Brillouin optical time domain analysis employing a doubly resonant short cavity fiber ring laser with active stabilization

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Abstract

We employ a new Brillouin ring laser (BRL) source based on an actively stabilized doubly resonant short cavity layout for Brillouin optical time-domain analysis (BOTDA) sensing. Compared to BRL designs that we have previously demonstrated, it presents improved SNR, lower spectral bandwidth and pump-probe frequency shift values with high temporal stability.

1. Ring-laser BOTDA experiment

Brillouin Optical Time Domain Analysis (BOTDA) measuring systems are a type of Distributed Optical Fiber Sensors (DOFS) that use the Stimulated Brillouin Scattering (SBS) to simultaneously detect temperature and strain distributions over tens of kilometers long single-mode optical fiber (SMF) with high spatial resolution. In particular, for BOTDA sensors based on pump-probe scheme, the spatial resolution is determined by the pulsed pump temporal length and is limited to 1 m by the 10-ns phonon lifetime in silica fibers [1]. Because of this, they offer interesting implementations in fields such as structural health monitoring, oil & gas pipeline control and security. BOTDA sensing consists in the location for every point in the fiber of the pump-probe frequency shift where the SBS is most efficient, known as Brillouin Frequency Shift (BFS), which is dependent on both temperature and strain. The BFS is usually estimated by sweeping the frequency shift of the

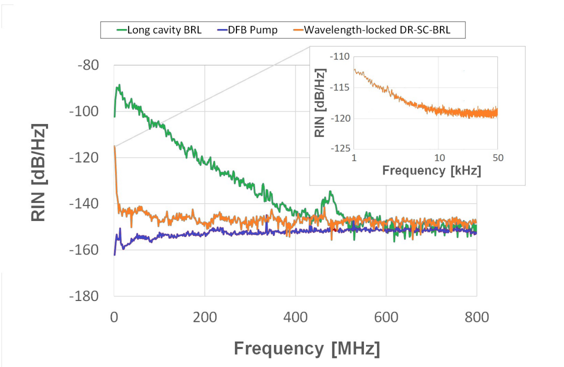

Fig. 4. RIN measurement and comparison

pump-probe signals, reconstructing the Brillouin Gain Spectrum (BGS) along the fiber and locating the peak through Lorentzian curve fitting. In order to achieve accurate BFS estimations, the pump-probe source is required to provide signals with low relative intensity noise (RIN) levels and narrow spectral linewidth and the possibility to tune the pump-probe frequency shift over hundreds of MHz with sub-MHz precision.

In [2], we have demonstrated a cost-effective solution based on a 2 km long Brillouin Ring Laser (BRL), in which the probe signal was generated through SBS of the pump signal and we employed this solution in BOTDA measurements achieving a frequency resolution of ~0.3 MHz in the BFS evaluation corresponding to a temperature and strain resolution of ~0.3 °C and ~6 με respectively over more than 10 km long sensing fiber. In this work, we propose an improvement design based on a short cavity SC (~4 m) Brillouin ring laser that is devised to be resonant for both pump and probe frequencies. We used a wavelength-locking scheme based on the heterodyne-detection technique to tune and stabilize the pump-probe frequency over the BGS of the sensing fiber. Compared to the 2 km-long cavity, the novel layout dramatically reduces RIN levels by suppressing mode hopping effects, while also maintaining low threshold power (~ 10 mW) and conversion efficiency due to the double resonance effect [3]. As can be seen from fig. 1, the SC-BRL RIN is lower than the long-cavity design in the whole 1-800 MHz range, showing values from -140 dB/Hz down to -90. In the low-frequency range (0-50 kHz), RIN levels are around -110 dB/Hz. This improvement translates to a SNR improvement of 22 dB that corresponds to a theoretical reduction of strain and temperature evaluation by a factor of 3.5 [4].

In addition, we have characterized the performance of the stabilization scheme in terms of temporal stability of pump-probe frequency shift over a tuning range of more than 200 MHz observing fluctuation less than 200 Hz over 10 ms (the timescale of a single BTODA measurement) and 400 Hz over 120 seconds, showing excellent stabilization capabilities.

References

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