Deeply-etched DBR gratings for Photonic Integrated Circuits and Tunable Lasers

B. Docter,[1] J. Pozo,[1] F. Karouta,[1] S. Beri,[2] I.V. Ermakov,[2] J. Danckaert[2] and M.K. Smit[1]

[1] OED group, COBRA, Technische Universiteit Eindhoven, The Netherlands
[2] Department of Applied Physics and Photonics, Vrije Universiteit Brussel, Belgium

Deeply-etched DBR gratings are versatile components for application in Photonic Integrated Circuits. A fabrication technology was developed that allows integration of deeply-etched DBR mirrors with other active and passive components on an InP chip. As a demonstration of the many applications of the DBR mirrors a novel discretely tunable laser based on filtered feedback is presented. The laser has a simple tuning method and the potentially sub-ns switching speed makes the device promising for packet-switching applications. Because of the simple control scheme, the device also has potential for low-cost applications like metro- and access networks.

Introduction

Deeply-etched DBR gratings are a new set of components that increase the design flexibility in photonic integrated circuits [1]. Whereas usually cleaved chip facets are used to form broadband mirrors, the deeply-etched DBR mirrors can be placed anywhere on a chip. This results in a much higher accuracy of the position of the mirrors and therefore, when the mirrors are used to create laser cavities, the mode-spacing of such cavity is very well defined.

In this paper we present the progress we made in the fabrication of deeply-etched DBR mirrors in an active-passive integration technology [2]. We demonstrate the new possibilities that are offered by this technology by presenting a novel discretely tunable laser based on filtered feedback. We show that this device has very interesting features such as stable and simple wavelength control.

DBR design

The DBR mirrors are fabricated in a double etching process [1] that allows the integration of shallow etched Semiconductor Optical Amplifiers with deeply etched DBR mirrors as schematically shown in figure 1. A side-view of the DBR mirror is shown in figure 2. We use an n-doped InP substrate with a bulk 100 nm thick Q1.55 active layer, surrounded by Q1.25 confinement layers for the active areas. The total thickness of the waveguide layer is 500 nm. The p-doped top cladding is 1.5 µm thick to avoid light being absorbed in the heavily doped InGaAs contact layer. The passive waveguide layer consists of a 500 nm thick Q1.25 layer.

The DBR mirror section is etched to a depth of at least 1.5 µm below the active layer to ensure maximum reflectivity. The line space ratio of the DBR grating is 360/825 nm. This corresponds to a 3rd order (3/4 λ) grating when filling the etched areas with BCB (n=1.54).

Figure 3 shows the calculated reflection spectra of the 3rd order design for a number of different grating periods. Figure 4 shows the measured DBR reflectivity for λ=1.55 µm for DBR mirrors with different number of periods. The reflectivity is lower than the simulated values due to small fabrication imperfections, but still sufficient for our purpose of creating broadband laser mirrors.

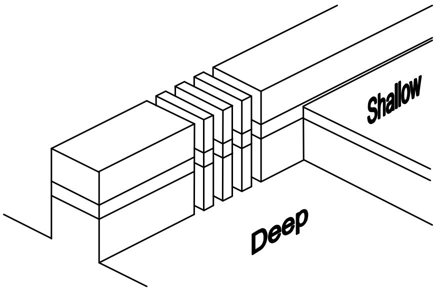


Figure 1: Schematic picture of the double etching technology

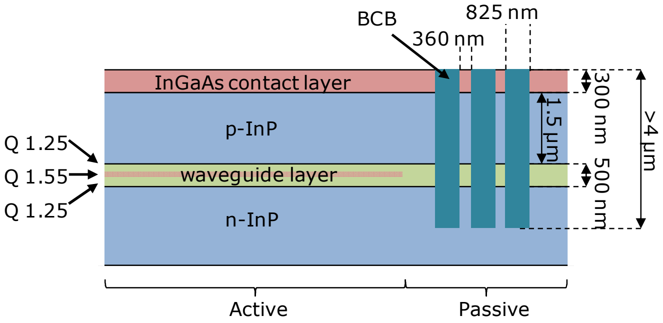


Figure 2: Side view of DBR mirror section

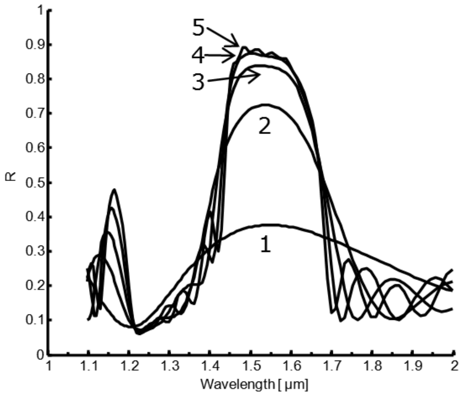


Figure 3: Simulated reflection spectra of 3rd order BCB filled gratings. The numbers in the plot indicate the number of DBR periods.

