Superluminescence: Pioneering the Future of Visual Excellence in AR/VR Displays

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Abstract

This work presents GaN-based superluminescent devices (SLDs) based on horizontal cavity surface emission architecture in the blue wavelength region, operating under pulsed conditions. Unlike traditional lasers, these devices minimize speckle, enhancing visual clarity and precision. The surface emission architecture reduces optical complexity and packaging costs, enabling scalable power through arraying. Key performance metrics, including spectral linewidth, output power, efficiency, and far-field divergence, will be discussed in the context of AR/VR display applications.

Author Keywords

AR/VR displays; Horizontal cavity surface emission architecture; Scalable power; Speckle-free emission

1. Introduction

Efficient, high-power light emitters with low etendue, low speckle, and broad spectra are essential for applications in displays, spectroscopy, and measurement. While lasers offer high power and low etendue, they suffer from speckle, and LEDs struggle with coupling efficiency. Superluminescence occurs when high carrier density in a waveguide generates amplified spontaneous emission with suppressed optical feedback [1, 2], producing light with spatial coherence and broad spectral width. The emitted power depends on carrier density, modal gain, waveguide loss, and length, with superluminescence offering a higher spontaneous coupling factor (~10^{-3}) than lasers due to its broader spectral content. At high current densities, SLDs can achieve efficiency comparable to lasers, outperforming LEDs. This study investigates blue-emitting SLDs, first in edge-emitting and then in surface-emitting configurations.

2. Comparison of edge and surface-emitting SLD

This study investigates the suppression of optical feedback in superluminescent diodes (SLDs) using shaped waveguides and angled facets (Figure 1). Edge-emitting SLDs with 2.5 µm ridge waveguides and 7° angled facets were fabricated from a multiple quantum well structure. Blue SLDs showed spectral breakdown after threshold due to partial feedback, likely due to strong substrate absorption. To improve blue SLD performance, substrate-emitting SLDs based on InGaN quantum wells were developed, integrating 45° angled facets to prevent light feedback and improve stability [3]. Advanced etching and AR coating techniques were used for bottom surface emission.

Figure 2 shows the spectral evolution of 1 mm and 1.5 mm long bottom-emitting SLDs under pulsed operation. The superluminescent threshold occurs at 300 mA (~10 kAcm^{-2}), and the operational voltage ranges from 6 V to 8 V. Characterization of the SLDs took place under pulsed operation, employing a 220 ns pulse length and a 1% duty cycle. Under these conditions, the two emitting apertures yielded a maximum peak power of 2.2 W with a driven current of 1.5 A (~50 kA cm-2).

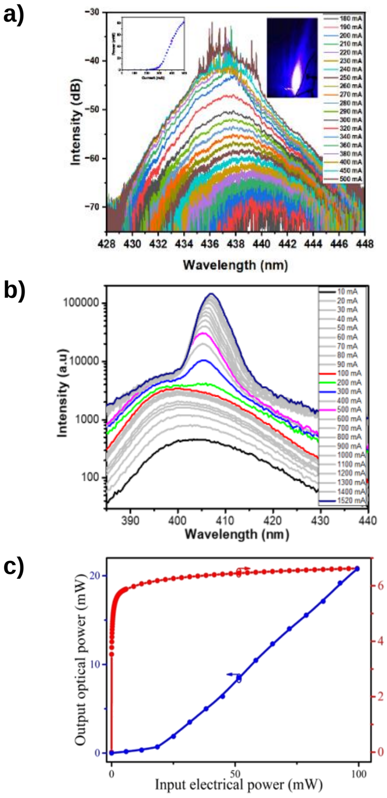

Figure 2. a) Spectral characteristics of blue edge emitting SLDs under pulsed operation (1%). b) Spectral evolution of substrate emitting SLD. c) L-I-V characteristic of substrate emitting SLD.

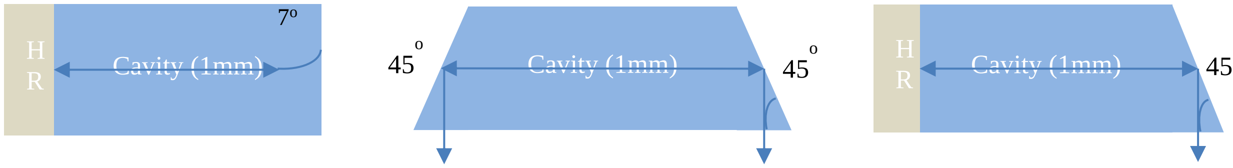

Figure 1. Concept for edge emitting SLD with 7º tilted waveguide (left), concept for surface emitting SLD with two output beams (middle) and single output beam (right).

Throughout the superluminescent regime, the spectrum remains smooth and broad. The increase in the noise floor correlates with the intensity escalation, attributable to the implementation of a filter aimed at preventing spectrometer saturation.

