Chapter 1

Introduction

1.1 Review of Wavelength Tunable Laser using FPLD

Wavelength-tunable optical pulses are very important for wavelength division multiplexed (WDM), optical time division multiplexed (OTDM), and optical code-division multiple access (OCDMA) communication systems [1-4]. Actively mode-locked fiber lasers are attractive optical sources to realize such light sources. Generally, fiber lasers are actively mode-locked by several kinds of modulators such as Mach-Zehnder modulator [5] and electroabsorption modulator [6]. In recent years, fiber lasers for generating wavelength-tunable pulses by using a Fabry-Perot laser diode (FPLD) or a distributed feedback laser diode as both a modulator and a tunable filter were presented. The tuning range was up to 4.8 nm [7-9]. Furthermore, a modified scheme by using a high birefringence fiber loop mirror in the ring cavity as filter and a FPLD as a modulator also has been proposed. The tuning range of this fiber laser was about 10 nm. The best SMSR was 29.2 dB and the pulsewidth was 60.4 ps [10]. In this system, the selected wavelength output from a FPLD is arranged to be fed back into the FPLD and results in a single-wavelength emission when the feedback pulse timely overlaps with the emission pulse. However, the repetition frequency is determined by the cavity length of fiber laser. This mode-locked scheme is difficult to have widely wavelength-tunable range and a constant repetition frequency and pulsewidth at different wavelengths.

The FPLD in external-injection schemes also have been developed [11-16]. The external-injection scheme is generally injected by a continuous wave tunable laser source. When the injected wavelength coincides with one of the wavelengths of the FPLD lasing modes, single wavelength optical pulses can be produced. Recently, due to the high cost of continuous wave tunable laser source, a dc-driven FPLD together with the fiber Bragg grating (FBG) has been used as an external-injection source. The SMSR in this system was about 20 dB [14]. Another FPLD together with a tunable filter and an erbium doped fiber amplifier (EDFA) as an external-injection source was also presented. The SMSR is better than 30 dB over the wavelength-tunable range of 19 nm [15-16]. However, the wavelength-tunable range of these systems are limited by the overlap spectrum of two FPLDs.

1.2 Review of Fiber Bragg Grating Sensor Network

FBG sensors have been identified as very important sensing elements especially for the strain measurement in smart structures [17-20]. In many applications, the arrays of FBG sensors are required for multipoint or distributed measurement. The multiplexing of FBG sensors is therefore essential to reduce the cost per sensing point and to increase the competitiveness of FBG sensors against the conventional electrical sensors. A large-scale FBG sensor system with 60 sensors has been experimentally demonstrated by using a combination of WDM and TDM techniques [17].

Such research associated with sensing network survivability would be an ongoing challenge for the practical applications of the multipoint FBG sensor systems. Therefore, enhancing the survivability of a FBG sensor network is very important. However, the in-line topology, star topology, and tree topology generally adopted in a FBG sensor network cannot protect the sensing network [21]. Moreover, a broadband light source is usually used in a FBG sensor system. Because the optical power reflected from a FBG is weak, the sensing resolution and the capacity of a fiber sensor system would be limited by the broadband light source.

1.2.1 Multiplexing Techniques

One of the attractive advantages of a FBG sensor system is the multiplexing capability. The techniques for multiplexing FBGs include the WDM technique, spatial division multiplexing, TDM, code division multiplexing access, and frequency modulated continuous wave multiplexing [17,22-24]. The most popular technique for FBG multiplexing in a sensor system is the WDM technique. The simplest light source for a WDM-FBG sensor configuration is a broadband source, such as an EDFA or a LED. The sensor number to be multiplexed is determined by both the operating wavelength range required for each FBG sensor and the total useable bandwidth of the broadband source. In recent year, using intensity and wavelength division multiplexing (IWDM) technique to increase the sensor number has been proposed [25]. A FBG with two specified low-reflectivity peaks has to be fabricated for this IWDM scheme. Such a specific FBG with dual peaks therefore can be addressed when its one peak overlaps with that of another single-peak high-reflectivity FBG and its second peak can be used for decoding the wavelength shift. However, an un-measurable gap would be induced when the bandwidth of the single-peak FBG is slightly broader than that of the dual-peak FBG. Thus a single-peak high-reflectivity FBG with a narrow bandwidth also has to be fabricated [25]. Furthermore, a signal processing method for the IWDM scheme without using the FBG specifically fabricated has also been reported [26].

