Journal of the Optical Society of Korea
Vol. 13, No. 3, September 2009, pp. 330-334

DOI: 10.3807/JOSK.2009.13.3.330

Frequency Swept Laser at 1300 nm Using a Wavelength Scanning Filter Based on a Rotating Slit Disk

Mansik Jeon, Unsang Jung, Jae-Won Song, and Jeehyun Kim*

School of Electrical Engineering and Computer Science, Kyungpook National University, 1370 Sankyuk-dong, Buk-gu, Daegu 702-701, Korea

Junghwan Oh†

Mechanical Engineering, Pukyong National University, San 100, Yongdang-Dong, Nam-Gu, Busan 608-739, Korea

Jinseob Eom

Department of Electric and Electronic Engineering, Kangwon National University, 192-1 Hyoja-Dong, Chuncheon 200-701, Korea

Chang-Seok Kim

School of Nano Science and Technology, Pusan National University, 30 Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea

Young-Ho Park

School of Electronics and Electrical Engineering, Kyungpook National University, 386 Gajangdong, Sangju 742-711, Korea

(Received June 9, 2009 : revised July 31, 2009 : accepted August 4, 2009)

A simple and compact frequency swept laser is demonstrated at 1.3 μm using a wavelength scanning filter based on a rotating slit disk. The laser is comprised of a pigtailed semiconductor optical amplifier, a circulator, and a wavelength scanning filter in an extended cavity configuration. The wavelength scanning filter is composed of a collimator, a diffraction grating, a rotating slit disk, and a mirror. The instantaneous laser output power is more than 5 mW. The scanning range of the laser is extended to 80 nm at the maximum level, and 55 nm in the full width at half maximum at a scanning rate of 2 kHz.

Keywords: Frequency swept laser, Wavelength scanning filter, Rotating slit disk

OCIS codes: (140.0140) Lasers and laser optics; (140.3560) Lasers, ring; (140.4480) Optical amplifiers; (050.1950) Diffraction gratings

I. INTRODUCTION

Over recent years, frequency swept lasers have been attractive sources in various applications, such as optical reflectometry, sensor interrogation, and optical components tests and measurements [1-3]. Recently, the applications of frequency swept lasers have begun to make a mark in the biomedical imaging fields, including spectrally encoded confocal microscopes and optical coherence tomography (OCT) [4-6]. These application fields demand a broadband wavelength scanning range, a high speed repetition rate, a narrow instantaneous linewidth, and a high output power. A broadband wavelength scanning range is required to achieve high axial resolution in optical imaging and a high sweeping speed is needed to obtain real-time 2D or 3D OCT imaging [7, 8]. In addition, a narrow instantaneous linewidth and a high

---

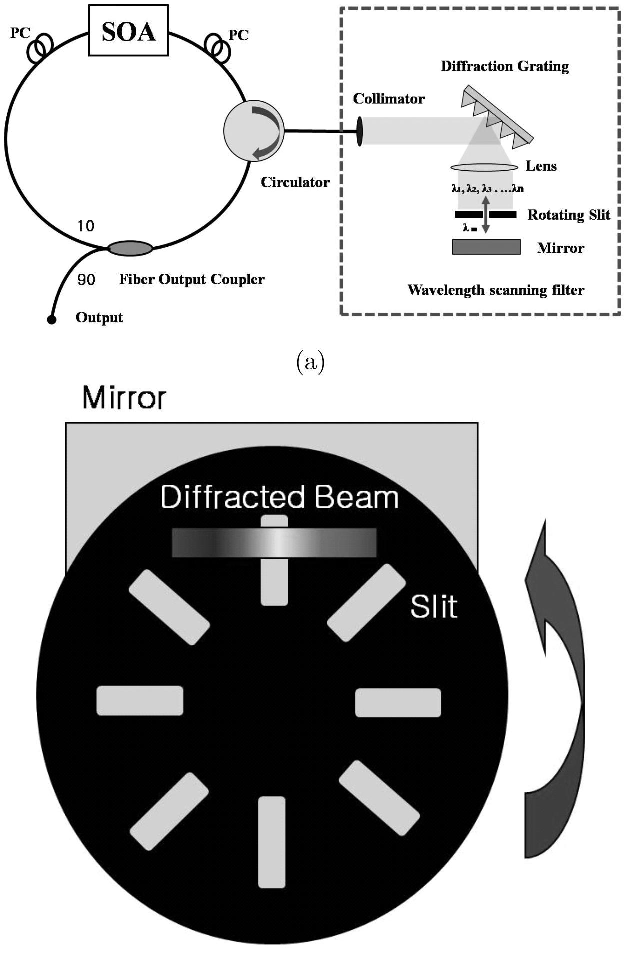
*Corresponding author: jeehk@knu.ac.kr,

† Corresponding author: jungoh@pknu.ac.kr

output power are required to achieve a longer scanning depth. Also, in fiber sensor interrogation applications, a wider working wavelength range enables users to facilitate a higher number of sensors.

