Vertical integration of dual wavelength index guided lasers

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of 27 In$_{0.5}$Ga$_{0.5}$As quantum wells (QWs) with In$_{0.5}$Al$_{0.5}$Ga$_{0.5}$As spacers. Every nine QWs are periodically located at antinode positions where the internal field has maximum intensity within the active region. An additional two-period In$_{0.5}$Al$_{0.5}$As/In$_{0.5}$Al$_{0.5}$-Ga$_{0.5}$As mirror was grown onto the active region in order to confirm the resonance. To realise the CW lasing by photopumping, we employed SiO$_2$/TiO$_2$ dielectric layers as a top mirror instead of a monolithic structure because the dielectric mirror has a high level of transmittance for the pumping light. The entire structure was completed by deposition of a 12 period SiO$_2$/TiO$_2$ dielectric layer using an e-beam evaporator. The SiO$_2$/TiO$_2$ dielectric mirror revealed a reflectivity of 99.9% at 1.55μm and a transmittance of 84% at a pumping wavelength of 1.05μm. The pumping laser light was incident from the front side of the wafer (through the SiO$_2$/TiO$_2$ mirror) and focused onto a spot 25μm in size. The laser emission was monitored by an optical multichannel analyser (OMA) from the rear side of the wafer (polished surface of the InP wafer) which was mounted on the temperature controlled stage of the cryostat. The lasing characteristics were measured at various temperatures ranging from 150 to 260K.

Fig. 2 shows a light in-light (L-L) curve of the 1.55μm VCSEL at 220 and 260K. The minimum threshold power was as low as 17mW at 220K. At this temperature, the calculated threshold power density is 3.4kW/cm$^2$, which is equivalent to a current density of 2.9kA/cm$^2$. The real threshold power will be less than this value if the light absorption in the path of the pumping light is taken into account. The temperature range in which the threshold power is nearly flat is ± 5K at -210K.

Fig. 3 shows the evolution of the emission spectra at 220K below and above the threshold for CW photopumping. The wavelength of the laser at 220K was ~1553nm. The linewidth of the laser peak is estimated to be less than 0.6nm considering the limitation of OMA resolution of 0.2nm. The thermal shift of the emission wavelength, stemming from the temperature dependence of the refractive index and layer thickness, was found to be 0.1nm/K which was in agreement with previous reports.

In conclusion, we have demonstrated CW lasing in an InAlGaAs/InAlAs/InP based 1.55μm VCSEL by photopumping. The entire structure was completed with a SiO$_2$/TiO$_2$ dielectric mirror employing a periodic gain structure. The minimum threshold density was as low as 3.4kW/cm$^2$ at 220K.

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Vertical integration of dual wavelength index guided lasers

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The vertical integration of two GaAs-based lasers operating at different wavelengths has been achieved with the use of re-growth technology. A V-channel substrate inner stripe structure was used for the bottom laser and a ridge waveguide for the top laser. Both lasers shared a common electrode and can be powered independently or simultaneously. This represents a promising method for fabricating integrated lasers with different wavelengths.

Introduction: Multiwavelength sources are becoming more and more important for satisfying the increasing demand for higher capacity optical communication systems, such as wavelength division multiplexing (WDM) and advanced printing applications. One of the main requirements for WDM systems is that it should be straightforward to couple such multiwavelength sources into the same fibre. Also, highly advanced printers use two laser spots instead of one to increase the printing speed. As such, it is of great interest to develop integrated multiwavelength sources (laser diodes in particular) to meet the requirements for these applications.

In this Letter we present a dual wavelength laser device based on GaAs technology. The device was a V-channel substrate inner stripe (VSIS) structure fabricated using a two-step growth. The two wavelengths can be designed fully independently of each other. Both lasers are index-guided and hence both can be engineered to emit light in the lateral fundamental mode. The distance between the two laser spots is determined by the relative position of the top ridge and the bottom V-channel. In our case we have chosen a distance of ~20μm.

