Laser Locking for Sodium by Modulation Transfer Spectroscopy

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***Abstract*—This article serves as an explanation on the principle of Modulation Transfer Spectroscopy which has been widely used as an advanced laser locking technique. The nonlinear phenomenon - Four Wave Mixing occurs when the laser frequency detuning $\triangle$ is sufficiently far away from the resonance frequency of the atomic transition ω_0. This characteristic acts like a sensor which provides us a chance to monitor the location of the laser frequency and enable the feedback system of the laser controller to achieve frequency locking.**

I. Introduction

With the invention of first laser in 1960 [1], we are able to produce coherent light, they have high fidelity of frequency, polarization and and direction of beam propagation. laser has been vastly used in many field of Physics. Ranging from the discovery of Gravitational Wave, controllable nuclear fusion to table top experiments such as Quantum Optics, Atomic, Molecular and Optical Physic. These research fields require distinct features of LASER in practice and demand the output beam of laser with pure and controllable frequency. With the advanced precision of laser equivalent to extremely narrow bandwidth, a group in JILA, University of Colorado at Boulder had created an optical atomic clock with unprecedented precision in 2008 up to 10^{-16} level [2], and a few years later they pushed the limit up to the level of 10^{-18} [3] which enable the time keeping in ultra high accuracy and have been widely used in science research and industry. Among all the Atomic Physics laboratory, they need to study the science by manipulating those atomic species of interests by laser with different light property which corresponding to the specific transition between quantum states. The problem is the configuration of laser make it's beam characteristic highly sensitive to acoustic, mechanical noise and also the working temperature and current. To address these problem, we need to build and spectroscopy as a frequency sensor and feedback the error signal to frequency controller and let the electronic do the rest to stabilize the laser efficiently. There are many proposed scheme on spectroscopy, yet, all these methods are not generally able to entirely to eliminate the background noise. Therefore, we have Modulation Transfer Spectroscopy, which combined the advantages of high frequency detection with a very effective cancellation of all types of background [4][5].

II. Modulation Transfer Spectroscopy

(Phase)Modulation Transfer Spectroscopy is a pump-probe scheme spectroscopy. Namely it use two counter propagating beams referring to the pump and the probe beam. The pump beam pass through an Electro-optic modulator (EOM) and acquires a phase modulation and pick up a side-band. If a phase modulated optical pump beam pass through a resonant gaseous medium and introduce a unmodulated probe beam which runs collinearly but in opposite with the pump beam. If the interaction of two counter-propagating beams with the gaseous medium is nonlinear enough which suffice to transfer the side-band to the unmodulated beam. This transfer phenomenon is called Four-Wave Mixing.

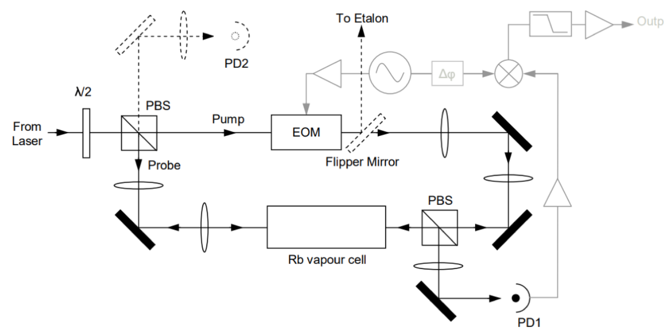

Fig. 1. Schematic setup of MTS

Four wave mixing: The beam with carrier frequency ω_c pass through the EOM and the phase has been modulated shown as (1) where the ω_m is the modulation frequency of the EOM and δ is the modulation index, if we decompose the E by Bessel function[7], we arrived (2) with approximately keep the dominant component.

$$E = E_0 sin[\omega_c t + \delta sin(\omega_m t)] \tag{1}$$

$$\approx \frac{1}{2}E_0[-\frac{\delta}{2}e^{i(\omega_0-\omega_m)t} + e^{i\omega_0 t} + \frac{\delta}{2}e^{i(\omega_c+\omega_c)t}] \tag{2}$$

Here we observed three obvious frequency component in the modulated pump beam. When FMW happens by means of χ^3 - third order of susceptibility , the frequency component $\omega_c \pm \omega_m$ transfer to the unmodulated probe beam,shown as Fig.2 and the probe beam beats with the fourth wave. The beat signal is a measurement of the detuning of laser frequency. Which is in the form:

$$S(\omega_m) = \frac{C_m}{\sqrt{\Gamma^2+\omega_m^2}}\sum_{n=-\infty}^{\infty} J_n(\delta)J_{n-1}(\delta) \times [(L_{(n+1)/2} + L_{(n-2)/2}) \times cos(\omega_m t + \phi) + (D_{(n+1)/2} + D_{(n-2)/2}) sin(\omega_m t + \phi))] \tag{3}$$

Where

$$L_n = \frac{\Gamma^2}{\Gamma^2 + (\Delta - n\omega_m)^2} \tag{4}$$

and

$$D_n = \frac{\Gamma(\Delta - n\omega_m)}{\Gamma^2 + (\Delta - n\omega_m)^2}$$

(5)

Therefore, the beat signal is a function of detuning of frequency Δ, which is a dispersion-like lineshape that we can monitor on an oscilloscope and let the laser controller to lock at the zero crossing point where corresponding to the laser hits the right frequency when it swap through a certain range of frequency.

