Optical rotatory dispersion based wavemeter used in 1310 nm and 1550 nm wavebands

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We propose a rotatory-dispersion based wavemeter, aiming to reduce the cost and complexity, and retain sufficient measurement accuracy. We have built the wavemeter in-house around very low-cost components, and the no-scanning nature leads to a compact and robust instrument. We give a description of the construction and operating principle, and provide experimental proof in two communication interesting windows. Testing experiments indicate that an absolute measurement accuracy of ±6 pm is believed to be achievable. Besides, this design allows a customizable operating waveband over visible and most of the near-infrared spectrum.

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1. Introduction

In many experiments concerned with high-resolution spectroscopy, atomic physics, photochemistry, communication systems and fiber sensors, tunable laser are required, and they must first be tuned to an interesting wavelength precisely to ensure the most meaningful experimental results. Then the need for optical wavemeter has emerged, and numerous designs have been proposed over the years. Most of them are based on interferometric concepts, such as Fizeau or Fabry-Perot interferometer [1, 2], or a Michelson wavemeter [3-7]. The most commonly used is the scanning-Michelson interferometers which have become a fundamental tool in many laser laboratories, providing accuracies of order 10^{-9} to 10^{-11} [8, 9]. These interferometrically based instruments require high-precision scanning mechanisms and stable designs, which inevitablely leads to high cost, relatively fragile and substantially bulk instruments. On the other hand, a lot of designs have focused on low-cost, compact and robust wavemeters which retain sufficient accuracy for many utilizations, and Wollaston prism based wavemeters have been researched most extensively [10-14]. Here we present a compact wavemeter design which is based on optical rotatory dispersion (ORD) effect. We have built the wavemeter in house, and the entire instrument has a component cost of less than $3000. Testing experiments in two near infrared wavebands (1310 nm and 1550 nm) have showed a measurement accuracy of ±6 pm. The wavemeter has been used in our routine work.

2. Design and operational principle

In our design, a kind of ORD medium should be used to provide an ORD curve describing the relationship between wavelength λ and wavelength-dependent rotatory angle $\theta(\lambda)$. The operational principle behind the ORD based wavemeter is that, a function of λ, say $F(\lambda)$, is measurable which is related to λ through $\theta(\lambda)$, and an unknown wavelength can be determined by the measured $F(\lambda)$ together with a pre-fitted ORD curve. Fig. 1 shows the instrument construction in which quartz crystal is used as the ORD medium. It is a dual-beam optical polarization measuring system, consisting of polarizer P, quartz rod Q of 55.7 mm in length, polarizing-splitter S, two photoreceivers D_1 and D_2 (Model 2033 from New Focus), and a signal processing unit. The influence of light intensity fluctuation can be reduced effectively when adopting the dual-beam technique. To ensure a precise alignment, two stops with diameter of 0.8 mm were placed front and behind the quartz rod respectively. When a plane-polarized light passes through quartz rod Q, its polarization plane will rotate according to optical activity. Emerged light from Q is split into two via splitter S, and then received by D_1 and D_2 respectively, producing two electrical signals J_1 and J_2. When the input wavelength changes, J_1 and J_2 changes correspondingly due to the changement of $\theta(\lambda)$. At orthogonal-bias condition, we have

$$\theta(\lambda) = \frac{1}{2}\arcsin\frac{J_1 - J_2}{J_1 + J_2} \tag{1}$$

When the length of quartz rod is around 55.7 mm chosen, orthogonal-bias condition can be met simultaneously both for 1310 nm band and 1550 nm band. In our design, $F(\lambda)$ is chosen as

$$F(\lambda) = \frac{J_1 - J_2}{J_1 + J_2} \qquad (2)$$

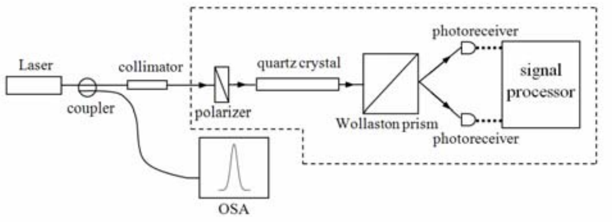

Fig. 1. Optical layout of the wavemeter (inside the dash line), and experiment setup used in constructing ORD curve and characterizing the wavemeter.

