Optically Pumped Cesium Beam Clock Using Monochromatic Light

Chen Liu, Yuanhao Li, Sifei Chen, Lifeng Fan, Yanhui Wang
State Key Laboratory of Advanced Optical Communication, System and Network,
School of Electronics, Peking University
Beijing 100871, China
wangyanhui@pku.edu.cn

***Abstract*—We propose a new method about optically pumped cesium beam clock. Due to the magnetic field of selecting magnet, the pumping light and detection light use the same frequency laser which makes system structure simpler. The short-term frequency stability is $1.8\times10^{-12}\tau^{-1/2}$.**

***Keywords*—Atomic clock, Cesium beam, Optical pumping, Frequency standard**

I. Introduction

Traditional optically pumped cesium clock can be realized in two schemes. In the first scheme, the pumping and detecting laser use (F=4→F'=4) and (F=4→F'=5) transition of Cs D_2 line respectively. Frequency difference between these two lines is 251 MHz. The detecting laser can be shifted by an acousto-optic modulator to pump the atoms [1]. In the second scheme, the laser is locked on the transition (F=4→F'=4) of Cs D_2 line or (F=3→F'=4) of Cs D_1 line [2]. The pumping laser and detecting laser use the same frequency, but the signal intensity is lower than cyclic transition line.

Here, we propose a new scheme about optically pumped cesium beam clock. This scheme does not require an acousto-optic modulator and adopt the cyclic transition line to detect atoms. We use state-selection Cs beam tube which is same with the optically detected magnetic-state-selected cesium clock (OMCC) [3]. Due to the magnetic field of selecting magnet, the pumping laser and detecting laser use the same frequency laser which avoid using acousto-optic modulator to realize an optically pumped cesium beam clock. Also, the cesium beam has a slower and narrower velocity distribution as they pass through the magnet. The short-term frequency stability is $1.8\times10^{-12}\tau^{-1/2}$.

II. Methods/Results

Fig. 1 shows the experimental setup. An ECDL (External Cavity Diode Laser, DL PRO, Toptica) is used to both pump and detect the Cs atoms. The laser is tuned to resonant with F=4→F'=5 transition. The beam diameter is about 5 mm. The pumping efficiency of the π-polarized laser is better than σ-polarized laser. The laser frequency is stabilized to the F=4→F'=5 transition line of the saturated absorption spectroscopy[4]. Half wave plate and polarized beam splitter (PBS) can split the laser into two beams and control the ratio of these two beams. We use half wave plate and PBS to split the stabilized laser into two beams. These two beams are used to pump and detect the cesium atoms respectively. The intensity of the detecting laser and the pumping laser are 1.5 mW and 18 mW respectively.

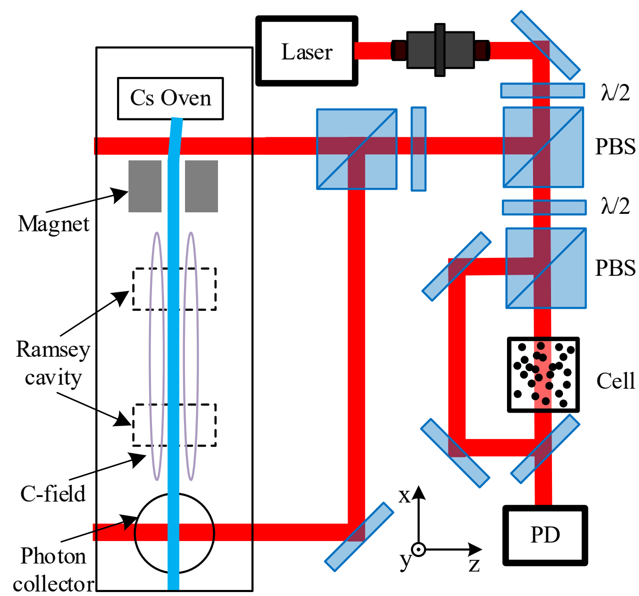

Fig. 1. Experimental setup. PD: photo detector. PBS: polarized beam splitter. λ/2: half wave plate.

In the Cs beam tube, a two-wire magnet is used to select the atoms F=3. About 8 mm away from the magnet where the magnetic field is about 600 Gauss, a laser is used to pump the atoms. A constant magnetic field (C-field) is applied to distinguish the transition lines. To narrow the linewidth, we used the Ramsey's separated oscillating field method. The distance between the two interaction regions is 160 mm. The optical detection region is surrounded by magnetic shields. The laser beam is perpendicular to the atomic beam. A light collector composed of a set of mirrors, focuses the fluorescence onto the photodiode to increase the detection efficiency. A photodiode (Hamamatsu S5107) is used to detect the fluorescence signal.

In this scheme, the Zeeman sublevels of the cesium ground states are shifted due to the magnetic field of the selecting magnet. The perturbed atoms can be pumped to F=3 by the laser stabilized to the cyclic transition line of Cs D_2. To study the phenomenon of the relationship between the frequency of the laser and pumping efficiency, here we used two lasers. One is stabilized to the transition (F=4→F'=5) to detect the state of the atoms. The other is used to pump the atoms with the frequency of the laser swept. For the purpose to study the pumping efficiency which is equal to the study of the result of the state selection, so the microwave is turned off.

