Update on the Development of Cesium Atomic Fountain at NPL, India

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Abstract

National Physical Laboratory India (NPLI) has been developing a cesium atomic fountain primary frequency standard. We have succeeded in trapping about 10^7 Cs atoms, cool them to about 5 μK by both magneto-optical trap (MOT) and polarization gradient cooling (PGC) and launch them up by moving molasses method. We have demonstrated the fountain action by launching the atoms up to 72.9 cm up and detection of the return signal by measuring the fluorescence. Work is underway to interrogate the launched atoms with microwaves and observe Ramsey fringes.

1. Introduction

Cesium atomic fountains are the primary standards of frequency with highest levels of measurement accuracy, which is much more than any other measurement device currently available. Such fountains are already operational at some leading National Metrology Institutes (NMI) and some are still being developed worldwide [1,2]. The increasing number of fountain frequency standards operated by several NMIs worldwide has contributed to the maintenance of the global timescale at an unprecedented level of accuracy, with fractional uncertainty reaching below 10^{-15}. At the NPLI we started developing a cesium fountain frequency standard a few years ago.. The aim of the activity is to build a primary frequency standard with a relative uncertainty at about 1×10^{-15}. Achieving this level of accuracy requires a remarkable combination of technological innovations in precision lasers, magnetic shielding, vacuum technology and advanced optical, electronic and mechanical systems besides control over the atomic and optical environment.

On the way to realize a primary frequency standard, we have already demonstrated an atomic fountain. We have launched a ball of cesium atoms in a definite atomic state to a height of about 73 cm. In this paper, we present design details of the fountain and recent results on laser cooling and trapping of atoms, characterization and launching of cold atomic cloud and fluorescence detection of atoms on their way back down to the detection chamber.

2. Description of NPLI Atomic Fountain

The NPLI fountain has a (0, 0, 1) geometry of the magneto-optical trap (MOT) for cooling and launching operations. The atoms are first loaded and cooled in MOT followed by further cooling in optical molasses (OM). They are launched using moving molasses and cooled further with polarization gradient cooling. In this section, we describe the basic design details of the fountain.

2.1 Physics Package

The Physics package of our fountain is shown in Fig. 1. The structure has a base area of 0.85 m^2 and is 2 m tall. As shown in Fig. 2 it is divided into four main levels. Level 1 contains the two 20 l/s ion pumps, level 2 contains the magneto-optical trap (MOT) and the fluorescence detection region, level 3 contains the Aluminium drift tube and magnetic shielding and level 4 has the two more 55 l/s ion pumps.

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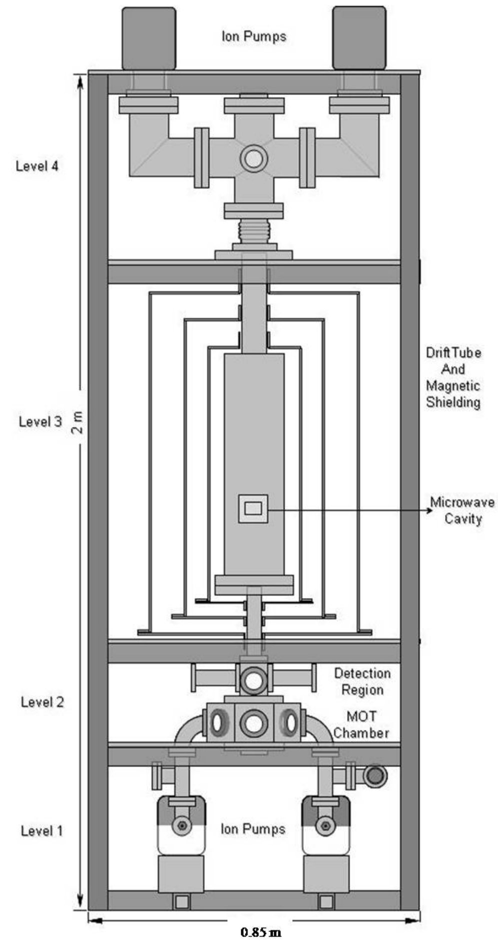

Fig. 1: NPLI atomic fountain

The Cesium atoms are cooled in a MOT followed by Optical Molasses (OM) in an octagonal stainless steel chamber with optical viewports. Two coils in anti-Helmholtz configuration are used to create a magnetic field gradient of 1.78 G/cm at the center of the MOT. In addition, three pairs of Helmholtz coils (in X-Y-Z directions) around the MOT compensate the residual magnetic field in the centre of MOT. The source of Cs is a temperature controlled cold finger containing a Cs ampoule attached to the MOT chamber. The fluorescence detection region lies between the fountain drift tube and the MOT. The vacuum enclosures in the atom cooling zone, drift zone and the top zone have been individually assembled and tested for vacuum performance. After assembling the whole fountain, the level of vacuum reached overall is better than 1 x 10^{-9} torr. The entire drift region is shielded using three layers of mu metal enclosures with an overall shielding factor of better than 10^5. A uniform C-field is produced using a solenoid. The homogeneity of the C-field is about 1nT in the drift region.

