Study on the characteristics of the λ/4 Phase-shift DFB Yb^{3+}-doped fiber lasers

Jia-lin CHEN, Bai CHEN , xiao-xin FENG, li WANG, Zun-qiLin
(National laboratory on High Power Laser and Physics, Shanghai Institute of Optics and Fine Mechanics, The Chinese Academy of Sciences, Shanghai 201800,China)

ABSTRACT

At first, we made a approximativeλ/4-shifted DFB Yb-doped fiber laser with double exposure method .The length of Yb-doped fiber is 10cm. Secondly, we processed the fiber laser by UV trimming. In addition, the running characteristics of the λ/4 phase-shift DFB Yb^{3+}-doped fiber CW lasers were researched. The fiber laser have the following excellent characteristics: Output power of 25mW, fluctuation of less than 2%, 100% single longitudinal mode, 27dB polarization extinction ratio, 60dB signal-to-noise. What is more, the effect on the fiber lasers is also researched from several factors such as temperature, mechanism perturbation and fresnel reflection of fiber end section.

Key words DFB fiber laser; single longitudinal mode; Yb^{3+}-doped; λ/4 phase-shift；double exposure

1 INTRODUCTION

The λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser running in the 1053 nm , can be one important alternation to be used as a seed light source in the front-end systems of the ICF laser driver. Single frequency fiber lasers are of considerable interest for a variety of important applications in telecommunications and sensor systems. Distribute Bragg reflector (DBR) fiber lasers have been reported [1, 2], but they typically need to be short (a few centimeters) to be reasonably robust against mode-hopping, which is one of the key requirements of single frequency lasers. Longer fiber lasers would be desirable if frequency stability could be maintained, especially since the optical line width in long fiber lasers would be desirable if frequency stability could be maintained. Especially since the optical line width decreases with increasing cavity length. A quarter wavelength(λ/4)phase-shifted distributed feedback(DFB)laser, in which an additional optical phase of π/2 is introduced into the DFB region, has been extensively developed as a highly reliable single-longitudinal-mode (SLM) laser [3]-[5]. The main longitudinal mode oscillates exactly at the Bragg wavelength and the threshold gain difference between the main longitudinal mode and side ones is the largest in theλ/4-shifted DFB structure. Furthermore, the output power from one facet can be increased by

joannajiajia@163.com phone 86 021 69918273; fax 86 021 69918800

Passive Components and Fiber-based Devices, edited by Yan Sun,
Shuisheng Jian, Sang Bae Lee, Katsunari Okamoto, Proc. of SPIE Vol. 5623
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.568482

introducing an asymmetric structure into the λ/4-shifted DFB laser. As a way to adjust the parameters of fiber grating, UV trimming can be applied flexibly in their making process.

2 THE THEORY AND EXPERIMENT

2.1 numerical simulations

Forgetting the exportation of SLM, demand produces λ/4 phase-shifted in the DFB construction. We can gain the equation of threshold gains[6]:

$$\left[-\gamma_- \coth\gamma_- \frac{L}{2} + (\alpha^- j\delta_-)\right]\left[-\gamma_+ \coth\gamma_+ \frac{L}{2} + (\alpha - j\delta_+)\right] = \left|\kappa_+\right|^2 \qquad (1)$$

from equation(1) we can known Fig 1 shows the spectrum of modes of a stepped structure for comparison that of a uniform structure.

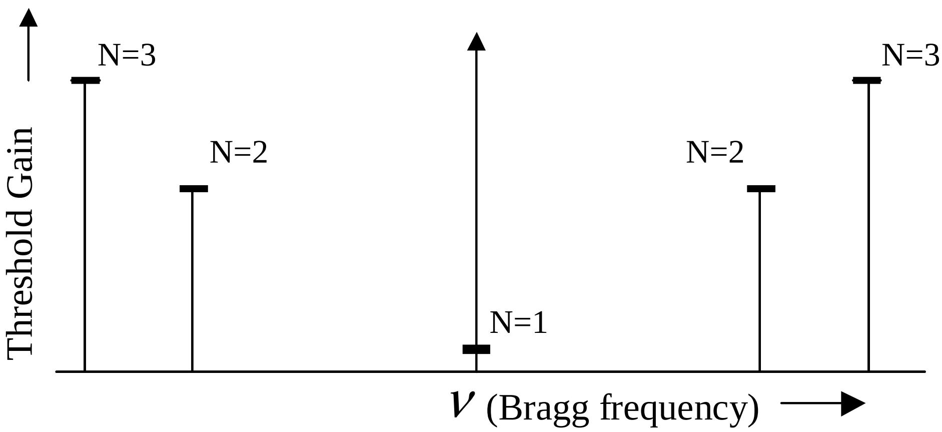

Fig1 Diagram illustrating the mode spectrum and requird threshod gainsfor an phase-shift DFB laser

