Observation of the Hydrogen 1S-2S Two-photon Transition Excited by an Ultraviolet Mode-locked Laser

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***Abstract*—We report on an observation of the 1S-2S transition in atomic hydrogen using an ultraviolet mode-locked laser. The 243 nm femtosecond laser is produced through second-harmonic generation and sum-frequency generation from a Ti:sapphire mode-locked laser. After cooling the atoms to 7.8 K, a florescence signal with 800 kHz linewidth is observed. Our scheme provides a potential approach to realize the high-precision frequency standard based on hydrogen transition.**

Keywords—direct frequency comb spectroscopy; 1S-2S transition; component; ultraviolet laser.

I. INTRODUCTION

As the simplest atom, hydrogen plays an important role in modern physics [1]. The transition spectroscopy in atomic hydrogen can be utilized to determine the Rydberg constant and the value of the proton charge radius [2, 3]. The 1S-2S two-photon transition frequency is known with the highest accuracy of any in hydrogen [4] with its 1.3Hz natural linewidth. However, the transition requires ultraviolet laser source, which relies on frequency doubling technology. Compared with continuous-wave (cw) lasers, mode-locked lasers can provide higher conversion efficiency in frequency doubling process and cover broader spectra range, making it a good choice for measure the transition in hydrogen atoms.

II. METHODS

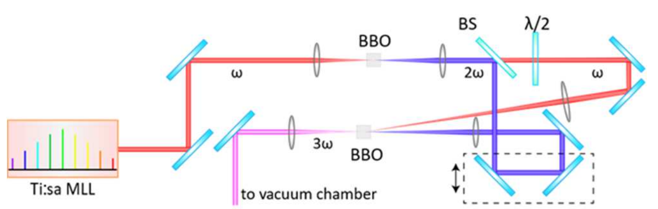

Fig. 1. Experimental setup for 243 nm ultraviolet mode-locked laser generation. A 99.75 MHz Ti:sapphire laser whose output covers 729 nm band is frequency doubled firstly. Then the rest light and its second harmonic are mixed for sum-frequency generation. Ti:sa MLL: Ti:sapphire mode-locked laser. BBO: BaB2O4. BS: beam splitter.

Here, we propose a scheme to observe the 1S-2S two-photon transition of hydrogen using a 243 nm mode-locked laser. The ultraviolet optical pulses are originated from a Ti:sapphire mode-locked oscillator whose output covers 729 nm wavelength and produced through second-harmonic generation (SHG) and sum-frequency generation (SFG). Fig. 1. shows the experimental structure to generate the ultraviolet lasers. In the first stage, the pulse train at 729 nm is focused on a 2 mm long BBO crystal for SHG. In the second stage, the pulses at 364.5 nm and the surplus pulses at 729 nm are mixed in another 2 mm long BBO for SFG, then the 243 nm pulses are acquired. The spectra are shown in Fig.2.

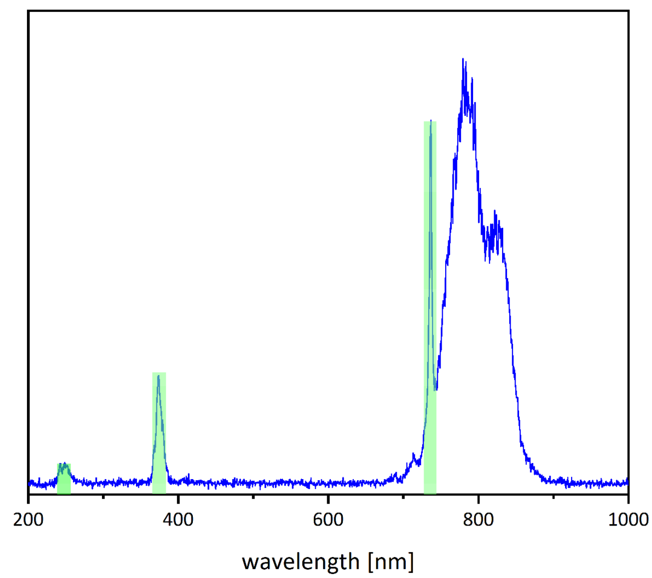

Fig. 2. Spectra of lasers. Dashed regions are the third harmonic, the second harmonic and the fundamental frequency successively from left to right.

The 243 nm pulse train is then injected into a vacuum chamber to excite atomic hydrogen. Fig. 3. shows the structure of our vacuum chamber. A thermal gas cracker is used to produce an ion-free atomic hydrogen beam. The beam enters the cryogenic nozzle which is cooled to 7.8 K by a G-M refrigerator. After cooling, the atomic hydrogen leaves the nozzle and then interacts with the ultraviolet laser pulses in the chamber. To suppress the Doppler broadening, the incident 205 nm light is reflected backward.

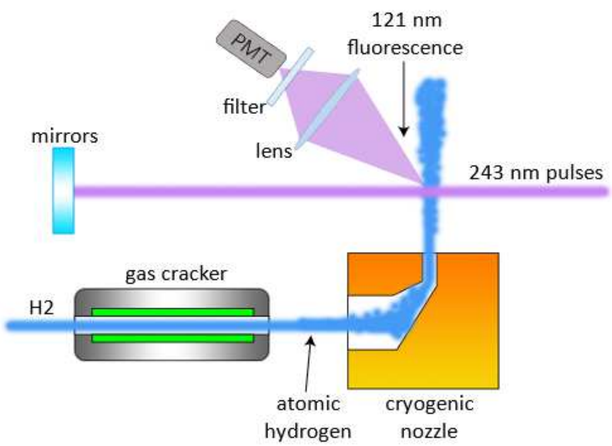

Fig. 3. Structure of the vacuum chamber. The nozzle can be moved in three dimensions.

When excited atoms decay from the 2P state to the 1S state, the 121 nm florescence is emitted. Using a photomultiplier tube (R10454, Hamamatsu) to collect the florescence, we can characterize the transition intensity.

III. RESULTS

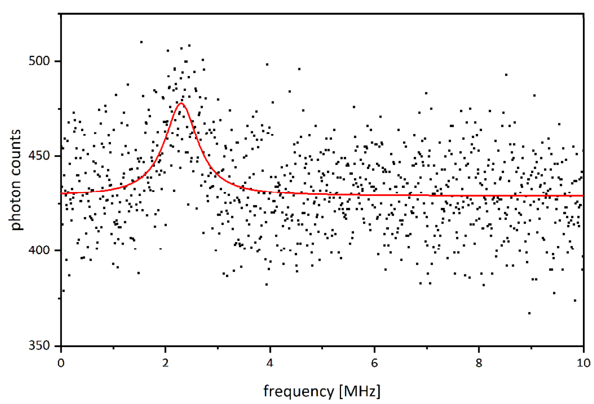

Fig. 4. The direct frequency-comb spectroscopy of hydrogen 1S-2S two-photon transition.

By scanning the laser's frequency using an acousto-optic modulator, we obtain the direct frequency-comb spectroscopy of hydrogen 1S-2S two-photon transition, which is shown in Fig.4. The full width at half maximum (FWHM) of the spectral line is about 800 kHz.

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