Characterisation and modelling of a compact multiwavelength ringlaser

E.A.J.M. Bente[1], Y. Barbarin[1], J.H. den Besten[1], J.J.M. Binsma[2], M.K. Smit[1]

[1)] Eindhoven University of Technology, Dept. of Electrical Engineering
Den Dolech 2, 5612 AZ Eindhoven, The Netherlands
[2)] JDS Uniphase, Prof. Holstlaan 4, 5656 AA Eindhoven, The Netherlands

Detailed spectral characteristics have been measured of an integrated compact multi-wavelength ringlaser under a wide range of operating conditions. The laser consists of a single PHASAR and four semiconductor optical amplifiers. It can produce 7 different wavelengths in the 1.5micrometer region, three of which could be produced by driving two SOAs simultaneously. The frequency selective mechanism that led to these combination wavelengths was established and a rate equation model of the laser was written that reproduces the observed behaviour of the laser. Input parameters to the model were derived from the simulation of a number of integrated extended-cavity Fabry-Perot lasers.

Introduction

For WDM networks, lasers that can be switched between different pre-selected wavelengths are a useful alternative for the commonly used arrays of distributed feedback (DFB) lasers or distributed Bragg reflector (DBR) lasers. Such wavelength switchable lasers can be fabricated by integrating a series of semiconductor optical amplifiers (SOA) with a PHASAR on a single chip using an active/passive integration technology. Several of such devices with different geometries and properties have been produced and demonstrated in the InP/InGaAsP material system [e.g. 1,2,3,4]. Particular issues are: a) trying to produce as many choices for wavelengths with a minimum number of SOAs and b) whether more than one wavelength needs to be delivered at the same time in one waveguide. One of the lasers that was demonstrated by den Besten et al [1], is the world's most compact wavelength switchable ring laser. It was demonstrated that driving one or two of the four SOAs could produce seven different wavelengths. In this paper we focus on the wavelength selection mechanism for the wavelengths produces when two SOAs are operated. The behaviour of the laser is simulated using a rate equation model, using parameters for the SOAs that where checked against results obtained with extended cavity FP lasers built with similar SOAs.

Laser operation

The operation of the ringlaser can be explained using the mask layout that is shown in figure 1. The laser contains four 500μm long, 2μm wide amplifiers integrated with the wavelength selective element, the PHASAR, via waveguides. Deep etching of the curved waveguides allows for the compactness of the device. A small fraction, estimated at about $5*10^{-4}$, of the laser light is coupled out of the resonator by leading the outer waveguides of the waveguide array to the edge of the wafer. The PHASAR has a channel spacing of 1.6nm (200GHz) and a Free Spectral Range (FSR) of 15nm. Further details on fabrication and design can be found in [1]. When only one of the SOAs is operated at a time, four different wavelengths are produced with a spacing of 3.2 nm.

