Grating Coupler Integrated Semiconductor Laser Diodes

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Abstract: The work of the author's group will be reviewed on implementation of various integrated photonic devices by monolithic integration of quantum-well DFB/DBR lasers and grating couplers for optical wavefront conversion within the waveguide and/or at the waveguide-free space interface. The devices include integrated photonic sensors, master-oscillator power-amplifier and broad-area lasers with outcouplers, and lasers with couplers for beam shaping.

Introduction: Grating components in an optical waveguide offer various passive functions based upon phase matching and the principle of holography.[1] Variety of integrated photonic devices can be implemented by monolithic integration of quantum-well (QW) DFB/DBR lasers and grating components for optical wavefront conversion within the waveguide and/or at the waveguide-free space interface. The grating components are designed by specifying the patterns required for coupling / wavefront conversion functions, and optimizing the cross-sectional structure parameters to maximize the coupling efficiency, reduce the radiation losses and simplify the fabrication process. In this presentation, the work of the author's group will be reviewed.

Monolithic Integrated Photonic Sensor Devices: Figure 1 shows an integrated photonic interferometer displacement/ position sensor,[2] constructed with a GaAs/AlGaAs SQW DFB laser, photodiodes and grating components in a passive waveguide where the QW is disordered to reduce the propagation loss. The guided wave is outcoupled by a collimator (curved-line) grating coupler to form a sensing beam, and the beam reflected by a moving mirror is back coupled and focused into the PDs by a grating beam splitter. The forward wave is partly reflected and focused by a DBR into the PDs to give reference waves which interfere with the signal wave. The mirror displacement can be measured by monitoring the periodic photocurrent variation. The device was fabricated by MOVPE growth, selective QW disordering, and grating fabrication by EB writing and RIE. The sensor operation of 0.43μm interference period was demonstrated. An integrated photonic disk pickup head with the similar device configuration was also studied.[3]

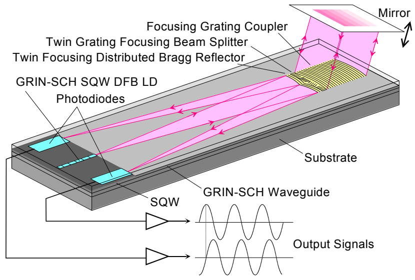

Fig.1: IP displacement sensor.

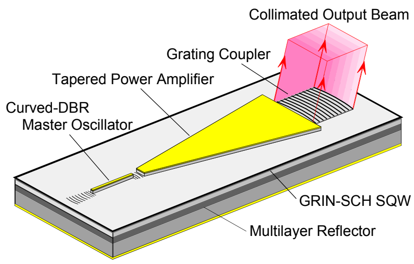

Fig.2: MOPA with grating coupler.

MOPA and Broad-Area Lasers: High-power laser diodes of narrow spectral width integrated with a coupler for output beam collimation or focusing can find many applications as a pump source for nonlinear-optic devices and fiber amplifiers. Figure 2 shows an integrated master oscillator power amplifier (MOPA) with grating outcoupler.[4] The device consists of a DBR oscillator and tapered power amplifier using an InGaAs/AlGaAs QW, and a collimator grating coupler, which eliminates the need of external lens. A curved DBR and a grating coupler of surface groove type are adopted, so that the device can be fabricated without regrowth. The wavefront distortion caused in the amplifier can be compensated for by the appropriate coupler design. Stable single-mode output of power up to CW 183mW (390mW PA output) at 985nm was obtained under 3.0A PA injection. Figure 3 shows a lensless tunable extended-cavity laser using integrated tapered amplifier / grating coupler.[4] Related work includes

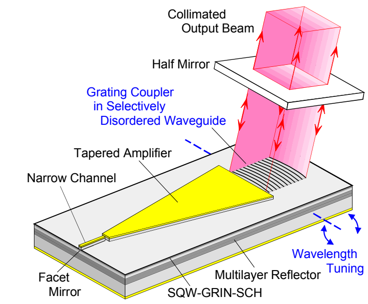

Fig.3: External-cavity tunable laser.