Many different types of frequency swept lasers have been demonstrated for these applications [9-14]. A commonly used technique for fabricating such lasers is to employ an external cavity configuration. A Littman-Metcalf configuration and a Littrow configuration are typical external cavity configurations [4] [9, 10]. Both configurations are constructed by combining a diffraction grating and a reflective mirror for wavelength scanning. The frequency swept laser adapting the Littman-Metcalf configuration tunes a wavelength by adjusting the angle of the reflective mirror, while one using the Littrow configuration adjusts the angle of the diffraction grating. Another commonly used frequency swept laser configuration is a SOA based ring laser with a narrowband wavelength scanning filter such as a Fabry-Perot filter or an intracavity wavelength filter based on a polygonal mirror scanner [11-14]. These wavelength scanning filters perform at a very high level of finesse and have a large dynamic range, but they are very sensitive to vibration and require precise manufacturing mechanisms to overcome this over-sensitivity. Their manufacturing costs are also usually expensive because of the complicated manufacturing process.

In this paper, a frequency swept laser is demonstrated at 1300 nm. The proposed frequency swept laser is designed with a SOA and a wavelength scanning filter which includes a collimator, a diffraction grating, a reflective mirror, and a rotating slit disk. The wavelength scanning is achieved by a rotating slit disk. The proposed frequency swept laser does not require a high-cost Fabry-Perot filter or complicated motion-control systems such as a galvanometer scanner and a polygonal mirror. It can be implemented at a low cost using a simple structure.



(a)

(b)

FIG. 1. (a) Experimental setup of frequency swept laser and (b) the rotating slit disk configuration viewed in front.

II. EXPERIMENTAL SETUP AND PRINCIPLE

Figure 1 (a) shows schematics of the frequency swept laser. The frequency swept laser uses a ring cavity geometry and consists of a pigtailed SOA, two polarization controllers (PCs), an optical circulator, a wavelength scanning filter, and a fiber output coupler. Because of the polarization dependency of the wavelength scanning filter and the SOA gain medium, two PCs were placed in the cavity to align the polarization state to the axes of maximum transmission and gain. The circulator eliminates extraneous intra-cavity reflections and ensures unidirectional lasing of the ring cavity. The laser output is obtained from the fiber output coupler, which provides 90% for the output and 10% for the feedback function. The wavelength scanning filter consists of a collimator, a diffraction grating, a focal lens, a rotating slit disk and a mirror. Figure 1 (b) displays a front view including a light spectrum, a rotating slit disk, and a mirror. The wavelength scanning filter acts as a narrow band transmission filter for active wavelength scanning. The wavelength scanning is done in the following way. When the light is generated from the SOA, the light contains a broad gain amplified spontaneous emission (ASE) spectrum. It is connected to the input port of the optical circulator. The broadband light exits the circulator and enters the collimator. The collimated beam enters the open-air wavelength scanning filter. When the light is collimated by a collimator, it strikes the diffraction grating which is placed after the collimator and reflects the collimated incident light at different angles according to the wavelength of the light. Because the light contains a broadband spectrum, the reflected light forms a line pattern spatially separated by wavelength. A focal lens is placed after the diffraction grating and focuses the spectrally distributed light onto a mirror through a rotating slit disk. The mirror is placed at the focal plane of the lens and the rotating slit disk is closely placed in front of the mirror. The rotating slit disk is mounted on a shaft rotating with a constant revolution per minute (RPM). The rotating slit disk selectively transmits a narrow line-width spectrum from the broad line-width spectrum of the incident light. The rotating slit disk scans a spatially separated broadband spectrum. The spectral width of the filter is dependent on the slit width. The scan speed is dependent on the rotation speed of the disk. The scanning rate is simply set by the multiple slits on the disk which can increase the scanning repetition rate. Spectrally filtered light reflects from a mirror and is coupled back to the collimator through a focal lens and a diffraction grating. The reflected light exits the circulator. The circulator is connected to one arm of a 10:90 fiber output coupler. Only 10% of the entrance power of the coupler is fed to the opposite side of the SOA through a polarization controller. The light with a certain frequency is amplified and circulates in the ring cavity for more amplification while the ASE becomes suppressed.

