Atomic Beam Distribution in Calcium Beam Optical Clock

Lei Han[1], Xiaobo Xue[1], Hui Zhu[2], Qianqian Ji[1], Yu Chen[1], and Shengkang Zhang[1]
[1] Science and Technology on Metrology and Calibration Laboratory,
Beijing Institute of Radio Metrology and Measurement
Beijing, China

[2] State Key Laboratory for Superlattices and Microstructures,
Institute of Semiconductors, Chinese Academy of Sciences
Beijing, China

E-mail: hanlei1307@163.com

***Abstract*—Optical clocks have become a very important tool of investigating the characteristics of atoms and ions, for the state-of-art instability and uncertainty. While optical clocks with long running time is still a critical issue. In order to improve vacuum system design and minimize atomic beam divergence angle in optical beam clock, the resonance fluorescence signal of the atom interacting with laser is adopted to evaluate atomic beam two-dimensional distribution. The laser frequency is stabilized to atomic transition resonance frequency via absorption spectrum method. Meanwhile, the laser beam fixed on a two-dimensional displacement platform is exploited to depict the atomic beam distribution with the resonance fluorescence intensity variation corresponding to each laser incident position. The experiment is carried on the calcium beam optical clock to obtain the preliminary atomic beam distribution.**

Keywords*—atomic beam distribution; beam divergence angle; resonance fluorescence; optical atomic clock;

I. Introduction

The atomic clock is by far the most accurate time-frequency device, utilizing very precise atomic transitions. Increasing the running time of an optical clock is one critical issue that scientists are still working on. Calcium beam optical clock is a promising candidate among a variety of compact and robust optical clocks, for its minimal number of lasers and availability of these lasers.

In thermal atomic optical clock, the atomic beam divergence will cause the Doppler broadening, affecting clock transition linewidth and the contrast of transition spectrum [1-5]. Therefore, it is desirable to reduce the divergence of the atomic beam as much as possible through the design of mechanical structure. And the atomic beam distribution needs to be evaluated. The divergence angle is generally evaluated according to structural parameters of vacuum system or the linewidth of atomic transition spectrum [6-11]. However, the former method cannot evaluate the influence of vacuum system machining and assembly deviation, while the latter method depends on the clock transition spectrum and curve fitting.

Here, we demonstrate a method and experiment to evaluate atomic beam two-dimensional distribution with the resonance fluorescence signal of the atoms interacting with laser.

II. Experimental Setup

The experimental setup is shown in Fig.1. The laser is split into two beams by a half wavelength plate (HWP) and a polarizing beam splitter (PBS). The reflected beam is incident perpendicular to atomic beam along x-direction from the rear window B. And a photodetector on the top is used to stabilize laser frequency to atomic transition frequency with absorption spectrum method.

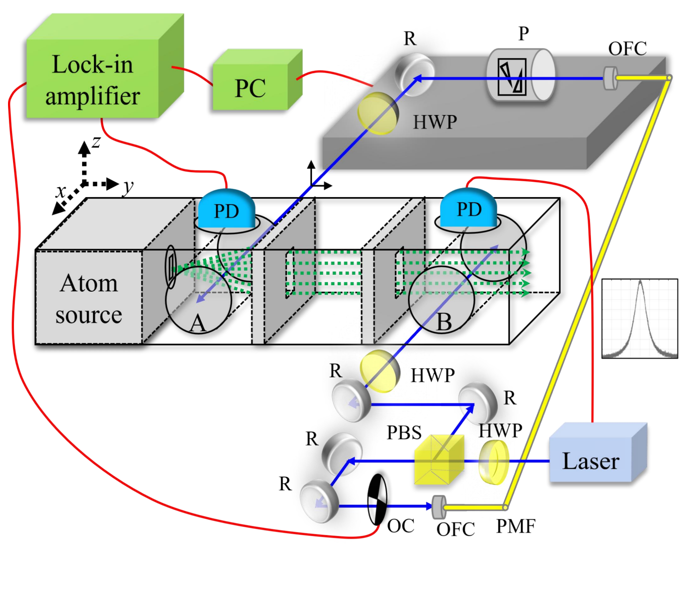

Fig.1 Schematic diagram of atomic beam distribution measurement system. HWP, half-wavelength plate; PBS, polarized beam splitter; R, reflector; OC,

optical chopper; OFC, optical fiber coupler; PMF, polarization maintaining optical fiber; P, shaping prism; PD, photodetector; PC, industrial personal computer.

The transmission beam is delivered through optical fiber to a two-dimensional displacement platform. The platform step-scans along y and z directions. The beam is incident to atomic beam at different positions from window A, while a photodetector on the top will detect fluorescence intensity. As the laser incident position changes, the resonance fluorescence intensity variation is detected to depict the atomic beam distribution in the front chamber. This fluorescence collection chamber is an approximate paraboloid structure.

III. Results

The experiment is carried on the calcium beam optical clock. By simulating the fluorescence detection efficiency of photodetector for different positions within the physical system, the atomic beam distribution in the y-z plane is preliminarily obtained.

