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Design and Fabrication of InGaAs Quantum Well Circular-Grating-Coupled Surface Emitting Laser

Osaka Univ., Ashim Kumar Saha, Takashi Sumitani, °Masahiro Uemukai, Toshiaki Suhara

E-mail: ashim@ioe.eei.eng.osaka-u.ac.jp

Circular-grating-coupled surface emitting lasers (CGCSEL)[1] consisting of a DBR and a grating coupler (GC) can emit light in the nearly vertical direction of the laser plane. They have many potential advantages such as beam shaping function and possibility of 2-D array formation. In the previous work [1], DBR and GC were fabricated by repeating EB writing of many small segments and therefore the device involved the problems of wavefront distortions caused by the stitching errors. In this work, we designed and fabricated InGaAs-based CGCSELs using surface gratings of circular DBR and GC written by electron beam with circular scanning mode for avoiding stitching error problem.

Schematic diagram of the CGCSEL fabricated using an InGaAs/GaAs single quantum well GRIN-SCH epitaxial wafer is shown in Fig. 1. When current is injected into the central active region, lasing occurs in the circular resonator formed by the DBR grating around the active region. Light transmitted through the DBR is radiated into air by the GC. A chirped GC for focusing the laser output at 3 mm above the laser was designed.

Rate equations were derived using scalar wave model for diverging and converging waves travelling inside the circular resonator. By solving rate equations for an active region diameter of 200 μm and 30% DBR reflectivity, threshold current of ~105 mA and output power of 22 mW at an injection current of 200 mA are expected. To obtain 30% reflectivity and higher transmissivity, vertical position and groove depth of the DBR grating should be optimized. Based on the coupled mode theory, we calculated the dependence of third-order coupling coefficient κ and first-order radiation loss coefficient α_{sub} of the third-order DBR on the grating groove depth. Fig. 2 shows that at 150 nm groove depth, α_{sub} is minimum and κ =110 cm^{-1}. Assuming a propagation loss of 50 cm^{-1} in the DBR region, the reflectivity and transmissivity of the DBR with 70 μm interaction length were calculated as 31% and 42%, respectively. For first-order GC, radiation loss coefficients into air α_a and into substrate α_s were calculated as a function of groove depth. Fig. 3 shows that the power distribution ratio $\alpha_a/(\alpha_a+\alpha_s)$ becomes maximum at a groove depth of 150 nm. The diffraction efficiency into air η_{air} of an 80 μm long GC was estimated as 35%.

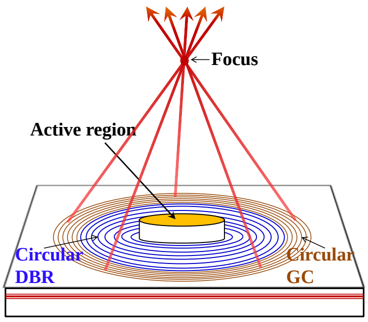

Fig. 1 Schematic diagram of CGCSEL.

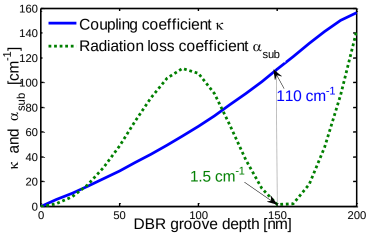

Fig. 2 κ *and* α_s vs. groove depth of DBR.

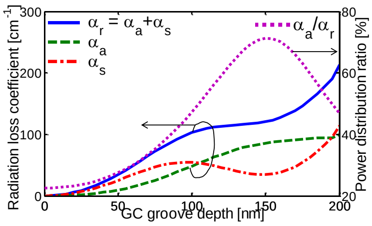

Fig. 3 Radiation loss coefficients and power distribution ratio vs. groove depth of GC.

The contact and upper cladding layers outside the active disk region were removed by EB lithography and reactive ion etching (RIE) process. To fabricate the circular DBR and GC, at first a 15 nm thick SiO_2 intermediate layer was deposited over the entire sample. EB resist layer of 80 nm thickness was deposited on the sample. Then the circular DBR and GC gratings were written using EB writing with circular scanning mode. After development, the DBR and GC patterns were transferred through the intermediate layer into the semiconductor epitaxial layer using two-step RIE. SEM images of the fabricated DBR and GC are shown in Fig. 4. Cr/Au top electrode was deposited. After reducing the thickness of the substrate, AuGe/Au bottom electrode was deposited.

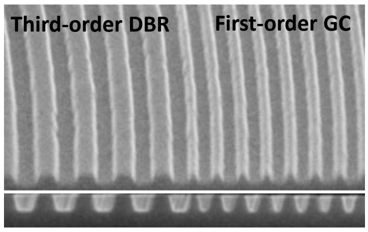

Fig. 4 SEM images of top view and cross sectional view of circular DBR and GC.

We tested the I-V characteristics of the device and good ohmic contact formation was confirmed. Evaluation of the laser performance is being continued.

[1] S. Kristjansson, M. Li, N. Eriksson, M. Hagberg, K.-J. Killius, and A. Larsson, *IEEE Photon. Technol. Lett.*, vol. 9, pp. 416–418, 1997.