DBR-free semiconductor disc laser on SiC heatspreader emitting 10.1 W at 1007 nm

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DBR-free semiconductor disc laser on SiC heatspreader emitting 10.1 W at 1007 nm

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We report a distributed Bragg reflector-free semiconductor disc laser which emits 10 W continuous wave output power at a wavelength of 1007 nm when pumped with 40 W at 808 nm, focused into a 230 µm diameter spot on the gain chip. By introducing a birefringent filter plate in the laser cavity the wavelength could be tuned from 995 to 1020 nm. The laser consisted of a gain chip located at the beam waist of a linear concentric resonator with an output coupling of 2.15%. The gain chip consists of a 1.574-µm-thick resonant periodic gain structure, with ten $In_{0.13}Ga_{0.87}As$ quantum wells embedded in strain-compensating $GaAs_{0.94}P_{0.06}$ barrier layers, van der Waals bonded to a silicon carbide intra-cavity heat spreader.

Introduction: Semiconductor disc laser (SDLs), also called vertical external cavity surface emitting lasers [1, 2], are a flexible semiconductor laser technology which provides high beam quality and high power at a range of wavelengths [3–5]. The use of optical pumping allows optimised design of the semiconductor multi-layer stack for optical properties and the external cavity allows the use of intra-cavity elements such as birefringent filters, frequency doubling crystals and semiconductor saturable absorber mirrors [6]. However, the distributed Bragg reflector (DBR) in SDLs adds significantly to the growth time and complexity and limits the thermal performance. In contrast, recently introduced DBR-free SDL technology [7–9] offers a potential solution to these limitations. DBR-free SDLs on diamond, emitting 6 W continuous wave (CW) output power at 1055 nm have been demonstrated in [8]. Here, we report a DBR-free SDL emitting 10.1 W continuous wave output power at 1007 nm with an incident pump power of 40 W using a silicon carbide (SiC) intra-cavity heat spreader. We demonstrate wavelength tuning, reaching a maximum power of 0.7 W between 995 and 1020 nm by introducing birefringent filter into the cavity.

Gain medium structure and processing: The semiconductor gain structure was fabricated by metal-organic-vapour-phase-epitaxy in a 3 × 2′ close coupled showerhead reactor on a GaAs substrate. The growth started with a 200 nm AlAs etch stop sacrificial layer deposited before the gain structure was grown. The gain structure consists of ten $In_{0.13}Ga_{0.87}As$ quantum wells (QWs) immediately surrounded by strain-compensating $GaAs_{0.94}P_{0.06}$ layers. To form a resonant periodic gain structure, GaAs spacer layers are placed between each QW so that they align with subsequent antinodes of electric field standing wave. $Ga_{0.5}In_{0.5}P$ cladding layers were deposited to prevent oxidation and provide a selective etch stop allowing removal of the AlAs sacrificial layer. A detailed schematic representation of the gain structure is shown in Fig. 1.

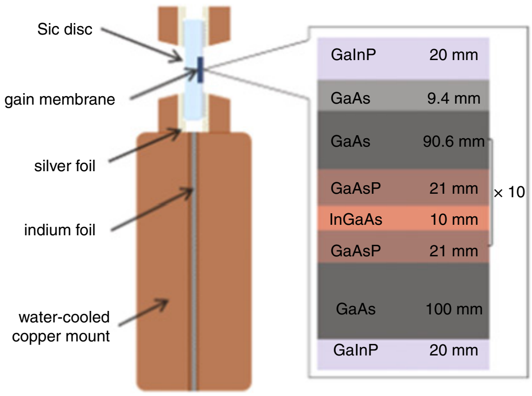

Fig. 1 *Schematic representation of semiconductor gain membrane on SiC heat spreader mounted in water-cooled assembly (left). Detailed schematic representation of gain structure is also shown (right)*

The semiconductor membrane was produced by selective etching to remove the GaAs substrate. A piece of the as-grown wafer was stuck onto a silicon wafer holder using crystal bond and an ammonium hydroxide (NH_4OH) and hydrogen peroxide (H_2O_2) etch was used in two steps: first, the sample was placed in NH_4OH:H_2O_2 solution with relative concentration of 1:2 and etched for 70 min followed by a second slower etch step lasting 10 min at a relative concentration of 1:20. Both etching steps were performed at room temperature. The processed gain membrane has a total thickness of ∼1574 nm and appears uniformly flat when viewed by high-resolution scanning electron microscope at a magnification of 400. The gain membrane was released from the silicon mount and broken into several pieces in acetone. A gain membrane with a size of ∼800 × 700 µm was transferred from the liquid to an 8 mm diameter, 300-µm-thick SiC heat spreader, where van der Waals bonding occurred. The SiC heat spreader was then mounted on a water-cooled assembly as shown in Fig. 1. Silver foil was used between the SiC and copper mount jaws to improve contact for better heat removal.