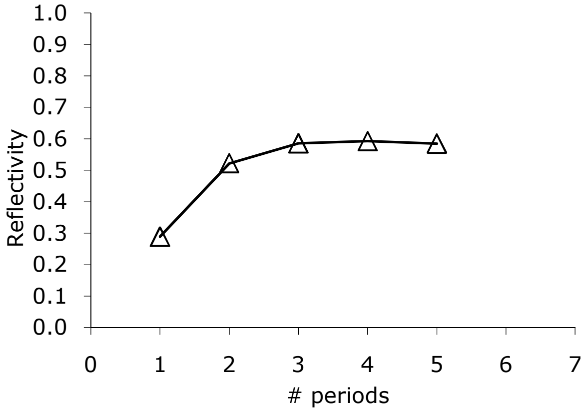


Figure 4: Measured DBR reflectivity as a function of number of DBR periods for λ=1.55 µm

Filtered feedback tunable laser

As a demonstration of the possibilities that are offered by the new DBR technology we developed a novel tunable laser based on filtered feedback [3]. A schematic picture of the novel Integrated Filtered-Feedback Tunable Laser (IFF-TL) is shown in Fig. 5. A Fabry-Perot (FP) laser is formed by an SOA and two deeply etched DBR mirrors. The laser cavity length is chosen such that the mode spacing equals the channel spacing in the standard ITU-grid used for telecom applications, e.g. 50 or 100 GHz.

The FP laser is coupled to an Arrayed Waveguide Grating (AWG) filter that splits the light of the FP laser in several waveguide branches. Each branch contains an SOA that works as an optical gate. When the SOA is not biased it will absorb the light, but when put in forward bias the light will be transmitted or even amplified. The light is then reflected by another DBR mirror and fed back through the AWG into the FP laser. The feedback light causes the laser mode with the largest feedback strength to dominate over the other modes and single mode operation is achieved. The feedback strength is controlled by the gates in the feedback branches. The output light leaves the chip through the opposite DBR mirror.

The laser modespacing is determined by the channel spacing of the AWG. In this first demonstration a 400 GHz channel spacing was chosen, using a 4-channel AWG. The concept can however be extended to more wavelengths.

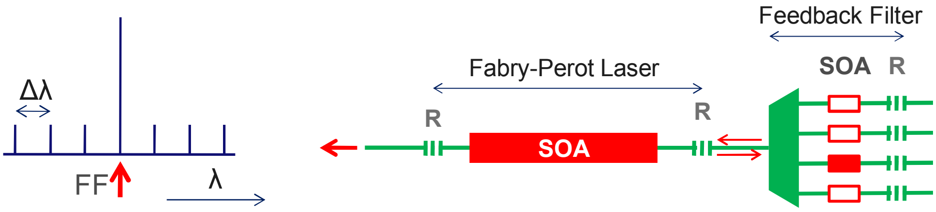
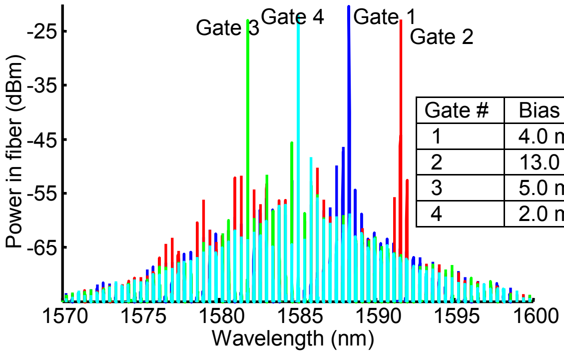


Figure 5: Schematic picture of the IFF-TL device. The inset on the right shows the possible laser modes, the mode spacing Δλ and the wavelength selected by the Filtered Feedback (FF) signal.

Compared to continuously tunable DBR lasers, the main difference is that the tuning mechanism is placed outside the main laser cavity. This means that there is no change in refractive index in the main FP laser cavity while switching the wavelength. Therefore the wavelength stability is improved and control schemes are much simpler. The limitation is that the device can only operate at a fixed set of wavelengths and cannot be tuned continuously.

