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Hybrid Si/III-V vertical-cavity laser for silicon photonics

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Recently, silicon-based photonic devices that can be monolithically integrated with Si-based electronics, so called Si photonics devices, have attracted much attention, since optical interconnects using these Si photonics devices has potential to solve most of limitations that short-distance electric interconnects for computers are facing. Among various Si photonics building block devices, a laser source with ultralow energy consumption still remains as one of technological challenges. For chip-level optical interconnects, the energy consumption per sending a bit signal is required to be squeezed down by factors of 100 to 1000 smaller than the existing technologies can provide.[1] In addition, this laser source is preferably required to operate at typical processor temperatures of 70 to 80 ^{o}C, to have a small foot print, to emit light into a planar Si photonic circuit, and to be single-moded for wavelength division multiplexing (WDM).[2]

Here, we suggest a novel hybrid III-V/Si laser structure based on a vertical cavity resonance that emits light to an in-plane waveguide. So far, a hybrid laser structure employing a vertical laser cavity has not been reported although the vertical cavity approach is advantageous for low energy consumption and high speed direct modulation. This may be attributed to the fact that the achievement of in-plane light emission from a vertical laser cavity is not straightforward. In the suggested structure, in-plane emission is realized by employing a recently-reported high-index-contrast grating (HCG) as a reflector as well as a router. The HCG is a one- or two-dimensional photonic crystal slab surrounded by a low refractive index material.[3,4] When light is incident to a HCG, all higher order diffractions except for the 0th order diffraction, occur along the HCG slab and excite in-plane photonic-bandgap (PBG) modes of the HCG. These excited PBG modes are easily scattered back to the free space mode, interfere with the 0th order transmission, and result in a very low vertical transmittance, i.e., a very high vertical reflectivity. When an in-plane output waveguide is placed into the HCG region, the light laterally propagating in the in-plane PBG modes can be feasibly converted into a waveguide mode of the inserted in-plane waveguide, as light output.

As shown in Fig. 1a, the suggested laser structure consists of a distributed Bragg reflector (DBR), a III-V active region, and a HCG that is connected to an in-plane output waveguide. Both the HCG and the in-plane waveguide are made in the Si layer of a silicon-on-insulator (SOI) substrate. This HCG reflects most of the vertically-incident light, e.g., 99.5 %, as well as routing a small fraction of the vertically-incident light, e.g., 0.17 % to the in-plane output waveguide. The mode profile of this laser structure, shown in Fig. 1b, clearly shows that a strong vertical resonance occurs between the DBR and the HCG simultaneously with the routing of light laterally to the in-plane output waveguide. This waveguide is placed into the right of the HCG, cf. Fig. 1a, overlapping with the tail of the optical mode and ensuring routing only to the right.

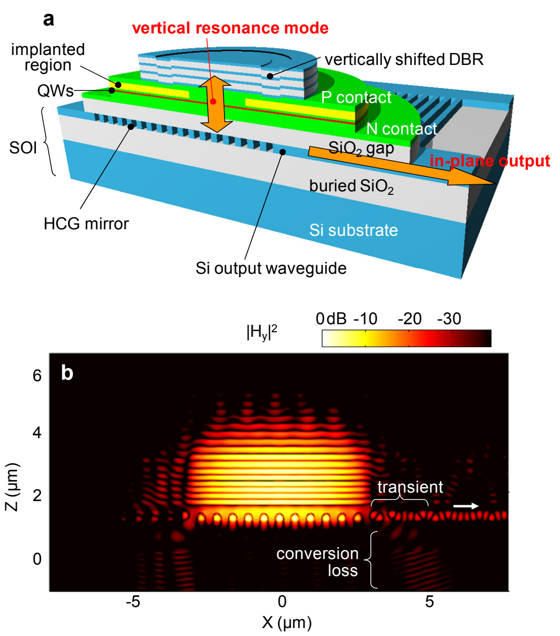

Fig. 1 – a. Schematic profile of the vertical-cavity in-plane-emitting laser structure. b. Normalized mode profile $|H_y|^2$ of the fundamental mode.

The considered laser structure has a 3λ-long active region including five 6.6-nm-thick InAlGaAs quantum wells (QWs) which is almost identical to that of 1310-nm-wavelength vertical-cavity surface-emitting lasers.[5,6] This active region with a 186-nm-thick SiO_2 gap layer deposited, is wafer-boned to the prepatterned SOI wafer. Then, the 5.5 pair dielectric DBR is deposited. For optical simulations, the finite-difference time-domain method is used to obtain the lasing wavelength, threshold gain, mode profile, and various losses.[6,7] The experimental results of reference VCSEL[5,6] are used to calibrated the power-current (L-I) curves.

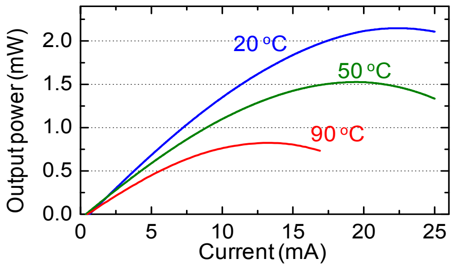

Fig. 2 – L-I curves at different temperatures.

The out-coupling efficiency defined as the ratio of the in-plane output power and the sum of all losses including mirror, scattering, and absorption losses, is 18.5 % for the specific design considered here. The mode conversion from the HCG mode to the waveguide mode occurs in the transient region, shown in Fig. 1b, and accompanies the scattering underneath the HCG, due to mode mismatching. The amount of this conversion loss is 23.3 % of the total loss and is expected to be considerably reduced by optimizing the topology of the transient region.[8] With a 3-dB reduction in the conversion loss, the out-coupling efficiency will exceed 30 %.

Output power (L) vs. current (I) graphs at different temperatures are presented in Fig. 2. The submilliampere threshold currents result from the small active region volume and high QW confinement factor. The high temperature operation is attributed to the high-temperature QW design and a low thermal resistance of 0.79 K/mW. About 1 mW single mode output at 70 to 80 °C is predicted with an electrical power input of about 18 mW (=10 mA × 1.8 V).

More detailed discussions can be found in Ref. 9.

Acknowledgements

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