2.2 Optical System

An Extended cavity diode laser (ECDL) in Littrow mode is frequency locked to a caesium D_2 line [crossover peak of ^{133}Cs $6^2S_{1/2}$ (F=4) $\rightarrow$ $6^2P_{3/2}$ (F′= 4 and 5) at 852nm], generated by high resolution saturated absorption spectroscopy. Tapered amplifier system TA-100 is used to amplify the frequency locked laser output.The frequency and intensity of the cooling beams is controlled by acousto-optic modulators (AOM) in a double pass configuration. Output from Tapered amplifier is introduced on to the Galilean telescope to reduce the diameter of the beam. Amplified laser output is divided into four horizontal cooling beams X1, X2, Y1 and Y2 (in x and y directions) and two detection beams (D1, D2) and two vertical beams Z1 and Z2. A re-pumping laser (Sacher Lynx) is tuned and locked to the transition ^{133}Cs $6^2S_{1/2}$ (F=3, M_f = 0) $\rightarrow$ $6^2P_{3/2}$ (F′= 4, M_f = 0) by high precision laser saturated absorption spectroscopy. The output beam is split and mixed with one of the cooling beams, Y_2 and a detection beam, D_2. Single mode polarization-maintaining optical fibers (PMFs) transfer the 6 cooling and re-pump beams and 2 detection beams to the Physics package from the optical table. All eight fibers give out diverging beam.

Therefore, at the output end of the fibers, the beams are collimated with home- made beam expanders and give out the desired beam size and polarization.

2.3 Electronics and Microwave Controls

The microwave interrogation is proposed to be performed using a TE011 cavity (Ramsey cavity) made of Oxygen Free High thermal Conductivity (OFHC) copper inside the drift region. Another TE011 cavity made of OFHC copper is used for state selection and is placed below the Ramsey cavity. The whole fountain sequence is electronically controlled using microcontroller cards which receive timing information from a PC.

3. Results

3.1 MOT Characterization

We are able to cool and trap atoms in the MOT. Detailed characterization of the MOT was recently done. Fig. 2 shows the image of a trapped cloud of Cs atoms captured with a CCD camera mounted on one of the viewport of the octagonal chamber. The number of atoms in the trap is determined from the fluorescence signal. For calculating number of atoms, fluorescence signal from the cold cloud was collected on a large area silicon photodiode using imaging optics consisting of lenses and irises. As the size of this photodiode, its spectral response and distance to the trapped atoms is known one could calculate the overall power of the emitted fluorescence light, which enables one to measure the number of atoms in the trap. With appropriate operating parameters, we could cool and trap cloud of cesium atoms with 10^7atoms at the center of the MOT. The size of the cold atom cloud is determined from the CCD image. The pixel output value of the CCD camera is proportional to the light intensity. In our case, the cloud size (diameter) was estimated to be 2 mm for a magnetic field gradient of 2.1 G/cm and detuning of 14.1 MHz.

The temperature of the cloud was measured using release and recapture method. Release and recapture method is one of the simplest technique first used by S. Chu and his collaborators in their study of Doppler cooling of atoms in an optical molasses [3]. A similar technique is used here to measure the temperature of cold atoms trapped in a MOT. We measured the temperature with different parameters and the average temperature of the cloud in MOT was about 127 µK.

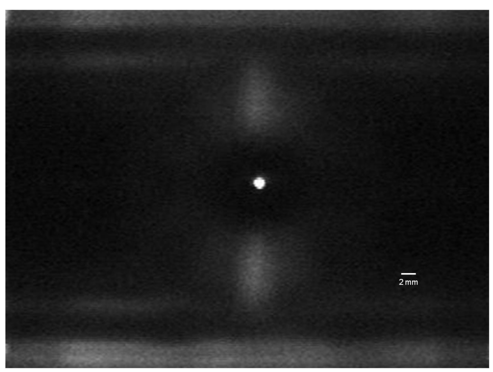

Fig. 2: Image of the cold Cs atom cloud captured with a CCD camera

3.2 Launching and Detection

Once trapped in MOT, the atoms are launched by upward directed beam tuned to a frequency $\nu_c + \delta\nu$ and the downward-directed beam to $\nu_c - \delta\nu$. This frequency detuning between the vertical beams gives an initial velocity, v to the atomic cloud which then travels up, reaches a toss height H_m (dependent on v) and then falls back under gravity. On the way down, the return signal is collected at the detection chamber. Detection is done by measuring the fluorescence from the falling atomic cloud. The time of arrival, T_{arr} is the time elapsed between the launch and appearance of the cloud appears at the detection window.

