Laterally Coupled DFB Lasers Based on InAs/InP-QDash Structures for Broadband Applications

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Abstract *Laterally coupled DFB lasers based on quantum dashes were fabricated by FIB lithography. CW-powers above 30 mW, high SMSRs, a modulation bandwidth of 7.6 GHz and singlemode emission from 1.5 to 1.9 µm 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. Single mode InP QDash lasers, crucial for fiber optics applications, are reported in this paper. We describe the fabrication of QDash distributed feedback (DFB) lasers as well as 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, side mode suppression ratio and a modulation bandwidth under pulsed bias conditions of 7.6 GHz. By embedding the QDashes into an InGaAs well layer also extended wavelength DFB lasers at 1.9 µm were realized, suitable for gas sensing application.

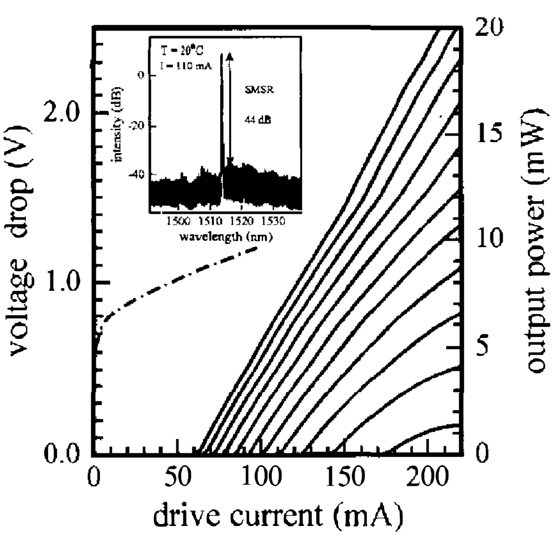

Fig 1: P-I-curves of a 1 mm long DFB-laser with the back facet HR coated at different operation temperatures from 15 to 65 °C in steps of 5 °C. The laser is operated in continuous wave mode. The inset shows the emission spectrum of the DFB laser at 20 °C with a CW drive current of 110 mA.

Layer design and 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 InAs dash layers having a 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 re-grown 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.

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. Due to the strong etching nonlinearity, an index grating is formed [8]. 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 single mode lasers. The sample was planarized 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.

Device characteristics

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 the material, we used, was around 1500 nm. Fig. 1 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. Puls ed operation up to 100 °C with output powers up to 110 mW was obtained. 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. The inset of Fig. 1 shows the emission spectrum at a CW bias of 110 mA with a single mode peak at 1513 nm. The high, 44 dB, SMSR was maintained over the entire regime of operation.

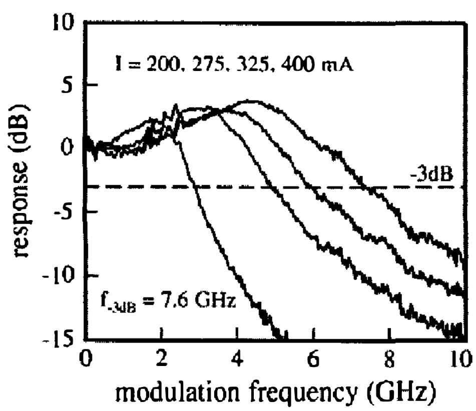

Fig 2: Small signal modulation response at four different pulsed (10 ms pulses at a duty cycle of 5 %) bias levels.

A swept frequency microwave signal from a vector network analyzer was combined in a broad band bias-T with either a CW or a pulsed (10 ms pulses at a duty cycle of 5 %). Fig. 2 shows normalized 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. 2 reveals that the response is not limited by nonlinear damping and therefore may be wider if higher bias levels would be used.

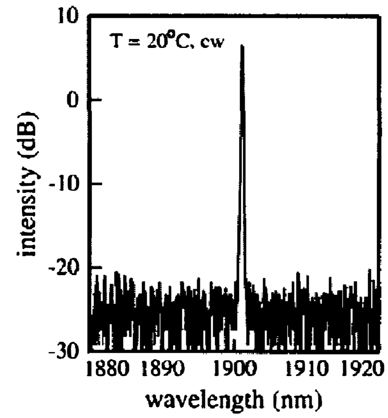

Fig 3: Emission spectrum of DFB laser at 1.9 µm. The SMSR is limited by the measurement setup.

Using thicker dashes [3] or the Dash in Well principle the emission wavelength of the laser basis structure could be shifted to longer wavelengths. 1 mm long broad area devices with uncoated facets show threshold current densities below 1 kA/cm^2 and slope efficiencies about 0.11 W/A per facet. Again utilizing the lateral grating technique DFB lasers emitting at 1.9 µm (cf. Fig. 3) were fabricated. A threshold current of 79 mA and an output power of more than 2 mW per facet at room temperature were achieved in cw operation mode.

Conclusions

We have reported on the fabrication and performance of laterally coupled DFB lasers based on InP QDash gain media operating from 1.5 to 1.9 µm. This includes the entire fibre optic wavelength range for broadband application and extended wavelengths for gas sensing. We have demonstrated for 1.5 µm lasers 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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