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Experimental Set-up of the 532nm Green Laser for the Measurement of the AC Stark Shift in a Cesium Fountain Clock

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Abstract

A short term stay at the LNE-SYRTE (Paris Observatory) has been accomplished in the summer 2007 in order to realise the optical set-up of a 532nm high power CW commercial green solid state laser (Verdi 5W). This green wavelength induces an AC Stark shift in the cesium fountain clock experiment FO1 [1]. The V5 laser is driven through a compact optical set-up into a 1, 1 cm hole microwave cavity where the 9.2 GHz clock interrogation is carried out. The present poster shows the details of the experimental optical set-up and demonstrates the use of a Thorlabs multimode optical fiber. A shift of 10^{-14} for 1W of green light is predicted [2]. We conclude this work by presenting the measured frequency shift induced for different intensities of the green laser [3].

Keywords: Time and Frequency Metrology, Physical and Optical Properties of Cesium, Optics, Telecommunications

Introduction

A short term convention with the LNE (Laboratoire National de Métrologie et d'Essais) has been established by Paris Observatory (SYRTE) during the summer and the fall 2007.

During my stay in july and august 2007 at the LNE-SYRTE, I built the compact optical set-up of a Coherent low noise commercial green solid state laser at 532 nm which had to be sent into the 1,1cm hole microwave cavity of FO1. The V5 laser is placed on a temperature controlled baseplate. This laser has been used without any water cooling and is strongly detuned.

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FO1 is a cesium atomic fountain experiment running at Paris Observatory since 1993. The short term project is based upon the publication of Katori et al [4] and the one of Zhou et al [2]. The authors calculate the light shift in the domain 400 nm to 700 nm and predict the existence of many magical wavelengths such as 604 nm. The validity of the calculation [2] is a subject of discussion.

Our experimental measurements will check this theoretical calculation [2] and proof the existence or the non existence of these magic wavelengths. The measurements will give a solid base for more sophisticated calculations.

An eventual positive result, idem the existence of a magic wavelength will open the possibility of a high-accuracy microwave clock integrating cold atoms captured in a magic optical lattice. It has the advantage of interrogating stationnary atoms using the microwave technology.

Reference [3] predicts that such a clock experiment will have a stability of $5.10^{-15}\ \tau^{-1/2}$.

My contribution consists in the construction of the optical set-up of a 5W commercial solid-state laser at 532 nm. This green laser is conducted along the vertical axis of the fountain (cavity hole of a 1,1cm diameter) via optics mounted on an optical table separated from the rest of the cesium fountain's optical set-up.

A first telescope (f_1,f_2) is necessary in order to focalise and converge the green laser beam initially parallel at the entrance of a Thorlabs multimode optical fiber (or angle clived fiber with polarisation maintain and upholding). A half wave plate varies the polarisation of the laser beam inside the multimode fiber. This in order to optimise the transmission over the optical fiber and realise a waist matching. We must avoid an eventual destruction of the fiber core which may occur in the case of a strong green power focused at the fiber entrance. This point is critical when using a monomode optical fiber. A simple matrix calculation has been undergone in this spirit. That is to adapt the waist of the frequency detuned green laser beam at the input collimator of the fiber (paraxial approximation of circular gaussian beams [5] via a ray matrices calculation made by myself).

The waist of the beam at the input collimator of the multimode fiber is given by the following equation:

$$\omega_0'(z) = \omega_0 \sqrt{1 + \frac{z^2}{z_R^2}} \quad (1)$$

where ω_0 is the $1/e^2$ radius or waist along the axial coordinate z. It is half the beam diameter equal to 2.25mm at the output of the solid state laser box. The Rayleigh length z_R is given by the equation:

$$z_R = \frac{\pi.\omega_0^2}{\lambda} \quad (2)$$

The distance between the laser box and the input collimator is L which is about 22,3cm.