We have recently demonstrated the fountain action where we could launch the atoms to different launch heights and detect the corresponding return signals. Fig. 3 shows the return signals with increasing launch velocities and thus increasing launch heights and also increasing times of arrivals, T_{arr}. The higher the launch height, the longer the time elapsed, more is the expansion of cloud and thus larger is the loss of atoms when cloud passes back through the microwave cavities. Tighter and cooler the ball of cesium atoms, higher is the launch. In order to achieve this fountain action, we have to cool atoms in a MOT, first by Doppler cooling and then by polarization gradient cooling method to bring the temperature of the cloud to about 5 μK. After demonstrating the fountain, the microwave interrogation of the atomic cloud will be done in order to obtain Ramsey pattern. Stability analysis and uncertainty budget calculations will be performed thereafter.

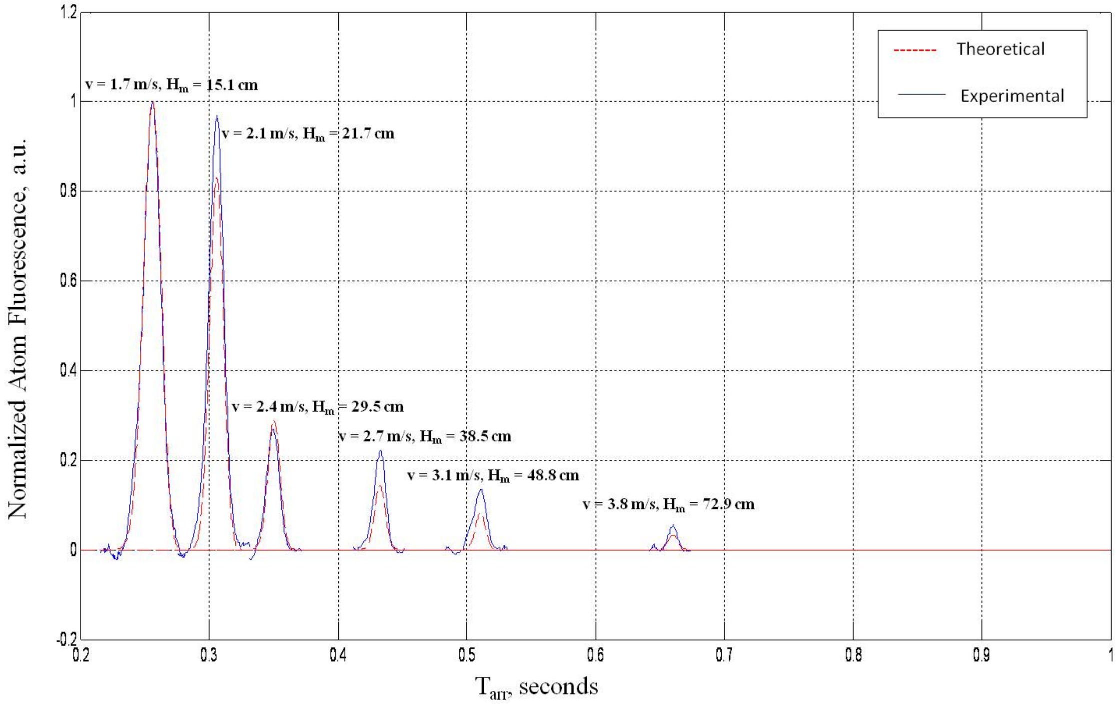

Fig. 3: Relative atom fluorescence as a function of time for various toss heights; solid blue: experimental data, dashed red: theoretical fit to the data assuming cloud temperature of 5μK and initial cloud radius of 3mm.

4. SUMMARY

A detailed description of progress in building NPLI Cs fountain clock has been presented in this paper. We are able to cool and trap a cloud of 2 mm diameter with about 10^7 Cs atoms. The temperature of the cloud in the MOT is 127 μK. We have demonstrated the fountain action by launching the atomic cloud up to 72.9 cm above the MOT center and have also detected the return signal. We will next be performing microwave interrogation of the atomic cloud in order to observe Ramsey pattern.

4. Acknowledgements

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