Noise and Dynamics of Stimulated Brillouin Scattering Microresonator Laser Oscillators

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***Abstract* – We experimentally study the noise induced from thermal bistability and the intracavity dynamics of a 1550 nm stimulated Brillouin scattering laser generated from a microresonator.**

I. Introduction

Narrow linewidth lasers are useful for a number of applications ranging from high-precision spectroscopy [1], to low-noise microwave signal generation [2] to coherent optical communications [3]. Recently, it was demonstrated that the intrinsic oscillation produced from the stimulated Brillouin scattering (SBS) process in a microresonator exhibited high spectral purity beyond that of semiconductor external cavity lasers and Erbium fiber lasers [4]. The essential enablers for this spectral purity are the narrow ~10–100 MHz SBS gain bandwidth and the high microresonator cavity Q [5]. These characteristics allow microcavity SBS lasers to outperform typical semiconductor external cavity lasers with free spectral ranges ~10-100 GHz by a factor of 1000. The goal of our work is to analyze the noise properties of a microcavity SBS laser, including the effects of thermal bistability and relaxation oscillation, and to show simple locking schemes capable of improving SBS laser noise.

II. SBS Microresonator Oscillators Results And Analysis

Figure 1 shows a schematic of our SBS laser system based on a silica microdisk resonator. A continuous wave (CW) semiconductor laser at 1550 nm pumps a microdisk resonator ($Q\sim10^8$) [4], whose low loss enables an SBS oscillation threshold at 5 mW pump power. The generated reverse-propagating SBS signal (P = 0.3 mW) is coupled out of the cavity and is separated from the incoming pump wave via an optical circulator. For operation of our SBS laser, the CW pump is blue-detuned from the cavity resonance peak where the response of the system is thermally stable.

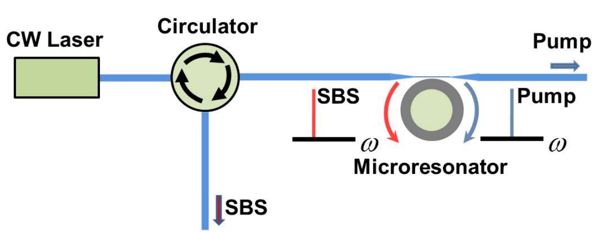

Fig. 1. Schematic of a 1550 nm SBS oscillator comprising a microdisk resonator cavity.

The relative intensity noise (RIN) of the generated SBS signal is analyzed via photodetection of the SBS output. Figure 2 shows the measured SBS RIN spectrum from 10 Hz to 10 MHz, and for reference, the original pump laser RIN. The SBS laser RIN is significantly higher (30 to 50 dB) than that of its corresponding pump, and we attribute this to an FM-to-AM pump-noise conversion process associated with coupling to a resonant cavity. Two effects further modify the SBS RIN spectrum. At low Fourier frequency, thermal bistability reduces FM-to-AM conversion since the cavity mode tracks the pump frequency. At high Fourier frequency, we observe a relaxation oscillation beyond which the SBS noise is strongly reduced.

To characterize the thermal tracking process, we measure the cavity thermal response by modulating the pump power via an external optical amplifier and monitor the transmission of the resonator normalized to its input modulation: see the inset of Fig. 2. The 3-dB bandwidth of the thermal response is 17 kHz; however, this response first begins to decay slightly past ~ 1 kHz. We attribute the slight reduction in RIN of Fig. 2 below 3 kHz to be due to this thermal tracking. That is, at frequencies slower than the system's thermal response, the heating or cooling of the cavity causes the modes of the cavity to follow the pump frequency fluctuations. We further reduce the FM-to-AM fluctuations imprinted on the SBS laser by locking the pump to the side of the cavity resonance via the pump frequency (Fig. 2, red trace). This servo, based on microcavity transmission, reduces the RIN significantly compared to the thermal lock case for frequencies up to the 100 kHz servo bandwidth. Furthermore, its implementation is simple and

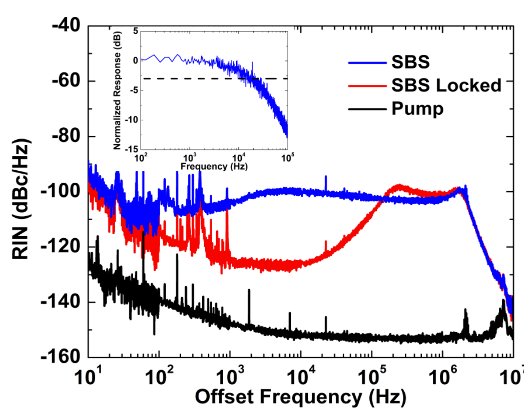

Fig. 2. Low frequency (10 Hz – 10 MHz) SBS laser RIN. The inset shows the thermal response of the microdisk resonator.

