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Characteristics of Indium-Gallium-Nitride Multiple-Quantum-Well Blue Laser Diodes Grown by MOCVD

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Abstract

Room temperature (RT) pulsed operation of blue (420 nm) nitride based multi-quantum well (MQW) laser diodes grown on c-plane sapphire substrates with lifetimes exceeding 6 hours have been demonstrated. Threshold current densities as low as 12.7 kA/cm^2 were observed for 10x1200 μm lasers with uncoated reactive ion etched (RIE) facets. The emission is strongly TE polarized and has a sharp transition in the far field pattern above threshold.

1. Introduction

Since the report of the first RT pulsed operation of nitride based laser diodes by researchers at Nichia Chemical Industries two years ago [1] a handful of research groups in Japan [2] [3] [4] and recently Cree Research in collaboration with North Carolina State and Brown Universities in the United States havereported pulsed operation, and in the case of Cree, short lived (15 sec) continuous wave (CW) operation [5]. Nichia now reports RT CW operation with lifetimes in excess of 1,000 hours [6]. Despite this significant progress by Nichia and others, the actual lasing mechanism and its relationship to the structural and electrical properties of these materials is not well understood.

2. Experiment

The laser structure shown in Figure 1 was grown on c-plane sapphire using a combination of atmospheric and low pressure MOCVD in a two-flow horizontal reactor. The chemical precursors used were trimethylgallium (TMGa), trimethylindium (TMIn), trimethylaluminum (TMAl), ammonia, bis(cyclopentadienyl)magnesium (Cp2Mg) and disilane.

The lasers facets were formed by Cl_2 reactive ion etching of 125 μm wide mesas of various lengths ranging from 400 μm to 2,000 μm. P-contact stripes were subsequently formed in the center of these large mesas with widths ranging from 3 μm to 20 μm. The n and p-contacts were formed by electron beam evaporation of Ti/Al/Ni/Au and Ni/Au respectively. Fabricated lasers were tested under pulsed operation with a duty cycle of about 0.025%.

3. Results

Figure 2 gives a photo of a 20x400 μm device operating above threshold showing the narrowed far field with some lateral interference due to multi-lateral mode operation. The projected far field pattern narrows abruptly at threshold. Using the central spot the vertical and lateral far-field half-angles were approximately 10° and 3°, respectively, for the 20 μm wide stripe.

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A typical light vs. current (LI) curve is shown in Figure 3. The LI curve shows characteristic super linear behavior. The highest differential efficiency was 1.1%. Output powers of these devices were limited by heating during the pulses. Nevertheless, peak powers as high as 17.6 mW were obtained. Most devices gave outputs in excess of 10 mW. Device yield was well above 50%. The emission above threshold was strongly TE polarized with an extinction ratio in excess of 60 as shown in Figure 4.

Spectra were collected above and below threshold using an optical spectrum analyzer with a resolution of 0.1 nm. A strong, well-defined mode spectrum appears at threshold as shown in Figure 5. The resolution is not sufficient to resolve the expected individual mode spacing for the cavity lengths tested. As a result the width of the observed peaks corresponds to the analyzer resolution. The lasing spectrum does, however, show an envelope modulation with a peak spacing around 0.35 nm similar to that observed by Nakamura et al.[1]. The origin of this modulation is still unclear.

Diodes of different length and stripe width gave a range of threshold current densities as shown in Figure 6, Figure 7 and Figure 8. As indicated the threshold current density decreased for increasing width and length in rough agreement with the expected reduction in cavity loss. With increasing cavity length the threshold current density approaches a minimum, indicating that internal losses (as opposed to mirror losses) dominate the cavity loss. The lowest threshold current density observed was 12.7 kA/cm^2 for a 10x1200 μm laser bar with uncoated facets at room temperature. Devices longer than 1200 μm could not be tested due to limitation in the pulse supply

A lifetime measurement done on a single device gave a lifetime greater than 6 hours. A 10x400μm device was operated pulsed above threshold at a power of 2.6 mW. LI curves taken at intervals during the test are shown in figure 9. Initially the LI curves improve (lower threshold.) This is most likely due to annealing of the contacts and or thermal activation of the p-type dopant due to heating during operation. After 4 hours the threshold current density increases slightly until the device fails catastrophically between 6 and 8 hours due to shorting of the p-n junction.

4. Conclusion

Pulsed operation of 420 nm blue laser diodes with a threshold current density as low as 12.7 kA/cm^2, output powers as high as 17.6 mW and lifetimes in excess of 6 hours are demonstrated. The power output of these devices is limited by heating during pulses. The lasing spectrum shows a "mode like" envelope modulation of unknown origin.

