Compact Digitally Tunable Laser

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Abstract-- We present a new design for a digitally tunable laser using two waveguide grating routers with different free spectral range. For an N-channel device both the number of required amplifiers and the number of required grating arms scale as the square root of N, resulting in a more compact device than previously demonstrated and better scaleability. Contrary to previously demonstrated devices with reduced number of amplifiers, all wavelength channels are multiplexed together in one common channel, allowing for a higher output power. Tuning speeds below 10 ns are envisioned. Experimental results are presented.

Index Terms-- digititally tunable laser, AWG, SOA, multifrequency laser, WDM

I. Introduction

Fast tunable lasers with switching times smaller than 50ns promise to be attractive components for next generation optical networks. A particular interesting application is the optical switch fabric as presented in [1] but they may for example also be used to built fast reconfigurable optical networks. A major class of tunable lasers are those which are formed by integrating a gain section and one or multiple tunable grating sections (DBR, SSG-DBR, GCSR-laser) [2]. In such a laser, the wavelength is switched by injecting current in one or more of the grating sections. These lasers however, typically require that the tuning current is controlled to within +/- 25µA to obtain accurate wavelength settings. This may inhibit fast tuning or limit the wavelength accuracy. Temperature changes in the grating sections during the tuning cycle may further complicate the operation of these devices. Digitally tunable lasers on the other hand, are formed by integrating an amplifier array with a passive wavelength selective element such as an arrayed waveguide grating router (AWG) [3][5] or a diffraction grating [6] and the wavelength is switched by turning amplifiers on or off. The operating wavelength is determined by the passive element and virtually independent of the current through the amplifiers. Switching speeds below 3ns (bias above threshold) and below 10ns (bias below threshold) have been demonstrated [3][6]. Traditional digitally tunable lasers need a separate amplifier for each wavelength channel. In such a case, yield considerations and grating size limit the maximum number of channels. In [5] however, a 40-channel device based on a chirped waveguide grating router (WGR) was demonstrated, using only 5+8=13 amplifiers. Single longitudinal mode operation was obtained but, since the fully multiplexed signal is only present in the WGR itself, the light had to be extracted from one of the outer arms of the grating, resulting in a low output power and, after amplification, a mediocre signal to noise ratio. In the present paper, we propose and demonstrate a device which, similar to the 40-channel device described above, for a given number of channels $N=N_1xN_2$, needs only N_1+N_2 amplifiers. However, in the new device the multiplexed signal is directly accessible, thereby greatly improving the maximum attainable output power.

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II. Device principle

Fig. 1 and Fig. 2 respectively show a schematic view and the actual mask layout of the device presented here. Two amplifier arrays are integrated together with two multiplexers with different free spectral ranges (FSR_1 & FSR_2) on a single chip. Both multiplexers have the same central wavelength and equal channel spacing $\Delta\lambda$ so their passbands overlap. However, if FSR_1 & FSR_2 - expressed in number of wavelength channels - share no common divisors, the total free spectral range for the transfer from one of the amplifiers at the left side of the device to one of the amplifiers at the right size of the device will be equal to the product of FSR_1 & FSR_2. By subsequently turning on the amplifiers of one amplifier array in combination with one of the amplifiers of the other array, every channel within the total free spectral range can be reached. Curvature of the gain will prevent lasing in multiple free spectral ranges. As shown in Fig. 1, the light can easily be extracted from the common waveguide in the center of the device. By carefully choosing the coupling ratio κ of the output coupler, the threshold current and the external efficiency of the laser can be optimized to maximize the output power for a given drive current.

Although two AWG's are needed, the total device size will be smaller than for previous devices [5], mainly because the required number of channels per device is very small (typically, FSR_1 & $FSR_2 < 10\Delta\lambda$). Moreover the device is scaleable. Not only does, as mentioned before, the number of required amplifiers scales approximately as $\sqrt{N}$ but also the number of grating arms in each individual AWG - and thus their size - scales as $\sqrt{N}$. (Note that in classic single AWG devices, such as the one presented in [5], device size scales as *N*). Below we present a 56-channel device (7x8) with 100GHz channel spacing, but devices with 72 (8x9) or even 88 (8x11) channels do not seem unrealistic.

Ultimately, the gain bandwidth of the SOA's will limit the total number of channels. When going to smaller channel spacing, the grating order - and thus the arm length - increases proportionally. However, the absolute filter bandwidth can remain the same, which means that relative to the channel spacing, the filter bandwidth can increase, allowing for less grating arms. Overall, we expect the device size to increase but without inhibiting for example a 50 GHz channel spacing. Note that, if no fast tuning is needed, temperature tuning can be used to reach every wavelength in between the designed grid (dλ/dT=0.1nm/K).

