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Frequency Stabilization of DBR Fiber Grating Laser Using Interferometric Technique

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***Abstract*—A technique for stabilizing the center frequency of a short cavity DBR fiber grating laser is reported. This method employs an all-fiber unbalanced-arm scanning Michelson interferometer as a frequency discriminator. Long-term frequency fluctuation of the tested fiber grating laser was improved from ±480 MHz to less than ±30 MHz.**

***Index Terms*—Fiber Bragg gratings, frequency stabilization, interferometer, optical fiber lasers, WDM applications.**

I. INTRODUCTION

DENSE wavelength-division multiplexing (DWDM) technology with channel spacing of 100 GHz or less is now becoming the global direction in optical fiber communication systems to effectively increase the transmission capacity and flexibility. To meet the stringent requirements of this tight channel spacing, laser sources with high wavelength stability, accurate emission wavelengths, and narrow linewidths are necessary. Short cavity fiber grating lasers (FGLs) based on fiber Bragg grating (FBG) written on rare-earth doped fibers are an attractive alternatives compared to semiconductor lasers for DWDM applications because of their wide tuning range, single-mode output, as well as the ease to fabricate FBG with highly accurate wavelength that matches the ITU wavelength grids. The operating wavelengths of the two types of FGLs, i.e., distributed feedback (DFB) and distributed Bragg reflector (DBR) fiber lasers are defined by the wavelength of the FBG. However, the FBG wavelength is highly sensitive to operating conditions, and it is also subject to large frequency fluctuation and wavelength drift under strong pumping conditions [1]. In [2], [3], acetylene absorption lines were employed to stabilize fiber lasers by adjusting the bulk diffraction grating, the operating wavelengths of the lasers thus limited by the distribution of the absorption lines. Moreover, FM modulation of the laser wavelength is normally required [3], which caused strong amplitude modulation for FGL [4]. In this letter, the frequency fluctuation characteristics of a DBR FGL with a single FBG as the output reflector was investigated by employing an all-fiber unbalanced-arm scanning Michelson interferometer, which converts the small wavelength drift of the FGL to measurable phase change [5]. A possible stabilization scheme using the error signal generated by the pseudoheterodyne detection method [6] is also demonstrated.

II. EXPERIMENTAL SETUP

The experimental setup is illustrated in Fig. 1. The DBR FGL is realized by fabricating a 1-cm-long FBG, with center wavelength of 1545.3 nm, as an output reflector at one end of a hydrogenated Er–Yb fiber. The reflectivity of the grating is about 95% and its bandwidth is about 0.16 nm. The other end of the fiber was butt joined to a dielectric broad-band mirror to establish the laser cavity, whose total length was about 3.5 cm. A 980-nm pump laser with output power of 80 mW was used to pump the FGL through a WDM coupler. An optical isolator was placed in front of the laser to block any unwanted optical feedback that would destabilize the laser. Single-mode laser output was confirmed by heterodyning with a single-mode external cavity tunable laser on a fast detector. The FBG was mounted on a piezoelectric transducer (PZT1) so that the output wavelength can be adjusted within 1.6 nm. The whole FGL was confined inside a thermally isolated rubber box and temperature stabilized to 23 ± 0.1 °C. The output of the FGL was split by a 3-dB coupler, with one port serving as the transmission port and the other being fed into the interferometer for frequency measurement.

The unbalanced-arm Michelson interferometer had another 3-dB coupler with two ∼5-cm-long fiber arms, with their ends coated with 250-nm-thick gold to act as mirrors. The measured reflectivity for these mirrors was about 90%. The round-trip length imbalance (d) of the interferometer was about 7 mm. One arm of the interferometer was glued onto a PZT stretcher, which was used to change the phase shift induced by the interferometer on the laser signal. The interferometer was packaged inside a vibration isolated and temperature stabilized aluminum box to within 0.02 °C.

The current produced by the photodetector as a result of the signal reaching it from the interferometer can be written as

$$I = A\{1 + k\cos(\omega t + \Delta\Phi_L)\} \quad (1)$$

where

A	constant that depends on the output intensity of the FGL, system losses, and the photodetection gain;
k	visibility of the interference signal;
ω	serrodyne modulation frequency of the interferometer;
$\Delta\Phi_L$	phase shift which is a function of d.