Acknowledgments

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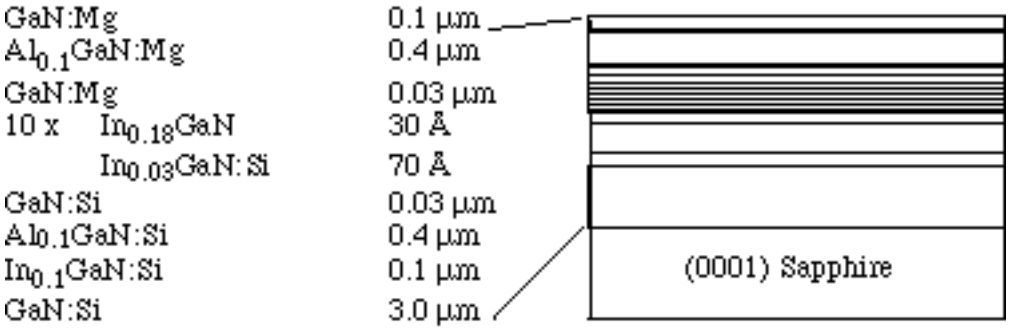

Figure 1. Epitaxial Structure

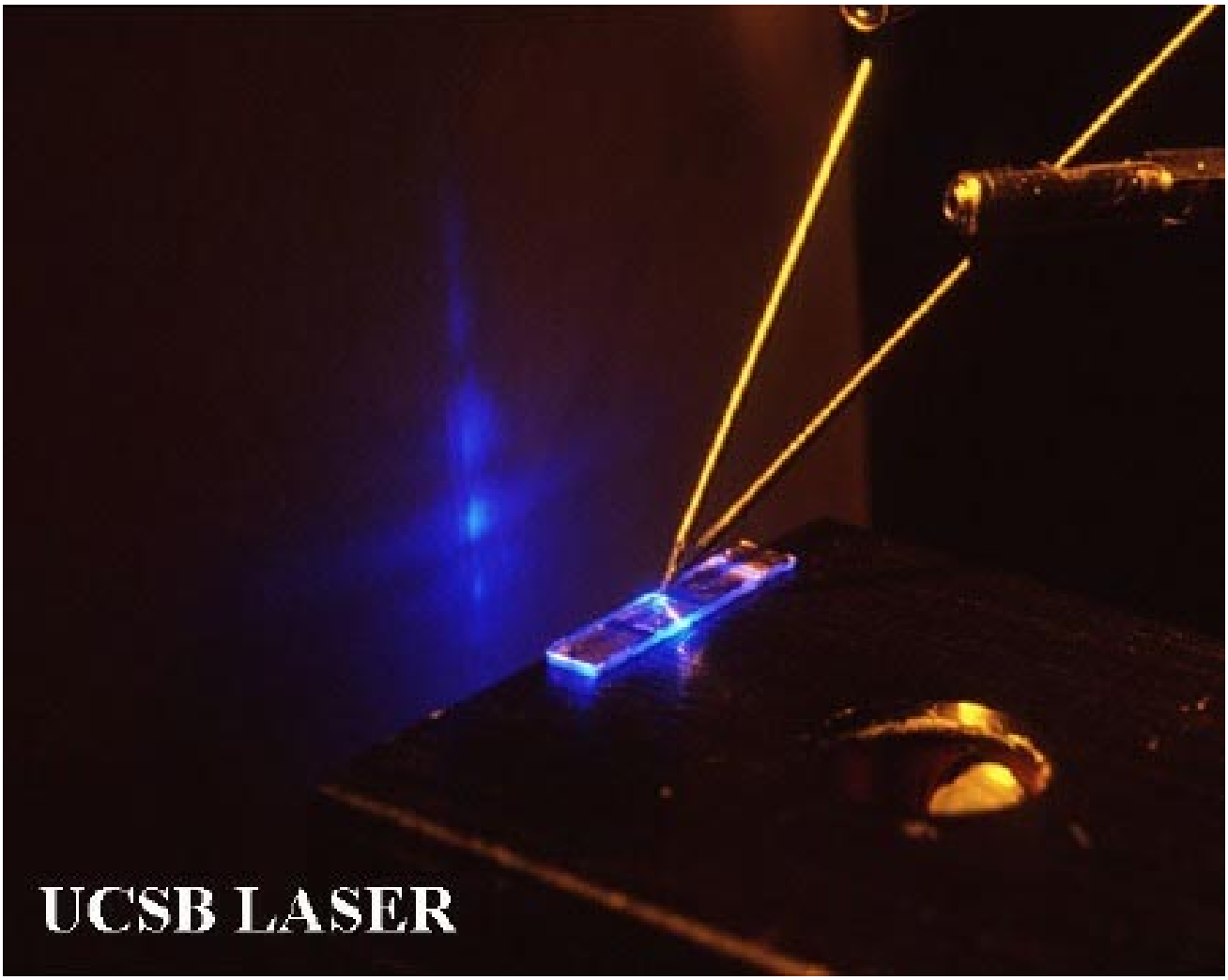

Figure 2. Photo of 20x400 μm device operating above threshold, showing elliptical far-field pattern.

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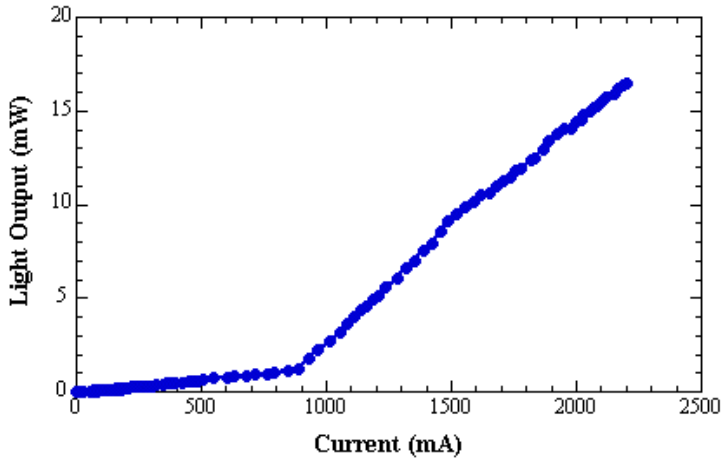

