Multi-wavelength fiber ring laser based on a chirped moiré fiber grating and a semiconductor optical amplifier

Shaohua Lu (鲁韶华)*, **Ou Xu (许 鸥)**, **Suchun Feng (冯素春)**, **and Shuisheng Jian (简水生)**

Institute of Lightwave Technology, Key Lab of All Optical Network and Advanced Telecommunication Network of EMC, Beijing Jiaotong University, Beijing 100044, China

**E-mail: lsh971@163.com*

Received September 4, 2008

A simple and cost-effective multi-wavelength fiber ring laser based on a chirped Moiré fiber grating (CMFG) and a semiconductor optical amplifier (SOA) is proposed. Stable triple-wavelength lasing oscillations at room temperature are experimentally demonstrated. The measured optical signal-to-noise ratio (SNR) reaches the highest value of 50 dB and the power fluctuation of each wavelength is less than 0.2 dB within a 1-h period. To serve as a wavelength selective element, the CMFG possesses excellent comb-like filtering characteristics including stable wavelength interval and ultra-narrow passband, and its fabrication method is easy and flexible. The lasing oscillation shows a narrower bandwidth than SOA-based multi-wavelength fiber lasers utilizing some other kinds of wavelength selective components. Methods to optimize the laser performance are also discussed.

OCIS codes: 060.3510, 060.3735, 140.4480.
doi: 10.3788/COL20090706.0469.

Fiber lasers exhibit many attractive features such as inherent single transversal mode and compatibility with optical fiber systems. In recent years, there is a surge of interest in multi-wavelength fiber lasers, since they are potentially useful for dense wavelength division multiplexed (DWDM) fiber-communication systems, optical fiber sensor networks, and spectroscopy. Both erbium-doped fiber (EDF) and semiconductor optical amplifier (SOA) have been used as gain media for multi-wavelength fiber lasers. In order to achieve stable EDF-based multi-wavelength lasing in the 1550-nm optical window at room temperature, one must overcome the homogenous line broadening and cross-gain saturation of EDF to suppress the unstable mode-hopping. Till now, various methods and fiber structures have been proposed to solve the problem[1−9]. But some of these approaches are not suitable for practical applications because of the complexity or the high cost of the system. SOA has a dominant property of inhomogeneous line broadening and can yield a very wide optical gain bandwidth so as to support many wavelength lasing oscillations simultaneously in the laser cavity [10−12]. Meanwhile, to obtain stable multi-wavelength lasing, the mechanism for wavelength selection has also been widely investigated, such as the combination of several fiber Bragg gratings[13], Mach-Zehnder interferometers[2,10], Sagnac fiber loop mirrors[1−3], sampled fiber Bragg gratings (FBGs)[7−14], Fabry-Perot etalon[7−11], and chirped Moiré fiber gratings (CMFGs) written in Er^{3+}-Yb^{3+} co-doped optical fiber[9].

In this letter, the CMFG written in normal hydrogen-loaded optical fiber is chosen to implement wavelength selection. The CMFG is an ideal transmissive comb filter with stable wavelength spacing, narrow filtering bandwidth, and uniform channel transmittance. It has extra advantages of low cost, easy fabrication, and flexible tuning of wavelength interval within a large band depending on the chirp value. A simple ring laser configuration based on a SOA as gain medium and a three-passband CMFG as wavelength selective element is proposed. Stable triple-wavelength lasing oscillations with wavelength spacing of about 0.36 nm have been experimentally demonstrated. The measured optical signal-to-noise ratio (SNR) reaches the highest value of 50 dB and the power fluctuation of each wavelength is less than 0.2 dB within a 1-h period.

A CMFG consists of two superimposed linearly chirped fiber Bragg gratings (CFBGs), which have the same chirp value and peak index modulation and differ only in their central wavelengths. Usually, it can be formed by writing the two CFBGs successively into the same part of a fiber and using the same phase mask with only a small longitudinal offset D between the double exposures which is adopted in this letter and depicted in Fig. 1. In essence, the moiré technique makes the refractive index modulation of the fiber core have a slowly varying sinusoidal envelope and introduces a π phase shift between two closely spaced sections of grating, resulting in the formation of one or more ultra-narrow passbands. For a given chirp, the interval of the passbands can be tuned by the offset D while the channel number is related to D and the grating length L[15]. This fabrication method obviously possesses a great advantage of repeatability and flexibility.

The schematic of the experimental setup for the proposed multi-wavelength fiber ring laser is shown in Fig. 2. A CMFG containing three transmission peaks is

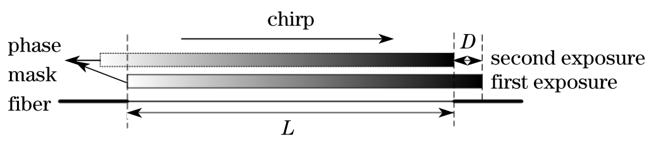

Fig. 1. Fabrication of CMFG by dual-exposure method with chirped phase mask.