Characterization

Fig. 6 shows the superimposed lasing spectra of the devices when operated at 45 mA. The text near the different laser peaks indicate which gate was operated. The forward bias on the different gates was between 2 and 13 mA. We can clearly see single mode operation for each of the channels. The SMSR for the various signals is at least 20 dB.
In Fig. 7 a smaller part of the spectrum is plotted. In this figure we observe the sub-threshold side modes that originate from the modes of the FP cavity. The mode spacing is 0.404 nm. This corresponds to a frequency spacing of 50.5 GHz, 1% deviation from the ITU spacing. The distance between the lasing channels is 404 GHz.



Gate #	Bias
1	4.0 mA
2	13.0 mA
3	5.0 mA
4	2.0 mA

Figure 6: Superimposed lasing spectra of the IFF-TL device while forward biasing the different gates. The laser was forward biased at 45 mA, the currents on the different gates are shown in the table.

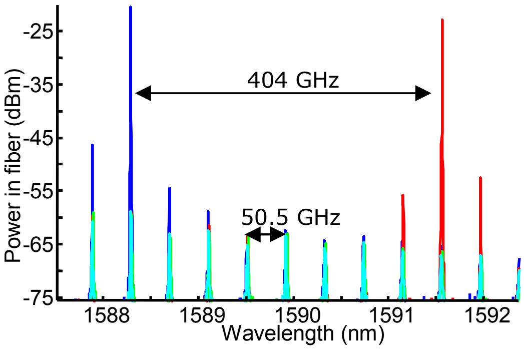


Figure 7: Detail of the lasing spectra showing 50.5 GHz FP mode spacing and 404 GHz mode spacing between AWG channels 1 and 2.

The plot in Fig. 7 clearly demonstrates the wavelength stability of the device. The FP side modes coincide exactly, no matter which gate is operated. This shows that the group index of the modes in the laser does not change, even though the gates are operated at different currents.

In Fig. 8 the lasing wavelengths are plotted as a function of the forward bias on the different gates. Also the possible FP-laser modes and the AWG channel passbands are plotted as a reference.

Within the 400 GHz AWG channels 50 GHz mode-hops are visible. These mode-hops are caused by a change of feedback phase due to the changing gate currents. The wavelength that has the most favorable phase matching will lock the laser. However, the lasing wavelength is usually stable over a wide range in gate currents. This shows that the control of the laser is not very critical and can be realized with relatively simple electronics.

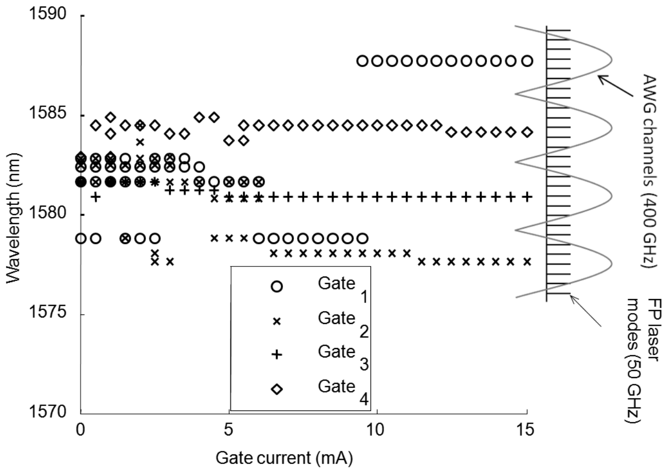


Figure 8: Lasing wavelengths as a function of different gate bias currents. The inset on the right indicates the position of the AWG channels and the possible FP laser modes. The device was driven with 41 mA on the main laser contact.

Conclusion

In this paper we presented a novel application of broadband DBR mirrors in InP-based photonic integrated circuits. The new tunable laser exploits the accurate positioning of the DBR mirrors to create a laser cavity with a very well defined mode spacing. The ability of integrating the laser with other passive components was used to create a filtering feedback circuit that can switch the laser.

The first characterization results show that the laser can switch between the wavelengths with a relatively simple control scheme. The wide operating regimes suggest that the device can be switched using simple electronics, which offers a potential cost saving compared to conventional tunable lasers.

We also expect that this device can switch very rapidly between the wavelengths, because temperature changes due to changing switching currents do not occur in the main laser cavity. However, the dynamic behavior of the device was not yet characterized experimentally.

References

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[2] J.J.M. Binsma et al. “MOVPE Waveguide Regrowth in InGaAsP/InP with Extremely Low Butt-Joint Loss,” Proc. IEEE/LEOS Symp. Benelux 2001

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