The ½ divergence angle θ_{fib} of the green laser inside the input collimator of focal length f_{IC} is given by:

$$2.\theta_{fib} = \frac{c}{f_{IC} - z_{fib}} \quad (3)$$

For indication, the second lens f_2 of the first telescope is moved forward through a z translation stage towards the laser box in order to converge the 532nm beam at the entrance of the optical fiber, just at a distance ε before the critical axial point z_{fib} from the collimator f_{IC} (see Figure 1 and Figure 2).

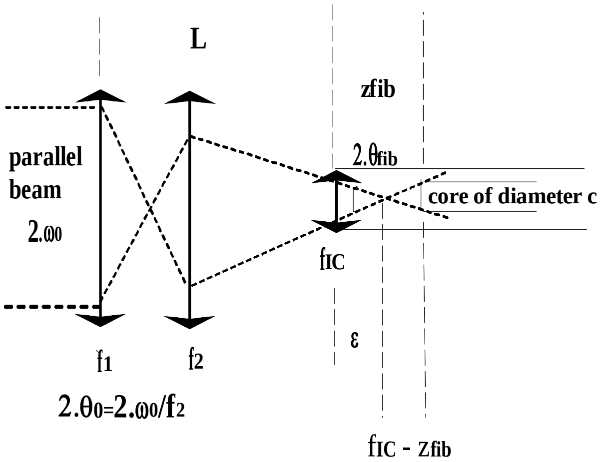

Figure 1: Convergence and Focalisation of the Green Beam of Wavelength λ =532nm at the Entrance of the Optical fiber where $\theta_0 = \dfrac{\lambda}{\pi.\omega_0}$.

The plot of $f_{IC} - z_{Fib}$ is made at ω_{Fib} =0 in order to determine the optimum distance between f_1 and f_2. Then we approach this distance separation to the calculated value 12cm (Figure 2).

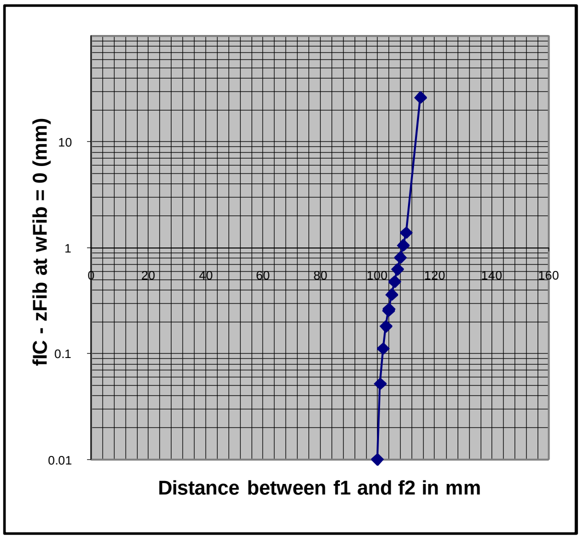

Figure 2: Logarithmic Scale of the Optimisation of the Convergence of the Green Beam at 532nm at the Entrance of the Multimode Fiber

This multimode fiber is used before an adapted telescope in order to irradiate cold atoms captured in an optical network [6] in the fountain. A half wave plate and a cube are used in order to control the green laser power sent through the atomic fountain. A quarter wave plate is placed before the second adapted telescope (f_3,f_4) to vary the polarisation of the green laser from linear to circular. The second telescope allows to adjust the laser spot size in the fountain's cooling region where the atoms are confined. It is important to identify the spatial profile along the x transverse and the y vertical axes of the green beam before/after the multimode fiber at many axial distances z from the input/output collimator. We average the spatial profile over many heights y before and after the multimode fiber.

We note that the second telescope placed after the fiber allows to have a double beam waist larger than the 11 mm diameter opening in the fountain cavity. The compact optical set-up is showed in the following scheme (Figure 3).