To demonstrate how suitably placed phase shift φ occur at locations Z. The transmittivity of such a grating with multiple phase shift can be calculated by using a scattering-matrix approach based on the coupled-mode theory.Specifically, transmission through a uniform section between neighboring phase-shift regions is governed by:

$$\begin{pmatrix} A_{out} \\ B_{out} \end{pmatrix} = \begin{pmatrix} S_{11}S_{12} \\ S_{21}S_{22} \end{pmatrix} \begin{pmatrix} \exp(i\varphi) 0 & \\ 0 & \exp(-i\varphi) \end{pmatrix} \begin{pmatrix} S_{11}S_{12} \\ S_{21}S_{22} \end{pmatrix} \begin{pmatrix} A_{in} \\ B_{in} \end{pmatrix} \qquad (2)$$

Where A and B represent the amplitudes of forward and backward propagating waves and the matrix elements of the S matrix are obtained by using the standard coupled-mode theory and given by:

$$S_{11} = (1-\gamma^2)^{-1}[\exp(\frac{iqL}{2}) - \gamma^2 \exp(-\frac{iqL}{2})]$$

$$S_{22} = (1-\gamma^2)^{-1}[\exp(-\frac{iqL}{2}) - \gamma^2 \exp(\frac{iqL}{2})]$$

$$S_{21} = -S_{12} = (1-\gamma^2)^{-1}\gamma[\exp(\frac{iqL}{2}) - \exp(-\frac{iqL}{2})] \qquad (3)$$

In(3)，L is the section length. $q = \pm i[k^2 - (\delta\beta)^2]^{\frac{1}{2}}$，and $r = (q - \delta\beta)/k.$，Further $k = \pi\delta n/\lambda_B$ is the coupling coefficient of grating and is the detuning from the Bragg wavelength λ_B related to the grating period Λ as $\lambda_B = 2n_{eff}\Lambda$.Here n_{eff} is the effective mode index and δn is the depth of index modulation.

The phase shift φ at a given location Z can be incorporated by multiplying the S matrix with the diagonal matrix with elements exp(±φ),corresponding to the phase shifts experienced by the counter propagating waves. The same process can be repeated to calculate the final S matrix for the entire fiber grating of length L. The transmission and reflection spectra are then obtained by imposing the boundary condition B_{out}（L）=0，and are given by:

$$R = \left|\frac{B_{in}}{A_{in}}\right|^2 = \left|\frac{S_{21}S_{11}e^{i\varphi} + S_{22}S_{21}e^{-i\varphi}}{S_{21}S_{12}e^{i\varphi} + S_{22}{}^2 e^{-i\varphi}}\right|^2 \qquad (4)$$

For observing the reflective spectrum of phase-shifted fiber grating directly we take kL=4.0, $\delta n = 2.0\times10^{-3}, \lambda_B = 1053nm$, When φ is vary, we take $\delta\varphi L$ as X-axis and s Y-axis.

From fig2(a), we can known：λ/4(orπ/2)phase shifted transmissible peak at the of the reflective peak. Fig2 (b) was showed: when phase shifted is larger thanπ/2, the transmissible peak deviates the center of reflective peak and moves toward short wave. When phase shifted is smaller thanπ/2, the transmissible peak deviates the reflective center of peak and moves toward long-wave direction. In order to obtain optimumλ/4 phase-shifted structure, we treat approximative λ/4-shifted Yb-doped DFB fiber laser with UV trimming. when we use double exposure method to produce phase-shifted in fiber grating, the quantity of shifted was decided by: [7]：

$$\varphi = \frac{2\pi}{\Lambda}\cdot\frac{\Delta n_2}{n_{eff} + \Delta n_1}L_2 \qquad (5)$$

Here，Λis the grating period，L_2 is the length of phase-shifted，$\triangle n_1$is the changeable quantity of the effective index of the whole fiber grating when first exposure; $\triangle n_2$ is the changeable quantity of refractive index in phase-shifted area after the area was exposured.. Here n_{eff} is the effective index. When the exposure is not saturated, n_{eff} increases along with the exposure .According to the equation（5）we can known Fig2（b）is the case that phase-shifted is larger thanλ/4,we can increase n_{eff} and made φ decrease toπ/2through UV exposure of the area where there is no phase-shifted. Fig2（c）is the case that phase-shifted is smaller thanλ/4,we can increase $\triangle n_2$ and made increase φ toπ/2 through UV exposure of the area where there is phase-shifted.

