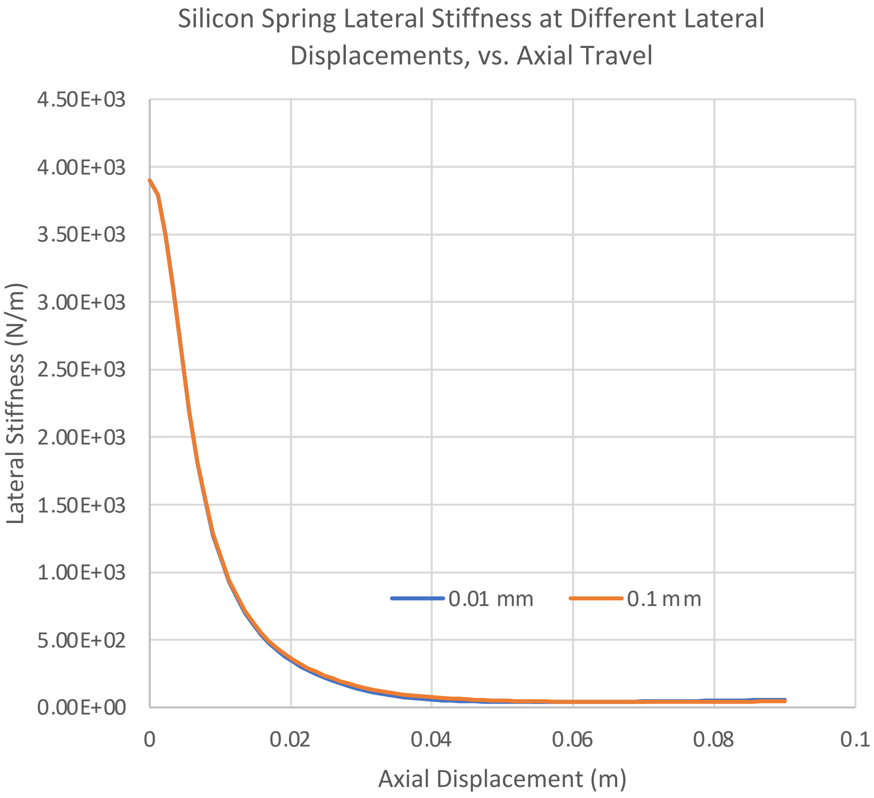
- Mounting shaft with two integral faying surfaces
- Central Tungsten mass (overall mass ~280 grams)
- Expected first resonance ~2.1 Hz
- Differential capacitance sensor attaches on +Z end
- Mounting the springs opposed to cancel rotation.
- Expect about 8.7 degrees of Z rotation at 1 G(earth) (~55 mm deflection).



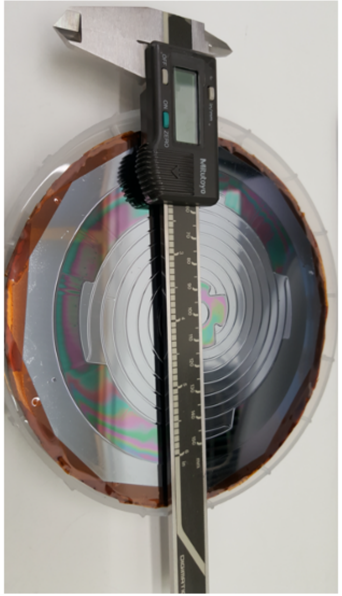


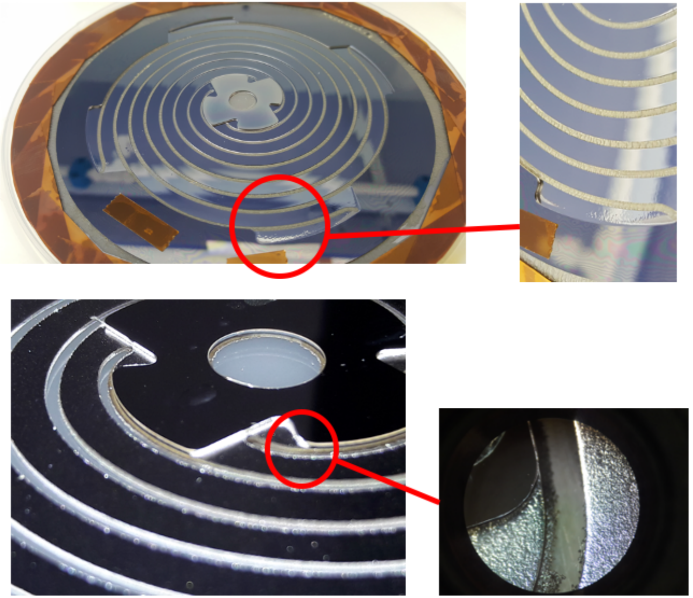
Key Analysis





Spring fabrication status





- The etch on the edges was ~200um deeper than in the center.
- The etch uniformity on the STS etcher is poor.
- We plan to use a SOI (silicon on insulator) wafer to mitigate the problem with the non-uniformity of the STS etcher

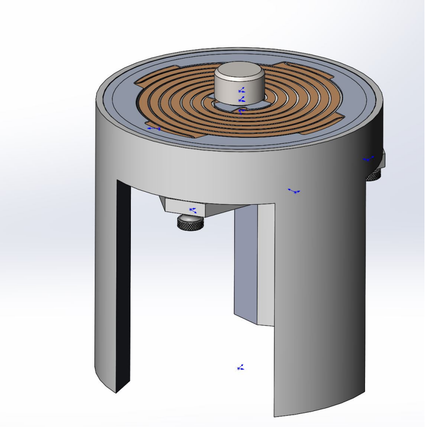
Summary

Significance

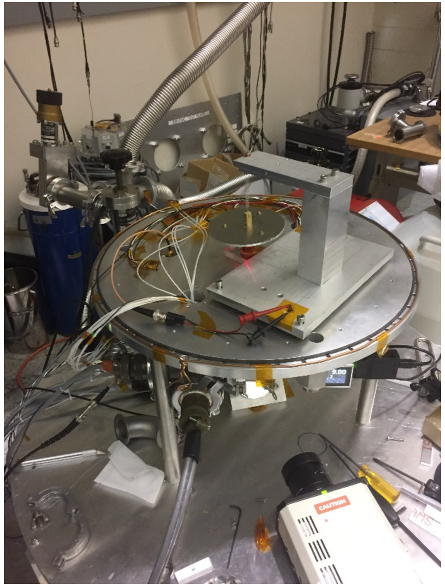
- A current lunar seismometer was deployed by the Apollo 11 astronauts. Analyses of the Apollo seismic data have changed our understanding of lunar internal structure.
- The NASA's current Artemis program will open up new opportunities to deploy more sensitive seismometers on the Moon.
- The new single crystal Si spring could potentially become a key element for the next generation Moon seismology reaching the 2x10^-10m/s^2/sqrtHz at 0.001Hz.

Next Steps

- The spontaneous concept task was halted and ended during the mandatory lab closure due to COVID-19
- The unfinished activities are (1) the spring fabrication using SOI wafer, (2) quality factor measurement in the existing vacuum test setup



Q-test jig and the spring



Vac-chamber and laser metrology