III. EXPERIMENTAL RESULTS

To characterize the bandwidth of the wavelength scanning filter, the SOA output is directly connected to the wavelength scanning filter. The SOA (INPHENIX IPSAD1301) has a peak gain at 1320 nm, 55 nm of 3 dB bandwidth, and 23.7 dB small signal gain at a 250 mA driving current. The SOA exhibits 2.1 dB polarization gain dependence. The filtered output is monitored by an optical spectrum analyzer (OSA) instead of feeding back to the SOA for the ring cavity configuration. Figure 2 shows the superimposed transmission spectra of the wavelength scanning filter measured with an OSA. The curves are a typical profile of the narrow band transmission filter at different scanning wavelengths, measured using ASE light from the SOA (dash of Figure 2). The measured spectrum is sampled with a 0.5 nm resolution. Wavelength scanning is achieved by using diffraction grating (1100 lines/mm) and by manually rotating the slit disk. The slit is 100 µm in width. The insert in Figure 2 displays the detailed spectrum of the central peak, which has a 0.8 nm FWHM.

Figure 3 (a) represents a linewidth of the frequency swept laser output in the ring cavity configuration which means the light is amplified by multiple rounding through the cavity. The laser output is obtained through the 90 % port of a fiber coupler. The laser output spectrum is sampled with a 0.01 nm resolution. The side mode suppression ratio (SMSR) has a minimum of 35 dB at a bias current of 250 mA. The 3 dB bandwidth is 0.026 nm at overall scanning range. The light from the broadband gain medium is spatially filtered by the narrowband wavelength scanning filter within the cavity. The spatially filtered light feeds back to the gain

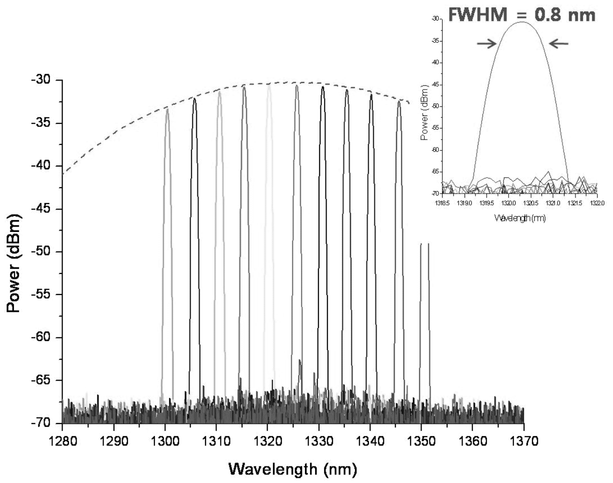
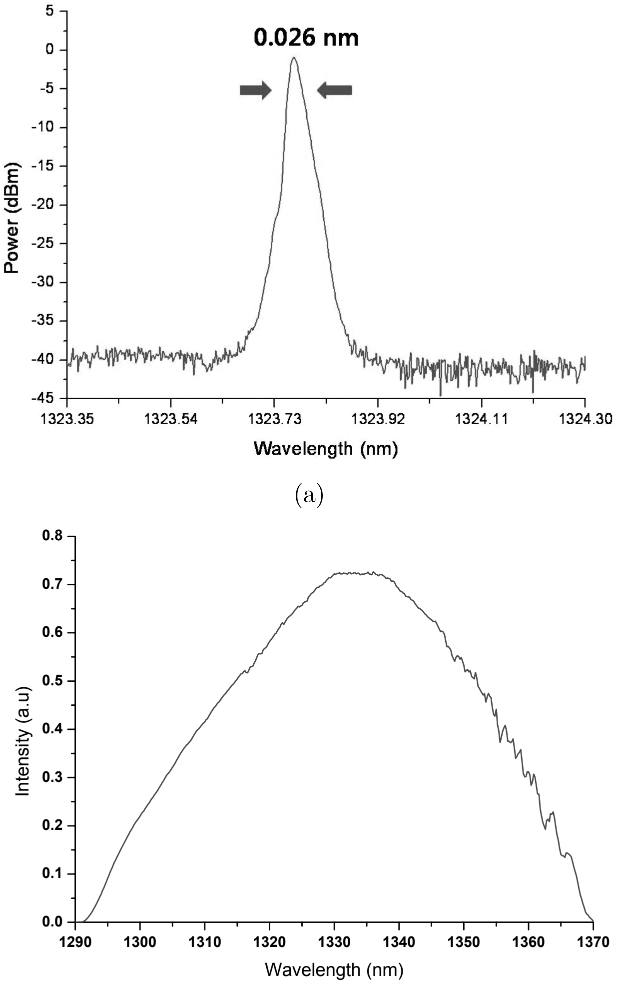


FIG. 2. Transmission spectra of the wavelength scanning filter.



