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Single-growth-step GaAs/AlGaAs distributed Bragg reflector lasers with holographically-defined recessed gratings

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Indexing terms: Distributed Bragg reflector lasers, Holographic gratings

A ridge waveguide GaAs/AlGaAs quantum well DBR laser fabricated with a simplified grating recess-technology and a third order grating is described. The reflector is fabricated on top of a recessed waveguide using holographic exposure followed by reactive ion etching. The laser operates on a single longitudinal and lateral mode with threshold current as low as 20mA, output power 5mW per facet and is intended for monolithically integrated interferometer applications.

Introduction: Distributed Bragg reflector (DBR) lasers are attractive light sources due to their narrow linewidth, good frequency stability and large sidemode suppression [1]. In addition, they are suitable for monolithically integrated optical circuits, because at least one cleaved facet can be replaced by a waveguide grating. Fabrication of DBR lasers is typically rather involved: where electron-beam direct write is used for grating definition, throughput is limited by the serial nature of this process [2, 3]; if regrowth after grating etch is required, for the formation of an upper cladding or for contact purposes, demands on material growth are significant [3, 4]; finally, for non-regrown waveguides with a thick upper cladding, a deep grating etch is needed in order to achieve sufficient coupling. Recently, single growth step DBR lasers with an e-beam defined grating requiring a deep (1µm) grating etch were reported [2].

We present in this Letter a single-growth-step DBR laser with a holographically defined grating fabricated in a recess etched into the upper cladding of the waveguide. This grating recess combines the advantages of a high coupling coefficient κ, resulting from the small buffer layer between waveguide core and grating, with a simplified grating etch process due to the small required etch depth. This relatively simple DBR laser fabrication procedure is fully compatible with a previously developed integrated optical interferometer process [5], making use of only two additional photolithography steps (dielectric patterning) and one additional etch step (grating etch).

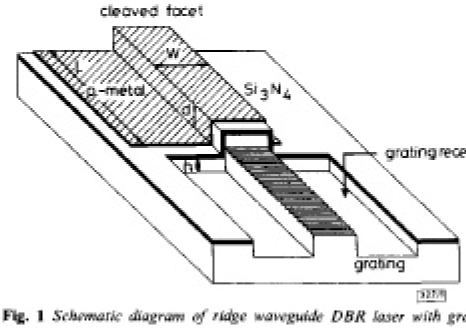

Fig. 1 *Schematic diagram of ridge waveguide DBR laser with grating recess*

Device fabrication: The laser layer structure was grown by MOCVD on an n-type, Si-doped (10^{18}cm^{-3}) GaAs wafer and consisted of an 1100nm n-doped (1.5×10^{18}cm^{-3} Si) $Al_{0.8}Ga_{0.2}As$ lower cladding, an undoped 180nm thick $Al_{0.3}Ga_{0.7}As$ waveguide core with one 8nm GaAs quantum well, a 780nm p-doped (10^{18}cm^{-3} Be) $Al_{0.8}Ga_{0.2}As$ upper cladding and a highly p-doped (8×10^{19}cm^{-3} Zn) 160nm GaAs cap layer. Magnetic field enhanced reactive ion etching (MERIE) in an $SiCl_4$ plasma was used to dry etch a ridge waveguide to a depth of d = 800nm (see Fig. 1). A 300nm layer of plasma-enhanced chemical vapour deposited (PECVD) Si_3N_4 for electrical isolation of the surface allowed us to selectively contact the top of the ridge and also served as an etch mask for the subsequent grating recess etch. Nitride was removed from the contact hole and recess opening by dry etching using a CF_4 plasma.

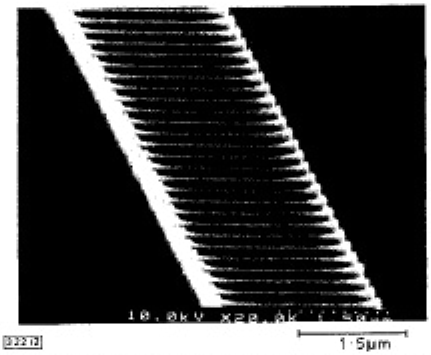

Fig. 2 *SEM photograph of portion of DBR (Λ = 385nm) on top of a 3µm waveguide*

Following p-metal evaporation (Ti/Pt/Au), the grating recess was etched into the upper cladding of the reflector section to a depth of h = 800nm by $SiCl_4$ MERIE, stopping 140nm above the $Al_{0.3}Ga_{0.7}As$ waveguide core. The device was then coated with a thin photoresist layer, leaving a thickness of 300nm on top of the recessed waveguide. Holographic exposure using an HeCd laser at 441.6nm, subsequent development and a soft-bake for resist sidewall smoothness improvement [6] yielded a suitable dry etch mask for the grating etch by MERIE. The rectangular third order grating with a unity line:space ratio was 140nm deep and had a period of 385nm (see Fig. 2). Wafer thinning to 200µm, n-metal contact (Ge/Au/Ni/Au) evaporation and cleaving to 1500µm length completed the process.

