A Laser Frequency Doubling Application in Ion Trapping

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Overview

- Big Picture-ion trapping/context
- Details and What I worked on
- Challenges/What I got done
- Summary
- Thanks

Backgound-ion trapping:

- Paul trap:
  - Earnshaw's theorem -no static E field can confine charged particles, look at $\nabla^2 V = 0$
  - So we use a pseudo-potential set up by a combination of static and alternating E fields at RF to confine the ion

Ion motion

QuickTime™ and a
Animation decompressor
are needed to see this picture.

(Jeff Sherman)

Ring Trap

- Ideally, hyperboloid electrodes

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TIFF (Uncompressed) decompressor
are needed to see this picture.

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TIFF (Uncompressed) decompressor
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- Ring trap allows better optical access, compensate with RF
  - probing
  - Cooling

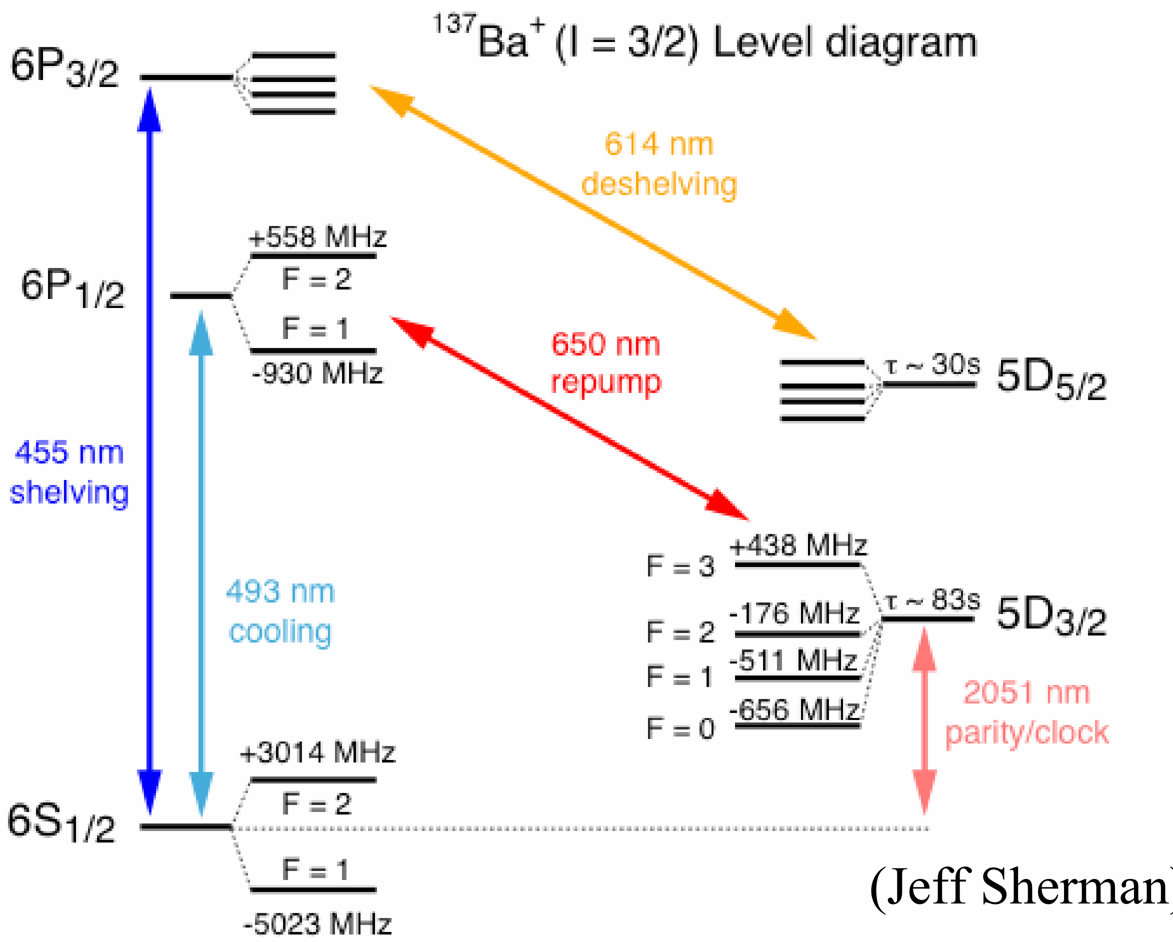
(http://tf.nist.gov/ion/qucomp/apparatus.htm)

(Jeff Sherman)

Background-Why $^{137}Ba^{+}$?

