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2013 Laser Phys. Lett. 10 075105

(http://iopscience.iop.org/1612-202X/10/7/075105)

Laser Phys. Lett. **10** (2013) 075105 (3pp) doi:10.1088/1612-2011/10/7/075105

LETTER

Tunable DFB fiber laser based on photo-thermal effects

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Received 19 November 2012
Accepted for publication 28 February 2013
Published 15 May 2013
Online at stacks.iop.org/LPL/10/075105

Abstract
A novel DFB fiber laser frequency tuning method involving introduction of a photo-thermal light resource into an optical fiber laser system is proposed. A theoretical analysis has been made and experiments have been done. The test results show that the static and dynamic frequency tuning range is about 112 MHz/100 mA and the tuning rate is more than 2 kHz. This method gives a simple way of achieving both relatively high dynamic tuning range and high tuning speed.

(Some figures may appear in colour only in the online journal)

1. Introduction

As a new light source, the tunable fiber laser can deal with the contradiction between dynamic range and spatial resolution in distributed optical fiber sensor system [1, 2]. For compact structure and natural compatibility with the fibers, the tunable DFB fiber laser is one of the hot points in current study [3, 4].

Traditional methods, such as mechanical tuning [5, 6], electromagnetic force tuning [7], thermal tuning [8], and piezoelectric ceramic tuning [9], cannot meet the demands for both large tuning range and high tuning rate. For instance, the mechanical tuning method can often achieve a large tuning range, but is limited by the mechanical structure, which makes it difficult to achieve high accuracy and fast tuning. The electromagnetic tuning method has a quick response, but the modulation range is too small and it is very sensitive to electromagnetic interference. The thermal tuning method can achieve a nanometer wide range of tuning, but its tuning speed is too slow for dynamic tuning, so it is only suitable for quasi-static tuning. The piezoelectric ceramic method has been made commercially available with a fast tuning speed and tuning range up to 20 pm, but the tuning voltage has reached 200 V.

In this letter, to solve the problems in the traditional tuning methods, a tuning scheme based on the photo-thermal effects is proposed. Experimental results show that the tuning range is about 112 MHz/100 mA and the tuning rate is more than 2 kHz, which provides a new fiber laser wavelength tuning method to achieve both relatively wide tuning range and high speed.

2. Principle

Absorption of light causes an increase of temperature of the cavity, and hence a the wavelength change of DFB fiber lasers due to the photo-thermal effect (dn_{eff}/dT) and thermal expansion effect ($d\Lambda/dT$). The main factor is believed to be the photo-thermal effect. In no strain conditions, when the ambient temperature changes, the wavelength shift of the fiber laser can be expressed as

$$\Delta\lambda_B = \lambda_B(\alpha + \xi)\Delta T$$

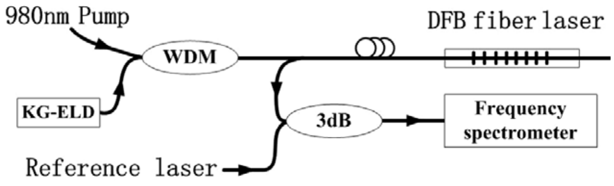

Figure 1. Schematic diagram of the static tuning system.

where $\alpha = (1/\Lambda)(\mathrm{d}\Lambda/\mathrm{d}T)$ is the thermal expansion coefficient of the active fiber and $\xi = (\mathrm{d}n_{\mathrm{eff}}/\mathrm{d}T)$ is the photo-thermal coefficient. The wavelength shift of the fiber laser is proportional to the temperature change, while the temperature change arises from the conversion of optical energy into heat related to absorption. Therefore, the wavelength tuning of the DFB fiber laser can be achieved by changing the power of another light source, which causes the photo-thermal effect of the active medium.

3. Experiments and results

We introduced the photo-thermal light resource (independently monitored laser diode: KG-ELD-905 nm) into the optical fiber laser system pumped by 980 nm LD and studied how the frequency output can be tuned by the thermal effects caused by the fiber lasers' active region's light absorption.

3.1. Static characteristics

A schematic diagram of the static frequency tuning experiment system is shown in figure 1. Via the heterodyning method, we positioned the optical fiber lasers in air and water, respectively. The pump source (JDSU: 29-7402-460-FL) is a 980 nm laser diode. A homemade DFB fiber laser with 44 mm grating length, annealing at 130 °C for 10 h, can produce a narrow line-width frequency in the C-band. A laser (Agilent 8164B) is used as the reference light source in this static test. The output wavelength is observed by a spectrum analyzer (Rohde and Schwarz). The photo-thermal light resource is the tunable light source. The laser has a drive power (ILX light wave: LDC-3724B), which could produce current to tune the laser. When the laser drive current changes from 50 to 450 mA, the laser's output frequency shifts.