DBR lasers with mask ridge widths W = 3 and 5µm and with L = 480, 730 and 880µm long gain sections were fabricated. The unpumped Bragg reflector lengths were 1000, 500 and 200µm. For measurement comparisons, 1500µm long Fabry-Pérot lasers were also made on the same chip.

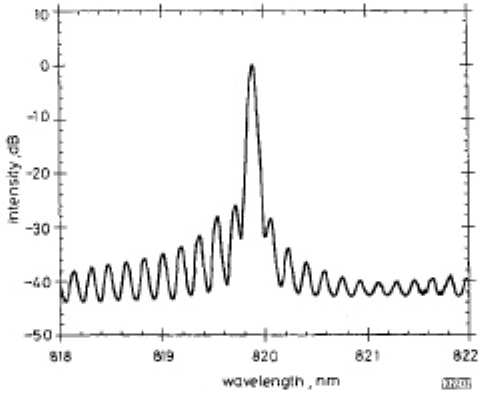

Fig. 3 *Optical spectrum of DBR laser at 2.3 I_{th}*

Results: Typical threshold currents of these simplified DBR lasers were I_{th} = 20mA, yielding J_{th} = 600A/cm² at an emission wavelength of 820nm; slope efficiency was 0.166W/A for emission from the cleaved facet. We compare this with Fabry-Pérot lasers which had I_{th} = 15mA, J_{th} = 450A/cm² at 833nm and an efficiency of

0.205W/A. A typical emission spectrum, measured with a high resolution grating spectrometer (0.64 m focal distance, 600 line per mm grating, 0.05nm resolution), at $I = 2.3\ I_{th}$ for the DBR lasers, driven CW at 300K, is shown in Fig. 3. The sidemode suppression ratio (SMSR) was 27dB and the main peak had a linewidth < 15MHz; measurement of the latter was equipment limited (scaning Fabry-Pérot Etalon, free spectral range = 2GHz, finesse = 150). The DBR devices had a temperature tuning coefficient of 0.7Å/K and operated in the same fundamental mode over a temperature range of more than 20K. The Fabry-Pérot lasers, on the other hand, had a temperature tuning coefficient of 2.5Å/K with mode hops every 3 to 5K.

The value of the SMSR is given by the coupling coefficient, $\kappa = 346\text{cm}^{-1}$, and the longitudinal mode spacing of 0.1732nm. We determined κ experimentally from the FWHM of the grating filter curve which could be determined approximately by measuring the laser spectrum at $0.96\ I_{th}$ [7]. Numerical modelling for this grating structure gave $\kappa = 392\text{cm}^{-1}$, calculated for a zero buffer layer thickness. This buffer layer is the remaining cladding layer between the top of the core and the bottom of the grating, and has been shown by simulation to strongly affect κ. Because this thickness is accurately controlled by the grating recess etch, we have a sensitive method for customising κ in this process.

The process compatibility with integrated optical sensor circuits permits this laser to act as a light source for interferometer circuits. The reduced demands on dry etching allow sensitive control of κ through variation of the recess etch depth thereby permitting easy optimisation of light intensity coupled into a following waveguide circuit.

Conclusions: Single growth step quantum well DBR lasers with a recessed grating mirror have been described. The third order grating, fabricated by holographic exposure and dry etching, appeared only on top of the recessed waveguide. A threshold current of 20mA, and a sidemode suppression ratio of 27dB were achieved when operated monomode at 820nm. The grating recess process allows easy customisation of κ, important for subsequent integration with optical integrated circuits.

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References

1 KOJIMA, K., and KYUMA, K.: 'Multi-quantum well distributed feedback and distributed Bragg reflector lasers', *Semicond. Sci. Technol.*, 1990, **5**, pp. 481–493

2 MAJOR, J.S., O'BRIEN, S., GULGAZOV, V., WELCH, D.F., and LANG, R.J.: 'High-power singlemode AlGaAs distributed Bragg reflector laser diodes operating at 8.56nm', *Electron. Lett.*, 1994, **30**, pp. 496–497

3 STOLTZ, B., DASLER, M., and SAHLEN, O.: 'Low threshold-current, wide tuning-range, butt-joint DBR laser grown with four MOVPE steps', *Electron. Lett.*, 1993, **29**, pp. 700–702

4 SMITH, G.M., HUGHES, J.S., OSOWSKI, M.L., FORBES, D.V., and COLEMAN, J.J.: 'Ridge waveguide distributed Bragg reflector InGaAs/GaAs quantum well lasers', *Electron. Lett.*, 1994, **30**, pp. 651–653

5 ZAPPE, H.P., ARNOT, H.E.G., and KUNZ, R.E.: 'Technology and devices for hybrid and monolithic integrated optical sensors', *Sensors and Actuators A*, 1994, **41**, pp. 141–144

6 ARNOT, H.E.G., ZAPPE, H.P., EPLER, J.E., GRAF, B., WIDMER, R., and LEHMAN, H.W.: 'Extremely short sidewalls for GaAs/AlGaAs ridge waveguides', *Electron. Lett.*, 1993, **29**, pp. 1131–1133

7 KOCH, T.L., and KOREN, U.: 'Semiconductor lasers for coherent optical fiber communications', *J. Lightwave Technol.*, 1990, **LT-8**, pp. 274–293