Static and dynamic properties of laterally coupled DFB lasers based on InAs/InP QDash structures

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Laterally coupled, complex distributed feedback lasers based on AlInGaAs/InAs/InP quantum dash layers were fabricated by maskless focused ion beam lithography. Continuous-wave powers above 30 mW at room temperature, sidemode suppression ratios of 44 dB and a modulation bandwidth of 7.6 GHz were demonstrated.

Introduction: Low dimensional optical gain material based primarily on GaAs quantum dots (QDs) has been studied extensively over the past few years. The wavelength limit of about 1.3 µm, set by GaAs QDs, required the development of a different kind of nanostructure for fibre optics applications near 1.55 µm, e.g. quantum dashes (QDash) grown on InP [1–6]. The QDash is an elongated nanostructure with quantum wire-like properties [7], which are similar to those of QDs. Singlemode InP QDash lasers, crucial for fibre optics applications, are reported in this Letter. We describe the fabrication of QDash distributed feedback (DFB) lasers in addition to their basic static and dynamic properties. The devices comprise laterally coupled DFB gratings defined by focused ion beam (FIB) lithography. The DFB lasers exhibit room temperature CW output powers above 30 mW, CW operation up to 65°C, a large, 44 dB, sidemode suppression ratio and a modulation bandwidth under pulsed bias conditions of 7.6 GHz.

Fabrication: The active region consists of four InAs QDash layers separated by 25 nm AlInGaAs barriers. The layers were grown by solid source molecular beam epitaxy with the InAs dash layers having a nominal deposition thickness of four monolayers. The active region is embedded on both sides in a 200 nm-thick InGaAlAs GRINSCH layer followed by 200 nm-thick quaternary cladding layers. The upper cladding layer is regrown by metal organic vapour phase epitaxy (MOVPE) and consists of 1700 nm p-doped InP with two InGaAsP etch-stop layers, covered by a highly p-doped 150 nm-thick InGaAs contact layer. All layers, except the quantum dash layers, are lattice matched to InP.

Ridge waveguide (RWG) structures with a width of 3 µm were defined by optical lithography. A Ti/Ni layer was evaporated and selectively removed from the unexposed areas to form the etch mask. A combination of dry- and wet-chemical etching guarantees smooth and vertical ridges. The wet etching stops on the first InGaAsP layer, which defines the ridge depth.

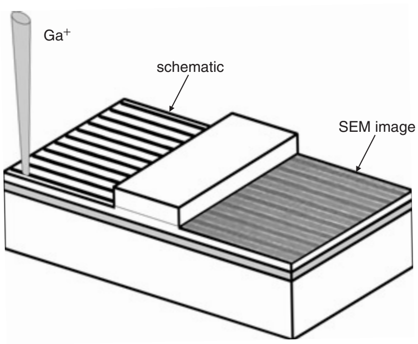

Fig. 1 *Schematic of implantation process and embedded SEM picture of lateral grating with period of 230 nm after etching*

The lateral grating was created by FIB implantation, which causes crystal disordering on the top part of the remaining InP layers. The disordered material is selectively removed using a HF-solution etch. Owing to the strong etching nonlinearity, an index grating is formed [8]. Fig. 1 shows a schematic drawing of the implantation process and a scanning electron microscope picture of the resulting grating. In addition, ions, which penetrate deeply into the active region by channelling, intermix during a rapid thermal annealing step. As a result, a self-aligned complex coupled grating is formed, which allows the fabrication of very stable singlemode lasers [9]. A κ_i of about 10 cm^{-1} can be estimated for the index part of the complex coupling coefficient. The sample was planarised by bisbenzocyclobutene (BCB), which serves as an insulator, before the contact layers were evaporated. The devices were cleaved and one facet was high reflection (HR) coated.

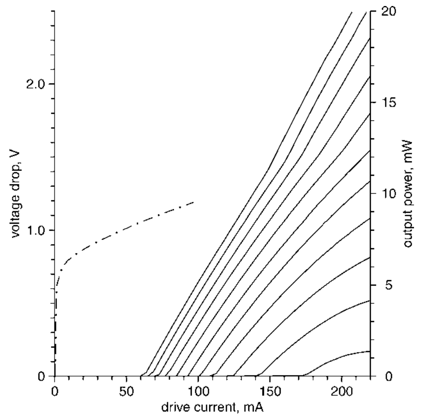

Fig. 2 *P-I-curves of 1 mm-long DFB laser with back facet HR coated at different operation temperatures from 15 to 65°C in steps of 5°C*