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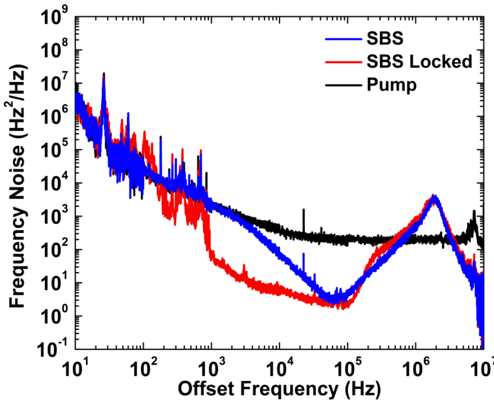

Fig. 3. SBS laser frequency noise

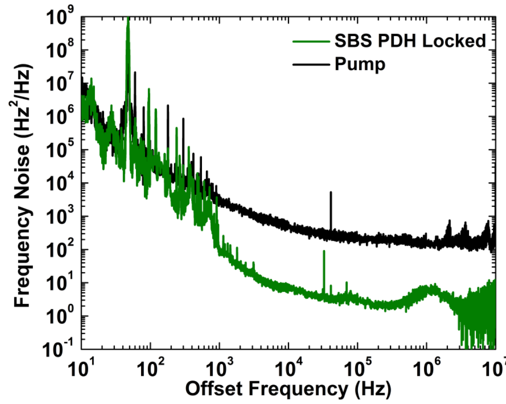

Fig. 4. SBS laser frequency noise with the injected pump Pound-Drever-Hall locked to the peak of the cavity resonance.

compact, requiring only photodetection and a servo with feedback to the pump laser current.

At ~2 MHz offset frequency, the SBS laser exhibits a relaxation oscillation resonance that decays at -60 dB/decade; see the red and blue traces in Fig. 2. Assuming the induced SBS density wave response to be fast, this resonance results from the bidirectional coupling between fluctuations of the SBS gain and fluctuations of the backward wave. The resonance frequency therefore depends on the lifetimes of the SBS gain and backward wave.

We have also investigated the frequency noise characteristics of the SBS microcavity laser. The frequency noise power-spectral density of Fig. 3 is measured using two separate unbalanced Mach-Zehnder interferometers with delay lengths of 200 m and 15 m, respectively. We consider two operating cases here with the CW pump laser stabilized to the microcavity either via thermal lock or via the pump laser frequency servo that maintains constant transmitted power. In the thermally locked case, the SBS laser frequency noise tracks the pump at low frequencies (< 1 kHz). However, beyond ~1 kHz, the thermal tracking weakens, and thus the SBS laser noise is reduced to a new floor level. In our measurements, we found this floor to scale inversely with the SBS power. With the intensity servo, the SBS frequency noise is further reduced even at Fourier frequencies well within the thermal locking bandwidth. The frequency noise of the SBS laser is likely limited by extraneous system noise below ~1 kHz. Nevertheless, near 10 – 100 kHz offset frequency, the SBS laser frequency noise is 100× below that of the ~1 kHz linewidth CW pump.

The system relaxation resonance at ~2 MHz is also observed in the SBS lasers frequency noise spectrum. To reduce this resonance, we tune the pump laser frequency near the peak of the cavity resonance (limited by the system's thermal stability) so that the pump detuning is near zero. This creates an imbalance between the lifetimes of the SBS gain and of the SBS backward wave that weakens their combined ringing response. Since the amplitudes and phases of the waves are in delicate balance in the microresonator, operating with zero detuning also decouples these two quadratures. This effectively nulls the FM-to-AM and AM-to-FM processes, further weakening the exhibited SBS resonance response. To demonstrate the level of relaxation oscillation reduction possible, we use a Pound-Drever-Hall servo system to lock the pump frequency at microcavity resonance. Figure 4 shows a reduction of 27 dB compared to the pump laser, which helps us experimentally establish the SBS frequency noise floor at ~2 Hz^2/Hz.

III. Conclusion

We have investigated the intensity and frequency noise behavior of a laser oscillating from the SBS gain generated within a microdisk resonator. Our measurements reveal the complexities of the thermal locking process and its impact on the noise behavior of the SBS laser. This thermal lock is a property of the resonant cavity, and thus applies to all microresonator-based systems. Moreover, we found that operating the pump with zero detuning can effectively damp the relaxation oscillation resonance of the SBS laser.

IV. Acknowledgment

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V. References

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