Absolute frequency measurement of rubidium 5S-7S two-photon transitions using a femtosecond laser comb

Hsiang-Chen Chui[1,2], Ming-Sheng Ko[1], Yi-Wei Liu[1], Jow-Tsong Shy[1], Jin-Long Peng[2] and Hyeyoung Ahn[2]

[1]Department of Physics, National Tsing Hau University, Hsinchu 300, Taiwan

[2]Center for Measurement Standards, Industrial Technology Research Institute, Hsinchu 300, Taiwan

Hsiang-Chen Chui's E-mail address: d897916@alumni.nthu.edu.tw

Abstract: The absolute frequencies of rubidium 5S-7S two-photon transitions at 760 nm are measured to an accuracy of 20 kHz using an optical frequency comb. They serve as important optical frequency standards for telecommunication applications. ©2005 Optical Society of America

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The 760 nm rubidium 5S-7S two-photon transitions, which provide a frequency standard for frequency-doubled 1520 nm laser in telecommunication applications, has been observed using a 760 nm diode laser [1] or a frequency-doubled 1520 nm diode laser using a periodically polled lithium niobate (PPLN) waveguide [2]. The characteristic of being insensitive to magnetic field of such S-S transitions is particularly interesting as a frequency standard, in comparison with the 778 nm rubidium 5S-5D transition, which has been recommended as the realization of the metric length unit meter [3]. The optical frequency comb based on the femtosecond Ti:sapphire laser has been developed as a powerful tool which directly links the microwave frequency standard to optical region [4]. As a "frequency ruler", the accuracy of such a frequency comb could reach as high as one part in 10^{-15} in measuring an unknown optical frequency. In this Letter, we report the frequency measurement of Rb 5S-7S transitions with an optical frequency comb [4].

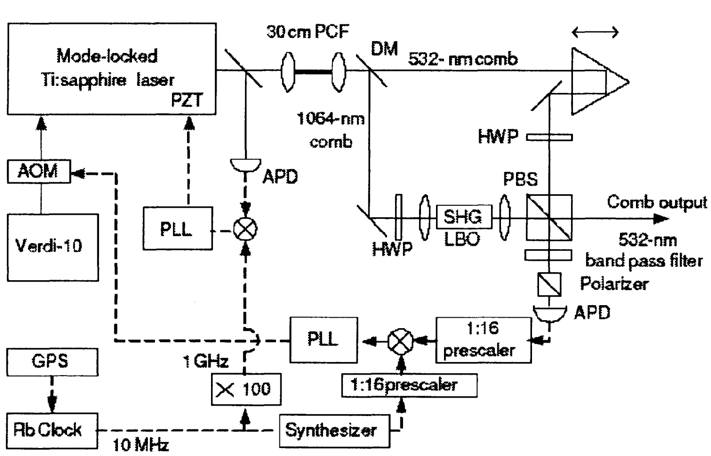

Fig. 1. The optical frequency comb system. DMs: dichroic mirrors; APDs: avalanche photodiodes; SHG: second-harmonic generation; AOM: acoustic-optic modulator; PZT: piezoelectric transducer.

The optical frequency comb was shown in Fig. 1 [5]. The f-2f technique was used to detect the offset frequency [5]. Typical signal-to-noise ratio of the offset beat signal was 30 dB in a 100 kHz resolution bandwidth. The offset frequency was phase-locked to another synthesizer by controlling the pump power using an acousto-optic modulator. This microwave source has a stability of better than 2×10^{-12} for integration time longer than 1 s. The uncertainty of the frequency calibration within one day of average is less than 10^{-15}. The stabilized repetition frequency and offset frequency have residual peak-to-peak fluctuations of <2 mHz and 30 mHz, respectively. This contributes frequency fluctuations of <0.8 kHz of the frequency comb near 760 nm.

The experimental setup of the Rb 5S-7S two-photon spectrometer was based on a 1520 nm external cavity diode laser and a PPLN waveguide frequency doubler [2]. One milliwatt of 760 nm laser beam was picked up using a glass plate to perform the absolute frequency measurement. The setup to measure the beat note of 760 nm laser (UNKNOWN) and the optical frequency comb is shown in Fig.2. A half-wave plate (HWP) is used to adjust the polarization of the UNKNOWN. The comb lines were filtered using the 760 nm bandpass filter with 10 nm bandwidth. The optical power of 760 nm comb lines is ~1 mW. The UNKNOWN and the 760 nm comb lines combined at a polarizing beam splitter (PBS). A polarizer was used to project the polarizations of the UNKNWON and comb lines to the same direction. The beat note was then detected using an avalanche photodiode (APD). Finally, the beat note was counted by a universal counter. The Allan deviation of the beat frequency is better than 2×10^{-11} at 10-s integration time.

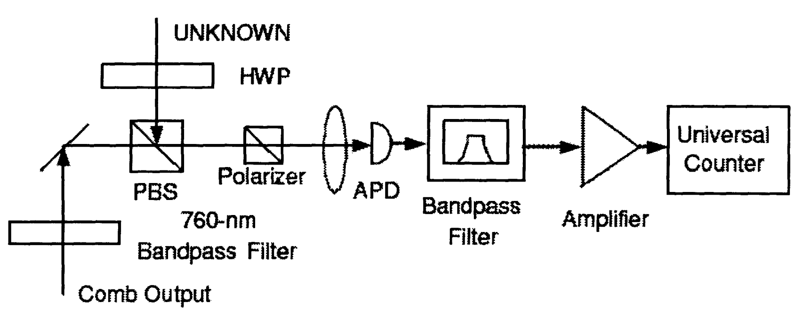

Fig. 2. The experimental setup for the beat note frequency measurement.

The measured laser absolute frequencies of rubidium 5S-7S two-photon transitions are shown in Table 1. Since the accuracy of our measurements could reach 20 kHz, several systematic effects can be analyzed and should be taken into account to deduce the transition frequency. With absolute frequencies measured under different temperatures, the measured pressure shift was found to be -51.7(5.0) kHz/mTorr. The shifts due to various systematic effects are summarized in Table 2. The frequency shift is mainly contributed by the pressure shift.

Table 1 The measured laser absolute frequencies of rubidium 5S-7S two-photon transitions.

Transition	Laser Frequency (kHz)
^{87}Rb F=2-2	394 397 384 383(20)
^{85}Rb F=3-3	394 397 906 927(20)
^{85}Rb F=2-2	394 399 282 765(20)
^{87}Rb F=1-1	394 400 481 965(20)

Table 2 The summary of systematic effects

Effect	Shift at 760 nm
Light shift	-280±4 Hz
Pressure shift	-55.3±5.3 kHz
Blackbody radiation	-665.8±4 Hz
Second-order Doppler shift	-240.6±0.1 Hz
Neighboring transitions	<10 Hz
Electronics	±500 Hz
Total	-56±6 kHz

In summary, the absolute frequencies of rubidium two-photon transitions have been measured to an accuracy of 20 kHz using an optical frequency comb. These transitions provide 4 frequency markers at both 760 nm and 1520 nm. The limitation of the accuracy, 20 kHz, is dominated by the observed transition linewidth (statistic) that is resulted from the jitter of diode laser, and pressure (systematic) of the Rb two-photon spectrometer, rather than the optical frequency comb, 0.8 kHz. Therefore, the accuracy can be further improved by increasing the laser stability and lowering the pressure in Rb cell.

Reference:

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