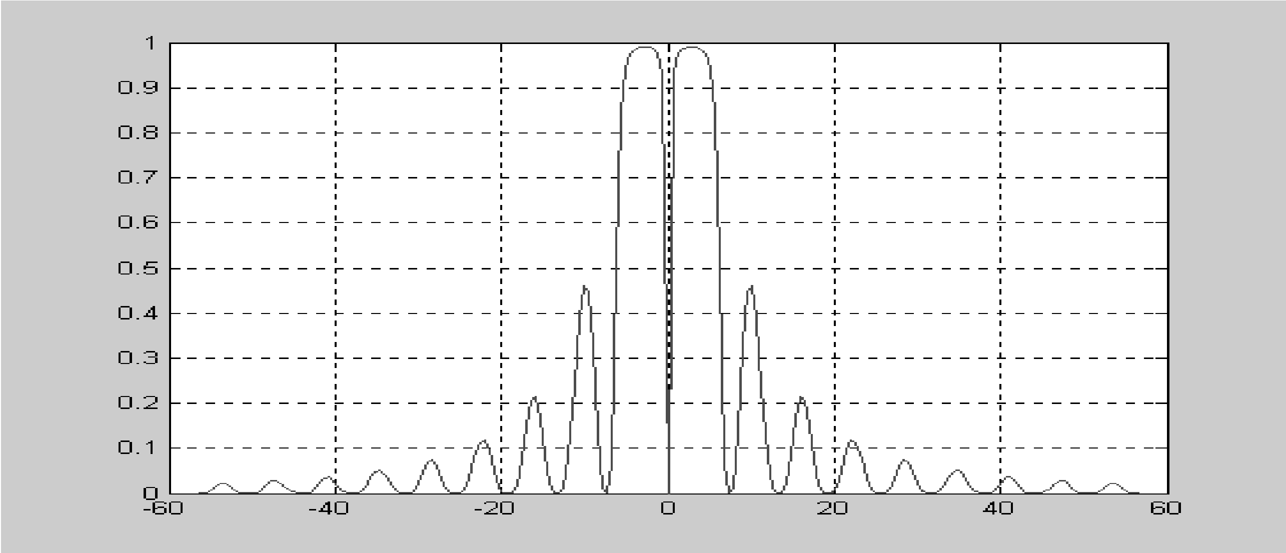

Fig2 (a) The reflectivity with$\pi/2$ phase-shift located at the center of the fiber grating

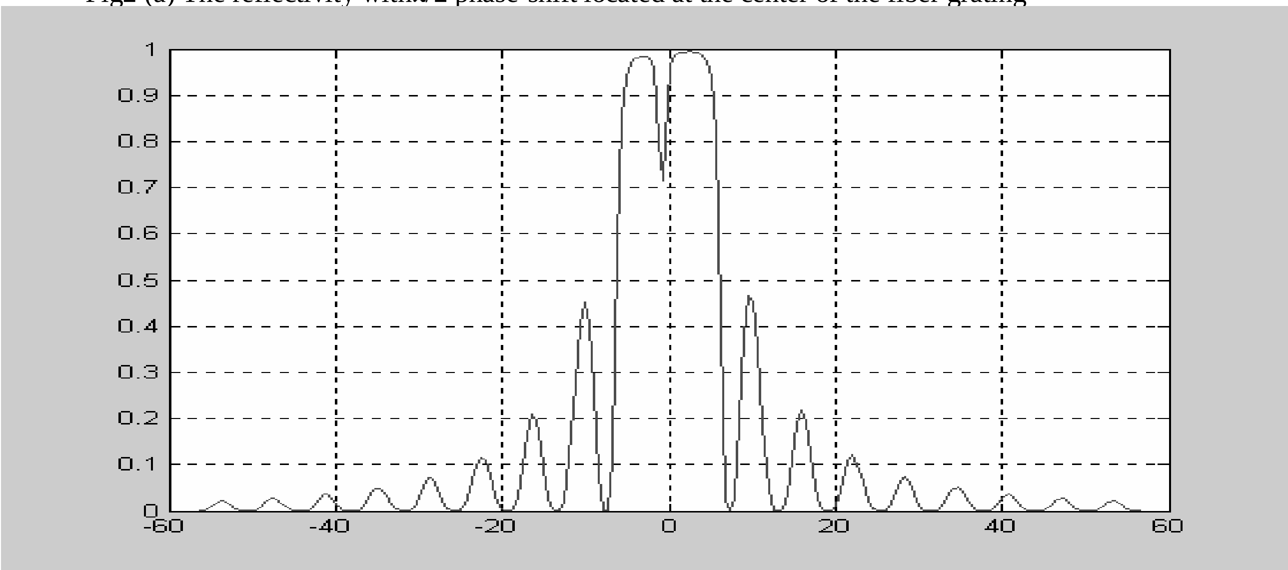

Fig2 (b) The reflectivity with$\pi/2$-($-\pi/16$)phase-shift located at the center of the fiber grating

