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HIGH-PERFORMANCE DC-PBH LASERS AT 1·52 μm BY A HYBRID MOVPE/LPE PROCESS

Indexing terms: Lasers and laser applications, Semiconductor lasers

Highly efficient operation of low-threshold 1·52 μm lasers grown by atmospheric pressure MOVPE is reported. The lasers were of a novel MOVPE/LPE hybrid design, based on the DC-PBH laser and operated with threshold currents as low as 11 mA and external quantum efficiencies up to 56%, and were characterised by near-circular far-field radiation patterns. This has allowed coupling efficiencies of 50% to be obtained between the devices and tapered-lens single-mode fibre.

Introduction: Metallo-organic vapour phase epitaxy (MOVPE) is currently viewed as one of the most promising epitaxial growth processes for the manufacture of a diverse range of optoelectronic and electronic devices, since it can produce sharp interfaces and complex structures over large areas. However, in the GaInAsP/InP material system required for long-wavelength optical communications, the stringent requirement of maintaining lattice-matched compositions throughout the growth of all heterojunctions has posed severe problems, especially for atmospheric pressure growth.[1] In the past, this has contrasted with the success obtained using the experimentally more complex low-pressure variant (LPMOVPE),[2] but recently we have reported the growth of abrupt high-quality GaInAs/InP heterostructures,[3] including the successful operation of double-heterostructure (DH) and multiquantum-well lasers at ~1·6 μm, by atmospheric pressure MOVPE.[4] The control over thickness and interface sharpness afforded by the MOVPE technique opens up many exciting possibilities, and, in the case of DH lasers, allows much greater control of the device characteristics and output radiation patterns than is possible using liquid phase epitaxy (LPE).

In this letter we wish to report on the atmospheric pressure growth of high-efficiency low-threshold DH lasers at $\lambda = 1{\cdot}52$ μm, and, in particular, to present operating characteristics of a novel MOVPE/LPE hybrid double-channel planar buried-heterostructure (DC-PBH) laser. Broad-area laser threshold measurements verify the high quality of the planar DH material. The work reported here represents the first low-threshold operation of 1·5 μm lasers to be grown using atmospheric pressure MOVPE, and the results indicate that the hybrid DC-PBH devices have superior operating characteristics to conventional two-stage LPE devices.

Experimental: The basic structure of the MOVPE/LPE DC-PBH is shown in Fig. 1. A thin buffer layer of *n*-InP ($t = 0{\cdot}5$ μm, $n \simeq 2 \times 10^{18}$ cm^{-3}) was first grown on a (100)-orientated S-doped InP substrate ($n \simeq 7 \times 10^{18}$ cm^{-3}). This was followed by the growth of an undoped active layer ($\lambda \simeq 1{\cdot}52$ μm, $t = 0{\cdot}15$ μm) and an upper *p*-InP confining

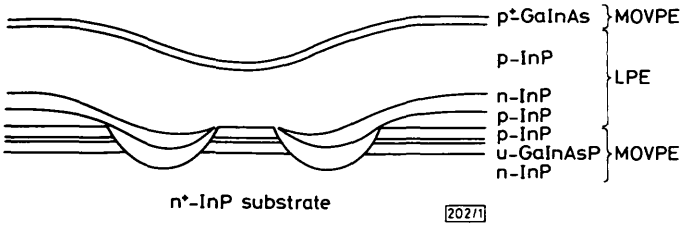


Fig. 1 *Schematic cross-section of MOVPE/LPE double-channel planar buried heterostructure laser*

layer ($p \simeq 3 \times 10^{17}$ cm^{-3}). For MOVPE broad-area lasers, the thickness of the *p*-InP was approximately 1·5 μm, and the structure was completed by growing a thin p^+ GaInAs contact layer ($t = 0{\cdot}1$ μm, $p \simeq 4 \times 10^{19}$ cm^{-3}). In the case of the DC-PBH lasers, the growth of the *p*-InP layer was terminated after ≃0·4 μm, and double-channel patterns were then formed by wet chemical etching to leave a 1·5 μm-wide central lasing stripe. The blocking layer structure was then formed by LPE, and the structure completed by growing a p^+ GaInAs contact layer ($t \simeq 0{\cdot}1$ μm, $p \simeq 4 \times 10^{19}$ cm^{-3}) by MOVPE, as for the broad-area devices.

