High power continuous and quasi-continuous wave InGaAsP/InP broad-waveguide separate confinement-heterostructure multiquantum well diode lasers

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The application of the broad-waveguide concept to InGaAsP/InP diode lasers has resulted in a fourfold reduction in internal loss to $1.3 cm^{-1}$ while achieving a record low threshold current of $73 A/cm^2$ per quantum well. Output powers of 5.2W continuous wave and 10W quasi-continuous wave are demonstrated for 200μm-aperture lasers emitting at 1.43μm.

The high power continuous-wave (CW) and quasi-continuous-wave (QCW) operation of diode lasers has proven useful for numerous applications, including both solid-state and optical-fibre laser pumping, range- or distance-finding technologies, and both invasive and non-invasive medical techniques. The QCW mode of operation is very important for many applications because higher peak powers can be achieved without sacrificing device reliability.

Until recently, most high-power laser devices have been limited to wavelengths < 1μm due to the high internal losses and low efficiencies associated with the InGaAsP/InP material system. Hence, system designers have been unable to take advantage of the eye-safe properties of lasers operating at wavelengths near and above 1.5μm. These wavelengths are often preferred for consumer and military applications where safety is a primary consideration. In addition, the wavelength range from 1.2 to 2.0μm is of critical importance to the non-invasive medical community where exact emission wavelengths are necessary for the measurement of blood properties, for example measurement of glucose levels in the blood.

We have reported the operation of broad-waveguide quantum-well (BW-QW) diode lasers at 0.81μm [1] and subsequently reported operation of BW devices at 1.5μm [2, 4], 0.97μm [3], and 2.0μm [5]. For all these wavelengths, we reported record low internal losses and extremely high internal and external differential quantum efficiencies. The reduction of internal losses associated with the BW structure permits the use of long-cavity devices (1–4mm) with only a very modest decrease in efficiency. Long-cavity lasers with increased contact stripe widths operate with reduced current density for the same output power, resulting in reduced junction heating.

The broad-waveguide separate-confinement-heterostructure multiquantum-well (BW-SCH-MQW) InGaAsP/InP structures were grown by low-pressure metal organic chemical vapour deposition using a horizontal reactor with substrate rotation. The active region consists of three 4.5nm thick InGaAsP QWs (bandgap E_G = 0.8eV, with 1% compressive strain) separated by 16nm thick InGaAsP barriers with a bandgap of 1.0eV. The same 1.0eV bandgap InGaAsP was used for the 30nm thick inner confinement layers. The outer confinement layers were InGaAsP with a bandgap of 1.13eV, and the cladding layers were InP. The measured threshold current density and internal losses for these BW-SCH-MQW structures were as low as $73 A/cm^2$ per QW and $1.3 cm^{-1}$, respectively [4].

We have reported the fabrication of BW Fabry-Perot lasers with varying contact stripe widths elsewhere [1, 3, 4]. The lasers reported here possessed a high-reflectivity dielectric stack reflector (> 95%) on the rear facet and a single anti-reflective dielectric layer (< 4%) on the emitting facet. Devices of varying lengths (1–4mm) were mounted p-side down on Ni/Au plated OFHC copper heatsinks using In solder. The heatsinks ($2 \times 11 \times 3 mm^3$) were attached to a water-cooled Ni/Au plated copper block using thermal conductive paste and mounting screws. A large-area thermopile detector and/or integrating sphere containing a small area thermopile detector traceable to NIST standards was used to measure total power accurately, and an InGaAs photodetector was used to measure the temporal shape of the light pulse during QCW operation.

Fig. 1 shows the CW output power-drive current (P-I) characteristics for 200μm wide × 2mm long cavity devices. A maximum output power of 5.2W was obtained at a drive current of 14A. At higher output powers, thermal rollover, i.e. reduced output power at increased drive currents, was observed. The measured series resistance for the diodes was 0.02Ω, and at the maximum drive current the diode voltage was only 1.3V. The differential external efficiency η_D in the linear portion of the P-I curve was 60%.

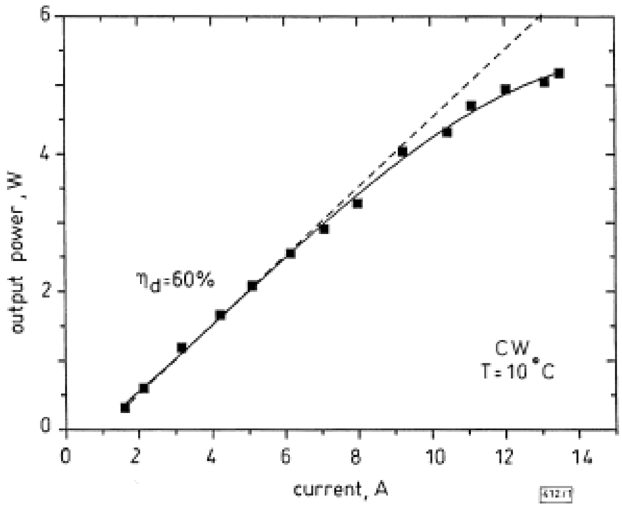

Fig. 1 *CW output power characteristics for InGaAsP/InP BW-SCH-MQW laser*

200μm aperture, 2mm cavity length, λ = 1.43μm

Fig. 2 shows the QCW P-I characteristics for 2 and 4mm long devices with 100μs current pulses. The differential external quantum efficiency h_D in the linear portion of the curves was 60 and 50% for the 2 and 4mm long devices, respectively. Thermal rollover of the P-I curve is observed at a lower power level and is more pronounced for the 2mm long device compared with the 4mm long cavity device, which shows a higher efficiency at very high output powers. The 10W output power level requires a drive current of only 31.5A for the 4mm long device compared with 40A for the 2mm long device. For the 4mm long device, the maximum power level was limited by the current supply and not by thermal considerations.

