Applications of Single Frequency Blue Lasers

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ABSTRACT
Gallium nitride (GaN) sources are becoming a regular part of today's world and are now key devices for lighting infrastructures, communications systems and quantum applications, amongst others. In particular, many applications have seen the shift from LEDs to laser diodes to make use of higher powers, higher bandwidths and increased transmission distances. Laser communication systems are well established, however there are applications where the ability to select a single emitted wavelength is highly desirable, such as quantum atomic clocks or in filtered communication systems. Distributed feedback (DFB) lasers have been realised emitting at a single wavelength where the grating structure is etched into the sidewall of the ridge. The main motivation in developing these lasers is for the cooling of ions in atomic clocks; however their feasibility for optical communications is also explored. Narrow linewidth lasers are desirable and this paper will explore how this is achieved. Data rates in excess of 1 Gbit/s have also been achieved in a directly modulated, unfiltered system. These devices lend themselves towards wavelength division multiplexing and filtered optical communications systems and this will be analysed further in the work presented here.
Keywords: Distributed feedback lasers, gallium nitride, optical atomic clocks, optical communications.

1. INTRODUCTION

There are a number of applications which can benefit from single frequency, gallium nitride (GaN) laser diodes such as cold-atom-based sensing [1], spectroscopy [2], security and defence [3] and optical communications [4,5], amongst others. The use of lasers in everyday appliances is becoming more common; however this paper looks specifically at distributed feedback (DFB) lasers to exploit the need for very precise wavelengths with narrow linewidth emission. GaN DFB lasers have been fabricated which exhibit CW operation and a high side mode suppression ratio (SMSR). Single wavelength blue laser sources have been demonstrated before using complex grating structures [6,7]. Here, we present a method where the grating is written into the sidewall of the ridge waveguide, removing the need for complex overgrowth steps which in turn limits epi-defects. These lasers have been characterised and analysed for their use in quantum sensing as well as optical communications and results are presented here.

2. FABRICATION & CHARACTERISATION

Devices were fabricated from AlInGaN laser epi-structures. The design consists of three InGaN quantum wells between GaN barriers, waveguide layers and AlGaN cladding layers. The device design is similar in concept to that described in [8]. Devices of this type are easier to fabricate since the etched feature is larger and therefore suffers less from etch lag effects. This is of even greater importance at shorter wavelengths and in materials which do not have a suitable etch stop layer. Furthermore, devices of this type have been shown to exhibit lower linewidths than their low order DFB counterparts [9].

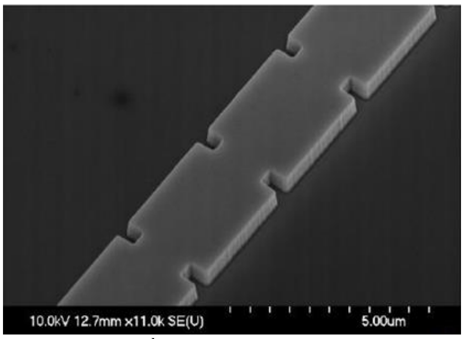

Figure 1. SEM image showing a 39th order sidewall grating etched into the laser ridge.

The grating was written into the sidewall of the laser ridge with a final width of 1.5 um in a mesa of 2.5 um. The etch depth is approximately 0.52 um. A scanning electron microscope (SEM) image of the etched ridge can be seen in Figure 1. More details on the choice of design and fabrication can be found in [10,11].
Devices ranging from 405 nm up to 435 nm have been fabricated and Figure 2 shows an LVI and a spectral plot for a device emitting at 408.5 nm. This device has a threshold current of 140 mA and emits over 16 mW of power at 250 mA. A number of devices have shown powers in excess of 20 mW, with threshold currents below 100 mA bringing the performance close to their FP counterparts. An SMSR of over 35 dB has been achieved with a spectrometer resolution of 6.5 pm.

