

Short-cavity lasers with deeply etched DBR mirrors for Photonic Integrated Circuits

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Deeply etched DBR mirrors are a new building block for complex Photonic Integrated Circuits. They greatly increase the design flexibility, since they can provide broadband reflection anywhere on the chip. In this paper we demonstrate the successful integration of DBR mirrors in short-cavity lasers. Devices with cavity lengths as small as 100 μm show stable CW operation at low drive currents. Devices with cavity lengths of 100 – 240 μm were used to characterize the DBR reflectivity. It is shown that the reflectivity is at least 30 % for a 2-period DBR mirror over a wavelength range of 1520 – 1580 nm.

Introduction

For future complex InP-based Photonic Integrated Circuits (PICs) there is a need for small light sources that provide a stable optical signal at low operating power. Especially in digital PICs, where potentially hundreds of components will be integrated on a single chip, low heat dissipation is crucial. Several groups have demonstrated low threshold lasers in the InP/InGaAsP material system, either using deep-etched DBR gratings[1], or vertical groove (VG) sidewall corrugation gratings[2,3]. Also, micro ring lasers are an interesting candidate, but these devices suffer from inherent bi-stability, which does not make them suitable for all applications.

Most of these devices use a single etch step process, where the active waveguide is etched to the same depth as the DBR mirror. This process requires a good sidewall passivation of the active layer, which is not trivial. In this paper we demonstrate the integration of deep-etched DBR gratings in a two-step etching process, where the DBR mirror is etched sufficiently deep, and the active waveguide is formed by etching a ridge to just above the active layer. Furthermore we present a characterization method to determine the reflection spectrum of the DBR mirrors.

Design

A schematic picture of the double-etched device is shown in figure 1 and 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. 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 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 360/750 nm. This corresponds to a 3rd order ($3/4 \lambda$) grating when filling the etched areas with BCB ($n=1.54$). The BCB results in a lower reflectivity per period, but since the diffraction of the transmitted light is less, the overall reflection can still reach more than 75% within 5 periods as shown in the FDTD simulation result in figure 3. The figure also shows that

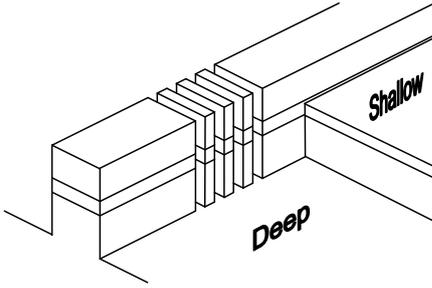


Figure 1: Schematic picture of the double etched device

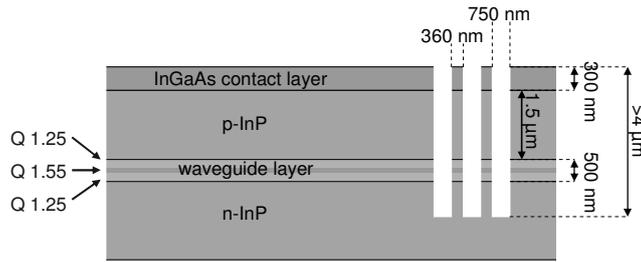


Figure 2: Side view of DBR mirror section

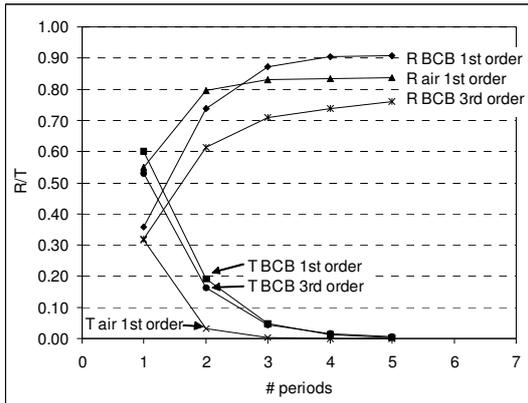


Figure 3: 2D-FDTD simulation results: Reflection and transmission of 1st and 3rd order gratings filled with BCB and air

