Butt-Joint Interfaces in InP/InGaAsP Waveguides with Very Low Reflectivity and Low Loss

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In this paper we report on the observation of reflection values < -50dB at active-passive butt-joint interfaces in extended cavity Fabry-Pérot lasers and 0.19dB loss at passive-passive butt-joint interfaces. A three step growth process has been developed using MOVPE with all metal-organic precursors. In the first epitaxy step, the active layer stack is grown up to 200 nm above the index guiding layer. The passive regions are etched using a SiNx mask, afterwards those regions are re-grown up to the top of the active regions. Finally the SiNx mask is removed and the top cladding is grown. We have investigated the minimization of the butt-joint reflection by crossing the interface at different angles. Measurements showed that the butt-joint reflection is below -50dB for angles above 12 degrees.

Introduction

Low butt-joint loss and low butt-joint reflection values on active-passive interfaces are essential in Photonic Integrated Circuits (PIC). Reflections down to – 50 dB affect the operation of integrated lasers [1] and lead to a modification of the mode structure. Modelocked lasers for instance are very sensitive to any reflections as explained in [2]. Furthermore, the noise at a modelocked laser output is dependent of the roundtrip cavity loss, consequently the lowest butt-joint loss is preferable for good performance. In this paper, we present active-passive device integration with butt-joints using selective area metal-organic vapor phase (MOVPE) regrowth with all metal-organic precursors. We report on the observation of 0.19dB loss for passive-passive butt-joint interfaces and reflection values < – 50 dB at active-passive butt-joint interfaces in extended cavity Fabry-Pérot lasers.

Fabrication of active-passive integrated devices

The layers were grown by Metal-Organic Vapor Phase epitaxy (MOVPE) with all metal-organic precursors (Figure 1) in a three-step process. In the first epitaxy step, the active film is grown (figure 1a). Then a doped 200 nm thick InP layer is grown. Mesa blocks are defined by photolithography using a 100nm SiNx layer as etching mask. The mesa blocks are 30 µm wide and spaced apart by 250µm. Block lengths vary from 20 to 2000 µm long and can be used to produce amplifiers, detectors or absorbers. The future passive areas are etched wet chemically 30 nm below the active layer, thus 530 nm are etched for regrowth. An overhang below the SiNx mask prevents the lateral overgrowth at the butt-joint (Figure 1b and 2). Then undoped λ = 1250 nm InGaAsP and InP layers are regrown by selective area MOVPE using the same SiNx mask (figure 3c). Undoped layers in the passive waveguide reduce the optical losses due to free carrier absorption. The thicknesses of both layers are matched to the original thicknesses. The SiNx mask is removed and finally a p-doped top cladding layer is grown as shown in figure 1d. The quality achieved could be directly seen from the SEM picture depicted in figure 3.

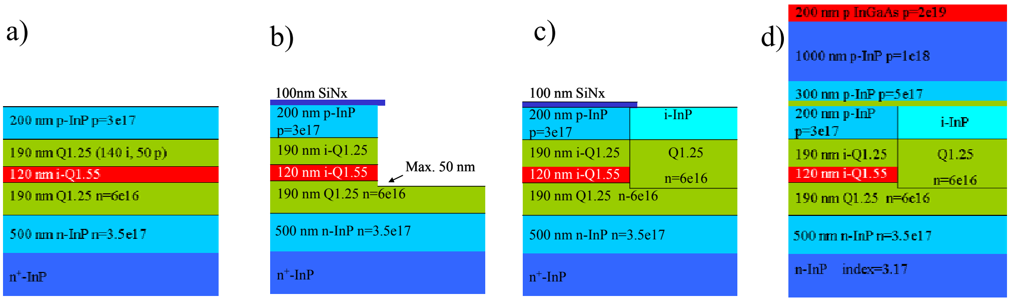

Figure 1 Process flow of the fabrication of the active-passive wafer

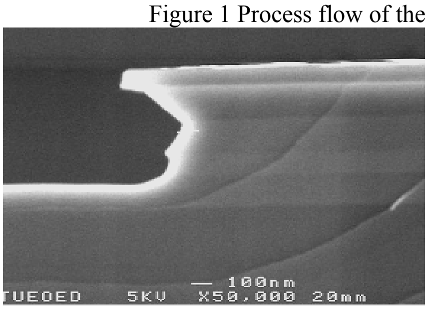

Figure 2: SEM picture of the overhang created after the wet etch in order to limit the overgrowth.