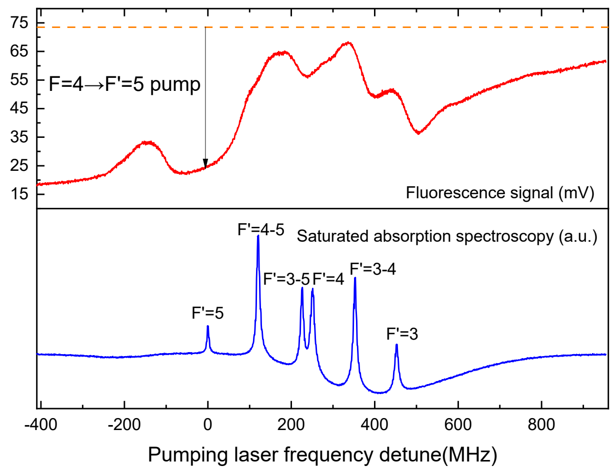

Fig. 2. The relationship between pumping efficiency and the frequency of the pumping laser. The blue line represents the saturated absorption spectroscopy of the pump laser. The red line is the fluorescence signal with the removal of the back ground. The dotted line represents the fluorescence signal without pumping laser.

As we use the magnet select the atoms F=3, the atoms F=4, m_F=-4 is also selected which is because the sign of the effective magnetic moment is positive for both atoms F=3 and F=4, m_F=-4. The atoms F=4, m_F=-4 do not interact with the microwave field, but contribute to the detection noise [6]. In Fig. 2, the fluorescence signal is proportional to the atoms in F=4. So, the lower the fluorescence signal and the better the state selection. When the frequency of the pumping laser is resonant with the F=4→F'=5 transition, the pump efficiency is relatively high.

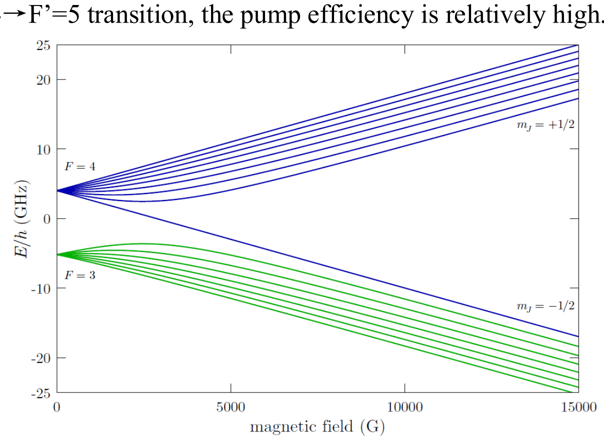

Fig. 3 Cesium $6^2S_{1/2}$ (ground) level hyperfine structure in an external magnetic field. The levels are grouped according to the value of F in the low-field (Zeeman) regime and m_J in the strong-field (hyperfine Paschen-Back) regime. [5]

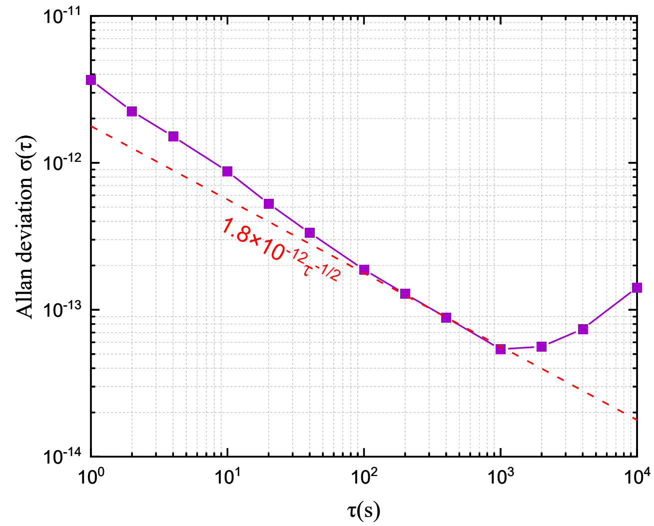

Fig. 4. The preliminary result of the frequency stability.

The laser (DL Pro) stabilized to the transition (F=4→F'=5) by saturation absorption spectrum is used to pump and detect the cesium beam. As the pumping laser in particular position, high optical pumping efficiency can be realized. As the fluorescence signal is minimum, the best position is achieved. The pumping efficiency is about 74%.

The Allan deviation is tested with an active hydrogen maser as the frequency reference. The Allan deviation is shown in Fig. 4. The shot-term frequency stability is $1.8\times10^{-12}\tau^{-1/2}$

III. Conclusions

In this paper, optically pumped cesium beam clock is realized as the cesium beam is pumped and detected using same frequency laser. The short-term frequency stability is $1.8\times10^{-12}\tau^{-1/2}$ and the stability deteriorates at σ(1000 s)=5.3×10^{-14}. In the future, our frequency stability goal is $1\times10^{-12}\tau^{-1/2}$ and the long-term stability should reach 7×10^{-15}. To improve this scheme, the short-term stability and the long-term stability should be studied further. For the short-term stability, the key point is the pumping efficiency which can be improved by adjusting the selecting magnet. For the long-term stability, the power of the laser should be stabilized and the ratio between pumping light and detect light should be improved to suppress the light shift. There are also several things should be considered, such as second-order Zeeman effect, cavity-pulling and Rabi-pulling effects.

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