1671-7694/2009/060469-03 © 2009 Chinese Optics Letters

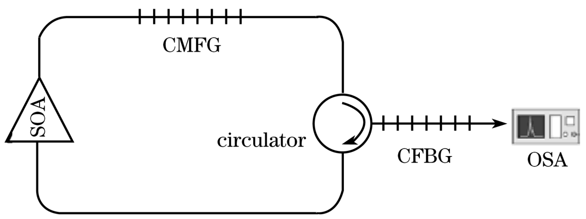

Fig. 2. Schematic of the experimental setup.

incorporated in the ring cavity, serving as a comb-like multi-channel filter to provide periodic loss in the spectrum domain for multi-wavelength lasing.

A CFBG which had a reflectivity of about 90% was utilized as the broadband reflective mirror and the output port of the laser. Figure 3 displays the measured reflective spectrum of the CFBG and transmission spectrum of the CMFG. The central wavelength of CFBG is the same as that of the CMFG, and the reflective bandwidth of the former is narrower but covers the three passbands of the latter. The circulator in the ring cavity provided unidirectional lasing oscillation. An ANDO AQ6319 optical spectrum analyzer (OSA) with the resolution of 0.01 nm was used to do all the measurements. It should be noted that the observed transmittance non-uniformity of three narrow transmission peaks of the CMFG was limited by the scanning resolution of the OSA.

Initially, the amplified spontaneous emission (ASE) from the SOA passes through the CMFG which is supposed to act as a comb filter, but the extra-band light will also go along with the three needed in-band elements. Then the CFBG cooperating with the circulator will filter out the extra-band light and reflect most of the needed light back to the ring structure. The multi-wavelength elements are subsequently amplified by the SOA, which is an inhomogeneous broadening medium. After passing through the CMFG and reflected by the CFBG, a larger portion of the multi-wavelength power is reintroduced to the SOA and reinforced. Such a process will continue until overall gain of the SOA is equal to the loss of the cavity. In this case, a stable multi-wavelength lasing operation can be established.

Figure 4 shows the output spectrum of triple-wavelength lasing operation at 1547.42, 1547.788, and 1548.149 nm corresponding to the three peak wavelengths of the CMFG when the SOA is driven with the injection current of 350 mA. Sixteen successive scans of the system output with a time interval of 5 s are carried out,

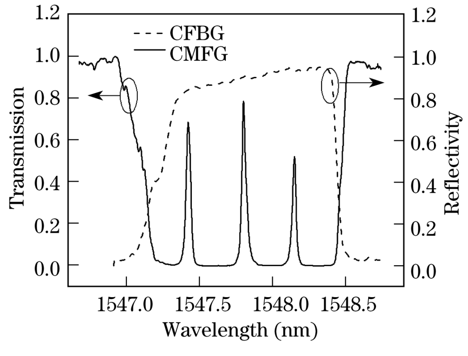

Fig. 3. Measured reflective spectra of CFBG and CMFG.

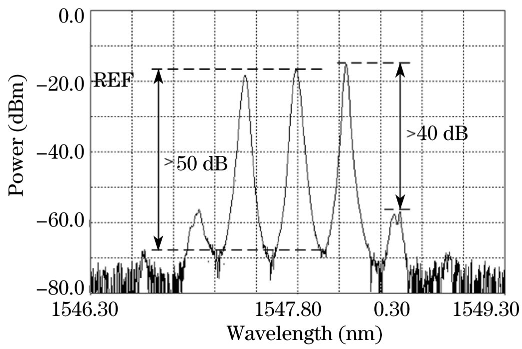

Fig. 4. Measured output spectrum of the triple-wavelength lasing operation.

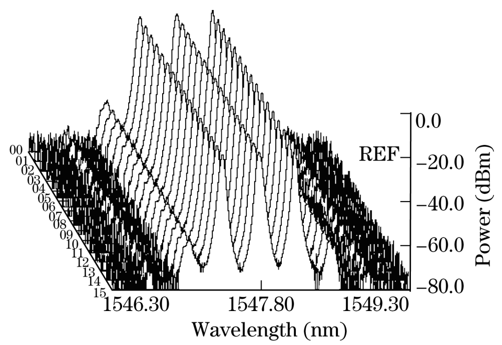

Fig. 5. Measured lasing output spectra with 16 repeating scans.

and the result is recorded in Fig. 5 which indicates a good short-term wavelength stability of the laser. In order to study the long-term stability of the multi-wavelength operation at room temperature, the output power fluctuation at each peak wavelength was measured for 1 h, and it was less than 0.2 dB.

It is the inhomogeneous gain broadening effect of the SOA that supports the stable multi-wavelength lasing. Meanwhile, it will widen the bandwidth of each lasing compared with those from homogeneous broadening media. Nevertheless, the CMFG shows an ultra-narrow filtering characteristic, which ameliorates the lasing bandwidth. The 3-, 20-, and 40-dB bandwidths of the lasing at 1548.149 nm were measured to be 0.024, 0.081, and 0.18 nm, respectively. These performance parameters are better than the previous reports that use SOA as the gain medium and Sagnac loop, sampled gratings, etc. as wavelength-selective component.