(a)

(b)

FIG. 3. (a) Output spectrum of the frequency swept laser (b) Peak-hold Output spectrum.

medium and then is amplified by the gain medium of the SOA. The amplified light experiences multiple round trips and multiple passes through the filter. The laser output will be amplified up to the saturation power limit of the gain medium. Operating the laser in the saturation regime will lead to an instantaneous linewidth which is significantly narrower than the filter bandwidth. Only longitudinal modes with frequencies are transmitted into the gain medium through the narrowband optical filter. The modes all experience optical amplification in the same gain medium. In the saturation with strong mode competition may occur in a unidirectional ring laser. The mode with the highest net gain will saturate the gain and any other mode will experience a negative net gain, which causes its power to fade away. The multiple roundtrips and multiple passes through the filter will lead to more and more mode completion. The mode competition in the laser can lead to a narrowing of the effective linewidth. The instantaneous laser output power is 5.34 mW. Figure 3 (b) shows the laser output measured with an OSA in a peak-hold mode. The wavelength scanning is operated from 1290 nm to 1370 nm. The total scanning range is 80 nm and the FWHM is 55 nm. The rotational rate of the rotating slit disk is 6000 RPM, yielding a scan rate of 2 kHz when the number of slits on the rotating slit disk is 20. The physical length of the cavity is approximately 5 m resulting in an optical path length of 7.15 m. In summary, the laser operates in the following conditions: 0.8 nm of the filter bandwidth, 80 nm of the total tuning bandwidth, 1 mW of the total spectrally integrated ASE power, 234(23.7 dB) of the small signal gain of the laser medium, 0.2 of the fraction of energy fed back after one roundtrip, 7.15 m of the physical cavity length of the ring, 1.46 of the refractive index of the cavity. The maximum theoretical sweep frequency for the proposed method in a full build-up of lasing cavity is 52.330 kHz. Whereas the theoretical sweep frequency at a single roundtrip is 91.477 kHz.

Figure 4 shows the temporal intensity profiles of the laser while scanning at 2 kHz. The y-axis of the trace represents instantaneous optical power. The peak power and the average power emitted by the laser are 5.3 mW and 4.1 mW, respectively. The wavelength is scanned sequentially in positive linear wavelength sweeps. The shape of the frequency swept laser output follows a Gaussian profile. The power fluctuation between adjacent full range scanning is due to inconsistent attachment of each slit to the rotating disk. This limitation can be overcome by the automated manufacturing of the slits on the disk with the help of a local machine shop.

IV. CONCLUSION

A simple, compact, and low cost frequency swept laser has been demonstrated. The laser output is scanned continuously from 1290 nm to 1370 nm at a 2 kHz repetition rate. The total scanning range is 80 nm and the FWHM is 55 nm. Its mechanical stabilization is achieved by utilizing a stationary grating and mirror. The frequency swept laser does not require any complex driving device which is needed for conventional galvanometer operating. A constant rotating speed can be easily expected from DC-motors. By further decreasing the laser cavity length and using a faster DC motor, improvements in speed should be possible without sacrificing power or coherence length. The demonstrated approach can be easily adaptable to either a 1.3 μm or a 1.5 μm wavelength range operation. The simple and robust configuration of the demonstrated frequency swept laser is expected to open many new biomedical imaging applications, sensor interrogation and optical communication system monitoring.