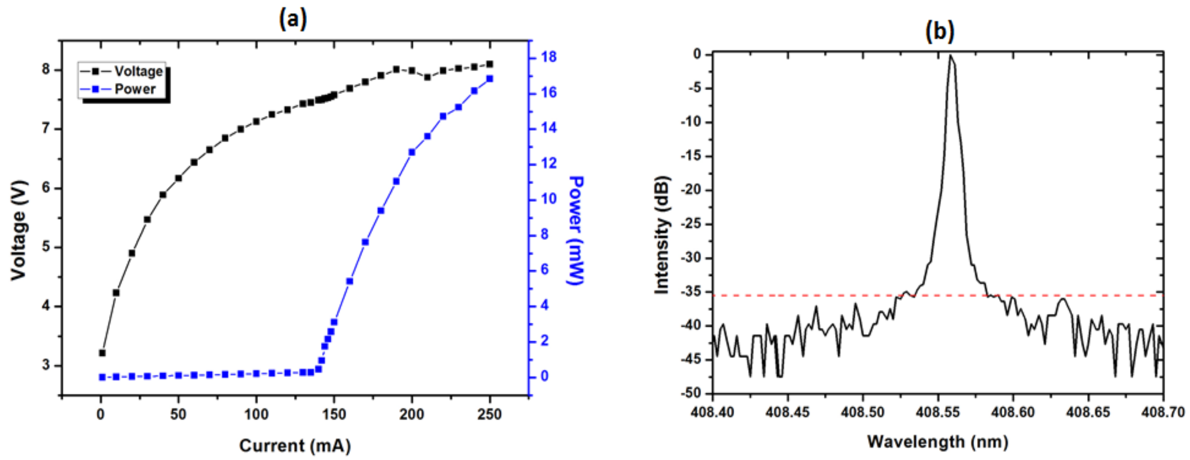

Figure 2.(a) A typical LVI plot for a blue DFB laser with a threshold of 140 mA and (b) spectral performance of the laser emitting at 408.5 nm showing an SMSR in excess of 35 dB.

For use in strontium ion optical clocks, 422 nm is the desired wavelength for the cooling transition. Typically a large, solid state laser is frequency doubled to generate light at these wavelengths. However, these are bulky and expensive so a DFB laser at 422 nm would offer a compact and less expensive solution. As well as this, it is important for these applications to have a narrow linewidth laser. For strontium ion optical clocks, ideally linewidths of less than 1 MHz are required, with power output in the range of a few milliwatts.

3. DFB OPTICAL COMMUNICATIONS

As well as their uses in quantum sensing, DFB lasers have a number of advantages for optical communications. Due to the nature of these devices, they would be ideal candidates for filtered communication systems [12] where background or solar radiation can be rejected reducing crosstalk. This is of particular interest in single photon detection based systems. In addition to this, wavelength division multiplexing (WDM) could be deployed using these devices to create either increased throughput through multiplexing or even allowing WDM enabled networking between many devices.

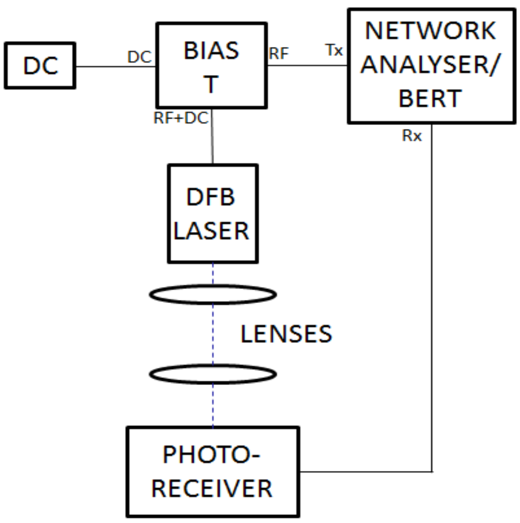

Figure 3. Experimental setup in order to measure frequency response and bit-error rates of a DFB laser.

An unpackaged DFB laser was tested for frequency response to understand the modulation capabilities of the device before eye diagrams were taken and bit-error rate analysis was carried out. The laser was kept at a temperature of 17°C. The output from the laser was collected and collimated using lenses, which was then transmitted in free space onto a photoreceiver (Newport 818-BB-21A). The RF signal was then sent back to the network analyser for frequency response measurements or back to the bit-error rate test (BERT) system for bit-error rate analysis. Alternatively, the signal can be fed back into a fast oscilloscope in order to view the data in the form of an eye diagram. The setup can be seen in Figure 3.

