第34卷第4期 中国科学技术大学学报 Vol. 34, No. 4
2004年8月 JOURNAL OF UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA Aug. 2004

Article ID: 0253-2778(2004)04-0385-05

High-resolution Wavelength Monitoring of a DWDM Transmitter Using Tunable Polarization Interference Filter [*]

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Abstract: A temperature-tunable polarization interference filter (PIF) made of YVO_4 crystal has been presented and applied for wavelength monitoring of a distributed feedback (DFB) laser in a dense wavelength-division-multiplexing (DWDM) optical communication system. This novel device offers a flexible way to monitor the operating wavelength of a transmitter over a wide capture range. Furthermore, the monitoring resolution of 0.02 nm can be obtained by tracking the temperature of the filter locked to a constant transmission value.

Key words: laser stability; tunable filters; birefringence; optical communication; dense wavelength division multiplexing

CLC number: Primary O438; Secondary TN929 **Document code**: A

0 Introduction

In a dense wavelength-division-multiplexing (DWDM) communication system, the channel spacing of the signals has been prescribed by ITU-T as 100 GHz or 50 GHz, i. e., 0.8 nm or 0.4 nm based on a wavelength of 1 552.52 nm, respectively. In order to avoid crosstalk and keep DWDM network in operation, it is usually required for the frequency of each laser to be stabilized within 10% of the channel spacing. That is, the permissible frequency drifts are ±2.5 GHz and ±5.0 GHz for frequency spacings of 50 GHz and 100 GHz, respectively. Distributed feedback (DFB) lasers are often used as optical transmitters in DWDM systems due to their low cost and

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[*] **Received date**: 2003-07-25

Foundation item: This work was supported by the Natural Science Foundation of Anhui Province (No. 01042402)

Biography: Chen Xi-yao, male, born in 1964, Ph. D candidate. E-mail: chenxy@mail.ustc.edu.cn straightforward implementation. However, the wavelength drift by temperature in a DFB laser is about 0.1 nm/℃, and the wavelength drift over lifetime due to the aging of the laser can be as large as several hundreds of picometers. Therefore, it is necessary to monitor and then lock the wavelength of each DFB laser in a DWDM network to the ITU grid.

Most existing monitoring techniques use interference-type optical filters as wavelength discriminators[1~7]. Among them, Fabry-Perot (FP) etalons are especially popular. In this paper, we report on the development of a tunable polarization interference filter (PIF) for wavelength monitoring of a DFB laser[8]. The filter consists of a pair of polarizers and a birefringent plate sandwiched between them. The birefringent plate used is made of yttrium orthovanadate (YVO_4), a positive uniaxial crystal which is transparent in the wavelength range of 0.4 ~ 5 μm. Its large birefringence makes optical devices more compact. And the birefringence and dimensions of YVO_4 crystal are sensitive to temperature. This means the transmission spectrum of the filter can be tuned by controlling the birefringence and optical thickness of the YVO_4 plate via temperature. In our design, this is realized with a heating coil surrounding the plate. By tracking the temperature of the filter tuned to a constant transmission value, changes in the wavelength of the transmitter can be monitored with a resolution of 0.02 nm.

The YVO_4 polarization interference filter offers a flexible way to monitor the DFB laser wavelength. Contrary to commercially available fixed-wavelength filters, the operation point of the PIF is not limited to the ITU frequency grid, but can be dynamically tuned over a wide wavelength range. As a result, the monitoring area can be enlarged without blind spots by using PIF.

1 Properties of the tunable filter

The YVO_4 polarization interference filter was fabricated by sandwiching a YVO_4 crystal plate between a pair of parallel polarization beam splitters (PBS). The crystal plate with the thickness of 14.301 mm was cut in such a way that the *c* axis lies in the plane of the plate surfaces. Thus the propagation direction of normally incident light is perpendicular to the *c* axis. The plate is oriented so that the slow and fast axes are at 45° with respect to the transmission axis of the two PBSs. The transmission spectrum of the filter is a sinusoidal function of the optical frequency[9]. The free spectral range (FSR = 97.3 GHz) of the filter was determined by fitting a sinusoidal function to the measured transmission data as shown in Fig. 1.