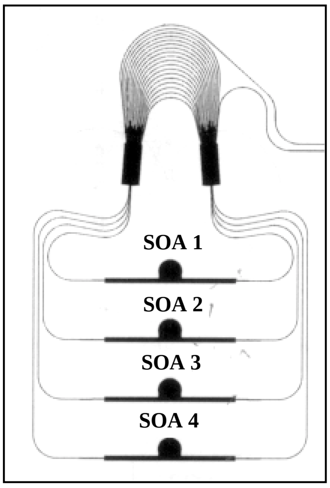


Figure 1. *Mask layout of the compact ring laser.*

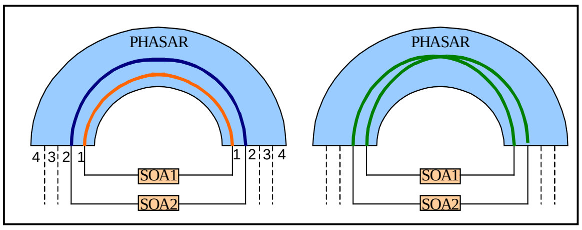


Figure 2. *Diagram of the ports on the PHASAR.*

This difference equals two channel spacings since the four waveguide connections to the PHASAR are equally spaced at both ends of the PHASAR. This is shown schematically in figure 2, which depicts the connections to the PHASAR. When two SOAs are operated, e.g. nrs. 1 and 2, a new wavelength λ_{AB} is generated that lies exactly in between the wavelengths generated using only SOA1 (λ_A) or SOA2 (λ_B). This can be understood as originating from a double roundtrip mode as indicated on the right-hand side in figure 2. Here light is coupled from port 2 on the left-hand side of the PHASAR to port 1 on the right and vice versa. The resulting wavelength λ_{AB} is thus halfway between λ_A and λ_B. To determine why this mode at λ_{AB} prevails over the modes with λ_A and λ_B, we have measured the characteristics of the laser and wrote a simple rate equation model.

Laser model

The rate equation model [5] given below was set up in a MathCAD worksheet and it describes the time derivatives of the average photon densities ϕ_A, ϕ_B and ϕ_{AB} at the three wavelengths λ_A , λ_B and λ_{AB}, and the carrier density in the two amplifiers N_A and N_B.

$$\begin{cases}
\dfrac{d\phi_A}{dt} = \phi_A \cdot \left[(N_A - N0_A) \cdot \left(Vg \cdot \alpha \cdot \Gamma \cdot \dfrac{L_{SOA}}{L_{cavA}} \right) - \dfrac{Loss_{cavA} - \ln(1-T)}{\tau_A} \right] + B \cdot \Gamma \cdot N_A{}^2 \cdot \beta \\
\dfrac{d\phi_B}{dt} = \phi_B \cdot \left[(N_B - N0_B) \cdot \left(Vg \cdot \alpha \cdot \Gamma \cdot \dfrac{L_{SOA}}{L_{cavB}} \right) - \dfrac{Loss_{cavB} - \ln(1-T)}{\tau_B} \right] + B \cdot \Gamma \cdot N_B{}^2 \cdot \beta \\
\dfrac{d\phi_{AB}}{dt} = \phi_{AB} \cdot \left[(N_A - N0_A) \cdot \left(Vg \cdot \alpha \cdot \Gamma \cdot \dfrac{2L_{SOA}}{L_{cavAB}} \right) + (N_B - N0_B) \cdot \left(Vg \cdot \alpha \cdot \Gamma \cdot \dfrac{2L_{SOA}}{L_{cavAB}} \right) - \dfrac{Loss_{cavAB} - \ln(1-T)}{\tau_{AB}} \right] \\
\qquad + B \cdot \Gamma \cdot (N_A{}^2 + N_B{}^2) \cdot \beta \\
\dfrac{dN_A}{dt} = -Vg \cdot \alpha \cdot (\phi_A + \phi_{AB}) \cdot (N_A - N0_A) - \dfrac{N_A}{\tau_{car}} - B \cdot N_A{}^2 - C \cdot N_A{}^3 + W_A(t) \\
\dfrac{dN_B}{dt} = -Vg \cdot \alpha \cdot (\phi_B + \phi_{AB}) \cdot (N_B - N0_B) - \dfrac{N_B}{\tau_{car}} - B \cdot N_B{}^2 - C \cdot N_B{}^3 + W_B(t)
\end{cases}$$

Here $N0_A$ and $N0_B$ are the transparency carrier densities in the amplifier; Vg is the group velocity; α is the gain per carrier; Γ is confinement factor; L_{SOA} is the length of the SOA; L_{cavA}, L_{cavB} and L_{cavAB} ($\approx Lcav_A + Lcav_B$) are the cavity lengths; $Loss_{cavA}$, $Loss_{cavB}$ and $Loss_{cavAB}$ are the intracavity losses, T is the fraction coupled out of the cavity for output; τ_A, τ_B and τ_{AB} are the cavity roundtrip times; τ_{car} is the carrier lifetime, B is the bimolecular recombination rate, C is the Auger recombination rate; and $W_A(t)$ and $W_B(t)$ are the carrier injection rates. The material parameters used have been taken from a simulation of a simple laser using the Apollo Photonics ALDS software. Using a single mode model and these parameters we have been able to fit PI curves from a series integrated extended cavity Fabry-Perot lasers with varying amplifier length, that were fabricated on the same wafer segment as the wavelength switchable laser.

