Self-Heating Based Locking of a Laser to a High-Q Si_3N_4 Microcavity

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Abstract: We demonstrate locking of a laser to an external silicon nitride microcavity resonance without the use of a photodiode. This is achieved by indirectly measuring changes in microcavity temperature that occur during resonant power buildup.

1. Introduction

Laser frequency stabilization is of critical importance in many applications such as optical metrology, optical communication and precision spectroscopy [1,2]. Active locking of a laser's frequency to a reference ensures stability even in the presence of slow temperature drift, mechanical fluctuations and intrinsic noise. At wavelengths away from atomic transition references, optical cavities serve as an excellent platform for stabilizing a laser's frequency [1,3]. Conventional techniques typically involve the use of bulk optical cavities and components, which prevents their usability in applications that need portability and compactness. Advances made in the development of high-Q microresonators over the past two decades have enabled their application to compact frequency stabilization methods [4–6]. With a few exceptions [7], however, most locking techniques involve the use of a photodiode in the feedback loop. In this work, we demonstrate an efficient locking technique based on "self-heating" of a Si_3N_4 microcavity that does not require a photodiode or any output coupling optics.

"Self-heating" refers to the rise in temperature of a microresonator due to material absorption during resonant power buildup [8,9]. Experimentally, the rise in microcavity temperature due to self-heating can be indirectly detected by measuring thermal shift in resonance positions due to the thermo-optic effect. However, such a method requires the use of output coupling optics and photodiodes at minimum, thereby limiting its use to microresonators consisting of drop ports. As chip-based photonic devices become increasingly complex, the ability to characterize thermal effects without needing access to optical drop ports is desirable. The technique that we present in this work utilizes integrated resistive microheaters – which are typically used to thermally tune microcavity resonances [10] – as temperature sensors to characterize self-heating without the use of a photodiode. We then use this temperature signal to assess the laser detuning relative to a cavity resonance, and demonstrate photodiode-free locking by implementing a PID loop on the cavity temperature signal.

2. Experiment

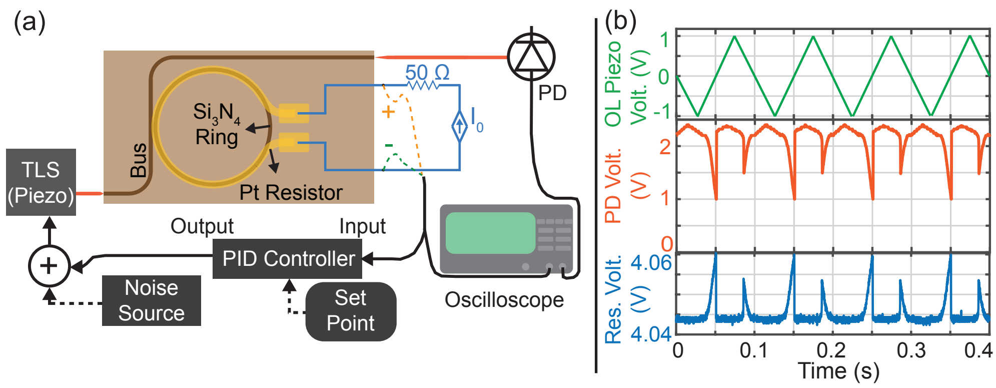

Fig. 1. (a) Schematic for self-heating based laser-microcavity locking. (b) Top - bottom: Open loop TLS scan voltage; Optical transmission measured on a photodiode; Voltage across the Pt resistor.