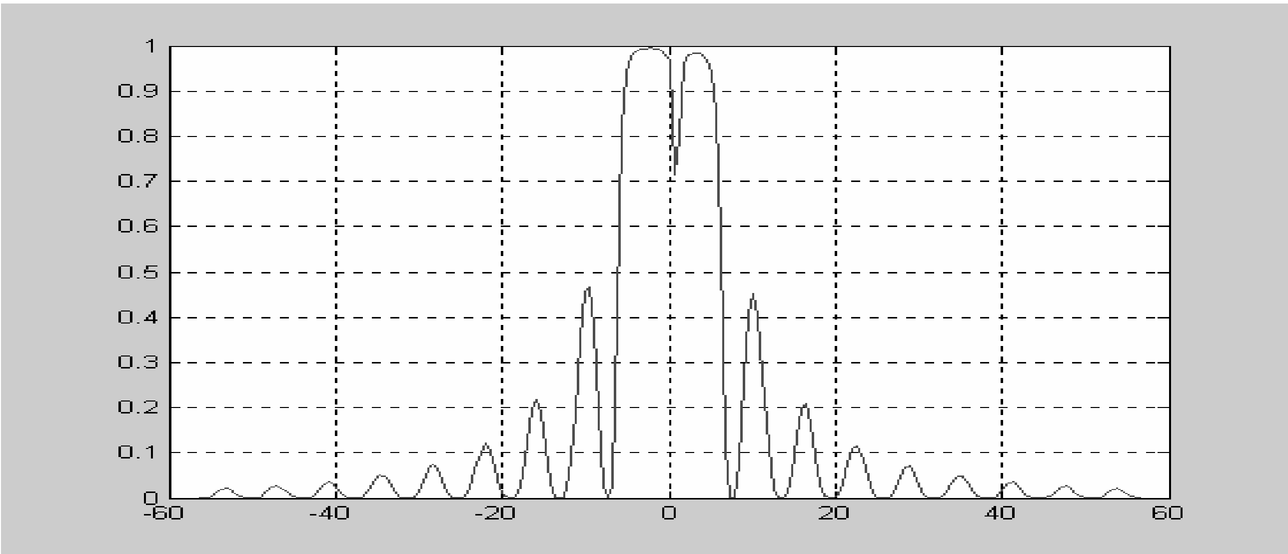

Fig2(c) The reflectivity with$\pi/2$-$\pi/16$ phase-shift located at the center of the fiber grating

2.2 experiment process

The experiment equipment that we adopt is shown in the Fig3. In our experiment, LD_1 pump light first passed by the WDM_1, then connected with an Yb-doped fiber, thus can provide a fluorescence light source. ISO is to prevent the emergence of fluorescence laser oscillation. LD_2 passed by WDM_2, connected with a phase-shifted fiber-grating make into the DFB laser. Spectrum was used to detect optical Signal at real time. Generally, spectrum used in many other experiments can only observe the laser or fluorescence, but our experiment equipment can observe laser and fluorescence at the same time. Open LD_1 and close LD_2, we can observe fluorescent spectrum; close LD_1 and open LD_2 we can observe laser spectrum. Our method is easy to operate, and benefits to UV trimming.

Experiment step as follows:

(1) Fig4 is Phase-shifted fiber grating spectrum which is after double exposure .Because phase-shift in the fiber grating is not a strict $\lambda/4$ phase-shifted ,we did not observe the laser spectrum in experiment.

(2) Open LD_1 and LD_2 at the same time ,we processed phase-shifted Yb-doped DFB fiber laser by UV trimming. After a while, we find the laser appear at 1052.96nm.

(3) Fig5 is laser spectrum recorded in this process, we continue trimming phase-shifted fiber grating with UV, we find that the output of laser becomes stronger and stronger continuously.

(4) We watched the laser with scan F-P interferometer and make UV trimming at the same time until we can observe the good running characteristic of the SLM laser that is showed by Fig7.