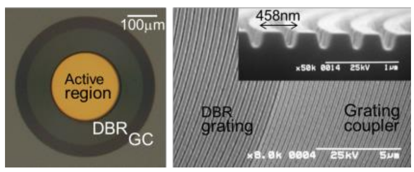

Fig.4: Circular DBR laser.

angled-grating broad-area DBR lasers with grating collimator outcoupler.[5] An unique laser is circular-grating-coupled surface-emitting circular-DBR lasers with focusing function as shown in Fig.4.[6]

Lasers Integrated with Grating Coupler for Beam Shaping: Laser diodes emitting beams focusing into two-dimensional multiple spots are potentially attractive for many applications, such as laser displays, printers, sensing,[7,8] and pumping of multicore fiber amplifiers. By appropriate modification of the focusing grating coupler (FGC) pattern, various beam-shaping functions can be incorporated. Multispot focusing by computer-generated waveguide hologram couplers[9] and integration in semiconductor lasers[10] were reported. A GaInP QW DBR laser with a periodic binary phase-shifted multispot focusing grating coupler was developed as a pump source for bio-fluorescence sensing using a micro fluidic circuit and micro-beads specimen array, and 3×3 square multispot formation of 400μm separation and 0.3mW power at 80mA injection was demonstrated as shown in Fig.5.[11] An integrated laser for producing 6×6 multispot output consisting of four sets of the DBR laser / coupler was demonstrated as shown in Fig.6. A method of designing n×n spot array output couplers by iterative optimization of a continuous phase shift modulating the FGC pattern was developed, and an integrated laser consisting of a GaInP QW DBR laser oscillator, a power amplifier and a coupler for 7×7 spot array designed by the iterative method as shown in Fig.7 was fabricated. Rotation-symmetric multispot focusing with equal spot intensities by grating couplers with periodic binary phase modulation was also demonstrated as shown in Fig.8.[12] By mixing two laser beams with slightly different wavelengths in a GaAs photoconductive photomixer, coherent THz waves at the beat frequency can be generated.[13] Another application of the phase-shifted FGC under study is integration with two DBR lasers for outcoupling and wavefront superposition toward implementation of a compact THz wave generation system.

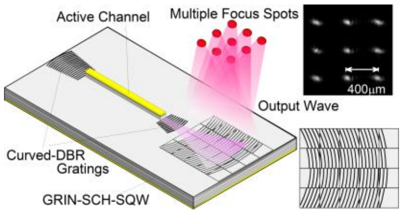

Fig. 5: DBR laser integrated with multispot focusing grating coupler.

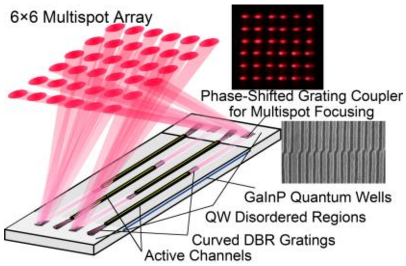

Fig. 6: Integrated multispot lasers.

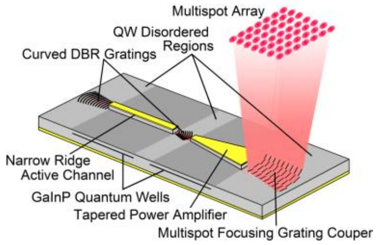

Fig. 7: Multispot MOPA laser.

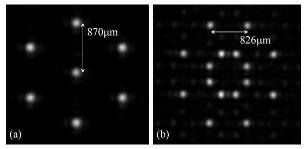

Fig. 8: Rotation-symmetric multi-spot focusing.

Area-Selective QW Disordering: A crucial requirement for the monolithic integration is reduction of passive waveguide losses. An attractive method is area-selective QW disordering. In the previous work, QW disordering by Si ion implantation and impurity-free vacancy diffusion using silica cap layer were employed. Recently, encouraging result has been obtained in disordering by F ion implantation in GaAsP QW.

Nanoimprinting Fabrication of Grating: Although the EB direct writing technique is a versatile and flexible method for accurate fabrication of gratings, the productivity is rather low. Our recent work includes cost-effective grating fabrication by room-temperature nanoimprinting technique using silica master molds fabricated by EB writing, organic Si polymer imprinting layer and RIE.

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