As depicted in Fig. 1(a), light from a tunable laser source (TLS) operating around ≈ 1550 nm is coupled into a Si_3N_4 microresonator ($f_{rep} = 110$ GHz, $Q_{loaded} \approx 1.5 \times 10^6$) through a bus waveguide. A constant current $I_0 \approx 10$

mA is fed through the integrated Platinum (Pt) resistive microheater and a series-connected bulk 50 Ω resistor, and the voltage drop across the Pt resistor is monitored on a real-time oscilloscope. Before closing the feedback loop, a $V_{pk-pk} = 2$ V ramp voltage (top plot in Fig. 1(b)) is applied across the TLS piezo input to scan across ≈ 12.5 GHz in the vicinity a cavity resonance. The optical power in the bus waveguide is ≈ 40 mW, leading to intracavity powers high enough to induce thermal resonance shifts due to self-heating [8], leading to the familiar triangular shape of the optical resonances shown in the middle plot of Fig. 1(b).

Self-heating of the ring also causes a rise in temperature of the integrated Pt resistor, which then changes its resistance (similar to bulk metallic resistors). This temperature dependence was verified by separate characterization measurements not shown here. Temperature-dependent change in resistance creates a voltage signal across the resistor, as shown in the bottom plot of Fig. 1(b). Put differently, this signal allows us to assess the laser detuning relative to the cavity resonance by simply measuring the voltage drop across the Pt resistor. In order to lock the laser to the cavity, we implement a PID loop as shown in Fig. 1(a). The set point is chosen to correspond to an in-resonance state. We test the active locking capability of this system by injecting noise to the TLS piezo input and monitoring the optical transmission using a photodiode.

3. Results & Discussion

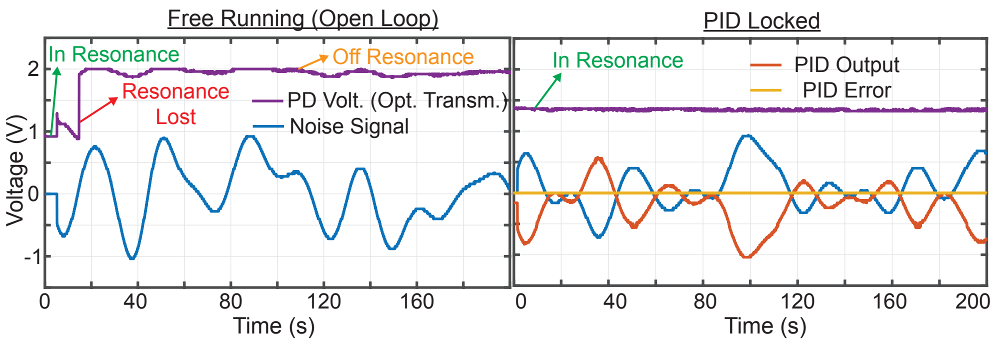

Fig. 2. (a) Free-running case: laser loses lock almost immediately after noise is injected. (b) PID-locked case: laser stays locked with the cavity even for prolonged duration of injected noise.

Fig. 2(a) shows the experimental measurements for the open-loop case. With no feedback control, the laser loses resonance almost immediately after the noise is turned on. This is seen by observing that the optical transmission sharply shoots up at around the 15 second mark and remains there. By observing the shape of the resonance in the middle plot of Fig. 1(b), one can see that this corresponds to the sharp edge of the cavity resonance. In contrast, Fig. 2(b) shows the closed loop case wherein the PID output fully compensates the noise injected into the TLS piezo, and the transmitted optical power (i.e. photodiode voltage) stays remarkably stable. A comparison of the photodiode voltage for this case with the middle plot in Fig. 1(b) indicates that the laser indeed remains in resonance. It is worth reiterating that the PID loop is based purely upon the self-heating-induced voltage signal, and the photodiode is used in this experiment only for monitoring purposes. This means that this stabilization technique can be applied in any complex photonic chip without the need for additional drop ports.

4. Conclusion

In conclusion, we have demonstrated a new technique that utilizes the self-heating phenomenon and the temperature-dependence of resistance of the integrated Pt resistor to lock a laser's frequency to a cavity resonance. This work not only demonstrates a powerful resource-efficient and compact frequency stabilization technique, but it also paves the way for thermal stabilization of microresonator-based nonlinear light sources such as optical parametric oscillators and soliton-generating microresonators.

References

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