3. Experiment and results

In experiment, the ORD based wavemeter shown in Fig. 1 was first used as a measuring system in constructing the ORD curve described by Eq. 2. Two tunable lasers in near infrared range (1250 nm~1360 nm, 1520 nm~1640 nm) were employed to generate the needed wavelengths in curve-fitting. As shown in Fig. 1, a fiber collimator was connected to tunable laser, producing a parallel beam and guiding it into measuring system. Some power was directed to optical spectrum analyzer (OSA, Agilent 86142B) through a coupler for monitoring. We tuned the laser step by step with an interval of about 1 nm, and read out the wavelengths from the OSA with readout resolution set to 1 pm, and concurrently measured J_1 and J_2 via the measuring system. At a single sampling process one hundred sampled data were taken and the sample mean was used as final result. To reduce thermal effect, the quartz rod was sealed in a small box made of double-layered ploxiglass and with reflection reducing coated plates as windows, and temperature stabilized at 25 ^{o}C with a stability of ±1 ^{o}C. The cooler in use is commercial available and very cheap. The fiber between laser and collimator was winded around a rotatable cassette to ensure a stable polarization state and produce a partially polarized light. And the light power transmitted from polarizer P can be adjusted from about 10% to 80% by rotating the cassette against P, allowing a suitable and a well fixed power on photoreceivers when used for lasers with different power levels. A suitable power means it can produce a suitable voltage in A/D conversion; and a well fixed power then ensure a good consistence and repeatability in photoelectric conversion. Fig. 2 shows experimental results which are the averages from numerous repeated measurements, and the fitted ORD curves with sixth-order polynomial. Experimental setup in Fig. 1 was also used in characterizing the wavemeter. Now the tunable lasers were used to generate testing wavelengths which were measured by OSA and by the wavemeter concurrently. By comparison, the largest deviation among all of the measured date covering each waveband was less than ±6 pm when taking OSA as reference (see Fig. 3), and repeated measurements showed a good repeatability and long term stability. So a measurement accuracy of better than ±6 pm was believed to be achievable.

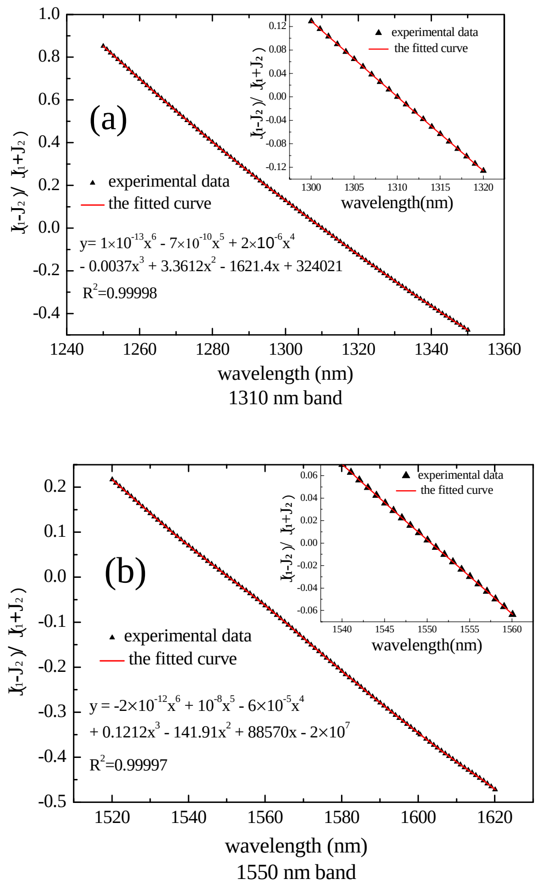

Fig. 2. Experimental results showing the relation between $(J_1-J_2)/(J_1+J_2)$ and wavelength λ and also the fitted ORD curve (Inset: Some enlarged experiment data, in order to give a clearer seeing.), a-1310 nm band, b-1550 nm band.

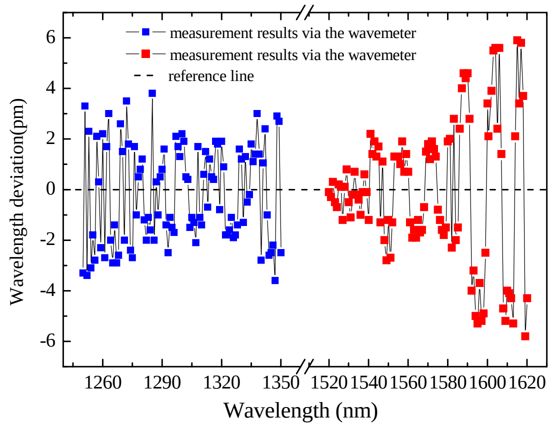

Fig. 3. Showing the deviations of one set of the measured wavelengths when taking OSA as reference represented by dash line.

All optical elements, including polarizer, quartz crystal and polarizing-splitter, can work well from 350 nm to 2500 nm, which enables a customizable operating waveband over visible and most of the near-infrared spectrum.

4. Conclusion

We have developed an ORD based wavemeter which is compact and very cheap. Testing experiments in 1310 nm band and 1550 nm band demonstrate a better than ±6 pm measurement accuracy. Besides, this design is applicable in visible and most of near-infrared spectrum.

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