Laser performance: The gain membrane was pumped using a fibre-coupled diode laser at a wavelength of 808 nm at an angle of incidence of 20° to the normal of the membrane surface. A ∼150 mm length linear concentric resonator consisting of two mirrors with radius of curvature 50 and 100 mm was built around the gain membrane. The pump spot diameter on the membrane surface was 230 µm and the output coupling of the cavity was 2.15%. Output power curves were recorded at heat sink temperatures of 12 and −10°C with incident pump power up to 40 W and are shown in Fig. 2.

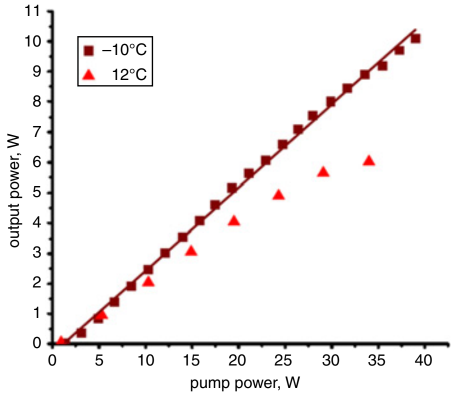

Fig. 2 *Output power as function of incident pump power for DBR-free SDL operating at heatsink temperatures of 12°C (triangles) and –10°C (squares)*

At 12°C heat sink temperature thermal roll-over of the output power can be seen and a maximum power of 6 W was achieved. When the heat sink temperature was reduced to − 10°C, no evidence of thermal roll-over was observed up to 10.1 W output power at 40 W pump power which represented our pump power limit. The slope efficiency of the laser was 20.3 and 27.5% at heat sink temperatures of 12 and −10°C, respectively. A representative optical spectrum of the laser, taken at a heat sink temperature of 15° and 5 W output power is shown in Fig. 3.

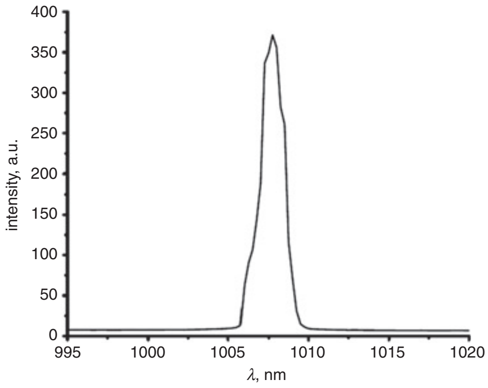

Fig. 3 *Representative optical spectrum of DBR-free SDL taken at 15° heat sink temperature and 5 W output power*

Wavelength tuning: The laser wavelength was tuned by rotating an uncoated 500-µm-thick quartz birefringent filter, which was introduced into laser cavity at Brewster's angle. We achieved wavelength tuning from 995 to 1020 nm, with a maximum power of 0.7 W under 3.1 W of pump power at a wavelength of 1007 nm. The measured power and optical spectra for a range of operating wavelengths are shown in Fig. 4.

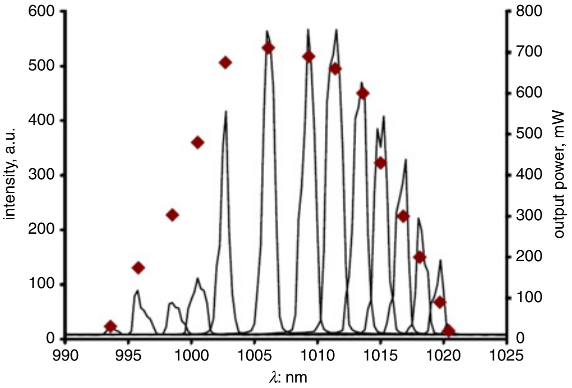

Fig. 4 *Laser spectra (solid curves) and corresponding output power values (red diamonds) at each tuning wavelength*

Conclusion: We demonstrate a 10.1 W continuous wave output power DBR-free SDL at 1007 nm at a heat sink temperature of −10°C, with a ten QW resonant periodic gain structure, van der Waals bonded to an 8 mm diameter, 300-μm-thick SiC heat spreader. We achieved laser slope efficiencies of 20.3 and 27.5% at heat sink temperatures of 12 and −10°C, respectively. The laser wavelength of output laser beam could be tuned from 995 to 1020 nm by introducing 0.5 mm quartz birefringent filter into cavity. Although SiC has a lower thermal conductivity than diamond, it is cheaper and more widely available, and its high surface quality allows for uniform and robust van der Waals bonding with low optical loss.

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One or more of the Figures in this Letter are available in colour online.

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