Figure 3. Light vs. current (LI) for 800 μm long device with a 5 μm stripe

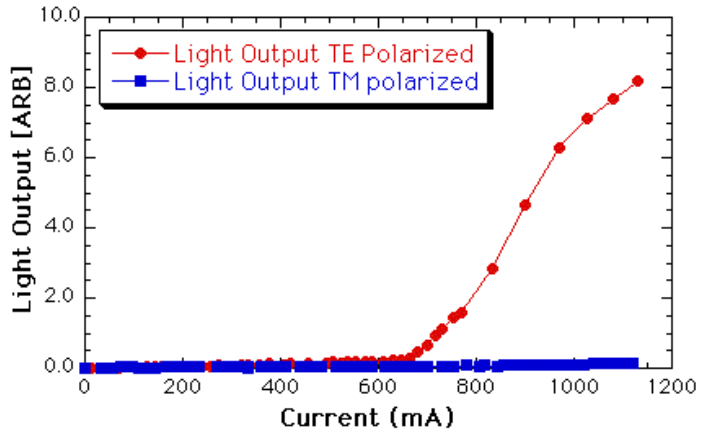

Figure 4. Light vs. Current (LI) with polarizer parallel and perpendicular to junction plane

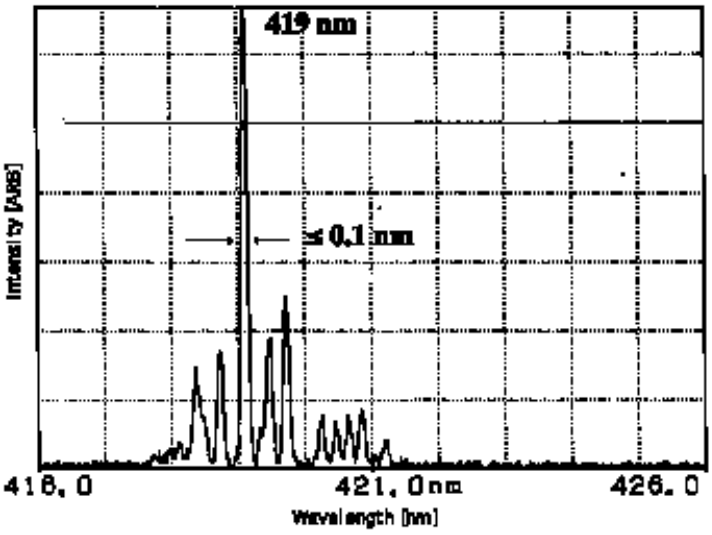

Figure 5. Above threshold spectrum for 400 μm long device with a 5 μm stripe width