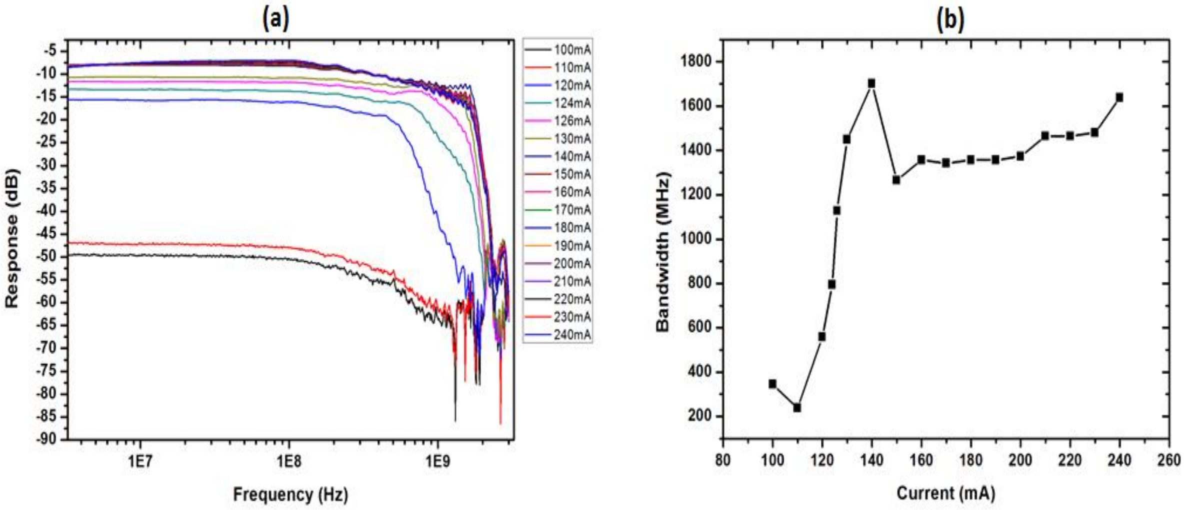

Figure 4.(a) Frequency response of DFB laser at varying current values and (b) -3 dB optical bandwidth as a function of drive current.

The maximum bandwidth of 1.7 GHz was achieved at a drive current of 140 mA. As seen in Figure 4(b), the bandwidth rolls over and this is due to the bandwidth limit of the photoreceiver. However, despite this limitation, this laser still achieved error-free data transmission up to 3 Gbit/s. Eye diagrams at data rates ranging from 1 Gbit/s up to 3 Gbit/s can be seen in Figure 5.

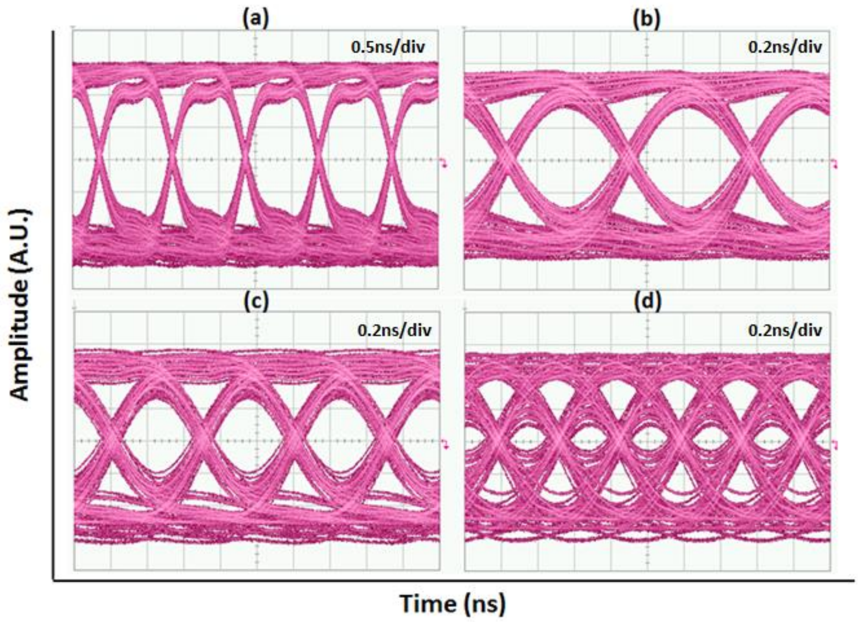

Figure 5. Eye diagrams at (a) 1 Gbit/s, (b) 1.5 Gbit/s, (c) 2 Gbit/s and (d) 3 Gbit/s.

4. CONCLUSION

In conclusion, single frequency GaN laser diodes have been fabricated and characterised for their uses in the quantum applications and optical communications. This paper introduces the fabrication method used to produce these lasers and presents their performance showing good output powers and high side mode suppression ratio. Their uses in optical atomic clocks is discussed before their performance for communications is portrayed showing a bandwidth of 1.7 GHz and error free data transmission achieved up to 3 Gbit/s. To further improve their performance, facet coatings can be used which will increase power output and reduce threshold current.

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