Technologies for high power, near IR semiconductor laser sources

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Abstract

There are numerous remote sensing applications that require compact, high output power laser sources in the near IR (NIR). Semiconductor laser devices in the 1300-1600nm range offer the advantages of low power consumption, high reliability and high power density compared to other commercially available laser technology. This paper presents the findings from a short scoping study to review the potential usefulness and define options for the development of the next generation of eye-safe high power semiconductor laser devices for military applications.

Keywords: Monolithic integration, Indium Phosphide, DFB laser diode

Introduction

The majority of current free-space optical transmission systems (range finders, comms and remote sensing) use emitter and detector technology in the 780-980nm wavelength band. However, eye safety limitations restrict the power output and usable range of such systems.

Sub 1400nm wavelengths are particularly hazardous since they are readily transmitted through ocular media and are focused to a spot on the retina 10 – 20 um in diameter. Thus, the intensity of such light at the retina will be on the order of 10^5 times greater than at the cornea. Hence, retinal damage thresholds are several orders of magnitude lower than those for corneal damage.

Devices in the wavelength range > 1400nm have the advantage of being outside of the ocular focus range of the eye, hence the threshold for eye-safe operation of such a device is increased by a factor of ~1000 before damage occurs.

Military applications for NIR laser sources

Potential military uses for NIR sources range from relatively ‘low-tech’ non-wavelength sensitive applications (such as rangefinding), to highly specialized fixed specification applications. A brief summary of diverse example requirements is given in the table below:

Application	Description	Source primary characteristics
Burst Illumination Imagery	Long range active NIR imaging at 1.4µm	Broad spectral bandwidth, large area scanning
Doppler LIDAR/ Vibrometry	Diagnosis of mechanical failure in critical equipment Detection of windborne bio-aerosols	sub−µs pulses, Narrow FOV fast scanning capability high spectral stability
Differential Absorption LIDAR (DIAL)	Gas/biological agent detection using comparative absorption spectroscopy	High spectral purity and stability, precise multi-wavelength or tunable
Optical triggering	Incoming projectile detection eg UAVs	Multimode, divergent beam for large area scanning
Range finding	Eg Future Infantry Soldier Technology	Compact, low power consumption, broad area

Semiconductor NIR LD technology challenges other technologies such as solid state pumped, fibre and external cavity lasers whenever factors such as power consumption, footprint reliability and cost are primary concern. In addition, semiconductor lasers will challenge in ‘high-spec’ applications due to inherent advantages such as high modulation capability (GHz), high spectral purity, stability and tunability.

Current High Power NIR semiconductor laser technology

Semiconductor laser technology emitting in the range 1300-1550nm is at an advanced stage of development due to the commercial drivers from optical fibre networking applications. However, the majority of such applications normally require single mode, low power devices (typically <10mW).

Broad area, multimode devices

Recent advances in the material quality of InGaAsP broad area structures has led to an increase in the potential power output of 1550nm devices, resulting in the commercial availability of high power, low duty cycle, multimode devices (100mW-1W) from a small number of manufacturers (Princeton Lightwave, Perkin Elmer, Tyco, Intense Photonics).

Singlemode devices

InGaAsP NIR single mode Fabry Perot (FP) devices have exhibited CW powers up to 1W at ~1480nm[1] in the laboratory. Typically, commercially available devices have maximum power in excess of 300-400mW targeted at telecommunications applications such as Erbium and Raman fiber amplifier pumping, OTDR and Optical Test Equipment.

DFBs

The distributed feedback laser (DFB) has superior output spectral qualities than an FP. Inclusion of a grating layer in the waveguiding region increases mode selectivity and stability, with side mode suppression ratios of 45dB routinely available. In addition, DFBs exhibit weaker wavelength-temperature dependence and lower relative intensity noise (RIN) than FPs of equivalent cavity size.

The industry definition of a ‘high power’ DFB is 40-50mW, however powers in excess of 440mW have been demonstrated at 1550nm [2].

Monolithic Integration

Monolithic integration of emitter and optical amplification elements on a single chip offers a potential route to increasing the output power and functionality of single mode devices. The DFB is well suited to integration since optical feedback obtained via Bragg grating rather than Fabry-Perot cavity. Hence there is no (semiconductor-air) facet requirement.

There are several components, in addition to the laser source, which are required to enhance power output and functionality:

SOAs

The Semiconductor Optical Amplifier has been used extensively as a linear gain element in all optical switching and routing applications. In its simplest form, the SOA can act as a broad-band optical power booster, with amplification factors of up to >17dBm demonstrated at 1550nm [3].

MMI couplers

The Multimode Interferometer is a power splitter produced from a passive slab waveguide. It exploits the principal of self-imaging, the ability of an optical mode to reproduce itself periodically along the propogation direction of a multimode waveguiding structure. Semiconductor MMIs have been demonstrated as power combiners and splitters, mode converters and wavelength multiplexers [4].

Integration techniques: Butt Coupled Regrowth

Butt Coupled Regrowth (BCR) is an integration technique that allows the combination of active and passive sub-components on the same InP substrate. The semiconductor layer structure required for the most critical optical element is defined in the base epitaxy. This is then selectively etched and several additional regrowth stages may be required to define additional elements. Active and passive sections can be combined by altering the composition and electrical doping of the regrown layers to produce non-absorbing waveguides.

