Portable Micro-Ring Resonator Based Frequency Combs for Optical Frequency Metrology

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***Abstract*— A temperature stabilized CMOS-compatible frequency comb based on an integrated optical micro-ring resonator is demonstrated. The instrument operates in the wavelength interval 1520-1600 nm with a wide free spectral range of 577 GHz. By embedding a highly sensitive "resistive thermal device" (RTD) on the surface of the chip to provide temperature feedback to the thermal electric cooler, the bench top unit achieves temperature stability of ~ 5:10^7 over a 24 hour period with good power stability. Our approach reduces the cost and complexity of existing high precision frequency combs currently used in the fields of metrology, remote sensing and stellar spectroscopy where high stability is required for prolonged periods of time.**

Keywords-component; Integrated optics; micro-ring resonator; Frequency comb; metrology

I. INTRODUCTION

With the emergence of frequency combs used for precision metrology over the past decade, there has been a pressing need to improve on the already present techniques that are available from optical clocks to high precision spectroscopy [1]. Of particular interest are the measurement of radial velocities that would be indicative of stellar phenomena, and the existence of exoplanets [2]. These measurements would require a comb that has a free spectral range (FSR) that is large enough to be able to be resolved accurately and calculated for easily, but would also need a long-term stability in order to eliminate drift and to be able to allow for precise measurements over an extended period of time [2-4]. In this paper we will investigate the compact micro-ring resonator as turnkey frequency comb source that is capable of generating a large FSR while maintaining a thermal stability for an extended period of time. Our results show that through the use of a thermoelectric cooling (TEC) device mounted in series with a resistive thermal device (RTD) has been able to not only maintain thermal stability, but also to rectify thermal imbalances, when they exist.

II. DEVICE CONCEPT AND FABRICATION

Figure 1A shows the schematic of the new device where the generation of the optical frequency comb signal arises from a combination of a wide band amplified spontaneous source (ASE) covering both C and L band between 1520 nm to 1620 nm and a micro-ring resonator. The PBS is used to linearize the ASE output and allow the polarization to be tuned for more versatility in measurement [8].

The integrated resonator device is mounted on the TEC, and is controlled and relayed with the RTD. The light source could easily be replaced with a fiber laser or filtered high power source, which would allow for a broader comb bandwidth, and could allow the comb spectrum produced to span an octave [5, 7]. The temperature dependence of the RTD-TEC combination can be directly measured without knowledge of the stability of the source. The electronic circuitry and power supply, along with all the optical components are fitted inside a standard high 19" rack mount. A photograph of the fabricated device is shown in Figure 1B.

The resonator used has a 47 μm radius and was fabricated with Hydex® high index core material (n=1.7), produced from chemical vapor deposition (CVD) onto a silica substrate similar to those reported in [5].

III. MEASUREMENT RESULTS

Figure 2 shows the output spectrum of the frequency comb with FSR of 577 GHz (4.6 nm) and Q factor of ~ 1x10^5, an acceptable spacing in order to achieve well-spaced peaks for astrophysical observations. To investigate the stability of the frequency comb, the output of the comb generator is monitored by a wavelength meter (HP 86120C). From the stability that is present within the device, measurements taken over a 24-hour period indicate that the device maintain its stability this period. Figure 3 show the ambient temperature and wavelength stability over a 24-hour monitoring period. From these data, it is apparent that the temperature can be stabilized within the TEC-RTD feedback component, and that the operational stability resulted in a wavelength fluctuation that was within 5 pm (min to max) with a standard deviation of less than 1 pm. These results show that this device's performance can produce a comb that is capable to measure to within 100 m/s for radial velocities. Furthermore, the longer-term stability shows that the device can operate in the range of hours to days, where other devices have only been able to maintain for much shorter time scales [6].

