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CBE Grown (GaIn)(AsP) Laser Diodes for Monolithic Integration

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Selective in-filling growth by chemical beam epitaxy (CBE) is ideally suited for the monolithic integration of InP-based laser diodes and photonic devices. We have embedded (GaIn)(AsP) laser diodes in InP and integrated quaternary SCH MQW laser diodes and waveguides by butt joining.

Rectangular grooves of 1.4µm depth oriented in [011]-direction were etched into InP substrates, either by wet chemical etching, ECR/RIE and by a combination of both, using SiN etch masks of 100 nm thickness. Wet chemical etching with $HCl:H_3PO_4$ yielded perfectly rectangular profiles, while an etch stop consisting of 50nm GaInAsP ($\lambda = 1.1\mu m$) ensured homogeneous etch depths across a full 2" wafer. ECR/RIE with CH_4, H_2 and N_2 gave nearly rectangular groove profiles.

For selective epitaxial growth TMI, TEG, AsH_3 and PH_3 were used as precursors with elemental Be and Si for p- and n-type doping respectively. Our SCH MQW layer structure is shown in Fig. 1. The growth was carried out on off-oriented (100)-substrates (nominally 2° towards next (011), sample A) as well as on exactly oriented (100)-substrates (sample B). Reducing the growth rate from usual 1.3µm/h to 0.4µm/h at high V/III ratios enforces planar growth of the InP buffer layer in the groove. The quaternary layers were then grown on the 700nm thick Si-doped InP buffer layer. The cross-section of selectively in-filled lasers - 4µm wide in this example - is shown in Fig. 2. The active layer of the laser structure of type A (off-oriented) is almost flat with a (111B)-facet at the left edge only, the width of this region is approximately 0.5µm. The off-orientation leads to a tilt of approximately 1.5° with respect to the substrate surface. In broad grooves we found off-oriented (100) surfaces on top. Symmetric in-filled structures (B) were found on exactly oriented substrates with (111B)-facets at both edges. All interfaces and the top surface were exactly (100) oriented.

Room temperature CL measurements were used to spatially probe the optical properties of the laser structure (see Fig. 3). Identically grown layers on unstructured off- and exactly oriented substrates are red shifted by 30meV. Structures of type A show a shift in CL-Peak positions with changing groove width, a red shift of 5meV is observed in going from 50µm to 3µm. In contrary structures of type B show a blue shift of 3meV.

4 µm wide in-filled laser diodes with quaternary quantum wells show threshold currents as low as 16mA in CW-operation comparable to lasers from planarly grown layers, while in-filled lasers with ternary quantum wells show threshold currents of 24mA (see Fig. 4).

Furthermore we butt joined laser structures and waveguides. A typical butt joint oriented in [011]-direction is shown in Fig. 5; only small distortions of about 1µm are observed. Incorporating those butt joints in ridge wave guides we could fabricate two-segment Fabry Perot resonators combining a pumped active laser with an unpumped waveguide. This only partially pumped laser diodes show remarkably low threshold currents. As an example Fig. 6 depicts the light-current characteristics of a 7µm wide Fabry-Perot ridge butt joining a 480µm long laser section and a 415µm long unpumped waveguide section; under CW-operation the threshold current is about 50mA.