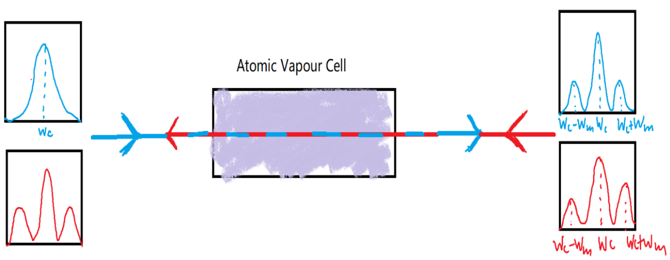

Fig. 2. Four wave mixing causes side-band transfer

III. Optical Setup

Sodium laser is in orange which is beautiful. We do not have orange light laser at the first place, instead we have a invisible - 1178nm wavelength laser and let it through a frequency doubler and let second harmonic generation to give the orange light. As shown in Fig.3. The dashed line circulating rectangle is the MTS setup , it just occupy a very tiny portion among the whole experiment, however, it is paramount as it acts like a

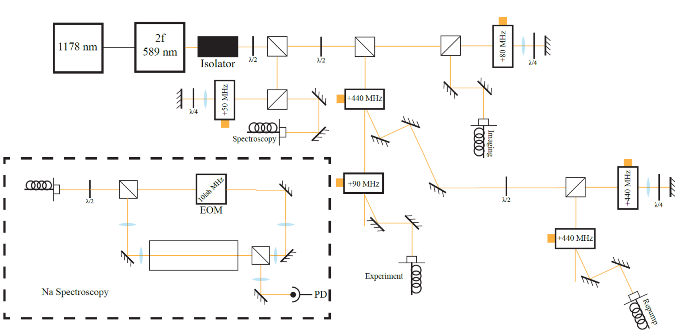

Fig. 3. Light Path of Sodium Laser

light quality examiner, to sense if the light frequency is correct and feed the signal in to the frequency controller. Once the frequency controller is locked to the zero crossing point of the error signal, when ever there exist acoustic and mechanical noise, or change of the diode temperature, the controller will adjust the Piezo (PZT) inside the laser to make a fine tuning of the optical feedback to the gain medium in the optical cavity. The actual response of the controller depends on the laser design. For instance, for a external cavity diode laser (ECDL) form the cavity by grating, the change of the length of PZT is actually changing the feed back frequency and also the amount of feedback light. For a Cat's eyes ECDL [6], in changing the PZT is about adjusting the external cavity length only, to do this corresponding to different circuit design of the proportionalintegralderivative loop. When everything is on set, then click the lock nobs on the laser controller and we can see strong and stable fluorescent in the atomic vapour cell. As shown in Fig.4

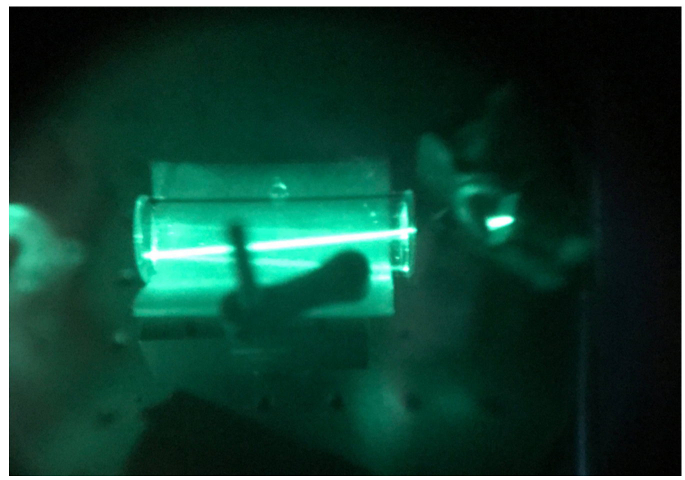

Fig. 4. Laser Controller

IV. Conclusion

This work is the kick off step for the functioning sodium laser to manipulate the sodium atoms. The out-coming sodium laser be further modulated will serve as the pump and re-pump beam, imaging beam and also for sodium cooling.

V. Acknowledgement

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