Fabrication: The dual wavelength laser structure was grown by metal organic chemical vapour deposition on a p-type GaAs substrate. The two perpendicular laser structures have a common n-type GaAs

References


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layer. The layer sequence was $pinip$. For the bottom laser VSIS geometry would ensure the index guiding of the laser. The first growth sequence consisted of a 1 µm thick $n$-GaAs blocking layer ($\sim 10^5$ cm$^{-2}$) on a $p^+$ GaAs substrate. Subsequently 3 µm wide channels were patterned and etched into the $p^+$ substrate using an etch solution of $H_2PO_3\cdot H_2O\cdot H_2O$ (1:1:3) at 0°C. After removal of the photoresist pattern the sample was trim etched by dipping it into $H_2SO_4\cdot H_2O\cdot H_2O$ (20:1) for 20s prior to loading in the growth chamber. Two graded index separate confinement heterostructure (GRIN-SCH) type structures were grown on the patterned substrate with a maximum of 60% Al in the cladding layers. The bottom structure has a 7nm thick GaAs quantum well (QW) sandwiched between two $Al_0.3Ga_0.7As$ barriers of 12nm thickness while the top structure has a 7.5nm QW of $In_0.3Ga_0.7As$ and 10nm thick GaAs barriers. It is worth noting that the $n^+$ GaAs layer which was used as the common $n$-electrode of both lasers was 7µm thick. This allowed more flexibility during the processing.

The top structure was processed into ridge waveguide lasers with a stripe width of 4µm parallel to the inner stripes but displaced by -20µm. The ridges were etched to a depth of -0.2-0.3µm above the active layer of the top laser. PECVD was then used to deposit a 200nm thick SiN$_x$ layer at 100°C prior to the removal of photoresist. Subsequently, 120µm wide channels were opened into the dielectric layer and then chemically etched down until the $n^+$-GaAs layer. Metallisation of Ti/Au (50/200nm) was used for the top $p$-contact and Ge/Ni/Au (20/15/200nm) for the $n$-contact. Both contacts were alloyed at 400°C for 1min in Ar ambient. The substrate was then polished to a thickness of ~120µm before metallisation of Ti/Au for the bottom $p$-contact which was also alloyed at 400°C for 1min under an Ar ambient. Fig. 1 illustrates the schematic diagram of the processing sequence for the dual wavelength laser.

**Results:** The devices were tested under pulsed conditions (2µs pulse at 28kHz) without any mirror coating or heatsinking. Laser operation was demonstrated by both top and bottom devices. Fig. 2 shows a typical spectrum where the two devices were powered simultaneously. The inset shows the corresponding light output against injected current characteristic. The top InGaAs laser had superior lasing characteristics compared to that of the bottom GaAs device. Threshold currents were 14 and 107mA for the top and bottom devices (400µm cavity length), respectively. As expected the threshold current for the top InGaAs laser was quite low [1]. However, the bottom GaAs laser had a higher threshold current than what was normally expected for standard GaAs lasers. This is partially due to the under-etch effect of the V-channel. Other possible reasons are discussed below. The lasing wavelengths for the InGaAs (at 20mA) and GaAs (at 120mA) were 982 and 837nm, respectively. Both devices achieved singlemode operation.

A cross-sectional view of the lasers is shown by the scanning electron micrograph (SEM) in Fig. 3. The VSIS structure could be identified from the recess in the substrate. The ridge could also be seen clearly which forms the lateral waveguide for the top laser. It is worth noticing the roughness of the top surface. The cause was probably the outdiffusion of $p$-dopant (Zn) from the substrate during the rather long time needed for the growth of the two structures during which the substrate temperature was $\geq 600^\circ$C. Also, since the bottom GaAs laser was grown first before the top InGaAs laser, the higher than expected threshold for the bottom device could be attributed to this effect which might have changed the $(pin)$ junction characteristics. The poor morphology might also explain the large scatter in the threshold currents among the devices. A possible way to improve the morphology would be to use an $n$-doped substrate to grow the reverse $nipn$ structure, using carbon doping instead of zinc [2] as the common $p$-electrode. It is well known that the diffusivity of $C$ is smaller than that of Zn and hence the interdiffusion effect of the $pn$ junctions will be minimised. Also, good planarisation after growth of the bottom laser structure may be helpful in minimising the distance between the two laser spots. In such a case, the ridge of the top laser can be positioned just above the VSIS channel of the bottom laser. This would be particularly useful for coupling the two light beams into the same optical fibre. The planarisation should occur during the growth of the common $n$-electrode.

