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TUNABLE RING LASER BASED ON A SEMICONDUCTOR OPTICAL AMPLIFIER AT 1300 NM USING A SIMPLE WAVELENGTH SELECTION FILTER

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Abstract

A simple, compact, and low cost tunable ring laser with a commercial semiconductor optical amplifier (SOA) was demonstrated. The tunable ring laser is based on an external wavelength filter cavity that is analogous with the Littman configuration with a diffraction grating, a mirror, and a simple slit. The unique structural advantage of this new system is that the slit is displaced to select a desired wavelength instead of tilting the mirror as in the Littman configuration. This allows easy control over the selected wavelength by the translating action of the slit. The full width half maximum (FWHM) wavelength turning range is 45 nm, and the wavelength resolution is about 2 pm. The demonstrated tunable ring laser has 2 mW output power. The side mode suppression ratios is 70–73 dB.

Keywords

semiconductor optical amplifiers; tunable lasers; tunable wavelength filters

1. INTRODUCTION

In general, a tunable laser source (TLS) is used to generate various wavelength emitted from a single wavelength light source. Commercial and scientific interest in tunable lasers continues to grow rapidly because of their potential application in optical components testing, fiber optic sensors, and wavelength division multiplexing (WDM) transmission systems [1,2]. Most TLSs are developed at the 1.5 μm wavelength region which the optical communication fields use. Recently the applications of TLS have expanded into biomedical imaging fields including spectroscopy and optical coherence tomography [3–5]. These fields demand different wavelength scanning ranges other than the 1.5 μm region. For example, Lasers have been actively studied at 800 nm ranges, which are useful for eye imaging. Optical penetration in biological samples is optimized for wavelengths in the vicinity of 1.3 μm [6,7].

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There are many methods to generate tunable wavelength emission. The examples include vertical-cavity surface-emitting lasers (VCSELs) with an optimized microelectromechanical system (MEMS) tuning structure [8], thermally widely tunable laser diodes with distributed feedback [9], sampled grating distributed bragg reflector (SGDBR) laser [10], and external cavity lasers (ECL) [11,12], and so on.

VCSELs use monolithically intergrated tuning microelectromechanical system structures. The manufacturing steps are complex in the structure and include difficult machinery controls to suppress mechanical vibrations. VCSELs usually also suffer from a narrow band tuning range and a low output power.

Tuned wavelengths in thermally tunable lasers are governed by the thermal coefficients, so the temperature sweeping range determines the wavelength scanning range. To extend the wavelength tuning range, the temperature control mechanism also needs to be improved. Most thermally tunable lasers are manufactured on monolithic structures, which tend to be integrated in higher complexity to cover a wider tuning range and peripheral circuits.

Other monolithic solutions like the SGDBR laser have been proposed with full-band tuning, but they also suffer from a complicated tuning mechanism requiring control of three or more tuning currents. These TLSs based on semiconductor processing usually require additional power stabilizing circuits. Also they need several structures such as sampled grating (SG) or super structure grating distributed bragg reflector (DBR).

ECL structures utilize a moveable MEMS mirror and different types of intracavity tunable filters. A Littman-Metcalf configuration and a Littrow configuration are typical external cavity configurations for ECLs. Both configurations are constructed by combining a diffraction grating and a reflective mirror for wavelength selection. An external cavity laser diode 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. Both configurations can achieve a narrow linewidth, broad tunablity, and a low-cost diode laser. These lasers have reliable spectral properties including a wide tuning range and uniform power distribution over the range. In addition, they provide a high optical power since the gain element can be designed purely for high power application without suffering from power-to-tuning-range compromise. However, since the reflective mirror or the diffraction grating should be precisely rotated in a mechanical sense, a highly precise rotating apparatus is required to select a specific wavelength. This may result in degraded laser stability, an increase in size, and an increased manufacturing cost. Therefore, a more mechanically stable and less stress-sensitive tilting structure such as a galvanometer scanner is needed for the wavelength selective feedback. Additional driving circuits are also required for the scanner.

Another commonly used ECL configuration is a SOA based ring laser with a Fabry-Perot filter (FPF). This FPF performs at a very high finesse and has a large dynamic range, but it is very sensitive to vibration and requires precise manufacturing mechanisms to overcome this over-sensitivity. Its price is also usually very high because of the complicated manufacturing process.