Good interface quality at the vertical active/passive interface is essential to avoid scattering loss and absorption, and this is a function of the etched interface and the epitaxial overgrowth quality.

We have employed RIE and ICP dry etching processes to minimize the sidewall roughness of etched InP/InGaAsP waveguides. Reproducible vertical etch profiles with surface roughness <20nm can be achieved routinely using a combination of dry and wet etch process (Fig 1).

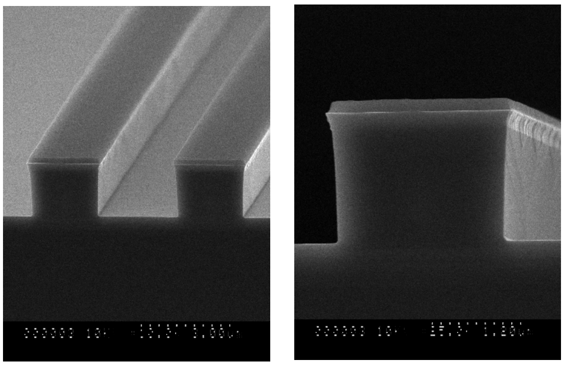

Fig 1: InP/InGaAsP waveguide structures etched using CH_4/H_2 RIE

In collaboration with IQE Ltd, we have developed robust epitaxial MOCVD overgrowth processes, which produce void free, continuous BCR interfaces. Figure 2 shows a SEM image of an InP/InGaAsP active-passive interface. The device has be cleaved parallel to the waveguide transmission direction. 'ACTIVE' is the active QW region, 'PASSIVE' is the re-grown passive waveguide region. The Quantum Wells (QWs) have been stain etched to highlight the position of the active region.

It can be seen that there is minimal undercut of the QWs during the selective etching process and a continuous, high quality semiconductor interface has been formed with minimal mass transport during overgrowth.

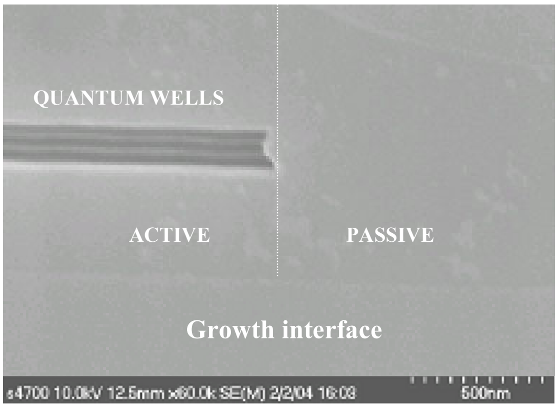

Fig 2: SEM image of an InP/InGaAsP Active–Passive component interface

Device demonstrators

BCR is a powerful integration technology that can be used to realize scalable, high power Photonic Integrated Circuit (PIC) architectures. Figure 3 shows a schematic example of such a device.

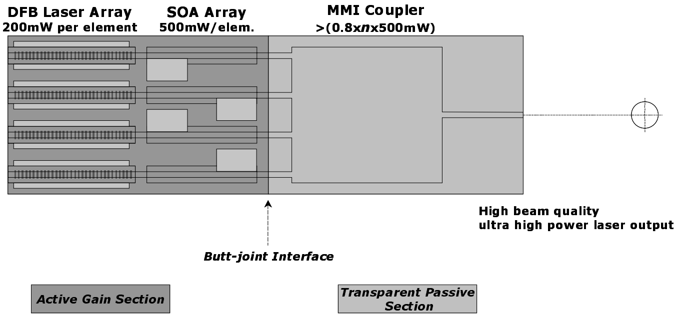

Fig 3: Schematic of a NIR high power device demonstrator

Multiple DFB elements are combined on the same chip using a multiple input MMI mode combiner. Each DFB has a SOA element as a power booster to overcome losses associated with the MMI coupling efficiency.

Such a device could be fabricated with three overgrowth stages- base epitaxy to define the DFB active region, an overgrowth to define grating layer and SOA structure, a final overgrowth to define the passive/MMI waveguide.

Theoretically this device is infinitely scalable to produce multi-Watt single emitters, the largest practical trade offs being the MMI loss associated with increasing input modes and the tolerable defect count over a single chip area.

Variations of this device include:

- incorporation of output waveguide array structure to produce a steerable output beam;
- a continuously tunable DBR HP source;
- DFB elements with multiple discrete output wavelength.

Future Directions and Summary

There is an emerging need for compact, high power NIR semiconductor lasers in a variety of high specification military applications. A particular technology gap exists for 1W+ multi-functional single mode devices.

Monolithic integration of several optical sub-components on a single InP chip offers the advantages of scalable, flexible device architectures with simplified packaging requirements and hence reliability. BCR is a technique well suited to the realization of such devices, but to our knowledge has not been used extensively in high power, single mode applications.

CST is developing a suite of process technologies for the implementation of rapid prototyping of PIC designs based on BCR. Currently this development is being driven by low power optical networking applications.

CST wishes to acknowledge that some of this activity was sponsored by EMRS DTC under contract EMRS/DTC/1/54. The remainder of this effort was funded by CST and IQE internal engineering.

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