(5) Finally, we saw that phase-shift fiber grating spectrum showed by Fig6 has more great improvement than before showed by Fig4.

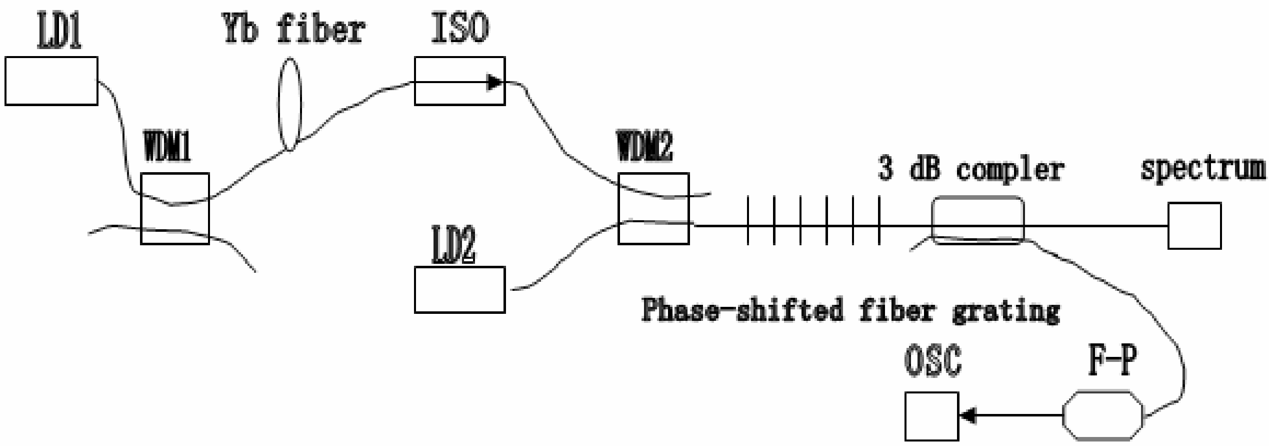

Fig 3 experiment setup

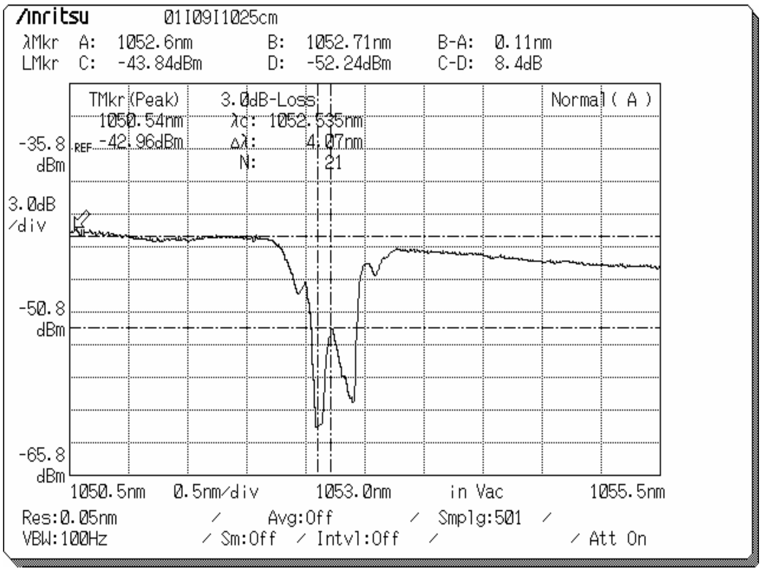

Fig 4 Primitive Phase-shifted fiber grating spectrum