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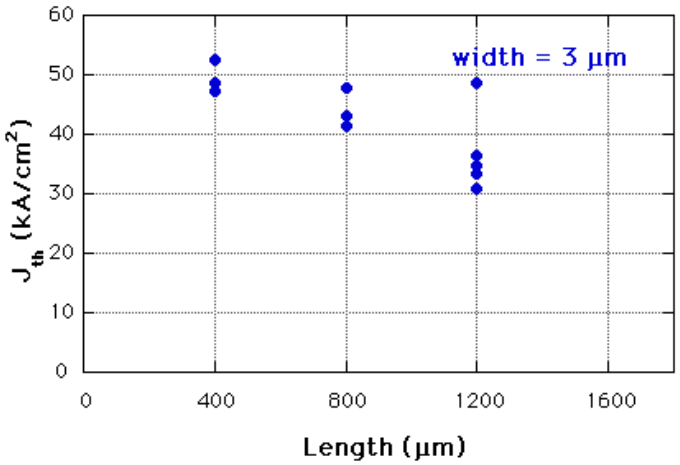

Figure 6. J_{th} vs. laser length for 3 µm stripe width

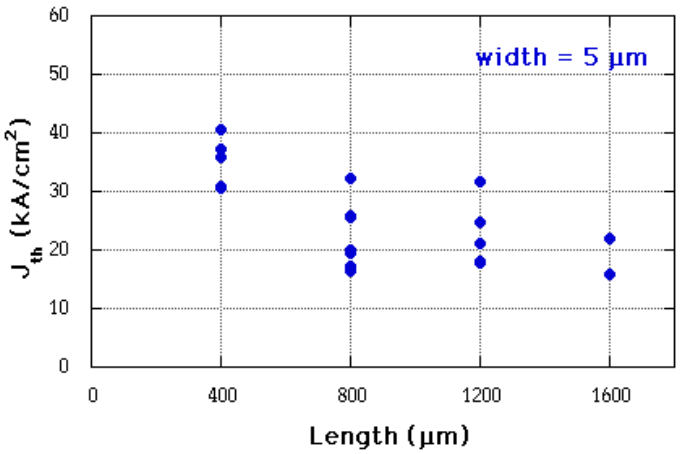

Figure 7. J_{th} vs. laser length for 5 µm stripe width

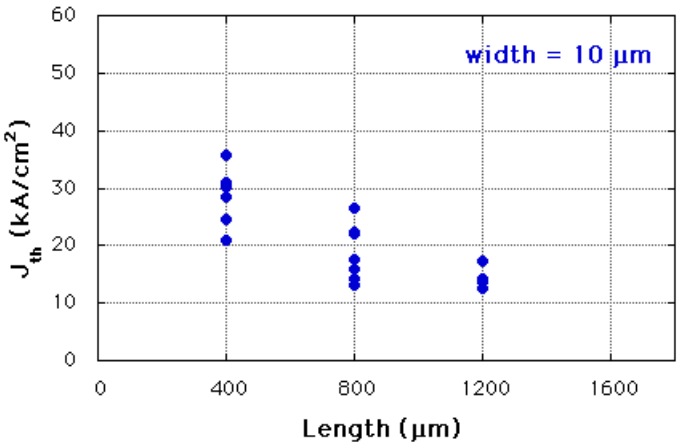

Figure 8. J_{th} vs. laser length for 10 µm stripe width

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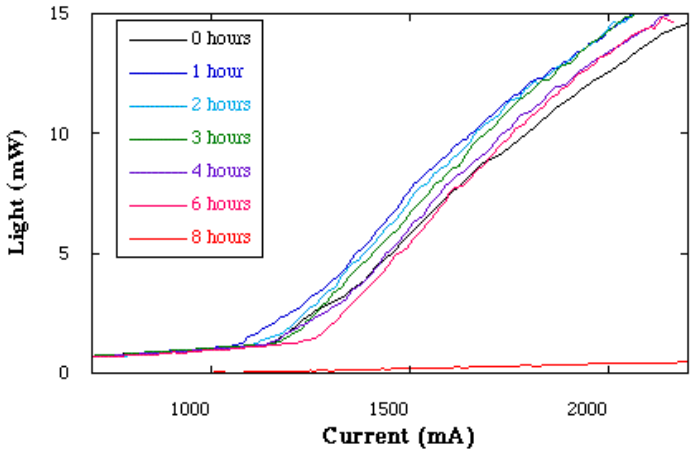

Figure 9. LI curves taken at various time interval during continuous pulsed operation

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