We have demonstrated for the first time the feasibility of vertically integrating two index-guided lasers using a V-channel
Compact 38GHz MMIC balanced vector modulators employing GaAs/InGaP HBTs

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The design and performance of a 38GHz balanced I-Q type vector modulator, using HBTs as switching elements, is presented. The MMIC chip can be employed to implement direct M-PSK and M-QAM modulation schemes in order to reduce hardware complexity and cost. A novel miniature microstrip coupler geometry can be employed to further minimise the modulator's size, yielding a circuit which only measures $1.4 \times 1.2\, \text{mm}^2$. The balancing topology can be used to remove the parasitics of the HBTs resulting in near perfect constellations, and the compact layout can greatly reduce the cost of expensive transmitter chip area.

Introduction: For millimetre-wave applications, direct carrier modulation has been shown to be an attractive means of reducing the complexity and cost of VSAT transmitters [1]. A common technique for realising a direct BPSK modulator is to employ a reflection topology using Lange couplers with transistors (FETs or HBTs) acting as switches on the direct and coupled ports [2]. In such a configuration the coupler’s dimensions play a vital role in the size of the overall circuit. In this Letter we describe a miniature microstrip coupler which has been used to reduce the size of the circuit [3]. When the switches are ON, the ideal voltage reflection coefficient is $-1$ (short circuit), and when they are OFF the ideal voltage reflection coefficient is $+1$ (open circuit). The reflected signals add at the output port only. It has been shown however that the parasitics of the switching elements start to dominate at higher frequencies, and the resulting amplitude and phase error characteristics are very difficult to tune out unless a balancing topology is employed [2, 3].

Modelling: With MMIC technology, a variable resistor is often realised using a voltage-controlled cold FET or HBT. Here, there is no voltage applied to the drain or collector termination of the transistor [2]. The advantage of using HBT technology is that it can be integrated with a high efficiency HPA and yield a low cost high performance single-chip transmitter. In the case of the cold-HBT, as the base bias is increased from zero, the collector-emitter resistance decreases. The junction capacitances of $C_{bb}$ and $C_{bc}$ are not always identical though, leading to highly nonlinear C-V characteristics. This can however be overcome by careful calibration of the bias. The process used to manufacture the monolithic modulator is the GMMT B-20 mixed signal HBT process [4], which provides a transit frequency of 50GHz.

Fig. 1 Circuit topology of miniature balanced vector modulator

Miniature balanced vector modulator: For quadrature modulation schemes an I-Q type vector modulator [5] can be employed. Here, a 3dB coupler is used to create two orthogonal channels. Each channel consists of a balanced bi-phase amplitude modulator, which employs two reflection-type modulators, operated in push-pull, in order to reduce the amplitude and phase errors caused by the single-stage modulator [2, 3]. Each channel is then modulated individually by a pair of complimentary signals, and then combined in phase with a 3dB Wilkinson combiner as illustrated in Fig. 1. Each bi-phase amplitude modulator has to be operated at a number of different amplitude settings (e.g., two settings for 16-QAM) with 0° and 180° phase offset. With reference to Fig. 2 it can be seen that the complete vector modulator needs to employ a total of nine couplers. Thus, by using the novel microstrip coupler the size of the overall MMIC circuit can be reduced by > 40% in comparison to using normal Lange couplers. The miniature directional couplers consist of two parallel-coupled microstrip transmission lines, which are separated by 5μm. Polyimide capacitors at the edges of the coupled region have been included to compensate for the inequality caused by the poor directivity suffered by microstrip directional couplers (due to inhomogeneous dielectric). The plates of the capacitor are separated by 1.4μm thick polyimide.

Fig. 2 Layout of 38GHz balanced vector modulator, chip size $1.4 \times 1.2\, \text{mm}^2$