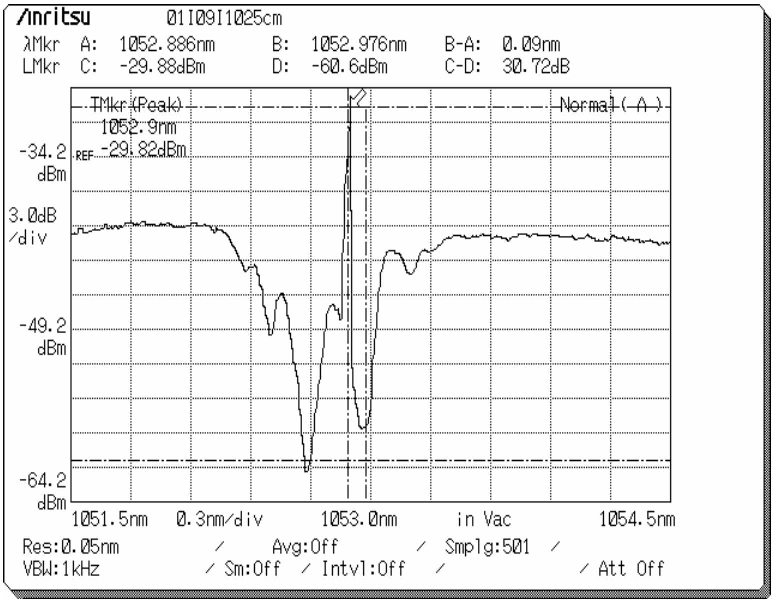

Fig 5 laser and fluorescent spectrum

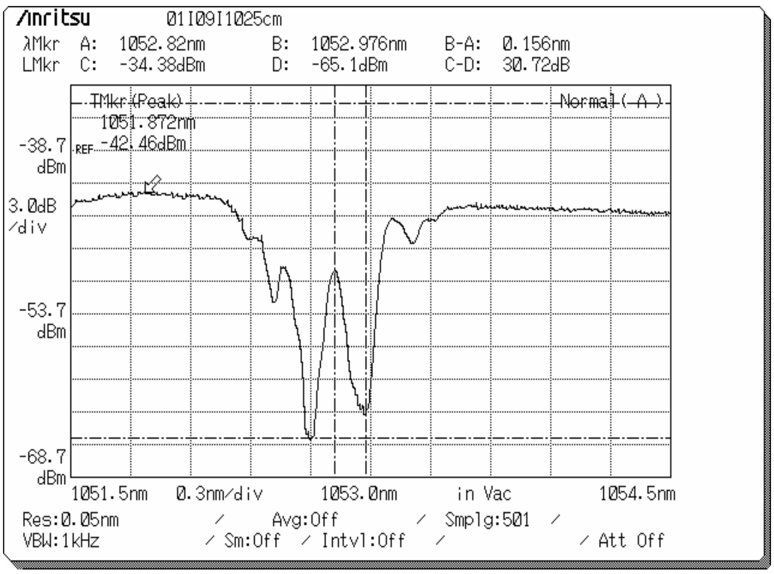

Fig 6 Phase-shifted fiber grating

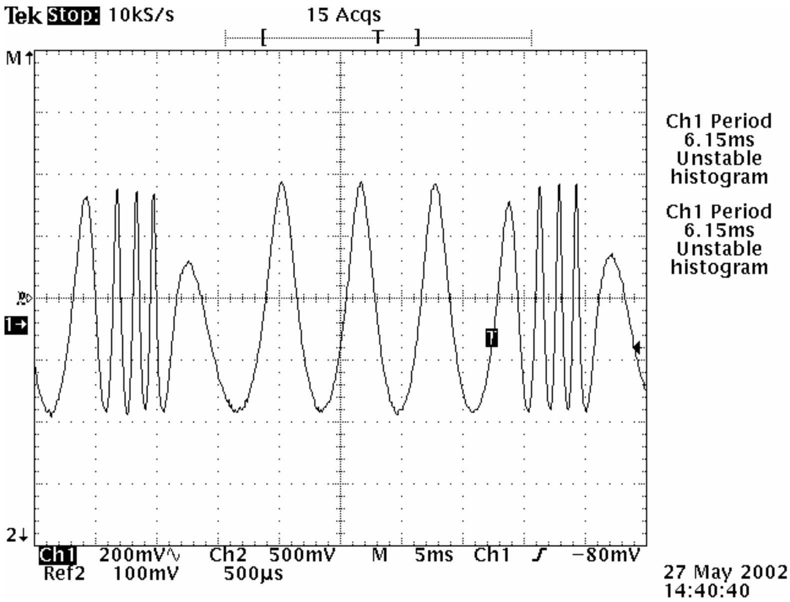

Fig 7 Wave shape of single mode lasing in Yb-doped F-P cavity fiber laser recorded by scanning F-P interferometer and oscilloscope