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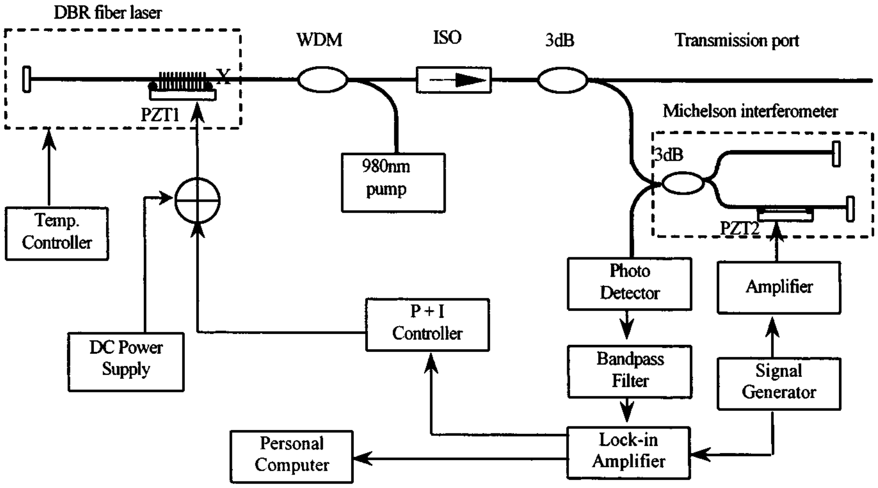

Fig. 1. Experimental setup for stabilizing the DBR fiber grating laser. Optical paths are drawn as thicker lines. X: Er–Yb fiber and single-mode fiber splicing point. WDM: 980/1550 wavelength-division multiplexer. ISO: Isolator. 3 dB: 3-dB coupler. []: Bulk broad-band mirror.

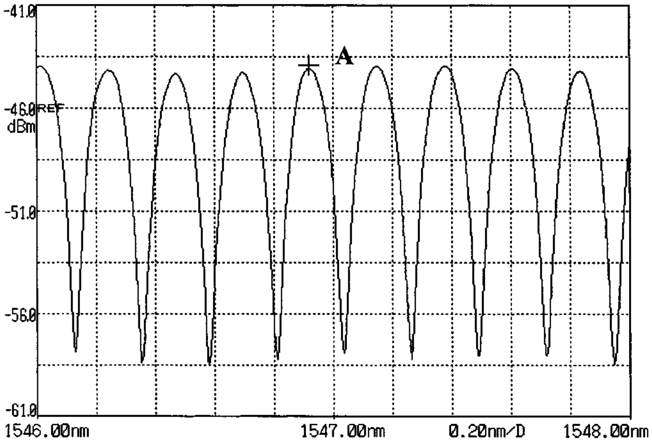

Fig. 2. Interference signal of the all-fiber unbalanced-arm Michelson interferometer measured with an optical spectrum analyzer. **A**: Fiber grating laser locking point.

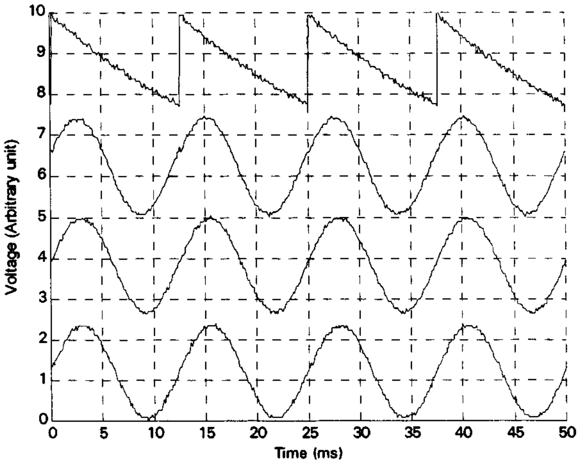

Fig. 3. Outputs signals for a stabilized fiber laser (i.e., $\Delta\Phi_L = 0°$). From top to bottom: Serrodyne modulation signal; detector output signal; filter output signal; reference signal.

