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Long-term wavelength drift compensation of tunable pulsed dye laser for sodium detection lidar

Yuan Xia [a,b], Xuewu Cheng [a,*], Faquan Li [a], Jihong Wang [c], Yong Yang [a], Xin Lin [a], Shunsheng Gong [a]

[a] *State Key Laboratory of Magnetic Resonance and Atomic and Molecular Physics, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan National Laboratory for Optoelectronics, Wuhan 430071, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *State Key Laboratory of Space Weather, Center for Space Science and Applied Research, Chinese Academy of Sciences, Beijing 100190, China*

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ABSTRACT

Wavelength stabilization for a pulsed laser presents more challenges than that of continuous wave laser. We have developed a simple and efficient long-term wavelength drifts compensation technique for tunable pulsed dye lasers (PDL) applied in sodium detection lidar system. Wavelength calibration and locking are implemented by using optogalvanic (OG) spectroscopy in a Na hollow cathode lamp (HCL) in conjunction with a digital control software. Optimization of OG signals for better laser wavelength discrimination and feedback control is performed. Test results indicate that locking the multimode broadband PDL to the Na atomic transition corresponding to 589.158 nm is well achieved although the temperature in the laboratory is unstable. Through active compensation, the maximum wavelength drift is reduced from over 5 pm to 0.42 pm in 10 h and the maximum wavelength drift rate of the PDL is improved from 3.3 pm/h to 0.3 pm/h. It has been used to efficient sodium resonance fluorescence lidar detection. This technique is economical and easy to implement, and it provides flexible wavelength control and allows generalization for some other applications which require the wavelength of tunable pulsed lasers to be fixed at an atomic resonance transition references.

1. Introduction

With large output energies and high resolution capability, pulsed lasers possess extensive applications in the fields such as atmospheric remote sensing, laser guide stars, laser isotope separation and some other laser spectroscopy studies. For the broadband sodium lidar applications, pulsed dye laser (PDL) plays an important role in studies of the complex mechanisms near the mesopause region of the atmosphere (∼80–105 km). High spatial and temporal resolution data are provided to indicate the seasonal and diurnal variations of sodium layers, which will furthermore drive on the study of dynamical processes in the atmosphere like gravity and tidal waves [1,2]. These lidars requires wavelength stabilization of laser source to an absolute wavelength reference corresponding to the sodium D_2 resonant transition in a long time. However, the PDL have poor long-term wavelength stability, which significantly affect the lidar echo signal. Instability of the laser cavity will give rise to a considerable wavelength drifts if no measures are adopted. What is more, the dye cell used in the PDL is more susceptible to temperature fluctuations and mechanical vibrations in experiment environment than other types of lasers.

To implement laser wavelength stabilization, a spectral line of an atomic or molecular transition, or a cavity fringe of a stabilized Fabry–Perot interferometer is used as the wavelength standard [3,4]. Various techniques for stabilizing a continuous-wave (CW) laser wavelength have been well developed and used in vary fields [5–10]. Nevertheless fewer methods have been proposed for a pulsed-output laser directly. The pulsed laser system contains more laser-intensity fluctuations and potential noise in mechanical adjustment, and the short pulse signals make the wavelength discrimination more difficult than that of CW laser [11,12]. Therefore the direct wavelength control and stabilization for a pulsed laser presents more challenges.

Stricklin et al. [13] demonstrated a design for reducing long-term wavelength drifts of a commercial PDL, in which interferograms generated by a Fabry–Perot etalon were measured and a liner CCD array was used along with an analog device. Bian et al. [14] presented a more simple method to stabilize a multimode PDL by searching the maximum slope of the transmission curve of an external cavity Fabry–Perot interferometer. These methods make

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* Corresponding author.
E-mail address: lidar@wipm.ac.cn (X. Cheng).

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use of purely optical reference for laser wavelength stabilization, which is useful when atomic resonance line references are not easily accessible. However, they may be more sensitive to drifts of temperature, pressure and aging of the apparatus than the schemes based on atomic and molecular spectroscopy. Gong et al. [15] reported a novel method for the wavelength stabilization of a pulsed difference frequency laser, which were successfully used in CO_2 differential absorption lidar.

The pulsed laser optogalvanic (OG) effect has been studied extensively and turned out to be useful for laser wavelength calibration or locking to a characteristic transition [16–19]. Atomic vapor cells which are usually required to be stabilized at high temperature are not needed. Using a commercial hollow cathode lamps (HCL), which is easier to operate and has a durable rated lifetime of more than 5000 mAh, an electrical signal for wavelength discriminating can conveniently be obtained. With the discharge plasma of HCL acting as a sensitive non-optical detector, the detection apparatus is greatly simplified. Besides, no background filtering is needed as the OG signal is insensitive to the background light. Another outstanding feature of OG spectroscopy technique lies in its many reference lines in the near-infrared regions [20].

In this paper, we present a simple and effective implementation of long-term wavelength stabilization of a PDL based on OG spectroscopy and digital control. To improve the signal-to-noise ratio (SNR) as well as provide better laser wavelength discriminating and tuning sensitivity, the normalization of the pulsed OG signals and the optimization of HCL operating parameters, mainly including the incident laser beam energy and the operating current, are discussed. Digital control based on virtual instrument software is designed to achieve convenient operation of laser wavelength scan/calibration and correction, flexible adjustment of feedback parameters, and visual monitoring of the laser performance. Experiments results indicate that for a multimode tunable PDL, the wavelength drifts encountered when the laser works in free-running mode are compensated successfully. The technique can suffice the application requirement for our sodium resonant fluorescence lidar and can also be generalized to locking pulsed lasers to some other characterized atomic transitions.