- A standby- relatively simple system as far as problems like cooling
- Very narrow 5D3/2 clock transition is the laser this project is concerned with at 2.051 microns
  - Very long lived meta-stable state results in a very precise frequency via energy time uncertainty, I.e. it makes a good clock
  - Singlet state on the clock transition free from Stark shifts
- Heavy -good for alpha dot measurement

Barium energy levels



(Jeff Sherman)

Why clocks/What about other ions?

- Allows exploration of more fundamental physics
- YES- use them too, for example indium, two optics tables over…
- The cool thing is if you have multiple very stable clocks that have different dependence on constants, e.g. alpha, you can investigate the change in those constants wrt time, something suggested by theories outside the standard model! A long term project.

Little Picture

- Need a very narrow laser for such high precision probing
- ULE (ultra-low expansion) cavity used for stable frequency reference:
- Fabry-Perot cavities only transmit for n half wavelengths,

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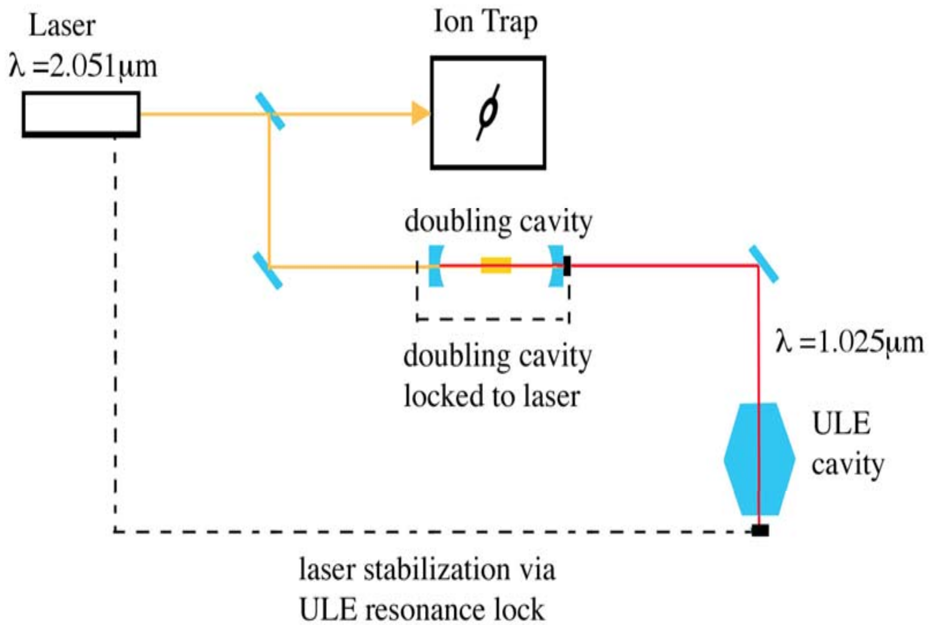
(Jeff Sherman)

...but

- it's designed for 1micron light(coatings are better).
- however, we can double our frequency- via second harmonic generation (SHG) using a nonlinear crystal, reference off the cavity and stabilize the 2 μm laser



General Set-up

SHG

- Nonlinear optical process

$$P = \varepsilon_0(\chi E + \chi_2 E^2 + \chi_3 E^3 \ldots)$$

- Passing laser through a crystal gives some 2ω light
  - Can think of 2 phonon interaction
  - Or anharmonic potential

$$\eta_{2\omega} = \frac{8\pi(2/m\pi)^2 d_{eff}^2 (NL_C)^2 I_\omega}{\varepsilon_0 n_\omega^2 n_{2\omega} c \lambda_\omega^2} \exp[-(\alpha_\omega + \alpha_{2\omega}/2)L] h(\sigma,\beta,\kappa,\xi,\mu)$$

Periodically polled expected efficiency, (Sutherland, p. 100)

SHG-phase matching

QuickTime™ and a
GIF decompressor
are needed to see this picture.