The temperature tuning of the filter is realized by feeding current through a heating coil surrounding the YVO_4 plate. Tuning of the filter by temperature is feasible due to the strong temperature dependence of the birefringence and thickness of the plate. The thermal optical coefficients of YVO_4 crystal are $\mathrm{d}n_o/\mathrm{d}T = -8.5\times10^{-6}\ \mathrm{K}^{-1}$ and $\mathrm{d}n_e/\mathrm{d}T = -3.0\times10^{-6}\ \mathrm{K}^{-1}$. The thermal expansion coefficient is $4.43\times10^{-6}\ \mathrm{K}^{-1}$ in the direction perpendicular to the *c* axis. In order to measure the temperature of the YVO_4 plate, twelve thermally sensitive diodes connected in series were deposited around it as a temperature sensor. The relation between the output voltage of these diodes and their temperature was measured with a thermocouple thermometer in advance. It was found that their relationship is linear and the resolution of 0.08K for temperature measurement can be achieved. The measured transmission as a function of the temperature of the filter is shown in Fig. 2. It can be seen that the transmission peak of the YVO_4 PIF shifts with temperature by about 4.3 GHz/K.

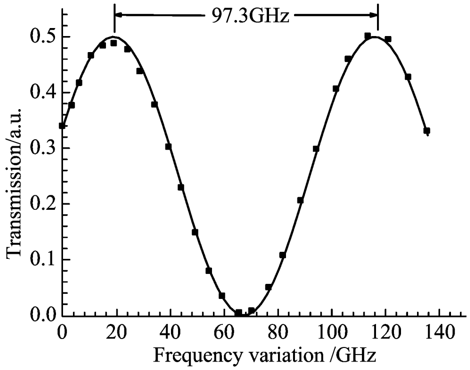

Fig. 1 Transmission spectrum of the YVO_4 PIF. Square dots represent measured data at a constant PIF temperature 42.5 ℃, and solid line is the fitted sinusoidal function

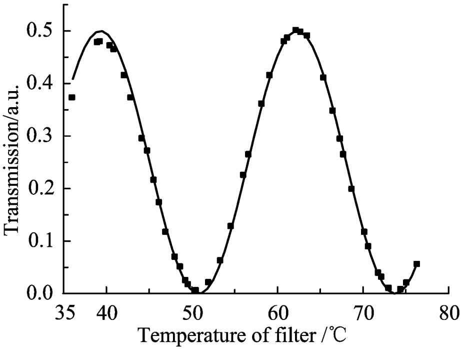

Fig. 2 Temperature dependence of the transmission of the YVO_4 PIF

2 Experiment and measurement

Drift of the transmitter wavelength can be monitored by measuring the temperature change of the filter when its transmission is kept constant. As shown in Fig. 3, about 5% of the total output of the DFB laser is tapped off for wavelength monitoring. This portion of light enters the monitor module and splits into two paths. The first path sends light directly to a detector, which uses the signal as a reference. The second path sends light first through a collimator, then through the filter and last to a second detector. The ratio between the two detector outputs is used to generate a feedback signal for maintaining the ratio at a selected constant value. This is achieved by adjusting the current through the heating coil and thus tuning the filter transmission spectrum. Monitoring the transmitted light intensity ratio of the two paths instead of the absolute filter output can exclude the fluctuation of the DFB laser output and the variation of the photodiode output due to their case temperature changing and aging. Variations of the ambient temperature did not affect the performance of the device on condition that operating temperature was more than 10 K above the ambient temperature.

In the experiment, the output power of the DFB laser (JDS Uniphase CQF915/2833 series) was 1.65 mW. Its line width is of the order of 1 MHz. By changing the current of thermal energy converter (TEC) inside the laser package, we can change the chip temperature of the DFB laser and consequently change its wavelength. For example, if we intend to increase the laser frequency, we can increase the TEC's current so as to cool the laser. The temperature range of 20 ~ 35 ℃ leads to a wavelength tuning range of 1.5 nm. The frequency variation was measured by using a scanning Fabry-Perot spectrum analyzer (Coherent Model 240).