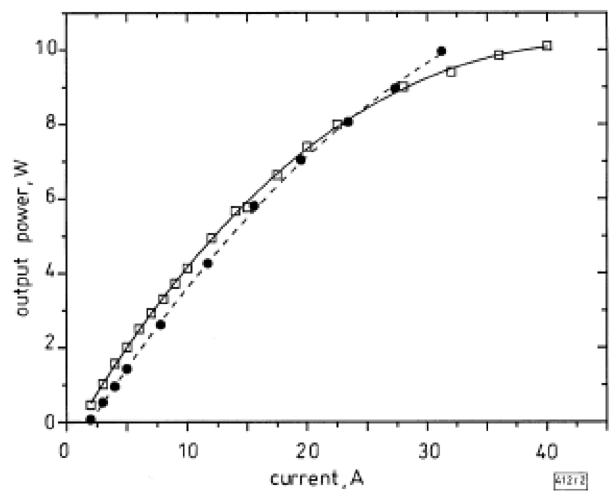

Fig. 2 *Quasi-CW output power characteristics for InGaAsP/InP BW-SCH-MQW laser driven with 100μs pulses at 100 and 50Hz*

□ L = 2mm, n_D = 60%
● L = 4mm, n_D = 50%

After testing devices with either cavity length, no irreversible changes were observed. For the 2mm device this behaviour indicates that the output power level is limited by thermal considerations and not catastrophic optical damage (COD). COD is routinely observed for all devices operating below 1.1μm and the absence of COD is a significant advantage since for reliable operation most high power laser devices can only operate at ~50% of their COD limit. Since thermal rollover is the limiting factor and not COD in InGaAsP/InP diode lasers, it may be possible to achieve reliable laser diodes with higher output powers.

Analysis of the emission spectra measured using a variable pulse width (1–100μs) revealed that the heatsink temperature varied even though it was mounted on a water-cooled stage. When the pulse width was < 10μs, the increase in heatsink temperature was negligible compared with the diode heating, while for pulse widths > 10μs the change in the heatsink temperature is comparable to the diode temperature increase. Since the thermal time constant τ for the diode is ~1μs, we used a 5μs pulse to determine the temperature rise of the *pn* junction of the diode. For a 4mm long device a temperature rise of only 10–12°C was observed for 10W output power and the spectral shift was 3meV/W. In pumping applications, this amount of spectral shift can easily be compensated for by reducing the temperature of the heatsink.

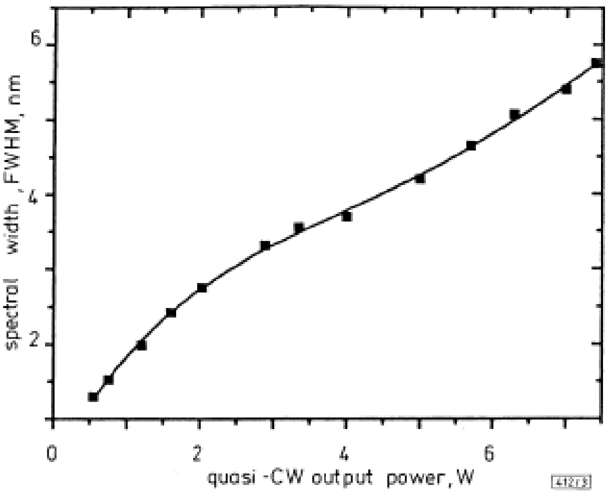

Fig. 3 *Spectral FWHM against output power for BW-SCH-MQW laser measured with 5μs pulses at repetition rate of 200Hz*

200μm aperture, 4mm cavity length, λ = 1.43μm, *T* = 15°C

The spectral broadening of the emission wavelength for diodes operating in the QCW mode is an important parameter for solid-state and fibre-laser pumping applications where the overall system efficiency is strongly dependent on the overlap of the peak laser emission wavelength range and the peak absorption wavelength range of the crystal or fibre. In Fig. 3 the spectral width (FWHM) as a function of the output power for a 4mm long device is plotted. These values were obtained using 5μs current pulses to avoid heating effects from the heatsink. The spectral width increased from ~2 to 5nm as the peak power changed from 1 to 6W. We believe that the spectral broadening in multimode lasers is the result of gain broadening caused by very high current densities (5–10kA/cm^2). Examination of the lateral near- and far-field distributions did not reveal any significant change across the entire range of driving current. The modulation of the near-field was less than 10% for all currents greater than twice the threshold current. The lateral far field (FWHM) varied from ~9° near threshold to ~12° at maximum output. These results suggest that the filamentation is not a problem in these devices throughout the large range of operating currents. The perpendicular far-field distribution was single-lobed (FWHM = 40°) for both CW and QCW modes of operation.

In conclusion, we have demonstrated record CW and QCW output power levels for InGaAsP/InP diode lasers of 5.2 and 10W using the BW device structure. The use of the BW structure has led to extremely low threshold currents of 73A/cm^2 per QW and a measured internal loss of 1.3cm^{-1}.

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