The maximum extinction ratios of the multi-wavelength laser output and the minimum one are about 50 and 40 dB, respectively. The deterioration of extinction ratio is induced by the two sidebands in both sides of the three dominant wavelengths (see Fig. 3), which can be suppressed by reducing the bandwidth of the CFBG. The output power difference among the three lasing oscillations may be caused by the inconsistent reflectivity of the CFBG at each lasing wavelength.

Since the SOA is polarization-dependent to a certain degree, a polarization controller (PC) can be placed in the ring structure and adjusted so as to equalize each lasing output power. In the experiment, the connecting joint between every two components in the laser configuration was active FC/PC joint, and this increased the cavity loss. Replacing the active joints by splicing ones, lower threshold and higher output power can be obtained.

The phase mask with which the CMFG and the CFBG were fabricated had a chirp of 1 nm and three transmission peaks with an interval of 0.36 nm were achieved. With this phase mask, variable wavelength amount and interval can be realized by precisely tuning the offset during the process of grating fabrication, but all the transmission peaks of the CMFG are limited in the bandwidth determined by the phase mask period and the fiber parameters. More wavelengths and the wavelength interval meeting the DWDM requirements are expected when using a phase mask with a higher chirp value.

We also experimentally investigated the temperature dependence of the CMFG. The results show that the transmission-peak wavelengths shift with the temperature simultaneously and have the same temperature coefficient as the normal FBG, and their transmittances remain unchanged. Therefore, the lasing wavelength can be fine tuned by controlling the temperature of the CFMG and the CFBG keeping the wavelength spacing invariant.

In conclusion, a multi-wavelength fiber ring laser source based on a SOA and a CMFG written in normal hydrogen-loaded optical fiber is proposed, and stable triple-wavelength lasing oscillations with the wavelength interval of about 0.36 nm have been experimentally demonstrated. The measured optical SNR reaches the highest value of 50 dB and the power fluctuation of each wavelength is less than 0.2 dB within a 1-h period. Due to the ultra-narrow comb filtering characteristic of CMFG, narrower lasing bandwidth is achieved compared with SOA-based lasers utilizing other wavelength selective components. Besides, the fabrication technology of CMFG is less expensive and more flexible than that of sampled gratings requiring precise apodization or phase shifts. All these make it an excellent wavelength selective component in the lasing operation. This laser scheme presents a simple and cost-effective solution to produce stable multi-wavelength lasing oscillations at room temperature.

This work was supported by the National Natural Science Foundation of China (No. 60771008), the National "863" Program of China (No. 2007AA01Z258), the Support Plan for New Century Excellent Talents (No. NCET-05-0091), and the Science Fund of Beijing Jiaotong University (No. 2007XM003)

References

1. X. P. Dong, S. Li, K. S. Chiang, M. N. Ng, and B. C. B. Chu, Electron. Lett. **36,** 1609 (2000).
2. W. Huang, H. Ming, X. Wang, and H. Xu, Chin. Opt. Lett. **3,** 253 (2005).
3. A. Zhang, M. S. Demokan, and H. Y. Tam, Opt. Commun. **260,** 670 (2006).
4. J. J. Veselka and S. K. Korotky, IEEE Photon. Technol. Lett. **10,** 958 (1998).
5. J. Sun, J. Qiu, and D. Huang, Opt. Commun **182,** 193 (2000).
6. K. Zhou, D. Zhou, F. Dong, and N. Q. Ngo, Opt. Lett. **28,** 893 (2003).
7. A. Bellemare, M. Karásek, M. Rochette, S. LaRochelle, and M. Têtu, J. Lightwave Technol. **18,** 825 (2000).
8. H. Takahashi, H. Toba, and Y. Inoue, Electron. Lett. **30,** 44 (1994).
9. G. Brochu, S. LaRochelle, and R. Slavík, J. Lightwave Technol. **23,** 44 (2005).
10. D. N. Wang, F. W. Tong, X. Fang, W. Jin, P. K. A. Wai, and J. M. Gong, Opt. Commun. **228,** 295 (2003).
11. H. Wang, M. Yao, H. Zhang, and B. Zhou, Chinese J. Lasers (in Chinese) **34,** 1502 (2007).
12. S. Li, J. Shao, Q. Shen, L. Shen, Z. Cao, J. Chen, Z. Wu, and M. Sang, Acta Opt. Sin. (in Chinese) **27,** 1802 (2007).
13. Q. Mao and J. W. Y. Lit, J. Lightwave Technol. **21,** 160 (2003).
14. Y. Liu, X. Dong, P. Shun, S. Yuan, G. Kai, and X. Dong, Opt. Express **14,** 9293 (2006).
15. L. A. Everall, K. Sugden, J. A. R. Williams, I. Bennion, X. Liu, J. S. Aitchison, S. Thoms, and R. M. De La Rue, Opt. Lett. **22,** 1473 (1997).