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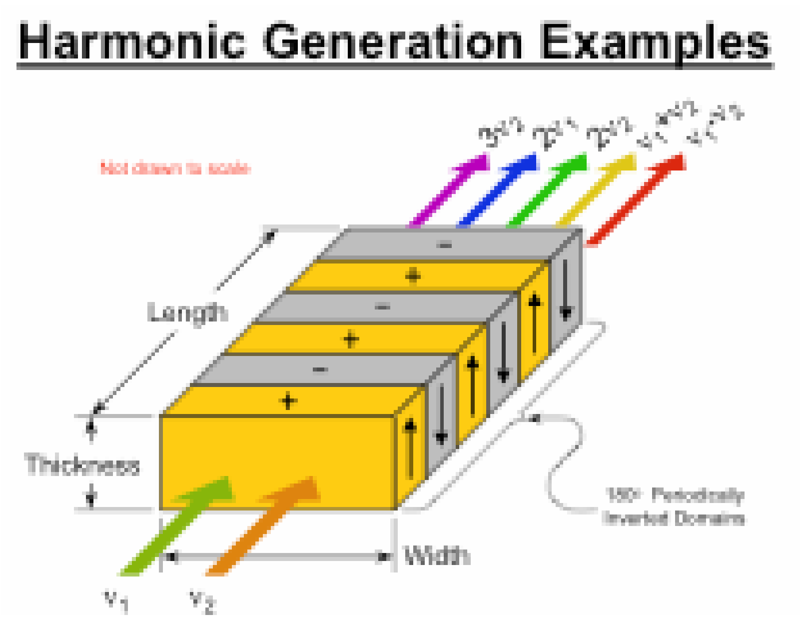
GIF decompressor
are needed to see this picture.

(http://www.fsm.pd.uwa.edu.au/phasematch.html)

- Phase matching corrects for SHG light traveling at a different speed than incident light and destructively interfering with SHG generated later in the crystal
  - Critical, quasi,temperature tuning
  - Our Nonlinear crystal- periodically polled lithium niobate (PPLN)

PPLN

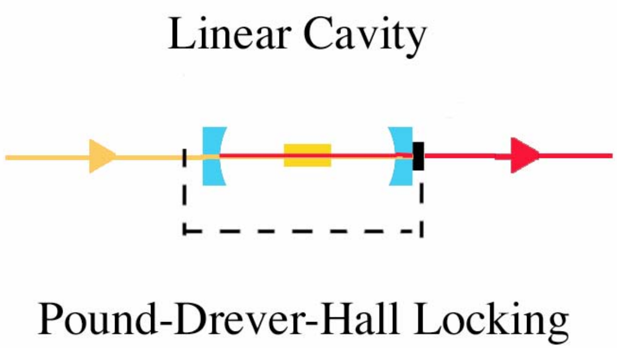


- Temperature tuned for different poling periods

(www.hcphotonics.com/waveguide.htm)

(http://www.thorlabs.com)

SHG- power considerations



- A cavity enhances output power
  - Different cavity options
  - Have to mode-match into the cavity

- Ideal Crystal length/waist size- Boyd and Kleinman 1960’s

G.D. boyd and D.A. Kleinman, J. Appl. Phys. 39:3597 (1968).