2. System description

The experimental set-up for wavelength control and locking is shown in Fig. 1. Pumped by a pulsed Nd:YAG laser, which yields a frequency-doubled light of 532 nm wavelength, the multimode tunable PDL (Sirah, CSTR-D-24), with double grating resonator, 2400 grooves/mm, and a spectral line width of 0.0012 nm, deliver a pulse at a repetition rate of 30 Hz. The grating used for wavelength tuning mounted in the laser cavity is connected to a stepper motor. One step of the motor move can result in a wavelength change of 0.2 pm.

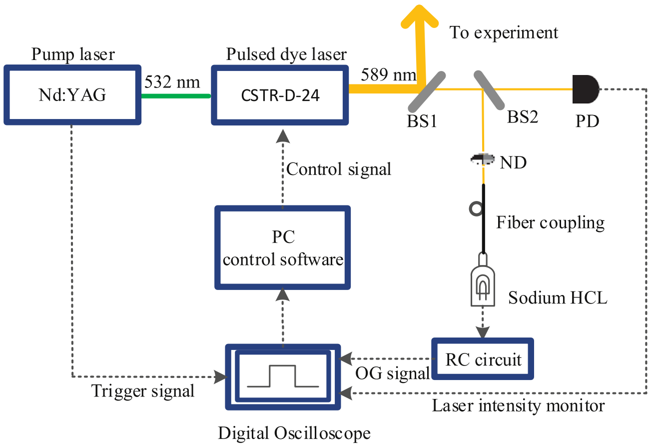

Fig. 1. The setup of wavelength automatic control and locking for pulsed dye laser. (BS) beam splitter; (ND) neutral density filter; (PD) photodetector.

In our experimental setup, the main laser beam is sent vertically up into air for upper atmospheric detection, while only a small fraction is split off for laser locking. A speed photodetector is used to monitor the laser intensity. A continuously variable ND filter is used to adjust the energy of the laser beam coupled into a fiber. The laser beam from the fiber illuminates the plasma through the window on top of a sodium HCL which has an absorbed wavelength at 589.158 nm. As the key component of this control system, the HCL is used to generate OG signal and acts as the wavelength discriminator. A RC circuit is used to read the discharge voltage. The voltage across the HCL vary with the laser wavelength. When the laser beam is resonantly absorbed in the plasma, the voltage reach a peak. If there is a wavelength deviation away from the right atomic transition central wavelength, the amplitude of the OG signal would decrease.

Generally a dedicated boxcar averager is used for measuring pulsed signals [19]. It is very helpful for static gate work, however it may be time inefficient if used for waveform recovery. High-speed digital oscilloscopes offer superior performance in waveform recovery applications. In our system, a digital oscilloscope (DPO 2014, Tektronix), which is available in many labs and can obtain more detail, is used to capture the whole pulsed waveform (rather than a simple voltage value) for more accurate detection of the OG signal intensity. The time-resolved OG signals recorded with oscilloscope are shown in Fig. 2. Due to the inevitable noise from shot-to-shot fluctuations of the pulsed laser, the signal is averaged result of multiple pulse, which would improve the signal-to-noise ratio (SNR). The number of averaged samples on the oscilloscope can be choose by the integer power of 2, and its maximum is 512. Determination of averaging samples should be according to the condition of system noise as well as the response speed of wavelength correction. In our experiment, OG signals are averaged over 128 samples, which can obtain high enough SNR. Larger averaging samples can suppress the laser and electronic noise or other interference better, however, longer acquisition time will be needed, and as a result the response speed will slow down. The blue curve with plus signs corresponds to the situation when the laser wavelength is not resonant to the desired electronic transition. The red curve with triangular signs corresponds

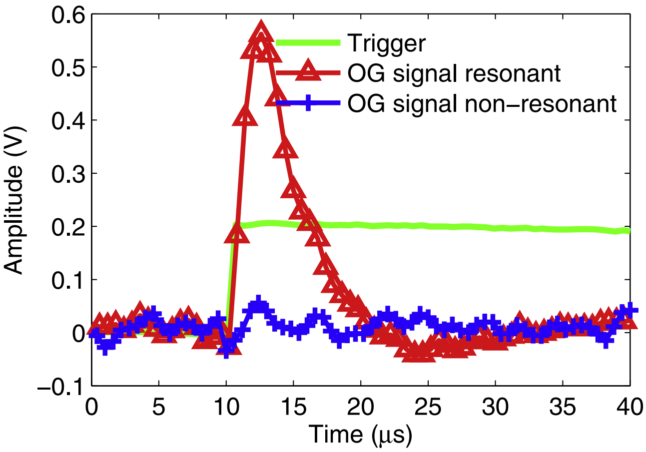

Fig. 2. The temporal profiles of observed OG signals derived from the sodium HCL. The HCL is operated at a discharge current of 9 mA and the energy of the laser bean directed through the HCL is about 80 μJ.