In this article, a TLS consisting of a SOA based ring laser with a wavelength selection filter which includes a diffraction grating, a reflective mirror, and a repositionable slit is demonstrated. The wavelength selection is achieved by simply translating the slit. Because the proposed TLS excludes a high-cost FPF or complicated motion-control systems such as galvanometer scanners, it can be implemented at a very low cost using a simple structure.

2. EXPERIMENT SETUP AND PRINCIPLE

The experimental scheme for the tunable ring laser is shown in Figure 1. The proposed tunable ring laser is composed of a SOA gain medium, a polarization controller (PC), an optical circulator, a wavelength selection filter, and an output optical fiber coupler. Each component is connected with an optical fiber to form a ring-cavity geometry. The wavelength selection filter includes a diffraction grating, a reflective mirror and a repositionable slit. The ring-cavity geometry with the optical circulator for unidirectional operation is chosen to optimize output coupling and rejection of amplified spontaneous emission (ASE) from the SOA. The circulator is for preventing a reflected light beam from returning back to the SOA. Because of polarization dependency of the grating 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 SOA (INPHENIX IPSAD1301) gain medium provides a high saturation power and a broad ASE spectrum. The SOA has a peak gain at 1340 nm, 50 nm of 3 dB bandwidth, and 23.7 dB small signal gain at 250 mA current driving. The SOA exhibits 2.1 dB polarization gain dependence. The wavelength filtering is achieved by using a collimator, a transmission type diffraction grating (Dickson1110 1 pmm Volume Phase Holographic (VPH) Transmission Grating for 1310 nm), a focusing lens, a repositionable simple slit mounted on a translation stage, and a reflective mirror in an external cavity configuration. The wavelength selection is done in the following way. When the light is generated from the broad gain SOA, the light contains a broad ASE spectrum. It is connected to the first port of the optical circulator which has three connection ports. The light exits the circulator at the second port and enters the open-air wavelength filter. When the light is collimated by a lens, it strikes the transmission grating which angularly separates the light in space. Resulting in the light with a different wavelength diffracts at a different angle. Another focusing lens is inserted after the transmission grating, which is placed at the back-focal plane of the lens. After passing through the focusing lens, the light is spectrally horizontally collimated, but vertically converges. Note that the direction of the grooves in the grating is vertical so that the grating diffracts the incident light horizontally and the light remains collimated vertically. A slit and a mirror are inserted at the focal plane of the focusing lens. The slit and the mirror are separated as close as the geometry permits. When the spectrally horizontally distributed light reaches the slit, only a small fragment, of the light with a 100 μm width can pass through the slit. The wavelength of the penetrated light is dependent on the horizontal position of the slit. As the slit translates along the horizontal direction, a specific wavelength can be tuned. It should be noted that the position of the slit and the mirror consistently remain on the focal plane of the focusing lens throughout the entire wavelength tuning range. While the wavelength selection is done in the horizontal direction, the light, penetrated through the slit, vertically focuses at the mirror to maximize the power coupling ratio back to the ring cavity. After reflecting back from the mirror, the light in the vertical view collimates again after the focusing lens and converges in the horizontal view. Finally after the transmission grating, the light in both views collimates and is coupled back to the optical fiber through the collimator. As mentioned above, the optical fiber is connected to the second port of the optical circulator. Now the light exits the circulator at the third port instead of going to the first port. The third port is connected to one arm of a 10:90 optical fiber coupler. The other side of the coupler is connected to the opposite side of the SOA through a PC. Only 10% of the entrance power of the coupler is fed to the SOA. The spectral width of the feedback light is about 0.8 nm. This spectrally narrowed light, in other words “filtered light”, enters the gain medium of the SOA to promote amplification. The light with a certain frequency is amplified and circulates in the ring cavity for more amplification while the ASE becomes suppressed. After multiple roundtrips, the filtered light power reaches ~2 mW. The laser output is taken from the 10:90 optical fiber coupler, which provides 90% for the output and 10% for the feedback function. The total length of the cavity is ~2 m and the round-trip loss of the cavity is estimated to be less than 6 dB.