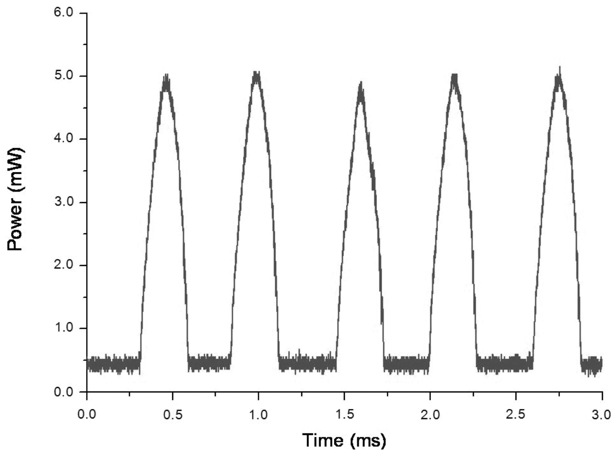


FIG. 4. Temporal intensity profile of the frequency swept laser.

ACKNOWLEDGMENT

This study was supported by a grant of the Oriental Medicine R&D Project, Ministry of Health, Welfare and Family Affairs, Republic of Korea (B080033), the Korea Science and Engineering Foundation (R01-2007-000-2056-0), the Korea Research Foundation, Next generation leading tech. grant(Daegu, EQMed), Ministry of Environment as "The Eco-technopia 21 project" (062-081-035), and BK21 project.

REFERENCES

1. B. Golubovic, B. E. Bouma, G. J. Tearney, and J. G. Fujimoto, "Optical frequency-domain reflectometry using rapid wavelength tuning of a Cr4+:forsterite laser," Opt. Lett. **22**, 1704-1706 (1997).
2. S. H. Yun, D. J. Richardson, and B. Y. Kim, "Inter-

rogation of fiber grating sensor arrays with a wavelength-swept fiber laser," Opt. Lett. **23**, 843-845 (1998).

3. E. J. Jung, C.-S. Kim, M. Y. Jeong, M. K. Kim, M. Y. Jeon, W. Jung, and Z. Chen, "Characterization of FBG sensor interrogation based on a FDML wavelength swept laser," Opt. Exp. **16**, 16552-16560 (2005).
4. S. H. Yun, C. Boudoux, M. C. Pierce, J. F. de Boer, G. J. Tearney, and B. E. Bouma, "Extended-cavity semiconductor wavelength-swept laser for biomedical imaging," IEEE Photon. Technol. Lett. **16**, 293-295 (2004).
5. G. J. Tearney, R. H. Webb, and B. E. Bouma, "Spectrally encoded confocal microscopy," Opt. Lett. **23**, 1152-1154 (1998).
6. J. H. Oh, H. Lee, and J. H. Kim, "Detection of magnetic nanoparticles in tissue using magneto-motive DP-OCT," J. Opt. Soc. Korea **11**, 26-33 (2007).
7. J. I. Youn, "Evaluation of morphological changes in degenerative cartilage using 3-D optical coherence tomography," J. Opt. Soc. Korea **12**, 98-102 (2008).
8. W. J. Choi, J. H. Na, S. Y. Ryu, B. H. Lee, and D. S. Ko, "Realization of 3-D topographic and tomograpic images with ultrahigh-resolution full-field optical coherence tomography," J. Opt. Soc. Korea **11**, 18-25 (2008).
9. V. J. Srinivasan, R. Huber, I. Gorczynska, J. G. Fujimoto, J. Y. Jiang, P. Reisen, and A. E. Cable, "High-speed, high-resolution optical coherence tomography retinal imaging with a frequency-swept laser at 850 nm," Opt. Lett. **32**, 361-363 (2007).
10. S. W. Lee, C.-S. Kim, and B.-M. Kim, "External line-cavity wavelength-swept source at 850 nm for optical coherence tomography," IEEE Photon. Technol. Lett. **19**, 176-178 (2007).
11. M. A. Choma, K. Hsu, and J. A. Izatt, "Swept source optical coherence tomography using an all-fiber 1300-nm ring laser source," Journal of Biomedical Optics **10**, 044009-1~044009-6, (2005).
12. R. Huber, M. Wojtkowski, K. Taira, J. G. Fujimoto, and K. Hsu, "Amplified, frequency swept lasers for frequency domain reflectometry and OCT imaging: design and scaling principles," Opt. Exp. **13**, 3513-3528 (2005).
13. S. H. Yun, C. Boudoux, G. J. Tearney, and B. E. Bouma, "High-speed wavelength-swept semiconductor laser with a polygon-scanner-based wavelength filter," Opt. Lett. **28**, 1981-1983 (2003).
14. W. Y. Oh, S. H. Yun, G. J. Tearney, and B. E. Bouma, "Wide tuning range wavelength-swept laser with two semiconductor optical amplifiers," IEEE Photon. Technol. Lett. **17**, 678-680 (2005).