A Ring Cavity

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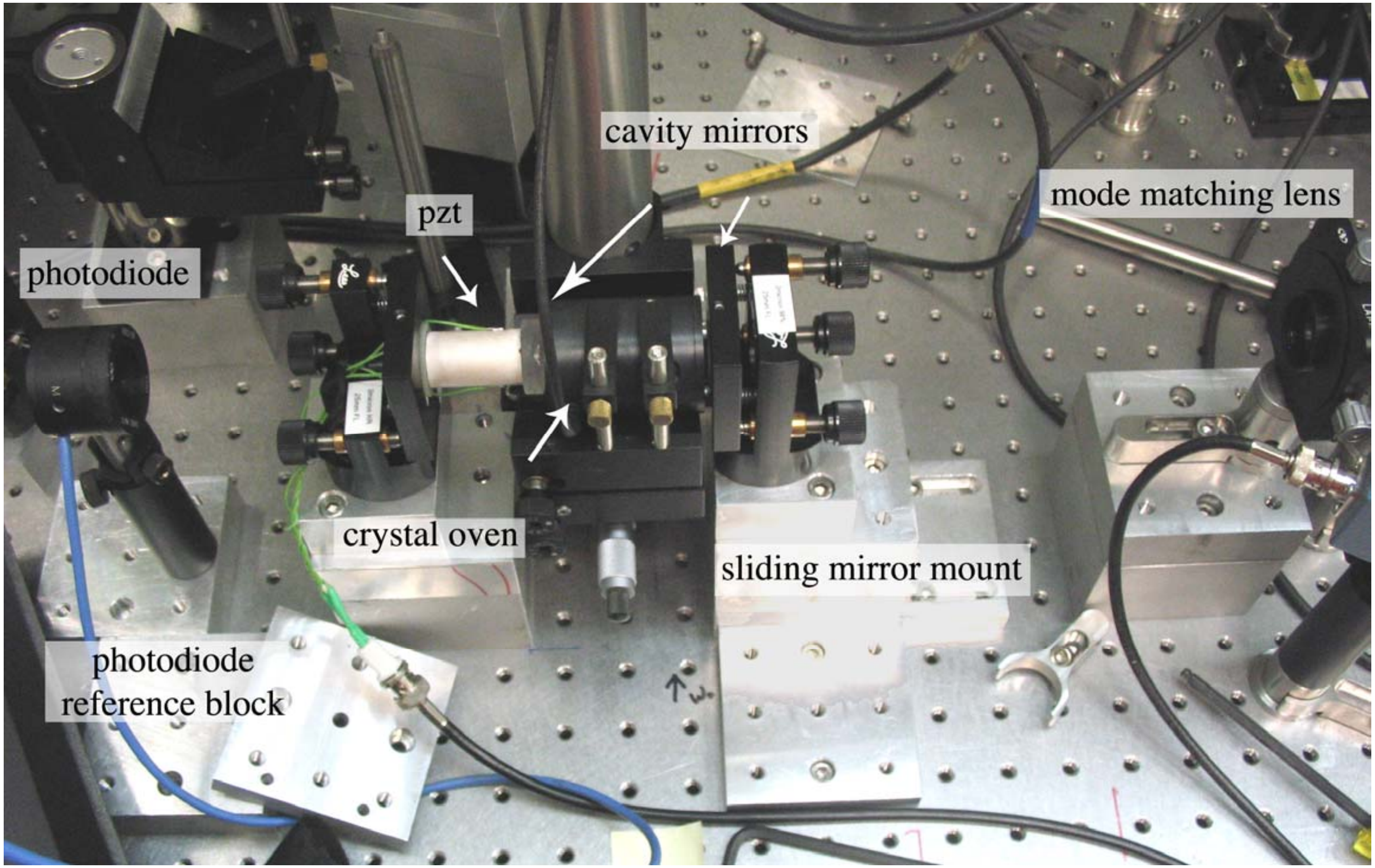
- 800 to 400 nm ring cavity (Jeff Sherman)