3 EXPERIMENT RESULT AND ANALYSIS

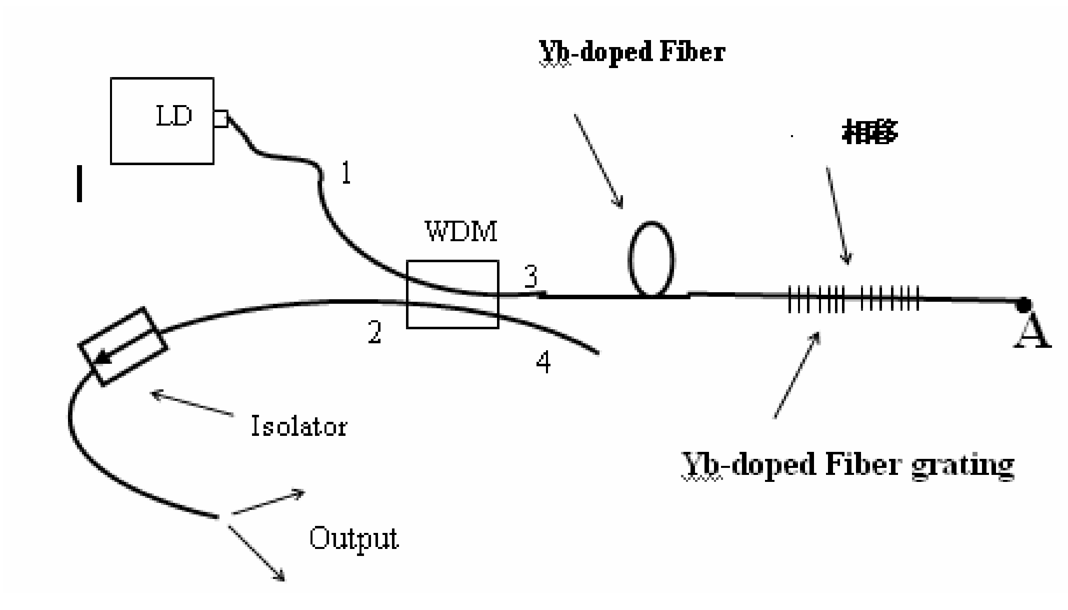

Fig 8 DFB fiber laser

The structure of the DFB fiber laser is illustrated in figure 8

3.1 The effect from the end Fresnel reflection

In the setup showed in Fig9, we found that the end Fresnel reflection from point A affects severely characteristic of the laser. we believe this is because the reflect laser from the end Fresnel reflection enters the DFB resonance cavity, and couple with the laser in the cavity. When we dip point A into the matching liquid of refractive index, the result proves that the output laser have good performance of the laser in their mode, polarization and power stability.

Thereafter, we connect point A with a bevel face, and also get the good result. Figure 7 is interference ring of the single longitudinal mode fiber laser after F-P interferometer.

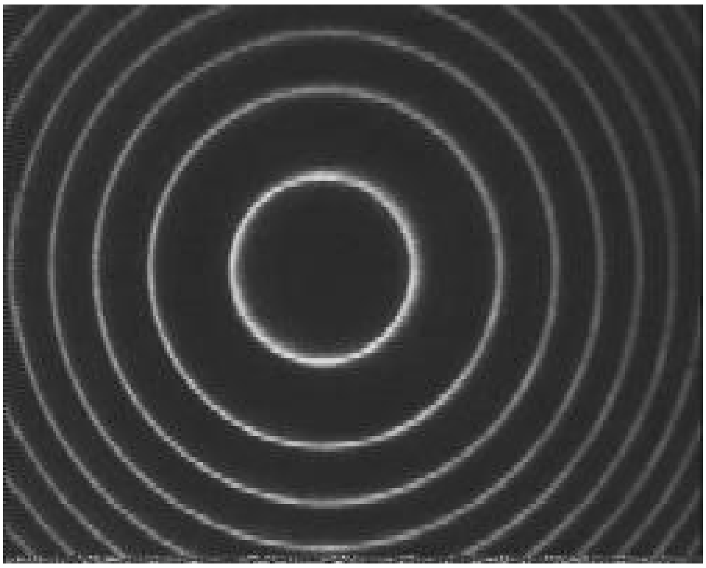

Fig 9 Interfere the ring of the single longitudinal mode fiber laser that CCD writes down after F-P interferometer.

3.2 Influence of mechanical perturbations

In order to research polarization property of the lasers produced by previous DFB structure, we let the laser pass through a polarizer. We found the laser have property of ellipse polarization, and the degree of ellipse polarization is about10dB.When a λ/4 slice is used, it becomes of line polarization, and the ratio of polarization extinction is about 27dB. When any part are disturbed in the previous setup, the power of laser varies obviously after polarizer .If removing the polarizer, there is not an obvious change in laser power when disturbing the fiber. This explains the polarization orientation of the laser will be changes, if fiber is disturbed . This is because that disturbing fiber will produce stress and strain ,which result in double refraction in fiber.