3. EXPERIMENT RESULTS AND DISCUSSION

Figure 2 shows the spectra of the wavelength selection filter. This is done by translating the slit with respect to the optical axis. Translation in the horizontal plane of the slit can be used to tune the wavelength while keeping the spectrum constant. The spectrum is sampled with 0.5 nm and the measuring sensitivity is set at HIGH 1. The 3 dB bandwidth is 0.8 nm at overall tuning range. Figure 3 shows the superimposed spectra of proposed TLS. The operating temperature is 25°C and the SOA current is 250 mA. Total tuning range over 80 nm is obtained, and the output power is about 2 mW at the peak wavelength. The 3 dB tunable bandwidth is at about 45 nm as shown in Figure 3. Stable oscillation was achieved for all 0.8 nm spaced determined by the moving slit from 1300 nm to 1350 nm. The output power was over 2 mW and the SMSR is over 70 dB for all channels. The laser output power can be increased by utilizing a higher output coupling ratio and by reducing cavity losses from the intracavity components. The SMSR has a minimum of 70 dB at a bias current of 250 mA and reaches its highest 73 dB. The laser is capable of tunning over the 80 nm width of the gain medium. The tuning is accomplished by translating the slit. The wavelength resolution is 2 pm.

Figure 4 shows the position-wavelength curves of the modes from 1260 nm to 1370 nm as measured from the auxiliary output. The position of the slit has a linear relationship with the filtered wavelength. Once a precalibration between the slit position versus the wavelength is performed, any desired wavelength can be selected by simply repositioning the slit.

4. CONCLUSION

This article proposes and demonstrates a simple but effective tunable ring laser with an external cavity wavelength filter. The wavelength tuning in the filter is achieved by translating a slit horizontally. Because the slit position along the optical axis remains constant over the entire tuning range, the power couple ratio of the filter is also uniform. The wavelength of the laser output was able to be tuned from 1280 nm to 1360 nm. The side-mode rejection ration of the laser output is 70–73 dB. The desired power ratio of the modes was obtained by adjusting the injected current level. The power output can be increased significantly by use of a booster SOA at the output.

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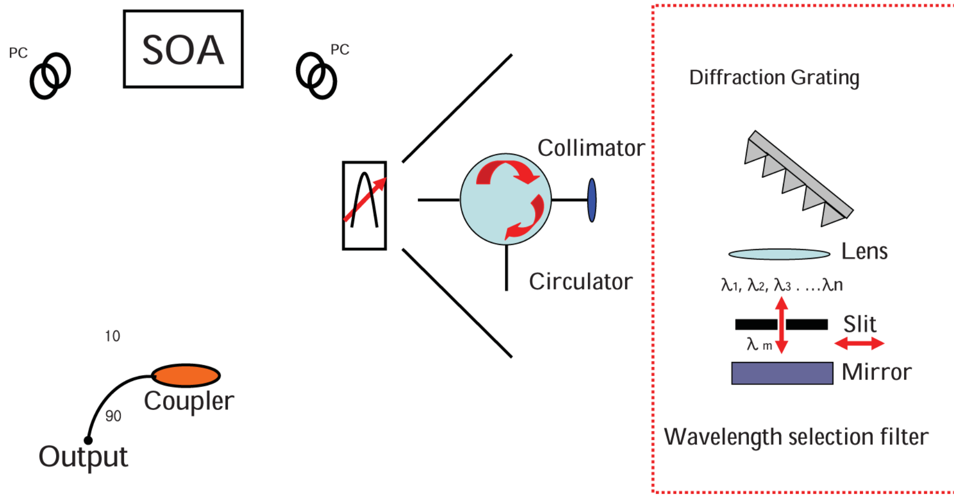

Figure 1.
The diagram of the tunable ring laser with a translating slit. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

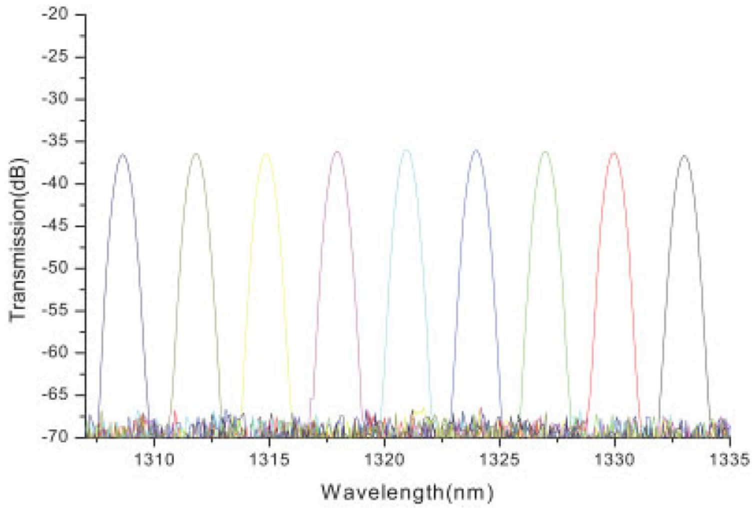

Figure 2.
The spectra of the wavelength selection filter. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