Cavity

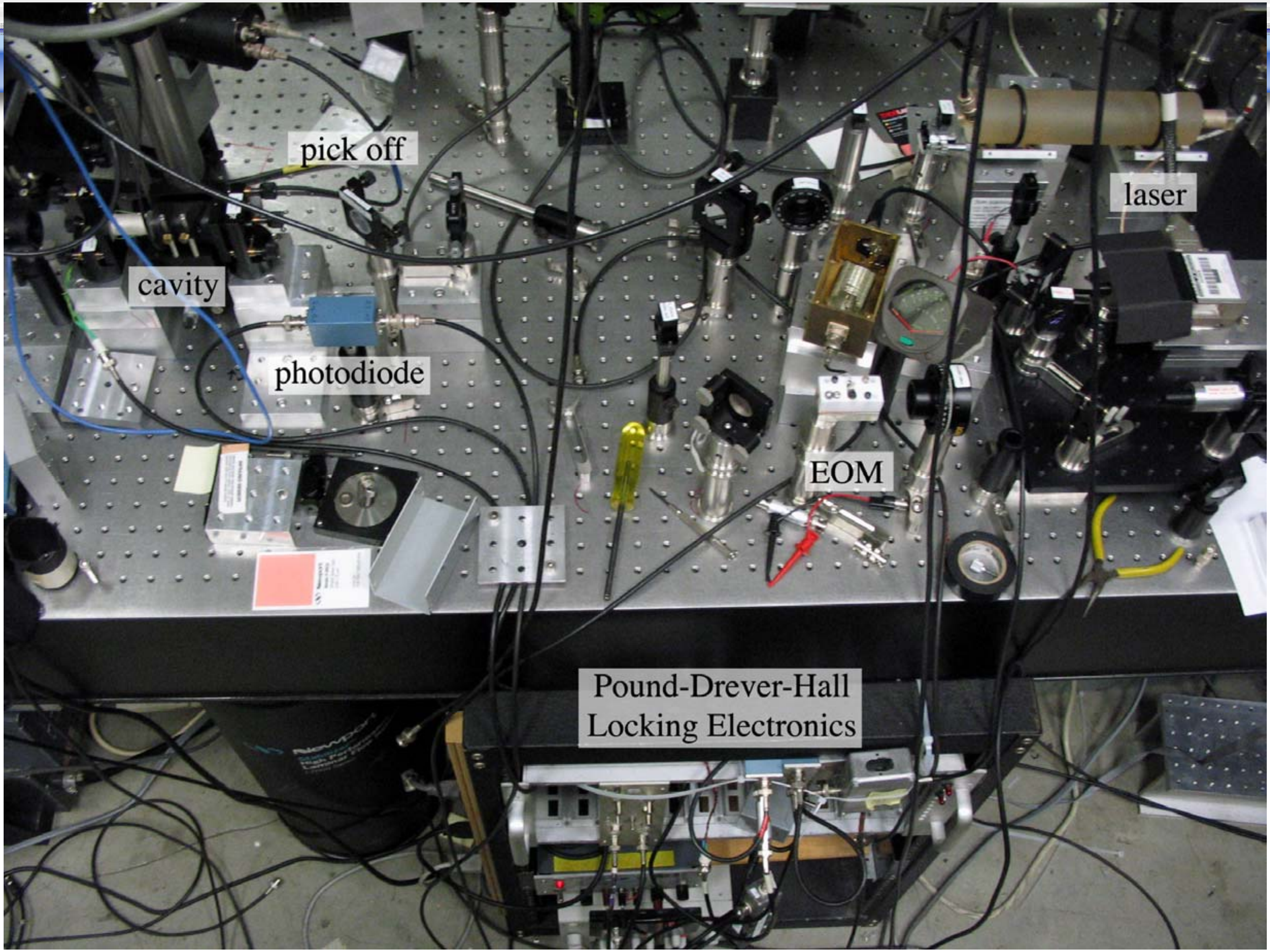


cavity mirrors
mode matching lens
pzt
photodiode
crystal oven
sliding mirror mount
photodiode
reference block

SHG-locking

- Lock cavity to laser resonance for 2ω output
  - Pound-Drever-Hall method, looks at the difference between promptly reflected and stored leakage to generate an error signal
- Larger goal-lock laser to ULE cavity for laser frequency stabilization

System


pick off
laser
cavity
photodiode
EOM
Pound-Drever-Hall
Locking Electronics

Challenges:

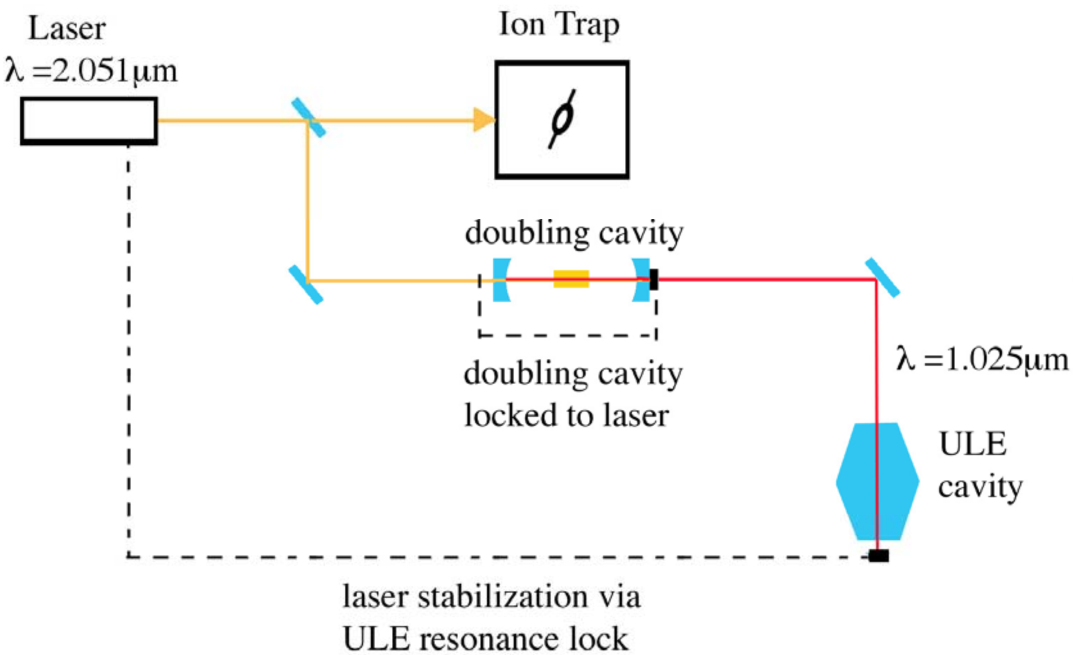
- IR laser difficult to work with
- We have mirrors but they create a waist too large for our crystal, so we needed new mirrors, which were delayed
- Laser scanning issue, the piezo in the laser for locking is not behaving as it should and not scanning as much it should for a given voltage

What I got done:

- Wrote MatLab programs to investigate appropriate cavity and mode matching schemes via equations derived from ABCD matricies
- Set up cavities with existing mirrors, Pound-Drever-Hall locking scheme, Single passed the PPLN crystal, ~5μW
- Built a beam profile measuring device with an optical chopper- useful for the invisible IR laser
- The last week, got 1 micron light out of our linear cavity, with improvements it will be plenty of power for locking the laser to the ULE cavity

Summary

- Barium ion trapping lab
- Double 2micron to get 1 micron, via SHG
- Lock laser to ULE cavity



General Set-up

Thanks

- Jeff Sherman
- Eryn Cook
- Will Trimble, Norval Fortson, Warren Nagourney, Amar Andalkar, and the rest of the group
- UW REU Program and NSF

Questions?

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Appendix- Pound-Drever-Hall Locking

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TIFF (Uncompressed) decompressor
are needed to see this picture.

(socrates.berkeley.edu/~budker/ Physics250/Physics250_Las_Stab.PDF)

Appendix- Useful Sources:

E. D. Black, "An introduction to Pound-Drever-Hall laser frequency stabilization", Am. J. Phys. 69, (1), jan, 2001.

G.D. boyd and D.A. Kleinman, Parametric interactions of focused guassian light beams, J. Appl. Phys. 39:3597 (1968).

H. Kogelnik and T. Li, "Laser Beams and Resonators" Applied Optics, Vol. 5, No. 10, p1550-1567, Oct 1966,.

Sutherland, Righard L. Handbook of Nonlinear Optics, NY: Markcel Dekker, 2003.

Yariv, Amnon and Yeh, Pochi, Photonics, New York: Oxford University Press, 2007.

Slide Content Sources:

http://tf.nist.gov/ion/qucomp/apparatus.htm

http://www.fsm.pd.uwa.edu.au/phasematch.html

www.hcphotonics.com/waveguide.htm

http://www.thorlabs.com

socrates.berkeley.edu/~budker/ Physics250/Physics250_Las_Stab.PDF