Characterisation results

When the double roundtrip loss $Loss_{cavAB}$ is taken to be: $Loss_{cavA} + Loss_{cavB}$, the model predicts that the double roundtrip mode does produce the most output power. However power at the other two wavelengths is only several dBs lower. To have the λ_{AB} mode dominate the spectrum by over 40dB this mode needs a lower intracavity roundtrip loss by several tenths of dBs at least. Initially we thought this lower loss could be related to the smaller mode spacing of the longitudinal modes of a double roundtrip mode. The longer cavity meant that this mode could be closer to the PHASAR transmission maximum. However, this advantage should be highly sensitive to temperature. The intensity of the three modes λ_A, λ_B and λ_{AB} should vary considerably with temperature. A series of output spectra at heatsink temperatures of 18 to 28°C, with the laser operating at the combination wavelength of SOA 1 and SOA 2, show that the mode is robust. A detailed comparison of the spectra reveals no significant change in the location of the cavity modes with respect to the central peak. Only a shift in wavelength of 0.12nm/°C is observed which is in line with the expected temperature dependence of the channel wavelengths of the PHASAR.

The spectra from the laser below the lasing threshold turned out to contain crucial information. The spectrum shown in figure 3 was recorded with 46mA through both SOA1 and SOA2. It shows in total six different combs of modes related to: a single round trip cavity through SOA1 (cavity A), a single round trip cavity through SOA2 (cavity B) and the modes related to the combined wavelength cavity (cavity AB). These are visible for both TE and TM polarisation. The modes in the middle of the spectrum only appear when both amplifiers are switched on. The important observation stems from the free spectral ranges in the different combs. The comb of TE modes on the right-hand side is from cavity A with an FSR of 180pm. The comb of TE modes on the

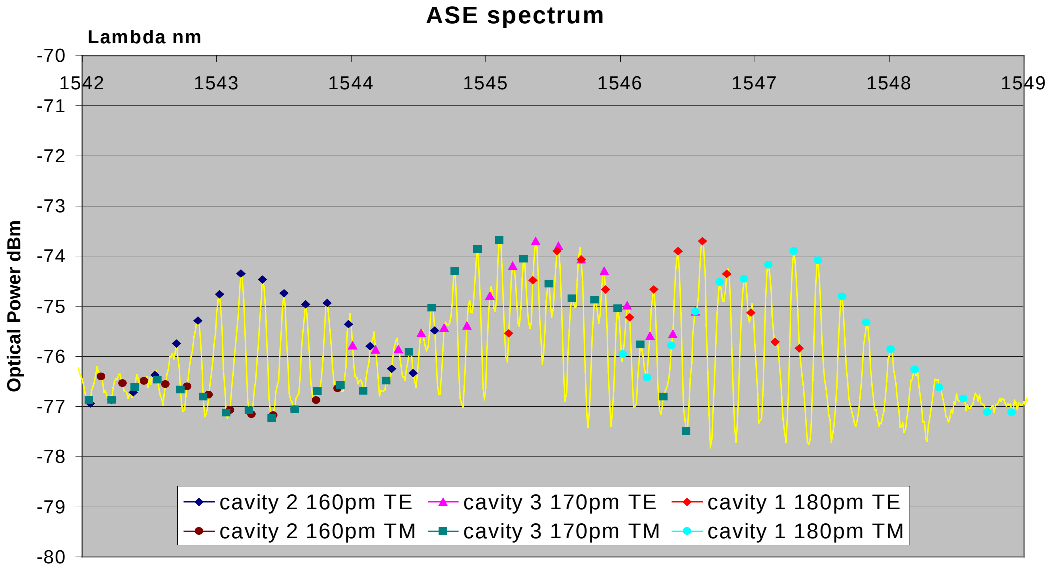
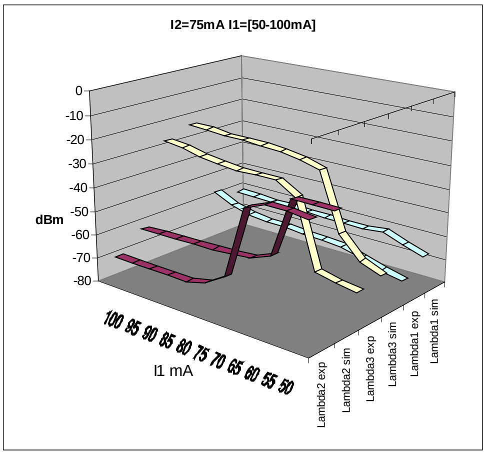