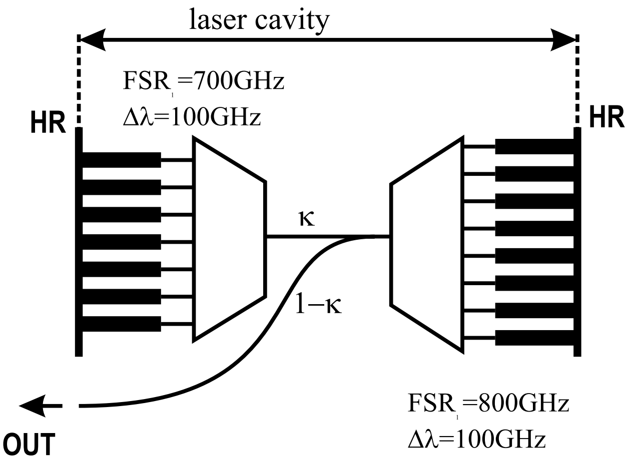

Fig. 1 Schematic operation principle

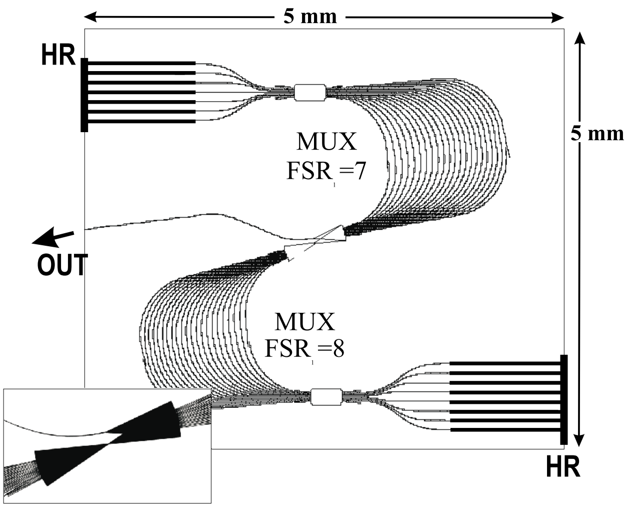

Fig. 2 Mask design for digitally tunable laser. Inset shows a close-up of the connection between both AWG's.

To obtain stable single longitudinal mode oscillation, the bandwidth of the intracavity filter has to be sufficiently small [7]. In practice, this means that a large number of grating arms have to be used in the AWG. However, for the device presented here, the light passes through two filters leading to a reduction of the total passband width. If both filters have the same passband width, the overall passband is reduced by a factor $\sqrt{2}$. This means that a smaller number of grating arms can be used for the individual AWG's, leading to a further size reduction.

III. REALIZATION AND EXPERIMENTAL RESULTS

The mask layout of the realized device is shown in Fig. 2. We chose a channel spacing of 100GHz, and a free spectral range of 700GHz and 800GHz for respectively the upper and lower multiplexer, resulting in a total FSR of 5.6THz or 56 channels. Instead of inserting a waveguide with a coupler in between both multiplexers a shown in Fig. 1, we minimized the device size by connecting the center of the lower multiplexer (FSR=800GHz) directly to the edge of the Brillouin zone of the upper device (FSR=700GHz). The common output waveguide is connected to the opposite edge of the Brillouin zone of the FSR=700GHz multiplexer. This setup is equivalent to having a 3dB coupler in between both devices but no additional space is needed. At the facet, the common output waveguide is angled to avoid reflections and an SOA is added to further amplify the output power. We tapered the star couplers in the center of the device down to 4μm (the width of the entrance waveguides to the multiplexers) to select a single wavelength channel. It is important to note that, by the specific layout of the devices, the dispersion in both central star couplers works in opposite direction. If this wouldn't be the case either no filtering action would be obtained or a short single mode waveguide should be added. Fig. 3 shows the simulated transmission spectra for both multiplexers individually and for the complete device. The transmission curves for the multiplexer with FSR=700GHz include the 3dB loss of the output coupler. This calculation takes into account the material dispersion but as can be seen from this figure, the walk off between the channels is negligible over this wavelength range. The absolute wavelength however, will move away from the perfect 100GHz grid when moving away from the central frequency. In a first order approximation, this shift is given by:

$$\delta\nu = i^2 \frac{\nu_0 \nu_{FSR}}{m n_0} \frac{dn}{d\nu}$$

with i the number of free spectral ranges away from the design frequency, ν_0 the design frequency, ν_{FSR} the FSR, n_0 the refractive index at the design frequency and m the grating order. For the 800GHz multiplexer, we find - with $m = 249$ and $-3<i<3$, a maximum deviation $\delta\nu<4$GHz, which is acceptable in a 100GHz spaced system. The dispersion of the slab region is not included in this calculation but a more detailed calculation shows that this effect is smaller by an order of magnitude and thus negligible. An important issue is matching the central wavelength of both multipexers. A variation of the refractive index or the thickness of the guiding layers over the wafer may shift the central wavelength of both filters with respect to each other leading to an imperfect overlap of the passbands and an increase of the intra-cavity loss.