The growth conditions for the various stages are now given. MOVPE layers were grown at atmospheric pressure in a conventional alkyl reactor modified to provide fast switching. The growth temperature was 650°C and reactant flows were adjusted to deposit the lattice-matched structure described above. Dimethyl zinc and hydrogen sulphide were used as the *p*- and *n*-dopants, respectively. The LPE growth was performed at ~595°C after suitably adjusting the supercooling of each melt.

Broad-area lasers were fabricated by alloying Au-Sn contacts to the *n*-side at 450°C and evaporating Ti-Au tunnelling Schottky barrier contacts to the *p*-side. Individual laser chips were then formed by cleaving to length and scribing the remaining two sides. Contacts to the DC-PBH devices were made in exactly the same way, after opening up 5 μm-wide windows over the buried heterostructure in a 2000 Å-thick layer of SiO_2 deposited by CVD after the epitaxial growth.

Results: Fig. 2 shows a set of light-output/current characteristics for a 400 μm-long MOVPE/LPE DC-PBH laser at dif-

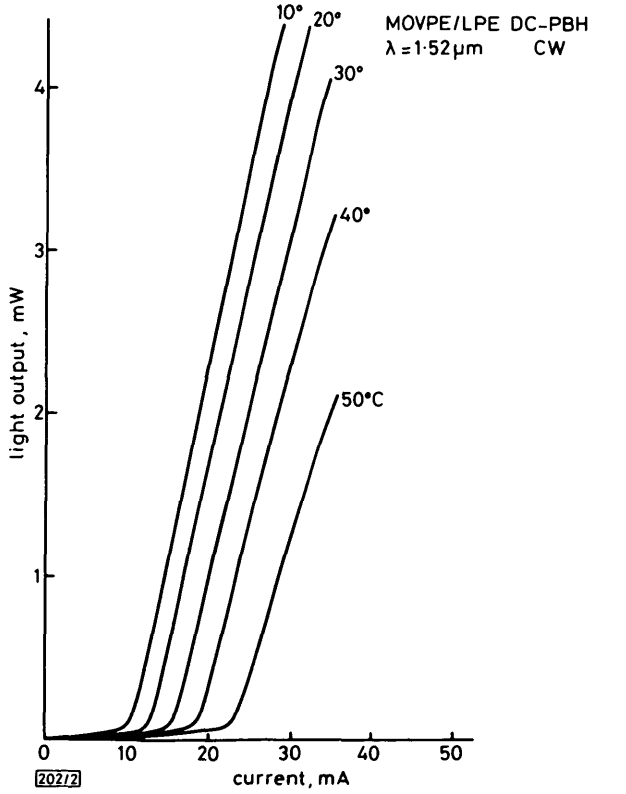


Fig. 2 *Light-output characteristics of MOVPE/LPE DC-PBH lasers at different heat-sink temperatures*

ferent heat-sink temperatures. At 20°C, the device has a threshold of 11 mA and operates with an external quantum efficiency of 28% per facet, which, to our knowledge, are the best values obtained for 1·5 μm DC-PBH devices by any growth technique. The temperature dependence of threshold between 20 and 60°C is described by a single value of $T_0 \simeq$ 53 K, which is similar to two-stage LPE devices,[5] but is lower than T_0 figures recently quoted for a VPE/LPE DC-PBH device.[6] However, no attempt has yet been made to optimise the *p*-doping level of the InP confining layer in our structures, which is known to influence T_0.

The values of I_{th} and T_0 agree reasonably well with the characteristics obtained from broad-area devices made from consecutive MOVPE runs with the same active-layer thicknesses. These devices showed threshold current densities of 1·6 kA cm^{-2} for 400 μm-long devices and 1·3 kA cm^{-2} for 1 mm-long devices, values which are close to the best so far reported by any MOVPE technique.[2] T_0 figures for the broad-area lasers were very similar to those reported above for the MOVPE/LPE DC-PBH devices.