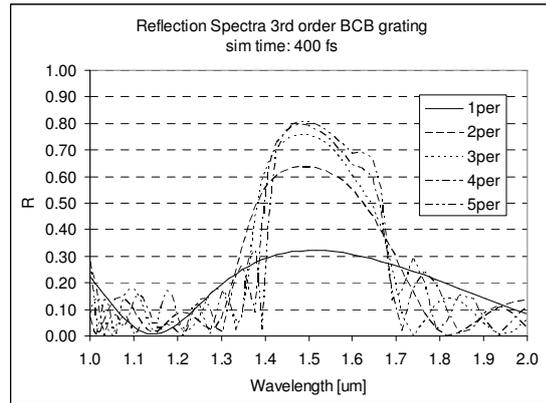


Figure 4: 2D-FDTD simulation results: Reflection spectra of 3rd order BCB filled gratings

the transmission of BCB filled gratings is higher than in the case of no filling. This is beneficial for the total efficiency of the laser device when used in an integrated circuit. We choose a 3rd order design over a 1st order design, because it is easier to fabricate. However, this compromises the reflection bandwidth somewhat and therefore also the fabrication tolerance. Figure 4 shows the calculated reflection spectra of the 3rd order design for a number of different grating periods. It is shown that the grating still has a high-reflectivity bandwidth of more than 200 nm, which is generally wider than the gain bandwidth of the material system used here.

Fabrication

For the fabrication of the DBR laser we use a 3-level masking process with separate lithography steps for the DBR pattern and the waveguide pattern as described in [4]. The shallow-deep definition is done by photolithography with a polyimide layer. We use polyimide instead of normal photoresist because it can withstand higher temperatures. After baking the polyimide at 300 °C the sample is etched in a Cl₂:Ar:H₂ ICP process to a depth of about 4 μm. Then the polyimide is removed and the rest of the device is etched to a depth of 1.9 μm in a CH₄:H₂ ICP process. This etching process is stopped just above the Q1.55 active layer, creating a shallow ridge waveguide. The chip is then covered with a thin (~75 nm) SiO₂ layer that serves as an adhesion promoter for the BCB that is used to planarize the structure. After the planarization the SiO₂ is removed from the top of the active waveguide by CHF₃ RIE and a Ti/Pt/Au contact is formed on top by photolithography and lift-off. The n-contact is also made by Ti/Pt/Au. Finally the

