

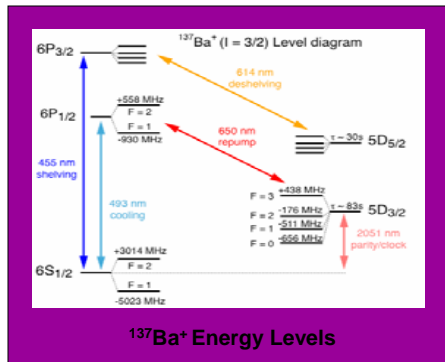
A Laser Frequency Doubling Application in Single Ion Trapping

Zach Simmons, UW Physics REU

Advisor: Dr. Norval Fortson, University of Washington

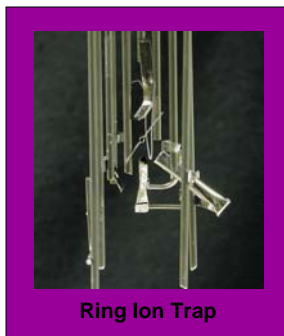
Introduction:

A clock frequency is useful as a time measurement tool but also as an absolute frequency reference. The meta-stable 5D3/2 transition in Barium ($t \sim 83\text{sec}$) has a very precise frequency as a result of time-energy uncertainty at $2.051 \mu\text{m}$ and so makes a very good clock. Other ions make good clocks too, and this is valuable because comparing super stable clock frequencies based on different atomic systems allows for the investigation of changes in fundamental constants with respect to time. This is new physics!, suggested by some theories outside the standard model.



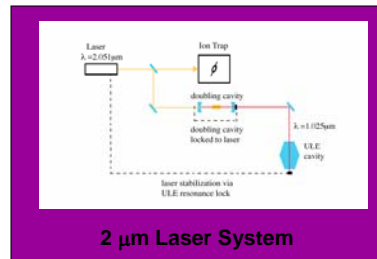
Background: Ion Trapping

Earnshaw's theorem prescribes that a static electric potential cannot trap a charged particle. However, a pseudo-potential (a potential that is instantaneously unstable, but on average to the charged Ba ion, stable) is capable of confining it. A Paul trap uses a combination of static E fields and E fields alternating at radio frequencies to accomplish this. The experiment uses a ring-shaped Paul-Straube trap, although not the ideal geometry, it provides access for lasers to cool and interrogate the ion.



Project Motivation:

In order to precisely investigate the clock transition in the ion, you have to have a very narrow frequency laser. Any laser will have some amount of spread and drift in its frequency. One way to stabilize this is to lock the laser to a transmission line of a stable Fabry-Perot cavity. The cavity only transmits when the optical path length between the mirrors is an integer number of half wavelengths, and if that length doesn't change then the frequency of a transmission line that gets through won't change either. A special, vertically mounted, ULE (ultra low expansion) cavity will be the reference cavity in this experiment.



Unfortunately the cavity is designed for $1 \mu\text{m}$ light (high reflective coatings can be made better at $1 \mu\text{m}$). However, this is accessible, provided we frequency double the $2\mu\text{m}$ laser. This can be accomplished with a nonlinear optical process, Second Harmonic Generation (SHG) and that was my project this summer.

Second Harmonic Generation:

$$P = \epsilon_0(\chi E + \chi_2 E^2 + \chi_3 E^3 \dots)$$

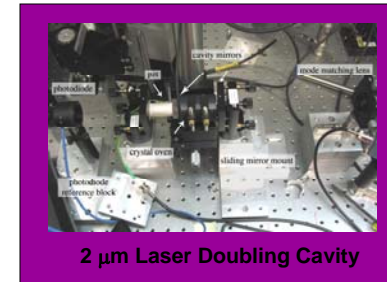
can be seen in materials with appreciable higher order electric susceptibilities e.g. Lithium Niobate

$$\eta_{2,\omega} = \frac{8\pi(2/m\pi)^2 d_{eff}^2 (NL_c)^2 I_\omega}{\epsilon_0 n_\omega^2 n_{2,\omega} c^2 \lambda_\omega^2} \exp[-(\alpha_\omega + \alpha_{2,\omega}/2)L] h(\sigma, \beta, \kappa, \xi, \mu)$$

Efficiency for PPLN (Sutherland, p.100)

Efficiency depends on a variety of factors: phase matching, geometry, power in, effective nonlinear coefficient

Set-Up:



The crystal we used was periodically poled lithium niobate (PPLN); it is in the oven in the center of the picture. In order to get sufficient output power to lock to the ULE cavity (SHG is inherently very inefficient) we used a resonant linear cavity.

Results:

Single passing the laser through the PPLN we were able to achieve at most about $5\text{-}10\mu\text{W}$ of output $1\mu\text{m}$ light. However, when we finally got the cavity set up, we observed at times more than 1mW of $1\mu\text{m}$ light, quite an improvement! With improvements in the apparatus and cavity locking mechanism, this will be more than enough to stabilize the laser off of the ULE cavity.

Thank You

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Barium energy level diagram, ring trap, and ULE cavity photo credits to Jeff Sherman

Selected Sources:

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