National Aeronautics and Space Administration

Microresonator-based Etalon for Visible Light Precision Radial Velocity Measurements

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Program: FY21 R&TD Topics **Strategic Focus Area: Extra-solar planets and star and planetary formation**

Objectives

- The objective of this activity is to improve the calibration of optical spectrometers to the precision needed to detect Earth-mass planets in the Habitable Zones of solar type stars. The masses and orbits of these planets are critical to interpreting the spectra which will one day be returned by a direct imaging flagship mission.
- Spectrometers require a stable wavelength reference for calibration. Current Laser Frequency Combs (LFCs) operating at visible wavelengths are large, complex, expensive, and unreliable and Fabry-Perot etalons have not yet demonstrated performance adequate for EPRV applications.
- Our goal is to develop actively stabilized micro-etalons in the visible with an initial goal of <10 cm/s over 1-year long-term stability and with a technology path to better performance. Within this overall goal, the specific aim of this R&TD effort is to address the thermal stability of the micro-resonator etalon.

Background

- The National Academy of Science's Exoplanet Strategy Report called for a major initiative in EPRV technology to achieve the goal of detecting habitable zone Earths. NASA and NSF have responded to the NAS report with an ambitious scientific, observational and technology program to meet this challenge.
- The technology proposed here is a continuation of a development effort started last year. In Year 1 we designed, built and demonstrated a crystalline whispering gallery mode (WGM) resonator composed of MgF2 operating over an octave in the visible. Coefficients of thermal expansion and refractivity are meant to balance one another to achieve the necessary stability. In Year 2 we investigated the long term stability of the compensation layers so as to avoid drifts the seen in more conventional FP etalons.

Approach

- The MgF_2 whispering gallery mode (WGM) resonator is illuminated with a white light source to operate as a compact etalon giving a series of well-defined spectral lines in the visible band (400-800 nm). The effort in this year had four milestones of which the first three (in bold) were accomplished at OEWaves. The 4th milestone to test directly the stability of the etalon was not accomplished given the need for additional design and testing of the microresonator.
  - **Milestone 1: Design a compensation technique using a material robust against long-term drifts.**
  - **Milestone 2: Fabricate a reference engineering sample of a compensated etalon**
  - **Milestone 3: Measure the thermal turning point of the compensated device**
  - Milestone 4: Heterodyne etalon lines with several reference laser lines, ascertain stability

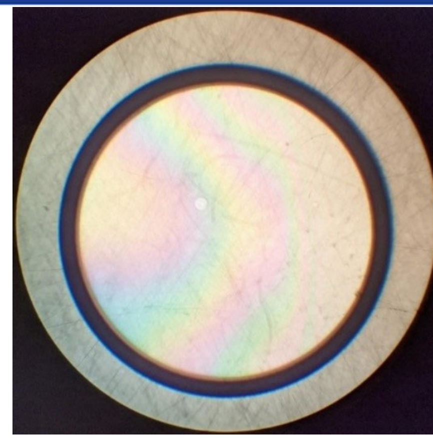

Fig 1. The fabricated 6mm compensated resonator (top view).

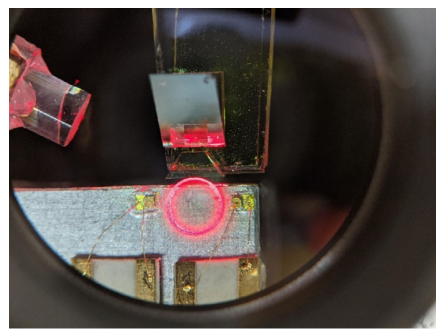

Figure 2. *A MgF2 resonator is coupled evanescently to AR coated BK7 prism. The temperature of the resonator is controlled with a Peltier stack wired to closed-loop thermo-electric cooler (TEC). The resonator is interrogated with a red laser, whose frequency is swept within multi-gigahertz span at 25Hz rate.*

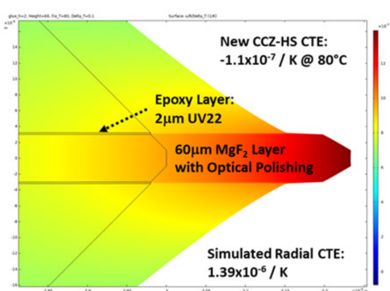

Figure 3. *The cross section of the simulated compensated resonator. With the new CTE of CZ-HS provided by the vendor, the suppression factor estimated from the simulation agrees with the experiment. The insufficient negative CTE of CZ-HS causes the under-compensation of the resonator. Customizing the negative CTE of the CZ-HS material is necessary for zeroing the radial expansion coefficient of the resonator at high temperature*

Results

- Our collaborators at OEWaves fabricated a number of MgF2 micro-resonators and conducted laboratory tests of their thermal stability. The MgF2 crystal was measured to have a minimum dn/dT in the near IR region in the range 70-120°C leading to a design point operating at high temperature. The thermal expansion was suppressed using a negative CTE material such as ClearceramZ-HS (CZ-HS). The compensated resonator consists of sandwich structure (CZ-HS – MgF2 – CZ-HS) bonded with a carefully selected epoxy. Figure 1 shows the MgF2 resonator used in the laboratory tests. Figure 2 shows the resonator illuminated by the red light laser used in the experiments.
- OEwaves measured a 5.3x thermal drift suppression factor at room temperature, and 3.8x around 80°C. The resonator is "under-compensated" and deviates from the design simulation, suggesting a mismatch between the predicted and real mechanical properties of the components. The suppression factor achieved (5x) is less than the goal of 50-100x suppression. A material with larger negative CTE will need to be identified and tested to improve the suppression factor further.

Significance/Benefits to JPL and NASA

- We have demonstrated that etalon performance can be achieved in the compact WGM resonator by showing broadband coupling and polarization selection to achieve 400 nm of spectral coverage in the visible spectrum while maintaining single mode-like performance.
- While the suppression of thermal drift has not yet been demonstrated at the required level, further design work suggests that the desired performance can be achieved. The NASA-NSF EPRV Initiative [3] represents a major opportunity for technology and science through the 2020s.
- Thanks to the R&TD program and President's Fund, JPL is now very well positioned to take scientific, technical, and programmatic leadership within this area. A number of NSF, NASA and private foundation grants have already been won based on our growing expertise. JPL will be in an excellent position to propose for NASA EPRV Initiative funds and to lead SBIR solicitations for PRV technology with 2 SBIRs already
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Publications

Leifer, S., Savchenkov, A., El Amili, A., Beichman, C., Matsko, A., Lai, Y.-H., Love, S., Strekalov, D., Schwab, C., Maleki, L., Halverson, S., Coddington, I., and Bagheri, M., "A Microresonator-Based Etalon For Visible Light Precision Radial Velocity Measurements", Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series,11447,2020

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