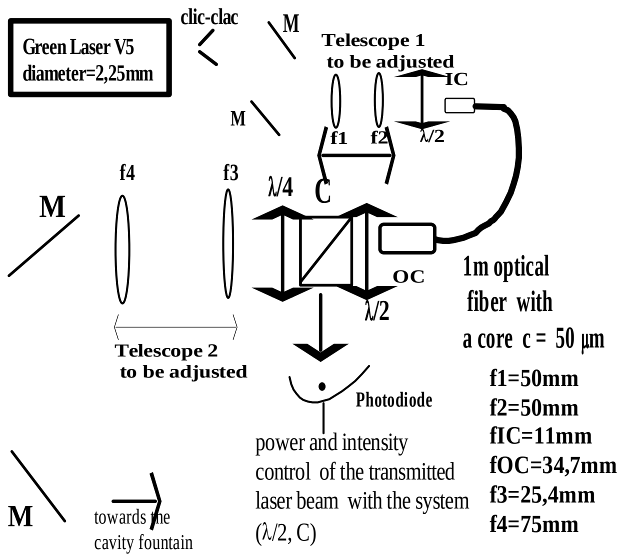

Figure 3: Scheme of the Compact Optical Set-Up of the Green Laser

All the optics at 532 nm have been mounted and well caracterised by myself. This optical set-up completes the one of the fountain experiment.

The measurements of the AC frequency shift have been undergone in september 2007.

A relative frequency shift of 10^{-14} for 1W light averaged over a beam area of 1cm^2 at 532 nm has been predicted [2,3]. The effective measurements are showed in Figure 4 for different possible intensities. An average value - 0,38.10^{-13} per W/cm^2 has been found for the green wavelength. These measurements took about a week. The analyse and the publication have been made in the same month, september 2007 [3].

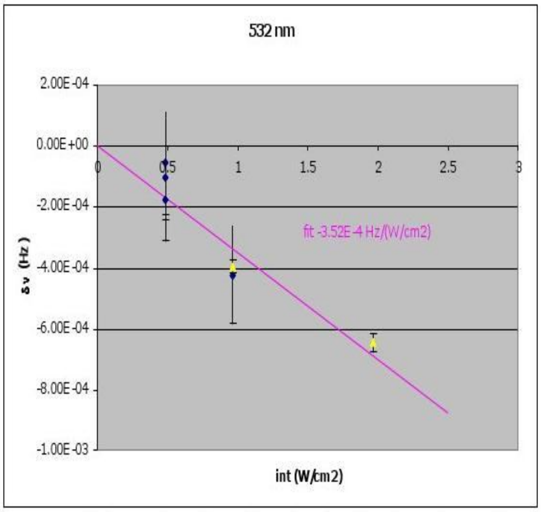

Fig. 1 Frequency shift induced by different intensities of a 532nm beam. The error bars give the statistical uncertainties on the frequency measurement.

Figure 4: The AC Stark Shift Induced by the Green Laser

The light frequency shift of the cesium microwave clock transition $\left|F=3, M_F=0\right\rangle$ to $\left|F=4, M_F=0\right\rangle$ induced at 532 nm is negative such as the one induced at 780 nm [3]. The 780nm infrared wavelength is delivered by a semi-conductor diode laser. The corresponding measurement is given in reference [3]. This makes it highly unlikely that a zero-crossing of the light shift exists between 532nm and 780nm, since there is no dipole resonance in the vicinity of these wavelengths.

Conclusion

We must conclude that the existence of a magic wavelength in ^{133}Cs as suggested in reference [2] is strongly questioned. There should be no magic wavelength as well as in rubidium clocks. The experimental measurement of the AC Stark frequency shift of the hyperfine transition in ^{87}Rb may be envisaged on FO2, a double cesium-rubidium atomic fountain, by an other team at the LNE-SYRTE.

I wrote this paper after a short stay at the LNE-SYRTE years ago for graduate students and especially for an educational purpose [7].

Acknowledgments

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