Thermal treatment method for tuning the lasing wavelength of a DFB fiber laser using coil heaters

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Abstract: The popular method for tuning the lasing wavelength of a DFB fiber laser is to apply strains along the fiber grating using a Piezoelectric Transducer (PZT) [1]. Although the tuning range of 3nm can be obtained by this way, the spliced connections between the grating and the conventional single-mode fibers are often broken down, especially when over stretched. To avoid this risk, in this paper, we propose a safer compact tuning method. By controlling the DC current in the coil heaters around the DFB grating, we obtained a tuning range up to 2.3nm without any mode hoping.

Keywords: DFB fiber laser, optical communications, tunable fiber laser.

Introduction

The development of high bit-rate, coherent optical communication systems using Wavelength Division Multiplexing (WDM) technique requires that the laser source have a very narrow linewidth, single frequency, stable polarization and tunable wavelength. The Distributed Feedback (DFB) fiber laser has been emerging as a promising alternative to the DFB semiconductor laser for use in CATV networks and high bit rate WDM communications. The advantages of the DFB fiber laser include fiber compatibility, compact size, and ultra-narrow linewidth [2].

The tunable DFB fiber laser can be also obtained by applying strains along the DFB grating. H.Yoon et. al. proposed a method using a PZT stretcher to tune the lasing wavelength of a DFB fiber laser [1]. The PZT stretcher creates a nearly uniform strain distribution along the grating, which would make the shift of the lasing wavelength. Although, this method can provide a tuning range up to 3nm without any mode hoping, the force-based methods generally show to be unsafe to the grating, especially when the grating is over-stretched. The structure of a DFB fiber laser includes a phase-shifted DFB grating whose two ends are spliced with two conventional single mode fibers. When we over-stretch the grating or stretch it several times, the two spliced connections are possibly disconnected. Furthermore, the stretching and twisting are two main sources that cause the instability of the polarization mode of the laser.

To avoid this risk, in this paper, we propose a new compact and safer thermal treatment method that can provide the tuning range up to 2.3 nm and no mode hoping was seen. The heated Ni-Cr coils were employed to create a nearly uniform temperature distribution along the grating. We also tested the operational parameters of the laser across the tuning range.
Theory Basis

The single frequency of a DFB laser is obtained by creating a phase-shift of \( \pi/2 \) in the DFB structure. The single wavelength of the laser is equal to the Bragg wavelength of the structure [3].

The Bragg wavelength of the grating depends on the effective index of refraction of the core and the periodicity of the grating. The effective index of refraction, as well as the periodic spacing between the grating planes, will be affected by changes in temperature. Consequently, the shift \( \Delta \lambda_B \) in the Bragg center wavelength \( \lambda_B \) is dependent on the changes in the temperature, which is given as:

\[
\Delta \lambda_B = \lambda_{Bo} (\alpha_A + \alpha_A) \Delta T_{FBG}
\]

Where \( \Delta T_{FBG} = (T_H - T_O) \) is the heating temperature in degree \( ^\circ \)C, \( \lambda_{Bo} \) is the Bragg wavelength at the reference temperature \( T_O \).

\( \alpha_A = \left[ \frac{1}{\Lambda} \frac{\partial \Lambda}{\partial T} \right] \) is the thermal expansion coefficient

\( \alpha_n = \left[ \frac{1}{n_{eff}} \frac{\partial n}{\partial T} \right] \) is thermo-optic coefficient

The rate of refractive index change is higher than the period changes, and which is the main contributor to the wavelength shift. The wavelength shows high sensitivity at higher values of \( T_H \). Though, under 100\(^\circ\)C, the change is considered linear [4]. In addition, the fiber Bragg gratings show excellent temperature stability in the temperature under 300\(^\circ\)C [5]. It is, therefore, permissible to think of a thermal method for tuning the lasing wavelength of a DFB fiber laser.

Experiment

The DFB fiber laser used in the experiment has the following specifications: grating length: 5cm, single wavelength: 1551nm, single polarization mode, linewidth: 30KHz, pumping power 9mW, maximum power peak: 40mW, SNR >50dB, SMSR > 40dB [6]. The Figure 1 shows the optical spectrum of the laser.

![Optical spectrum of the laser](image)

**Figure 1:** Optical spectrum of the laser
The basic idea is to create a controllable uniform thermal distribution along the grating. We rolled the Ni-Cr wire to form the coils with the internal diameter of 300\(\mu\)m and external diameter of 550\(\mu\)m around the DFB structure. The Ni-Cr coils were placed on a high temperature resistance Silicon substrate. By controlling the DC current intensity inside the coils, we created a nearly uniform temperature distribution along the grating.

![DFB fiber grating](image)

**Figure 2:** The Ni-Cr coil for heating the DFB fiber grating

We put the DFB fiber grating inside the Ni-Cr coil heaters, pumped the grating by GaAlAsP diode laser 980nm, which was controlled by a Laser Diode Driver Model 525. Changing the DC current inside the Ni-Cr wire, we controlled the temperature range from 22\(^{\circ}\)C to 135\(^{\circ}\)C. Increasing the temperature by controlling the DC current intensity, and observing the laser spectrum on the Optic Spectrum Analyzer (OSA) AQ 6317B, we realized the linear shifting of the lasing wavelength. The tuning range was 2.3nm and no mode hoping was seen throughout the tuning range (Fig. 3).

![Figure 3](image)

**Figure 3:** The shift of the lasing wavelength vs. the changes of the temperature

Using Delayed Self-Heterodyne technique (Fig. 4) [7], we tested the stability of the linewidth across the tuning range. At wavelength of 1551nm, the output power is 3dBm and the linewidth is 30KHz. At the wavelength of 1553.3nm, the output power of 3.2dBm, the linewidth is 30.4KHz.
Using the setup shown in the figure 5, we tested the single polarization mode stability of the laser throughout the tuning range. At 1551nm, the laser operated in the single polarization mode. The polarization extinction ratio was better than 20dB. At 1553.2 nm, the laser still operated in the single polarization mode. The polarization extinction ratio was about 16dB. Extinction ratio reduced due to the birefringence induced by the temperature. Though, the laser still operated in the single polarization mode.

Conclusion

We proposed a new thermal treatment method employing the Ni-Cr coil heaters for tuning the lasing wavelength of the DFB fiber laser. The tuning range is 2.3nm corresponding to the change of the temperature from 22°C to 130°C. No mode hoping was seen throughout the tuning process. This method shows safe and compact compared to the popular force-based methods. Across the tuning range, the laser keeps almost all of its important characteristics: single wavelength, single polarization mode, and ultra-narrow linewidth.
References