Figure 3. *A sub-threshold spectrum with SOA1 and 2 pumped at 46mA.*

left-hand side is from cavity B with a smaller FSR of 160pm, which fits the longer optical path (see figure 1). The TE modes in the middle however show an FSR of 170pm! We would expect half of this value since the cavity length of the double roundtrip loop is approximately twice as long! This indicates two things. Firstly we have to conclude that there is a single roundtrip resonance condition on the combined mode. This can be caused by cross-talk between the channels in the PHASAR. The extra modes that we expected to see in between single pass modes will lead to a 180 degrees phase difference between the light fields in the two waveguides entering the PHASAR. This apparently leads to lower transmission efficiency. The cross-talk will make that the total transmission through the PHASAR of the light at λ_{AB} from two adjoining waveguides at one side, to the two adjoining waveguides at other side of the PHASAR will be highest when the phases in the waveguides are (?) close to each other. Secondly when the fields are in phase, part of what is otherwise lost in PHASAR transmission as cross-talk into another channel is now used. Light that gets to the other waveguide stays in the cavity. The PHASAR in this laser has a poor cross-talk specification since one would expect this not to be of importance for wavelength selection inside a laser cavity. Using spectra as in Figure 3, we derived an effective transmission loss difference of about 1dB for the PHASAR in the single SOA modes and the combined SOA mode. Using this number we simulated the switching of the laser between a single SOA mode and the combined SOA mode when the current in one of the SOAs was varied. This is shown in figure 4 above.



Conclusion

The mechanism responsible for the wavelength selection in this discretely tunable ring laser turns out to be related to a property of the PHASAR when multiple inputs are used at the same time with coherent light. Using a simple three-mode rate-equation model the switching behaviour between the operating modes could be described. This work has been carried out under the framework of the OBANET IST-2000-25390 project and the Dutch NRC-Photonics programme.

References

[1] J.H. den Besten et al, “A compact digitally tunable seven-channel ring laser”. IEEE Phot.Tech. Lett. vol. 14, pp.753-755, 2002.

[2] J.H. den Besten et al, “An integrated coupled cavity 16 wavelength digitally tunable laser”, IEEE Phot. Technol. Lett., accepted for vol. 14, no. 12, December 2002.

[3] C. Doerr, C.H. Joyner, and L.W. Stulz, “40-wavelength rapidly digitally tunable laser.”, IEEE Phot. Technol. Lett., vol. 11, no. 11, pp. 1348-1350, Nov. 1999.

[4] J.H. den Besten et al, "An InP-based 4x4 channel multi-wavelength laser", In proceedings of the ECOC 2002 conference, pp. 3.3.4

[5] L.A. Coldren and S.W. Corzine, Diode Lasers and Photonic Integrated Circuits, Wiley series in microwave and optical engineering, John Wiley & Sons Inc., 1995, ch. 2, pp. 28-64.