A particularly useful and interesting output characteristic of the MOVPE/LPE DC-PBH lasers was the far-field radiation pattern, as shown in Fig. 3. It was found that the patterns in

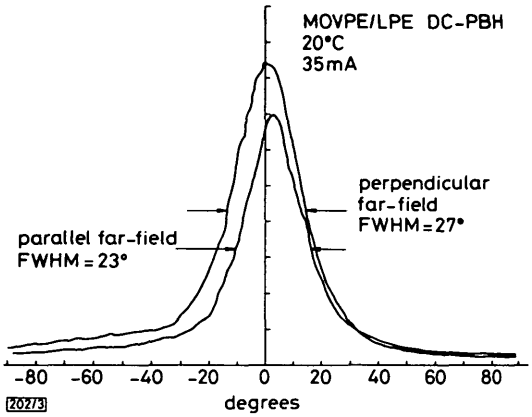


Fig. 3 *Far-field radiation patterns of MOVPE/LPE DC-PBH laser*

both the plane parallel to the junction and the perpendicular plane had similar FWHM values of 23° and 27°, respectively. This arises as a consequence of accurate control over the active-layer dimensions by MOVPE growth, and the facility to dispense with the antimeltback layer normally required in LPE/LPE DC-PBH devices. The MOVPE/LPE structures are therefore much more suited to producing narrow, circular far-field radiation patterns, and the implications for improved coupling to single-mode fibres are obvious. In fact, preliminary coupling experiments performed using the MOVPE/LPE DC-PBH laser diodes and tapered-lens single-mode fibre have resulted in measured coupling efficiencies of ≃50%. This result signifies a major advance in reducing the coupling loss of optoelectronic devices to single-mode fibre without resorting to complex lens arrangements.

Conclusions: We have shown for the first time that atmospheric pressure MOVPE is able to produce high-quality low-threshold 1·5 μm lasers, and have demonstrated this capability by fabricating both novel MOVPE/LPE DC-PBH lasers and broad-area devices. The broad-area lasers showed threshold current densities down to 1·3 kA cm^{-2} for 1 mm-long devices, while DC-PBH devices had thresholds as low as 11 mA, operated with efficiencies of up to 28% per facet and produced near-circular far-field radiation patterns.

The results reported here further demonstrate the potential of atmospheric pressure MOVPE for the manufacture of long-wavelength optoelectronic devices, and the laser characteristics obtained illustrate the substantial improvements made possible by the interface and thickness control of MOVPE.

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SECOND-ORDER SWITCHED-CAPACITOR BANDPASS FILTER IMPLEMENTED IN GaAs

Indexing terms: Filters, Bandpass filters, Switched-capacitor filters

A GaAs second-order switched-capacitor bandpass filter has been fabricated. Operation with clock frequencies up to 100 MHz and centre frequencies up to 4 MHz has been achieved, with an insertion loss of between 3 dB and 15 dB and a centre frequency accuracy of 90–98%.

Introduction: The use of switched-capacitor techniques for filtering applications is now well established. However, to date such applications have been mainly limited to relatively low frequencies (submegahertz) by the speed limitations of the implementing technology (generally NMOS or CMOS).

This letter describes the first reported attempts to increase the centre frequency range by using integrated circuits implementing in GaAs, although we have previously reported a transversal filter implemented in the same process.[1] The aim of this work is to implement a second-order bandpass filter with a clock frequency of up to 250 MHz, and a clock-to-centre frequency ratio of 25:1. The extension of switched-capacitor techniques into the megahertz range will allow the use of these techniques in applications such as clock recovery in data communications systems, agile filtering for radar and communications receivers, and video processing in television receivers. A higher level of integration in these systems may thus be achieved than has been possible in the past.

Technology: The switched-capacitor filter chip was fabricated using the STL standard G1 process for depletion-mode MESFETs (DFETs). This planar process uses an Si^{29} implant at 80 keV and a 2×10^{12}/cm^2 dose, which is annealed to give a uniform active layer. After implantation, evaporated and