3.3 Influence of temperature

Because the DFB structure is a fiber grating, and fiber grating is temperature-sensitive. thus, we have studied the temperature character of the DFB element In the experiment, we putλ/4 phase shifted fiber laser into temperature-controlled system and then measure the output power of the single longitudinal mode fiber laser . The power varies about 8%, if not turning on the temperature-controlled system. If the temperature-controlled system is used, the stability of the laser output power is improved greatly, and the variation of power is controlled in the scope of 1%. Moreover, we can get almost the same stability when temperature is set in different point from 3^0C to 42^0C.

3.4The threshold and power characters of the λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser

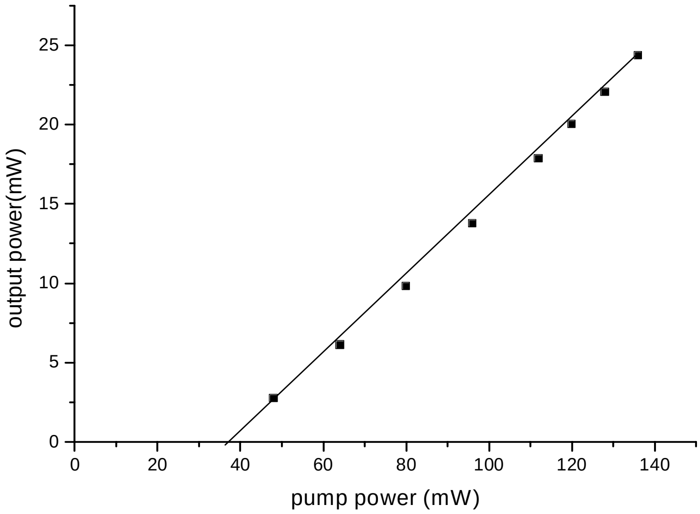

Figure 10 the power of the λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser

As seen in figure 10, the threshold of this laser is 38mW. When the pump power is 140mW, we can gain 25mW output power of single longitudinal mode laser. As can be found from the figure, when the pump power is 140mW, the laser is still not in the saturation state. Thus, if using more powerful pumps, we can get higher power of the laser in 1053nm. In addition; we have researched the component of spectrum of the laser power , through the spectrum. As illustrated in figure 11, the SNR of laser and fluorescence is up to 60dB. This shows that fluorescence has less contribution to the overall power.

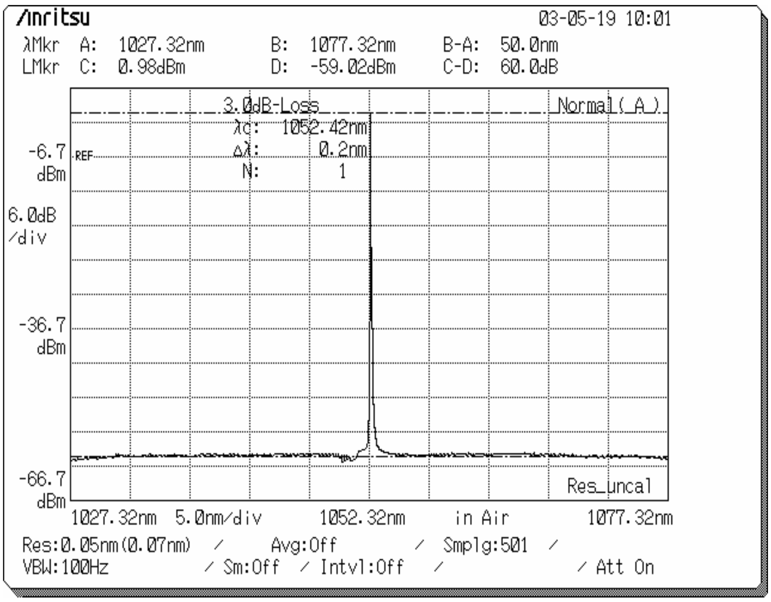

Fig11 The spectrum of The λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser

4 CONCLUSION

We can use two exposure and UV trimming to make λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser with good characters. Based on the research of the running characters of the λ/4 Yb-doped phase shifted DFB single longitudinal mode fiber laser we made:

The fiber end Fresnel reflection will disturb the phase shifted DFB single longitudinal mode fiber. Thus in order to gain the stable single longitudinal mode, we need to use ISO or glycerin to avoid the fiber end Fresnel reflection. Mechanical perturbations will change the polarization state of the fiber transmission; while the temperature change will cause the unsteadiness of the laser's output power. The fiber laser have the following excellent characteristics: Output power of 25mW, fluctuation of less than 2%, 100% single longitudinal mode, 30dB polarization extinction ratio, 60dB signal-to-noise.

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