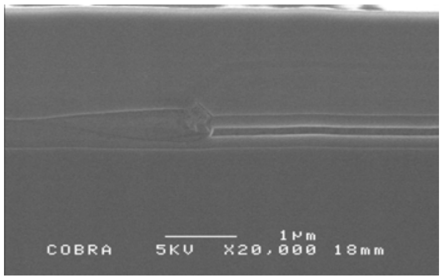

Figure 3: SEM picture of the fabricated butt-joint. The bright film is the active layer.

Butt-joint loss measurement

In the development of our active-passive integration technology, the quality of the regrown material and the butt-joint loss are first evaluated in passive-passive structures. The passive layerstack is grown and selective areas are etched and regrown following the same process as for active-passive integration. Interface losses are measured from waveguides crossing alternatively first-growth and regrown areas. These give a good indication of the quality of the process. Knowing accurately the losses from first-growth waveguides and regrown waveguides, the butt-joint loss per interface is extracted. All waveguide losses are measured using the Fabry-Pérot technique [3]. Figure 5 shows the structures used for the measurements.

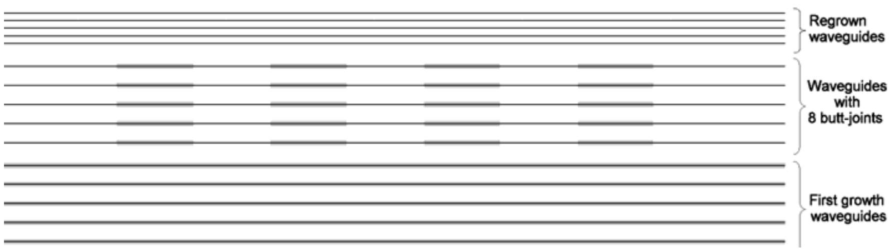

Figure 4 : Structures used from the butt-joint loss measurements.

Measurements have been performed on a chip fabricated using our new active-passive integration scheme. The shallow etched waveguides are 2 µm wide. 20 waveguides of each type have been measured. The average optical losses for first-growth waveguides are 2.64 dB/cm with a variation of ± 0.05 dB. The average optical losses for regrown waveguides are 2.72 dB/cm with a variation of ± 0.2dB. The increase of losses in the regrown waveguides is less than 0.1 dB. 22 waveguides with a total of 60 butt-joints have been measured. The losses per interface are between 0.1 and 0.25 dB with an average value of 0.19 dB and an accuracy of ± 0.02 dB. These results show that butt-joints of high quality are obtained.

Butt-joint reflection measurement

Butt-joint reflections are measured in integrated extended Fabry-Pérot cavities using the method described in [4]. The method is based on the analysis of sub-threshold amplified Spontaneous Emission (ASE) spectrum. The small reflections at the intra-cavity active-passive interfaces modify the mode structure of the laser. By fitting the calculated sub-threshold mode structure to the recorded data, values of the reflectivities are extracted. In the experiments the sub-threshold laser spectra are recorded with a very high resolution of 0.8 pm using the Optical Spectrum Analyzer APEX AP2041A. In that case, the transfer function of the OSA does not need to be taken into account.

Three series of integrated Extended Cavity Lasers (ECL) have been characterized. These lasers consist of a Semiconductor Optical Amplifier (SOA) waveguide connected to two or one passive waveguides terminated by cleaved mirrors. The waveguides are 2µm wide.

We have measured 9 ECLs having two butt-joints and different lengths of amplifier sections. In this series, the waveguide crosses the active region perpendicularly. The average reflection is $5.10^{-5} \pm 0.15.10^{-5}$ (– 43dB). This value is close to the theoretical value simulated with FIMMWAVE (6.10^{-5}) and 6 dB lower than the value we have previously reported in [4].

Furthermore, we have investigated the minimization of the butt-joint reflection by crossing the interface at 6 different angles (from 5 to 15 degrees). Two designs are plotted in figure 5: the laser channel is bent using adiabatic bends to cross twice the active area at 13 or 15 degrees. 24 ECLs with in total 32 butt-joints have been characterized. In figure 6, reflection values are plotted versus the angle of the waveguide to the normal. An upper trend is also indicated. 90% of the measured reflections are below this line with a trend of 0.1dB per degree. The results clearly show that the butt-joint reflection is below – 50 dB for angles higher than 12 degrees. We expect even lower values which, however, are difficult to evaluate due to the limited sensitivity of the measurement below – 53 dB.