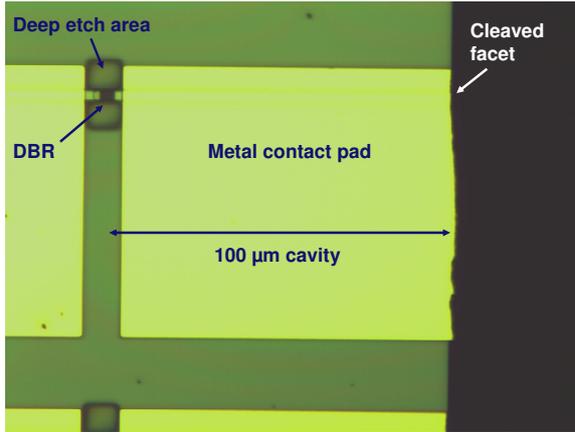


Figure 5: Microscope picture of cleaved chip

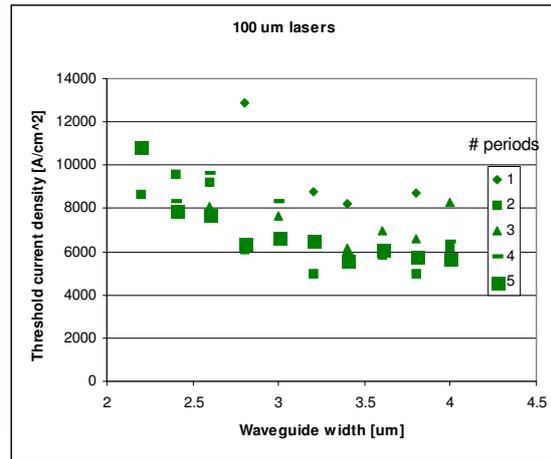


Figure 6: Threshold current densities

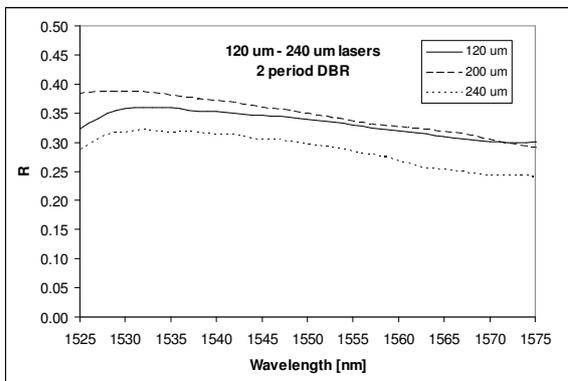


Figure 7: DBR reflectivity for 2 period gratings

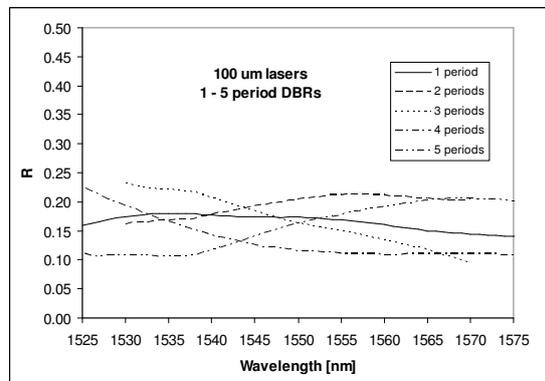


Figure 8: DBR reflectivity for 1-5 period gratings

chip is cleaved so that we form a laser cavity between a DBR grating and a cleaved facet, as shown in the microscope photo in figure 5.

Characterization

First the threshold currents were recorded for a set of 100 μm long devices with various waveguide widths. The threshold current densities are shown in figure 6. In these short-cavity devices the mirror loss dominates the threshold condition and it is therefore expected that the variation in threshold current density is mainly caused by a variation in mirror reflectivity. However, the measurement results do not show a clear trend in the threshold current density as a function of number of DBR periods.

To directly extract the mirror reflectivity from the threshold current density one needs to know the gain of the active medium as a function of current very accurately. The only way of obtaining some information about the gain in these structures is to measure the threshold current of a reference device with known mirror reflectivities, for example with cleaved mirrors. Because we do not thin the substrate, the minimum length of a cleaved facet laser is 800 μm. It thus operates at a much lower current density and therefore also at a different wavelength range.

To circumvent this problem we determine the current density at which the material gain of the (Q1.55) active layer is 0. At this transparency current density the modal field still experiences propagation losses due to high doping concentration in the other layers. These propagation losses can be obtained by using the well known Fabry-Perot formula:

$$\alpha = -\frac{1}{L} \ln \left(\frac{1}{\sqrt{R_1 R_2}} \frac{\sqrt{C} - 1}{\sqrt{C} + 1} \right) \quad (1)$$

In this equation R_1 and R_2 represent the mirror reflectivities and C is the contrast ratio between the maxima and minima in the Fabry-Perot fringe pattern, which can be measured using an Optical Spectrum Analyzer (OSA). Once we know the propagation losses (α) we can rewrite the equation and deduce the DBR reflectivity of our short cavity devices:

$$R_2 = \frac{1}{R_1} \left(\frac{\sqrt{C} - 1}{\sqrt{C} + 1} e^{\alpha L} \right)^2 \quad (2)$$

The transparency current density is measured using a method described in [5]. The losses obtained at the transparency current density are in the range of 100-120 dB/cm, depending on the wavelength. These losses are relatively high, due to the doping concentration of the layers surrounding the active layer. Using these loss values in equation 2, we estimate the mirror reflectivity of our short-cavity lasers. The results are plotted in figures 7 and 8. Also here we see that a larger number of periods does not lead to a higher DBR reflectivity. This indicates that probably the dimensions of the DBR mirrors are not optimal, possibly due to fabrication imperfections. This is currently under investigation.

Conclusion

In this paper we demonstrated the successful integration of deep-etched DBR gratings in a double etch fabrication process that is capable of realizing complex PICs. We also developed a characterization method to analyze the DBR reflectivity over a wide spectrum. The values obtained for the DBR reflectivity are lower than expected, this can probably be improved after process optimization.

References

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