Laser operated in continuous-wave mode. V-I curve at room temperature also shown

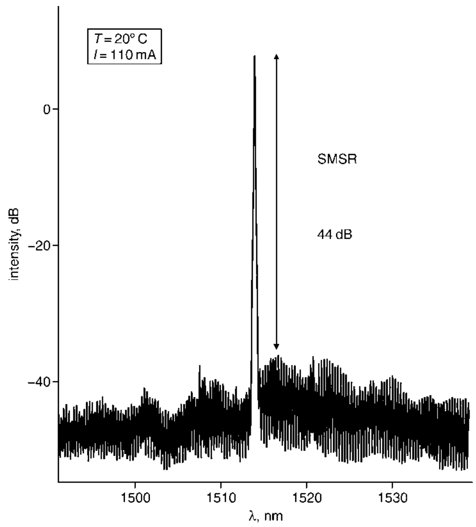

Fig. 3 *Emission spectrum of DFB laser at 20°C with CW drive current of 110 mA*

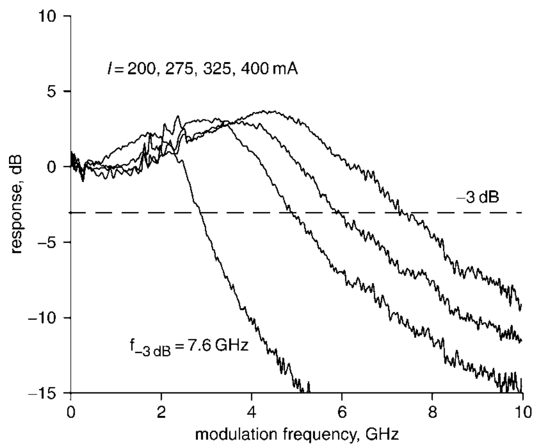

Fig. 4 *Small signal modulation response at four different pulsed (10 µs pulses at duty cycle of 5%) bias levels*

Device characterisation: DFB lasers with different grating periods between 225 and 232 nm, yielding emission wavelengths from 1485 to 1530 nm were fabricated and investigated. The gain maximum of about 25 cm^{-1} of the material we used was around 1500 nm. Fig. 2 shows the P-I-curves of a 1 mm-long DFB laser. The light was detected from the as-cleaved facet, which corresponds to 85% of the total output power. An unmounted laser with a grating period of 230 nm was measured under CW operation at different temperatures from 15 up to 65°C. The room temperature threshold current was 65 mA and the slope efficiency was 0.13 W/A. An output power higher than 30 mW was achieved at 15°C and the laser emitted more than 1 mW at 65°C. While the threshold current increases from 62 mA at 15°C to 100 mA at 45°C, the slope efficiency stayed nearly constant. For pulsed bias, the laser operated up to 100°C while its room temperature output power exceeded 110 mW.

Fig. 3 shows the emission spectrum at a CW bias of 110 mA with a singlemode peak at 1513 nm. The high, 44 dB, SMSR was maintained over the entire regime of operation. The temperature coefficient for wavelength shift was measured to be 0.11 nm/K, consistent with previously reported values for laterally coupled complex DFB and DBR lasers based on quantum dash gain media [6] and on GaInAsP quantum wells [8, 9].

For modulation bandwidth measurements, the lasers were mounted in a high frequency test fixture, which included a 35 Ω matching resistor. A swept frequency microwave signal from a vector network analyser was combined in a broadband bias-T with either a CW or a pulsed (10 µs pulses at a duty cycle of 5%) signal. The laser output was coupled to a 50 GHz detector, which was connected to the input port of the network analyser. S_{11} measurements reveal a return loss of less than −10 dB over the frequency range of interest, 50 MHz to 12 GHz, indicating a reasonably good input match. Fig. 4 shows normalised S_{21} measurements obtained for various levels of pulse bias. The 3 dB bandwidth at the highest bias level we used, 400 mA, is 7.6 GHz. Observation of Fig. 4 reveals that the response is not limited by nonlinear damping and therefore may be wider if higher bias levels were used. Modulation measurements with a CW bias showed narrower bandwidths of ∼4 GHz. The reduction is attributed to the poor thermal properties of the microwave test fixture.

Conclusion: We have reported on the fabrication and performance of laterally coupled DFB lasers based on InP QDash gain media operating in the fibre optics wavelength range near 1.55 µm. We have demonstrated an output power above 30 mW for CW bias at room temperature, CW operation up to 65°C, a 44 dB SMSR and a modulation bandwidth of 7.6 GHz.

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