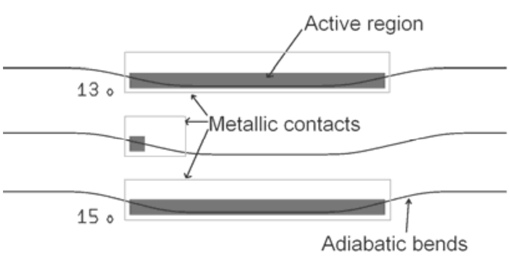

Figure 5: Design of the extended cavities with crossing of the active region under different angles.

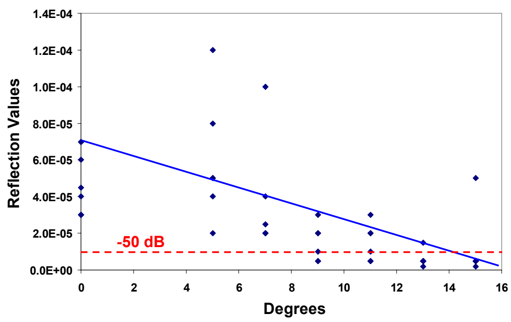

Figure 6: Butt-joint reflection versus the waveguide angle at the active region crossing.

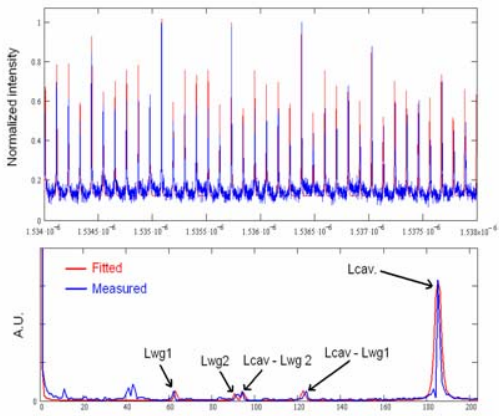

Figure 7: Sub-Threshold optical spectrum and its FT (measured and fitted) for an angle 5° (R = - 43dB).

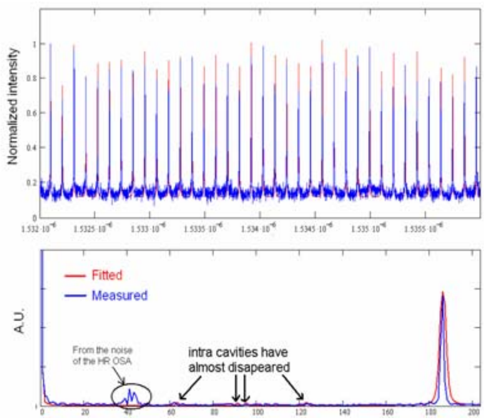

Figure 8: Sub-Threshold optical spectrum and its FT (measured and fitted) for an angle 15° (R = - 53dB).

Figure 7 and 8 depict the ESA spectra and their Fourier Transforms (experimental and fitted) of two ECL with waveguide crossing angles of, respectively, 5 and 15 degrees. For the angle of 5 degrees, the reflection is found to be – 43 dB. The spectrum shows a pronounced modulation which is very clearly reproduced in the Fourier Transform. The response of the HR OSA reveals three small peaks (around 40 in arbitrary unit) which are even present without input signal. They arise from the noise visible in the spectra and do not affect the measurements of the reflections. For the angle of 15 degrees, the reflection is found to be – 53 dB. The modulations in both the emission spectrum and the Fourier transform have almost completely disappeared. This confirms a reflection lower than – 50 dB necessary for good laser performance discussed in [1].

Conclusion

We observed reflection values < – 50 dB at active-passive butt-joint interfaces in extended cavity Fabry-Pérot lasers and 0.19dB loss at passive-passive butt-joint interfaces. Minimization of the butt-joint reflection has been obtained by crossing the interface at different angles. For angles larger than 12 degrees, reflections lower than – 50 dB are obtained which guarantee optimum laser performance.

Acknowledgments

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