3. SLD vs LD on Computer Generated Holograms

In collaboration with University College London, a 405 nm SLD was used in a holographic setup to capture a Computer-Generated Hologram (CHG) image, offering superior contrast and image quality compared to a commercial LD (Figure 3). The SLD's low temporal coherence and speckle-free emission reduce artifacts (Figure 4), while its high spatial coherence ensures sharp, focused holograms over long distances.

4. Conclusion

We have demonstrated GaN-based horizontal-cavity, surface-emitting superluminescent diodes that operate in the blue wavelength region, positioning them as promising candidates for next-generation display technologies. These devices offer high optical output power, a wide spectral range, and speckle-free emission, making them particularly well-suited for augmented reality and advanced holographic display systems. The epitaxial design and cutting-edge surface-emitting architecture, along with the integration of ridge waveguides and 45-degree total internal reflectors, enhance light extraction efficiency and ensure high output power. Our findings underscore the potential of GaN-based SLDs to transform optoelectronic applications, especially in the realm of 3D visualization.

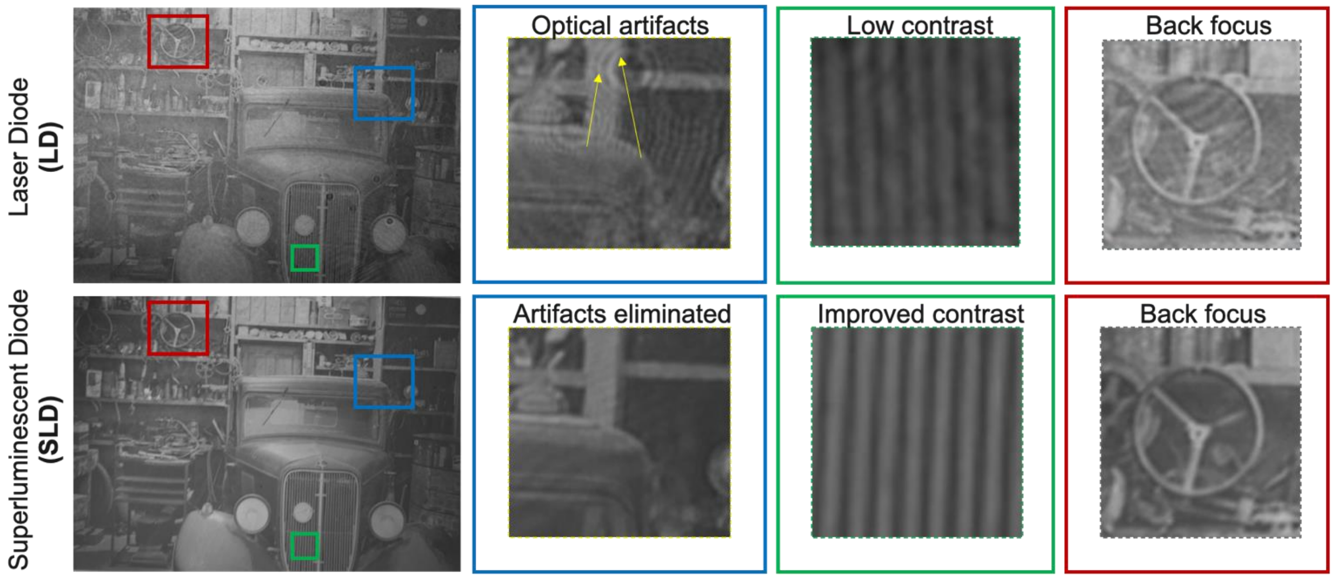

Figure 3. Hologram generated using a commercial LD and using Vivid's SLD. SLD shows higher contrast, minimal optical artifacts in comparison with commercial LD.

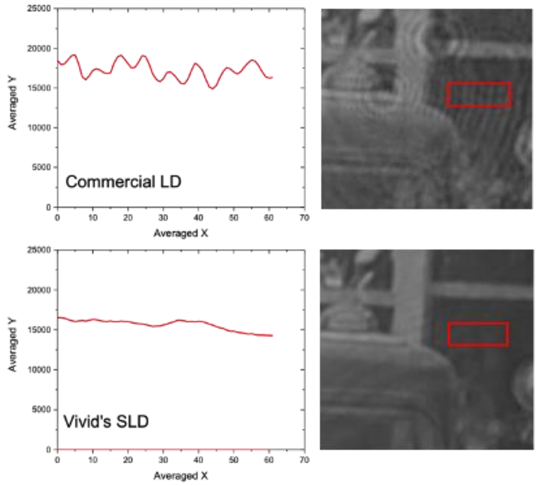

Figure 4. The circular oscillations with LD likely represent interference fringes or diffraction patterns caused by dust, which are mostly eliminated with SLD.

5. Acknowledgement

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6. References

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