Any shift in the laser wavelength $\Delta\lambda_L$ will give rise to a change in phase given by the well-known expression

$$\Delta\Phi_L = -\frac{2\pi n d}{\lambda_o^2}\Delta\lambda_L \tag{2}$$

where n is the refractive index of the fiber and λ_o is the nominal wavelength of the FGL. The output of the photodetector was then sent to an active bandpass filter with center frequency ω that remove the higher harmonics generated by the ramp flyback [6]. A lock-in amplifier was employed to measure the phase change [i.e., $\Delta\Phi_L$ of (1)] between the reference signal generated by the signal generator and the filtered output signal.

Frequency stabilization of the FGL is achieved by applying the error signal generated by the lock-in amplifier to a proportional-integrating controller circuit, which provided the compensation signal to control the movement of PZT1.

III. RESULTS AND DISCUSSION

Fig. 2 shows the transmission interference pattern of the interferometer measured with an optical spectrum analyzer. The free spectral range (FSR) of the interferometer was found to be 0.23 nm, which is in reasonably good agreement with the path imbalance of 3.5 mm. The fringe visibility was about 0.98. To measure the frequency fluctuation of the FGL, the central wavelength of the FGL was tuned to one of the peaks of the interferometric fringe (point **A** of Fig. 2) by applying 13 $\mathrm{V_{dc}}$ to PZT1 so that the FBG is strained. An 80-Hz saw-toothed modulation signal from a signal generator (upper trace of Fig. 3) with an amplitude of 4.5 $\mathrm{V_{p\text{-}p}}$ was used to drive the PZT2 for scanning one complete FSR. Therefore, the maximum measurable wavelength drift is about ±0.115 nm. The output signal of the photodetector was demodulated using the pseudoheterodyne technique, the phase to frequency responsitivity was measured to be 0.0125°/MHz by applying a known amount of strain to the FGL and measuring the phase response of the system.

Fig. 4 shows the phase change $\Delta\Phi_L$ measured by the lock-in amplifier every 5 s; the peak-to-peak phase change for the system under the free running condition with respect to the set point **A** was ±6°, which corresponds to a frequency fluctuation of ± 480 MHz from (2). When the feedback loop was closed,

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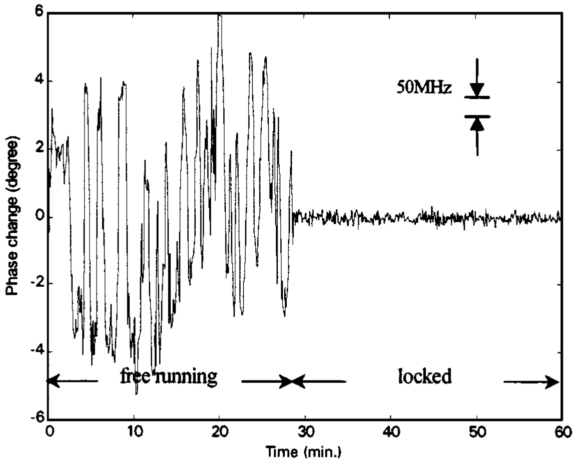

Fig. 4. Error signal with the fiber grating laser in free running condition and locked to the interferometer.

the peak-to-peak frequency fluctuation was reduced to less than ±30 MHz. Fig. 3 also shows various signal measured by an oscilloscope when the FGL was locked.

In order to evaluate the environmental perturbations that affect the performance of our system, we switched off the temperature controlling devices for the FGL. No significant frequency fluctuation was noted. This proves that our system can be used for most FGLs operating under different environmental conditions. Since the coherence length of most short-cavity FGLs are of the order of several kilometers, we believe that a better result can be achieved if the interferometer is replaced by one with a longer path imbalance to improve the whole system sensitivity. This technique could also be employed in DWDM network applications to stabilize several fiber lasers simultaneously by using the bandpass wavelength-division-multiplexing technique reported in [7].

IV. CONCLUSION

Frequency stabilization of a short-cavity DBR FGL was investigated by using an all-fiber unbalanced-arm scanning Michelson interferometer. An improvement in the frequency fluctuation of the FGL output from ±480 MHz to about ±30 MHz was demonstrated experimentally. This scheme avoids the problem of frequency dithering because it does not need to modulate the source frequency and should be suitable for different DWDM network applications.

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