We demonstrated that an optical laser can operate with <1 photons on average inside the cavity while also obtaining significant spectral narrowing of the emitted light relative to the single atom transition linewidth. We further explored the power output properties and threshold conditions of this laser. We made direct measurements that showed that the lasing frequency can be made >10000 times less sensitive to the resonance frequency of the optical cavity than is the case for normal lasers or for passive optical reference cavities. Such a large reduction in sensitivity would essentially remove both thermal and technical mirror vibrations as a limitation on laser linewidth.
ABSTRACT

We demonstrated that an optical laser can operate with <1 photons on average inside the cavity while also obtaining significant spectral narrowing of the emitted light relative to the single atom transition linewidth. We further explored the power output properties and threshold conditions of this laser. We made direct measurements that showed that the lasing frequency can be made >10000 times less sensitive to the resonance frequency of the optical cavity than is the case for normal lasers or for passive optical reference cavities. Such a large reduction in sensitivity would essentially remove both thermal and technical mirror vibrations as a limitation on laser linewidth. Other studies included how phase information can be stored and manipulated inside of our laser, such that it may be possible to have both an active laser and a passive Ramsey-like sensor in the same setup. We considered the fundamental limits on the atomic quantum information that can be extracted from the laser light and found that it corresponded closely to the fundamental atomic standard quantum limit on phase estimation.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

12/03/2014 3.00 Justin G. Bohnet, Zilong Chen, Joshua M. Weiner, Kevin C. Cox, James K. Thompson. Active and passive sensing of collective atomic coherence in a superradiant laser, PHYSICAL REVIEW A, (07 2013): 13826. doi:


TOTAL: 2

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper


TOTAL: 1
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**TOTAL:**

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**Patents Awarded**

**Awards**

Department of Commerce - Bronze Medal

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Student Metrics
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The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00
Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00
Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00
The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ...... 0.00
The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: ...... 0.00

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Sub Contractors (DD882)
Inventions (DD882)

Scientific Progress

Technology Transfer

See Attachment
Problem Studied

The goal of this work was to study a regime of optical lasing in which most of the phase information of the laser is stored inside of the gain medium rather than the intracavity light field. Theoretical studies indicated that such a laser might one day lead to millihertz linewidth optical lasers. Such a laser would be 100 times better than the current world’s best lasers, and extend optical coherence times to more than 1,000 seconds. The resulting ultrastable lasers would represent a dramatic breakthrough in fundamental precision measurement technologies impacting a broad range of metrology and research applications, including new optical atomic clocks, quantum information systems, gravity wave detection, optical interferometry, cavity-optomechanics, and the probing and control of quantum many-body systems that beat the standard quantum limits for measurement.

The goal of this work was to study many of the core theoretical predictions in a laser-cooled Rb system using synthetically engineered narrow optical transitions. This provides great flexibility for studying the core physical predictions, and should be understood as primarily a physics testbed for future attempts to develop ultranarrow lasers.

Summary of the most important results

We demonstrated that an optical laser can operate with <1 intracavity photon while also obtaining significant spectral narrowing of the emitted light relative to the single atom transition linewidth. We further explored the power output properties and threshold conditions of our laser.

We made direct measurements that showed that the lasing frequency can be made >10000 times less sensitive to the resonance frequency of the optical cavity than is the case for normal lasers or for passive optical reference cavities. Such a large reduction in sensitivity would essentially remove both thermal and technical mirror vibrations as a limitation on laser linewidth.
The *Nature* [1] paper describing this work (with accompanying context article in *Nature*) generated a large amount of interest, including three invitations to give Hot Topic talks at well-established international conferences [2], as well as popular international interviews and articles (Science Daily, Physics World, Phys.org, CNET, Photonics.com, Ars Technica R&D Magazine, German Public Radio, German wire service, *Nature Photonics*, etc.), and a NIST produced video describing the work.

We also considered how phase information can be stored and manipulated inside of our laser [2], such that it may be possible to have both an active laser and a passive Ramsey-like sensor in the same setup. The hybrid active/passive sensor might switch between modes of operation in response to changing environmental conditions such as vibration levels. To determine the quality of the sensor, we considered the fundamental limits on the atomic quantum information that can be extracted from the laser light and found that it corresponded closely to the fundamental atomic standard quantum limit on phase estimation. This indicates that such a sensor would be of high quality. The core concepts of hybrid active/passive sensors were later demonstrated outside of the grant period in the context of a hybrid magnetometer [4].

**Bibliography**