Although the current stability result needs to be improved by approximately 100 times for it to satisfy the detection requirement of radial velocities of exoplanets [2-4], stability can be improved by an increase of the number of resonant peaks, which has a correction factor of sqrt(# of peaks), and by improving the TEC design. With the device as operated within this experiment, it can be expected that by increasing the TEC-RTD feedback array to a two-stage TEC-RTD feedback, one can effectively increase the stability to a higher degree for a longer period of time. With the single stage, there was a sufficient lag within the response to the temperature reduction, which could and did have a pronounced effect on the wavelength stability (Figure 3). By increasing the TEC to a dual stage TEC, this lag could be reduced, as the temperature spikes would be greatly managed and reduced as well. This should result in less of an extreme for thermal stabilization at a given temperature.

IV. Conclusion

We have shown that a frequency comb created from an ASE light source pumping a micro-ring resonator is capable of maintaining both a good FSR spacing and a high temperature stability. Furthermore, due to the dual pumping nature of this comb to achieve C and L band emission, the comb can be tuned in order to further flatten the profile of the comb output [9]. By having good FSR, small linewidth, flattened profiling and good temperature stability, this device should perform well in attaining measurements of radial velocities within astronomical fields. Additionally, with the reduced size and cost of this device, its versatility can be capitalized upon and can be made part of smaller observational stations, increasing the adaptability of taking these measurements in optical metrology.

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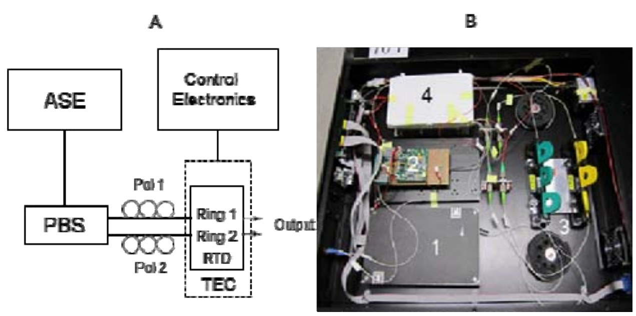

Figure 1 Fabricated portable frequency comb device. A) Schematic of the device where the frequency comb is generated from the micro-ring resonator response by the ASE excitation. B) A photograph of the frequency comb where 1 – ASE source, 2 – micro-ring resonator device, TEC and control electronic, 3 – polarization controller, 4 – PBS and fiber management.

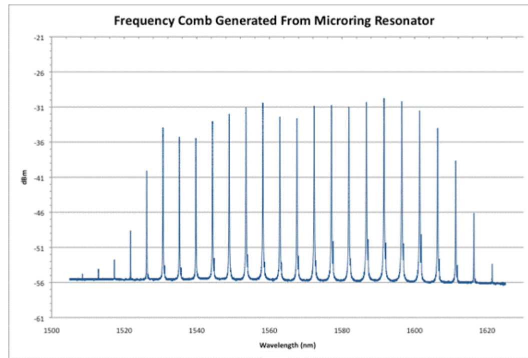

Figure 1 Frequency Comb signal from the resonator-based Er-doped ASE device. The comb effectively spans both the C and L band, and can be tuned for increased flatness via two LD pump diodes.

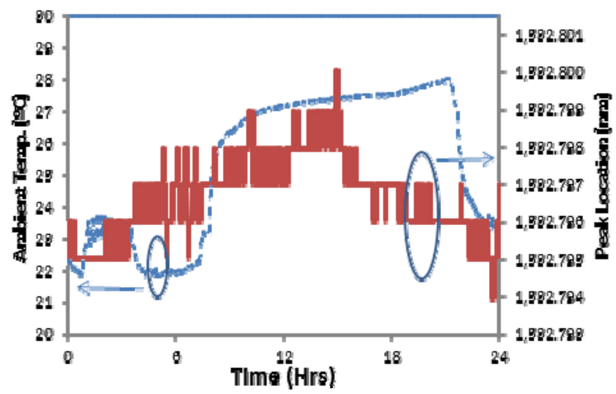

Figure 3 Stability of the frequency comb location drift over the monitoring period plot along with the ambient temperature. The min to max drift of the measured data is within 5 pm with one sigma at 1 pm.

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