32nd URSI GASS, Montreal, 19-26 August 2017

Laser frequency stabilization based on steady-state spectral-hole burning in Eu^{3+}:Y_2SiO_5

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Extended Abstract

Frequency stable laser local oscillators (LLOs) are key tools in the field of metrology. Applications of such LLOs include optical atomic clocks and low noise microwave frequency synthesis. The best stabilized lasers to date are obtained by locking their frequencies to Fabry-Pérot reference cavities, and their stability is intrinsically limited by thermomechanical length fluctuations of the cavity.

Spectral holes in cryogenically cooled Eu^{3+}:Y_2SiO_5 are a promising alternative to the use of mechanical references for laser frequency stabilization [1]. At 4 K, this material supports spectral holes at 580 nm with linewidths as narrow as 122 Hz and lifetimes of 106 s. The frequency shifts due to fluctuations in the ambient magnetic and electric fields, temperature, pressure, and acceleration are all small enough to reach laser frequency instabilities at the 10^{-17} fractional frequency level [2].

In this work, we demonstrate laser frequency stabilization to a steady-state pattern of spectral holes in Eu^{3+}:Y_2SiO_5 [3]. This pattern consists of three sets of spectral holes spaced in frequency by 46.2 MHz and 34.6 MHz (Figure 1), corresponding to the ground-state hyperfine splittings of $^{151}Eu^{3+}$. The Eu^{3+} population reaches steady-state as the spectral holes in the three regions are burned, and additional interleaved probing does not modify the absorption spectrum. Using this spectral-hole pattern, laser frequency stabilization experiments can be made to run indefinitely. We measure the fractional frequency stability of a laser locked to such a steady-state spectral hole pattern to be 4×10^{-16} $\tau^{-1/2}$ for $0.01\ \mathrm{s} < \tau < 10$ s, with long term linear fractional frequency drift of the order of 10^{-18} s^{-1}.

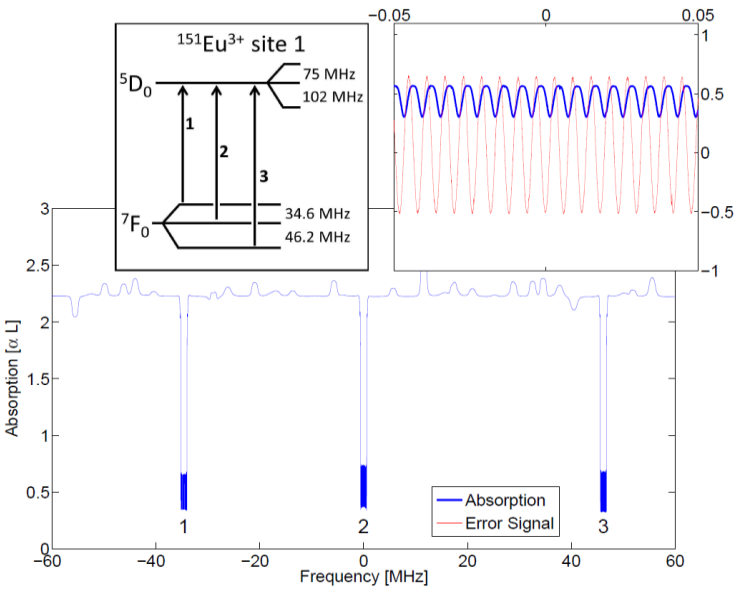

Figure 1. Absorption of a steady-state spectral hole pattern with three regions of spectral holes.

This work is supported by DARPA and ONR.

References

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