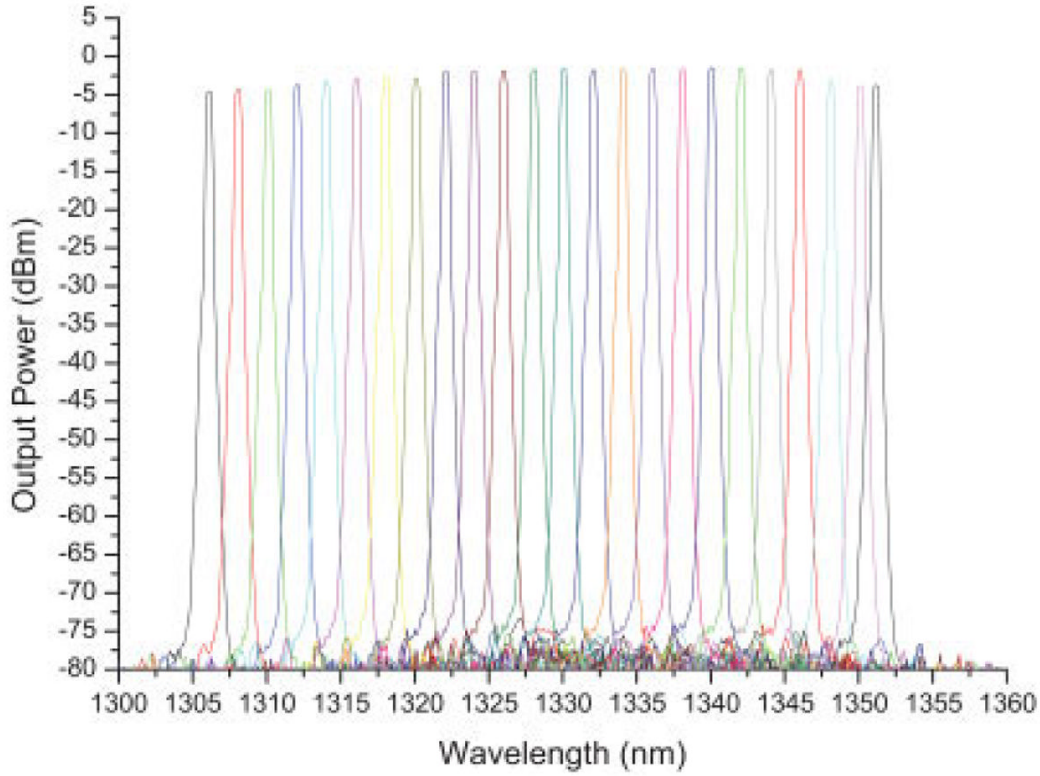

Figure 3.
The superimposed spectra of the proposed tunable ring laser. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

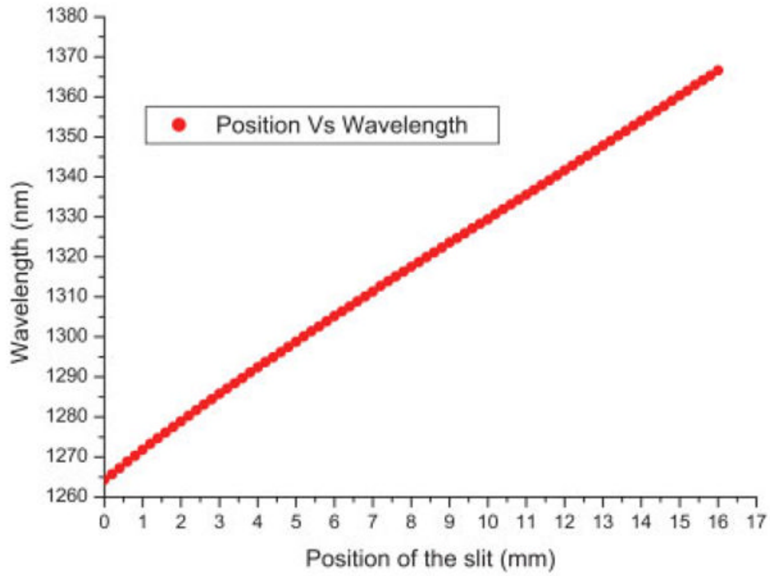

Figure 4.
The emission wavelength change versus the slit position. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]