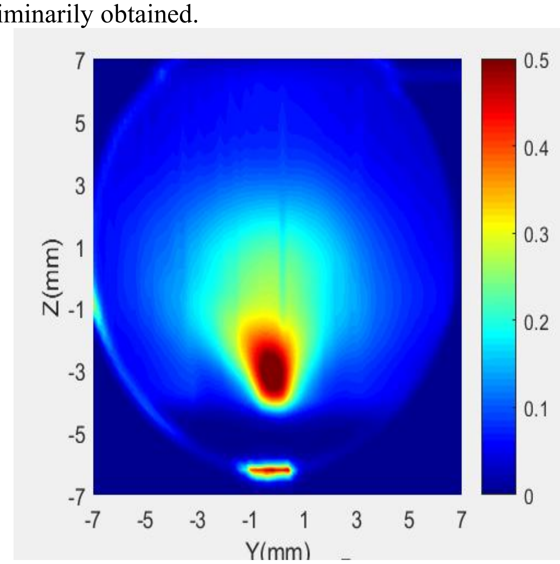

Fig.2 Fluorescence intensity measurement results for atomic beam distribution.

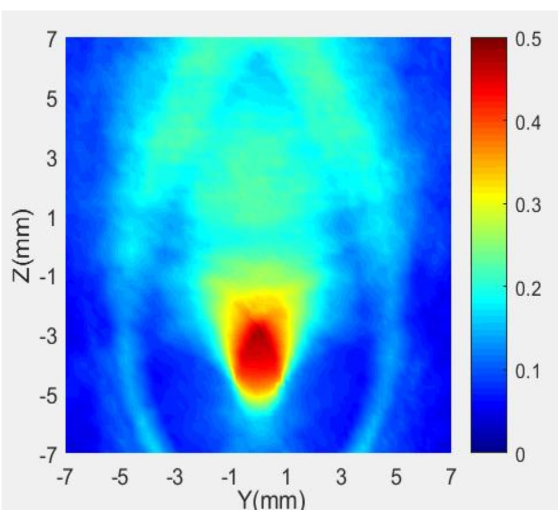

Fig.3 The simulated results of fluorescence detect efficiency of PD for different positions in the x=0 plane.

The result is shown in Fig. 2. The colormap reflects the measured distribution in the y-z plane. The fluorescence intensities detected by photodetector for each incident position are normalized. The blue circle outline represents the circular window shape. The larger color bar value denotes the higher fluorescence intensity and atomic density.

Since the fluorescence collection chamber is an approximate paraboloid structure, the detect efficiency of photodetector on the top for fluorescence intensity emitted at different positions within the chamber should be considered. We define the center of a pair of windows A as coordinate (0,0,0). For simplicity, we assume that the atomic distribution along x-direction is uniform and the detect efficiency in x=0 plane is simulated as shown in Fig. 3.

Dividing the fluorescence intensity of different positions in y-z plane as shown in Fig.2 by the simulated detect efficiency of corresponding positions in Fig.3, the atomic beam distribution is obtained as depicted in Fig.4.

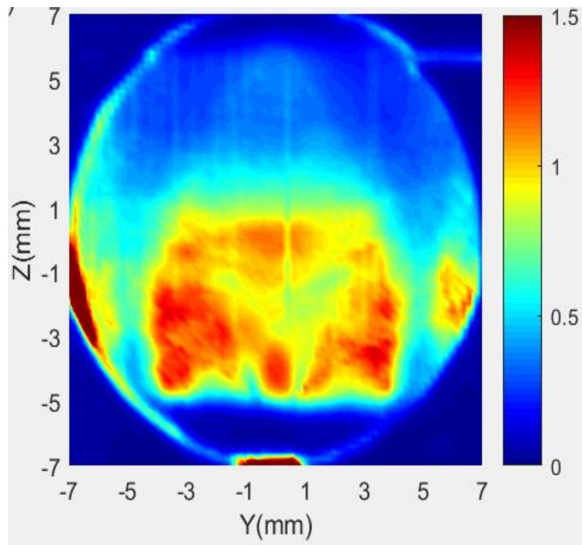

Fig.3 The simulated results of fluorescence detect efficiency of PD for different positions in the x=0 plane.

Along z-direction, the distribution shows a decreasing trend from the center of atom oven to both sides. The simulation of the fluorescence detect efficiency of PD for different positions in the three-dimensional space within collection chamber will be further supplemented for more comprehensive analysis, and a more accurate atomic beam distribution will be obtained.

The result will be used to analyze and measure the divergency angle of atomic beam, so as to optimize system design and improve the detected atom number. This method and experiment can also be applied for the atomic distribution in x-y plane for Doppler broadening research.

IV. Conclusions

A method to obtain the atomic beam two-dimensional distribution with the resonance fluorescence signal is proposed. And the experimental setup is carried on the calcium beam optical clock system to obtain the preliminary result of the atomic beam distribution.

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