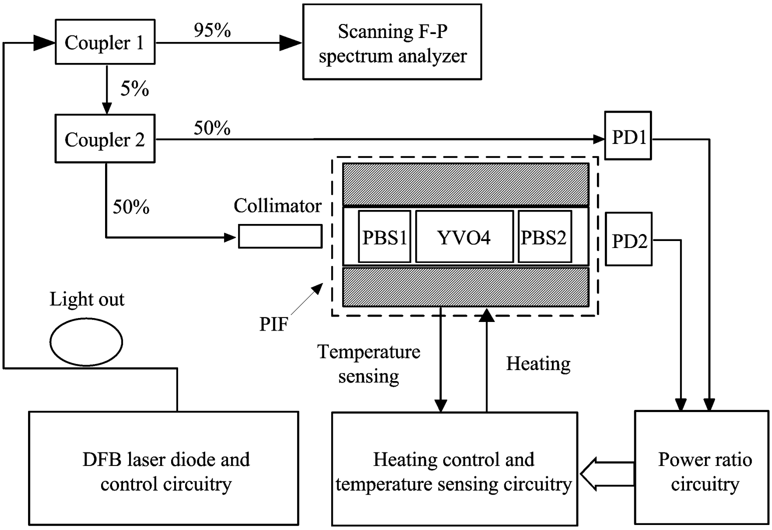

Fig. 3 Schematic of wavelength monitoring for a DFB laser

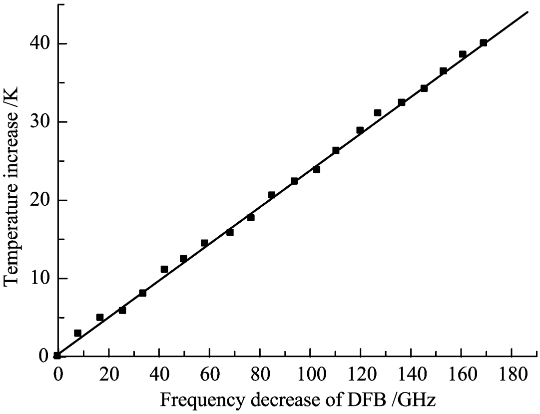

Fig. 4 Relationship between frequency change and temperature change

At the beginning, we changed the filter temperature carefully so that the laser frequency to be monitored was at the midpoint of a slope area in the filter transmission spectrum as shown in Fig. 1. When the wavelength of the DFB laser changed, the control system tuned the temperature of the filter to keep the transmission constant. The required temperature change was found to be linearly related to the change of frequency as shown in Fig. 4. The filter was capable of monitoring the frequency over a range of more than 100 GHz. By making a linear fit to the measued data, the sensitivity of the temperature for frequency change is determined as 0.23 K/GHz. The standard deviation of the fit is 2.15 GHz (i. e., 0.017 nm), which is less than 2.5% of the channel spacing in a 100-GHz DWDM system or less than 5% in a 50-GHz system.

3 Conclusion

In summary, we have demonstrated a tunable polarization interference filter for wavelength monitoring of a DFB laser in DWDM optical communication networks. The operation point of the filter was adjusted by changing the temperature of the YVO_4 crystal plate. The changes in the operating wavelength of the transmitter can be monitored by measuring the temperature changes of the filter when light transmittance was kept constant. The temperature variation was found to be linearly related to the changes in the frequency and the monitoring resolution of less than 2.5 GHz

(i. e. , 0.02 nm) can be obtained. Because of sinusoidal shape and tunability of its transmission spectrum, the YVO_4 polarization interference filter can be employed for monitoring any laser wavelength in DWDM systems without dead bands. Its wide wavelength capture range means that the filter can also been utilized in optical sensing systems.

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利用可调偏振干涉滤波器监视 DWDM 系统光源波长变化

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摘要:提出利用钒酸钇晶体偏振干涉滤波器对密集波分复用光通讯系统信道光源(分布反馈激光器)的波长漂移进行监视. 由于通过改变钒酸钇晶体的温度可以移动滤波器透射谱的峰值位置,因此该方法可以实现无盲区波长监视. 在实验中,保持滤波器的光强透过率不变,通过测量相应的滤波器温度改变,取得了 0.02 nm 的波长监视精度.

关键词:激光稳定性;可调滤波器;双折射;光通讯;密集波分复用