As shown in figure 2, the curve describes the relationship between the output frequency shift and the drive current of the thermal light resource. When the DFB laser is exposed in the air, with the drive current changing from 50 to 450 mA, the DFB laser output frequency shift amplitude reaches up to 112 MHz/100 mA, and the total tuning range reaches up to 448 MHz. When the DFB laser is placed in water, the tuning amplitude is just 2.5 MHz/100 mA. The reason for this difference is that the water makes the heat dissipate fast and the DFB laser active area can hardly change temperature.

So we can get the conclusion that the DFB laser surroundings are very important for the photo-thermal tuning technique. Appropriate packaging material with smaller specific heat capacity could increase the capability of photo-thermal tuning. The test results also demonstrate that the lasers' photo-thermal effect is the main factor that influences the tuning of frequency (112 MHz ≫ 2.5 MHz).

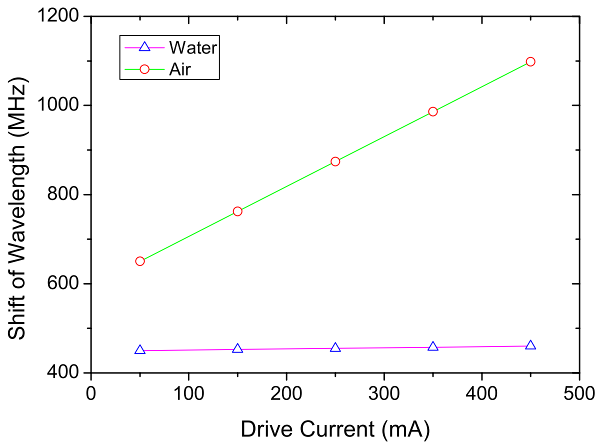

Figure 2. Relationship of DFB laser output frequency shift and thermal laser drive current.

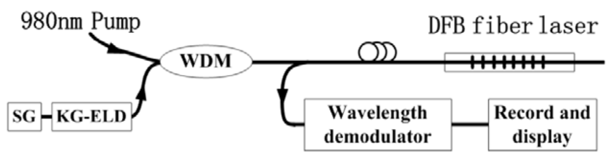

Figure 3. Schematic diagram of the dynamic tuning system.

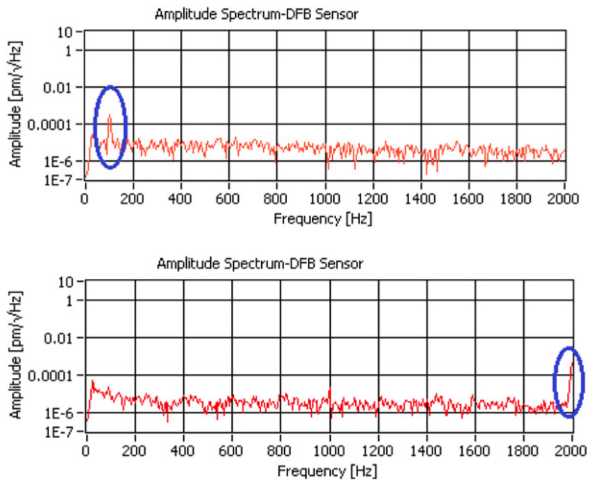

Figure 4. 100 and 2000 Hz tuning results.

3.2. Dynamic characteristics

A schematic diagram of the dynamic tuning test system is shown in figure 3. The drive current is modulated with high speed by utilizing the signal generator (SG), and drives the thermal laser to produce the modulated optic power signal. We observed that the DFB fiber laser output frequency or wavelength was also modulated. The high accuracy wavelength demodulator which was used in experiments is an apparatus which employs a phase-generation carrier to demodulate the shift of the laser's wavelength with high speed [10]. As can be seen in figure 4, 100 Hz and 2 kHz tuning speed is realized.

It can be seen from the above experiments that the DFB fiber laser output frequency is modulated with relatively high speed by modulating thermal light. The tuning rate is at least up to 2 kHz, currently limited by the demodulator's test band. So this tuning method which uses the photo-thermal effect could modulate DFB laser output frequency with both relatively large dynamic range and high speed.

4. Conclusion

Traditional thermal methods for fiber laser tuning almost all heat the active area externally; heat is transferred to the fiber grating by thermal conduction. Because the process of heating and conducting is relatively slow, it cannot achieve high speed tuning. A new method utilizing the photo-thermal effect based on the fact that fiber lasers absorb the thermal tuning light and its temperature can be quickly changed is proposed. The experimental results indicate that the photo-thermal effect is an good approach to realize fiber laser tuning with high speed, more than 2 kHz, and large range, up to 448 MHz. Compared with other optical fiber laser tuning methods, it has strong advantages: it just introduces a tuning light resource and a WDM into the original fiber laser system, a very simple structure. Moreover, it does not include any moving elements or electronic auxiliary devices like traditional methods, which will cause mechanical vibration and electromagnetic interference.

Acknowledgments

This work was supported by the National Natural Science Foundation of China under grants 60976044 and 61077059. The authors would like to thank Dr Rui Wang for contributing some useful suggestions and discussions.

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