1.2.2 Fiber laser scheme

The FBG sensor systems using a fiber laser scheme have been the focus of a great deal of research. In contrast with the FBG sensor system based on a broadband light source, the advantages of a FBG laser sensor includes its high resolution for wavelength shift and high optical signal-to-noise ratio (SNR) against the noisy environments in practical applications [17]. The simplest in-fiber cavity mirrors of a FBG laser can be constructed either by two FBGs with identical Bragg wavelength or by one FBG in conjunction with a broadband reflector. In general, the erbium-doped fiber (EDF) is adopted as the gain medium between two mirrors for a linear-cavity fiber laser. With a sufficient gain provided by a 980-nm pumping laser diode, the fiber laser lases and its lasing wavelength is determined by the Bragg wavelength of the FBG. When a strain or a temperature variation is imposed on the FBG, the Bragg wavelength drifts and the lasing wavelength shifts simultaneously. Another simple type of a fiber laser is the fiber ring laser, and its lasing wavelength also can be determined by a FBG. By inserting a tunable Fabry-Perot filter within the cavity, we can simply implement a tunable fiber laser for the application of a FBG sensor system [20,27]. However, the scanning rate of the tunable filter always limits the dynamic range of a fiber laser sensor.

Although the EDF laser has been widely discussed, a multiwavelength fiber laser is still an ongoing challenge since the dense WDM technique is the most important solution for high-capacity fiber communication or fiber sensor systems. However, because the homogeneous broadening of an EDF is dominant at room temperature, it is difficult to obtain stable simultaneous lasing with close wavelength spacing. Therefore, much attention is devoted on multiwavelength fiber laser at room temperature. For example, the technique by inserting variable attenuators into the EDF laser cavity for multiwavelength oscillations has been reported [28-29]. The cavity loss corresponding to each wavelength has to be balanced carefully in such arrangements. In recent year, the inhomogeneous broadened gain of the distributed Raman amplifier is used for a room temperature WDM source [30]. Over 58 WDM channels have been demonstrated previously by using a fiber Raman ring laser with a Fabry-Perot filter in the cavity [31].

Multiwavelength oscillations in a fiber laser source that uses a semiconductor optical amplifier (SOA) is also possible because of its inhomogeneous broadening property and broad gain spectrum. Recent an interesting technique is the use of two SOAs in the laser cavity in order to increase both the lasing bandwidth and the average power [32]. However, SOAs have a relatively high noise figure. Adding an extra SOA in the laser cavity will decrease the optical signal-to-noise ratio (SNR) of fiber laser. To overcome this drawback, an EDFA instead of an SOA can be inserted into the multiwavelength laser cavity. The gain can be increased, and the lasing bandwidth also can be broadened. Moreover, the optical SNR is higher than that of the two SOA systems [33].

1.3 Organization of the Dissertation

This dissertation consists of three related parts. In Chapter 2, simple and novel configurations of wavelength tunable lasers using FPLDs have been demonstrated. By adjusting the tunable bandpass filter in the laser cavity, the laser output can be tuned flexibly. In contrast with the conventional setup, our proposed scheme is easy to be constructed and has a wide tuning range. Moreover, we also present a simple scheme to generate wavelength-tunable optical pulses by a FPLD in an external-injection scheme. An EDFA in the scheme is used as both an external-injection source and an amplifier for the FPLD. The lasing mode of the FPLD is locked by the backward amplified spontaneous emission (ASE) of the EDFA. The performance of system operated at the different wavelengths is reported.

In Chapter 3, fiber-laser-based sensor networks are proposed and demonstrated. We present novel sensor networks with self-healing functions to increase the reliability of the sensor systems. Such a self-healing function for the sensor network can support real-time monitoring and reveal the sudden breakpoint of the fiber link. Furthermore, we use a linear-cavity fiber laser scheme for our proposed sensor system. This fiber-laser-based sensor network can avoid the reduction of the signal-to-noise ratio (SNR) because of the low-power broadband source together with its ASE noise. The advantage of our proposed fiber-laser-based sensor system can facilitate reliable sensor network for a large-scale and multipoint smart structure.

In Chapter 4, large-scale sensor networks using fiber laser scheme are proposed and demonstrated. We propose an IWDM-FBG sensor system using a tunable multiport fiber ring laser. For the IWDM technique, our proposed fiber grating sensor system can enhance the sensing capacity, SNR, and sensing resolution. Moreover, we propose a novel FBG sensor system using fiber laser schemes with a distributed Raman amplifier as a gain medium. The inhomogeneous broadening property of the distributed Raman amplifier is used for multiwavelength operation. We also propose a long-distant sensor system using an erbium doped waveguide amplifier (EDWA) and a semiconductor optical amplifier (SOA). The feature of our proposed fiber lasers can facilitate a long-distant or a large-scale fiber sensor system and can be easily extended for multipoint sensing applications. Finally, summary the research results will be given in Chapter 5. Suggestion for future work is also presented.

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