We realized the device in InP/InGaAsP using the monolithic integration process described in detail in [8]. Starting from a layer structure consisting of a 170nm Q1.3 slab layer, a 75nm Q1.3 rib layer and a gain layer consisting of 4 InGaAsP quantum well layers, first the quantum wells were removed in the grating region using a selective etch. Subsequently, the waveguides and the amplifier mesas were formed, followed by current blocking layer overgrowth, p-overgrowth and metallization. The passive waveguides and amplifiers are respectively 2.25 μm and 1.2 μm wide and the minimum bend radius is 620 μm. Total device size is approximately $5x5mm^2$. Using a reflectometer, we measured the reflection at the active-passive transition to be smaller than -50dB.

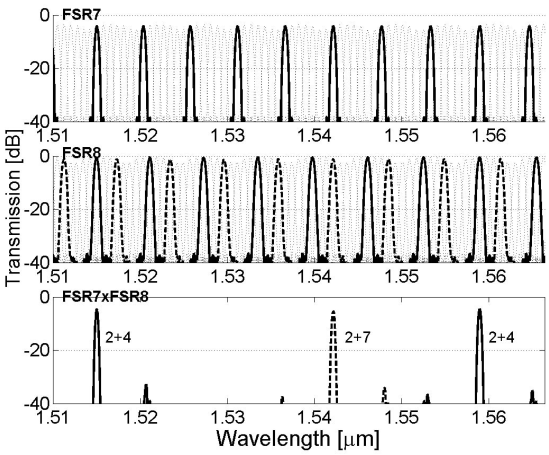

Fig. 3 Simulated transmission for mux 7 (upper row - channel 2 solid line), for mux 8 (middle row - channel 2 solid line, channel 7 dashed line) and for the combined device from channel 2 resp. to channel 4 (solid line) and to channel 7 (dashed line).

Fig. 4 shows superimposed oscillation spectra for a device where the current to the second amplifier of the upper multiplexer (FSR=700GHz) was held constant and amplifiers 1 to 8 of the lower multiplexer where turned on successively. No HR-coating was applied to this device and the spectra were measured directly from the upper multiplexer. As expected, we see the operating channel shifting over the different free spectral ranges. High side mode suppression ratio (>35dB for most channels), over 0 dBm fiber-coupled power and a threshold current of 2x35mA were measured. The variation in the output power between the different channels in Fig. 4 is caused both by the gain curvature and the non-uniform cavity loss. Since we're utilising the wrap-around properties of the AWG's, channels employing the edge amplifiers will see an additional cavity loss of up to 6 dB (3dB per AWG). By using optimised current settings, equalisation of the output power is easily obtained.

Unfortunately, tapering down the star couplers connecting both multiplexers to 4μm as described above, didn't suppress the neighboring channels sufficiently and the device is not operating at the edge of the Brillouin zone as designed but in a channel closer to the center of the upper multiplexer (for the upper multiplexer this channel has a considerably lower loss, while for the lower multiplexer this shift has only a minor influence). As a consequence, the output power cannot be measured from the output waveguide since the lasing light is no longer coupled into this guide. We believe inserting a short waveguide between both central star couplers will solve this.

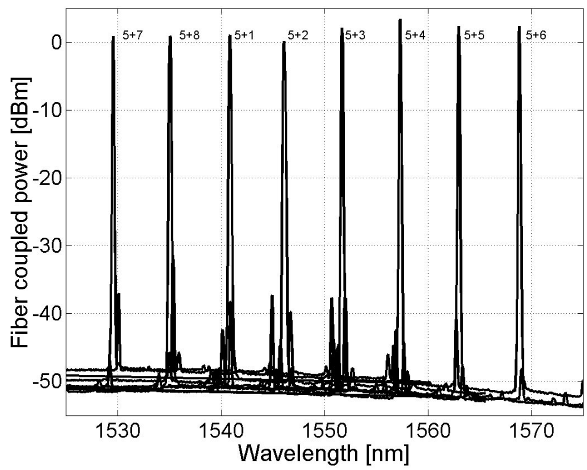

Fig. 4 Measured spectra for selected channels

IV. Conclusion

We presented a new and improved design for a digitally tunable laser. Since both device size and number of required optical amplifiers scale as the square root of the number of channels, large channel counts can easily be attained. Moreover, since all wavelength channels are multiplexed together in a common waveguide, higher output power levels can be reached compared to earlier devices. First experimental results verify the operating principle of the device.

V. References

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