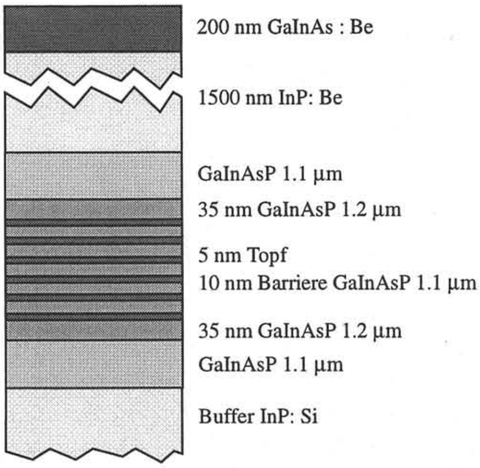

Fig. 1: Layer sequence of SCH MQW laser with 6 QW

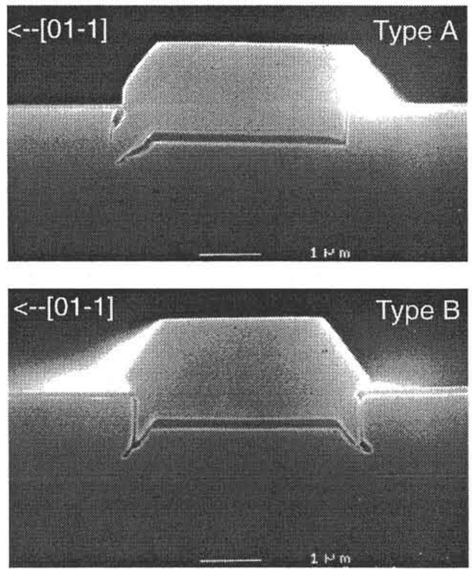

Fig. 2: Selectively in-filled laser diodes
Type A: off-oriented (100)-substrate
Type B: exact (100)-substrate

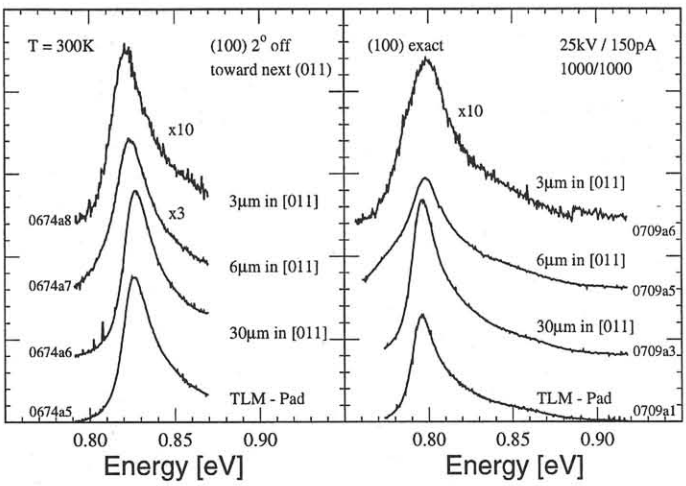

Fig. 3: CL-spectra of lasers oriented in [011]. The width of mesas is varied between 3µm and 50µm

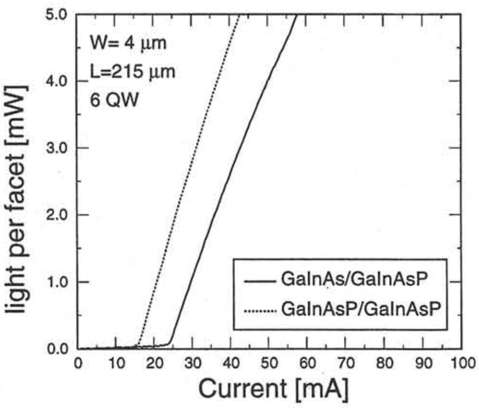

Fig. 4: Light current diagram of 2 different selective infilled laser diodes

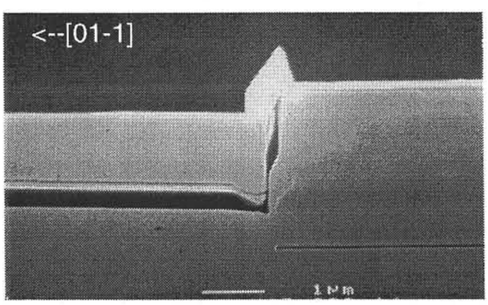

Fig. 5: Crossection of a butt joined laser structure (left) and waveguide (right).

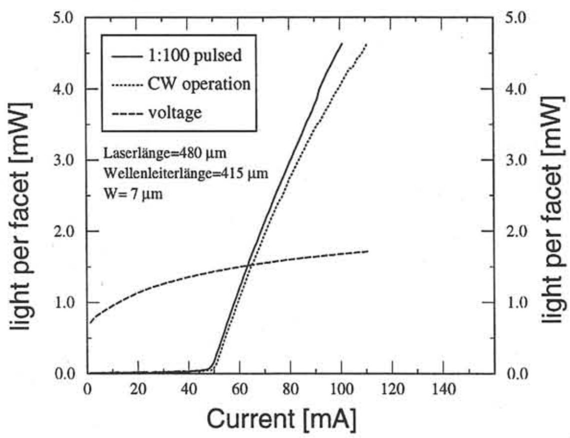

Fig. 6: Light current diagram of a butt joined laser structure and waveguide