Single-Output InAs Quantum Dot DFB Laser Using Integrated MMIR for Photonic Applications

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***Abstract*—We present monolithically integrated InAs-QD DFB lasers with a high-reflectivity multimode interference reflector (MMIR) for single-facet emission. The devices demonstrate stable single-mode operation at 1310 nm with high SMSR in range of 46 dB, validating suitability for scalable photonic integrated circuit applications.**

Keywords: InAs-QD, DFB, MMIR, PICs, monolithic integration

I. INTRODUCTION

Distributed feedback (DFB) lasers are essential building blocks in photonic integrated circuits (PICs), offering single-mode operation, narrow linewidth, and compact form factors. For integrated applications that demand efficient on-chip light sources, achieving high output power from a single facet with minimal fabrication complexity is a key design goal. Conventional single mode DFB laser designs typically require an intra-cavity phase shift or high-reflectivity (HR) coating on one facet and anti-reflective (AR) coating on the other, the latter approach to also control feedback and output directionality. However, these coating steps introduce added fabrication complexity and cost, and are often incompatible with monolithic integration.

To overcome these limitations, we present a novel InAs quantum dot (QD) DFB laser design incorporating a monolithically integrated high-reflectivity mirror using a multimode interference reflector (MMIR) [1]. The MMIR replaces traditional facet coatings and is implemented at one end of the DFB cavity to enable unidirectional emission from a single output, which in the integrated structure will naturally be low reflectivity. Together this then replicates the HR/AR coatings of a conventional DFB chip for the integrated format. MMIRs are based on simple multimode interference (MMI) structures, where two 45° etched reflectors are positioned at half the self-imaging length (L/2) within the MMI section, forming a compact and highly reflective mirror [1]. This configuration yields reflectivities on the order of 90% while maintaining fabrication simplicity and compatibility with standard lithographic and etching processes.

This architecture provides strong feedback from the integrated MMIR and eliminates the need for cleaved or coated facets. Combined with a tapered waveguide to suppress back-reflection and ensure smooth mode transition, the design achieves efficient, unidirectional lasing with reduced threshold and high slope efficiency. This makes it well-suited for scalable, low-cost PIC applications, especially in silicon photonics platforms where integration and manufacturability are critical. The MMIR operating principle and the simulation methodology used to analyze its performance is detailed in [1].

In this work, we focus on the design, fabrication, and characterization of InAs QD MMIR-DFB lasers to experimentally demonstrate a compact, monolithically integrated laser source with single-facet emission. The goal is to validate the MMIR approach as a practical and scalable solution for realizing efficient, unidirectional DFB lasers suitable for integration in photonic circuits. Through optical and structural characterization, we assess the performance of the fabricated devices and confirm the effectiveness of the MMIR in providing high reflectivity without adversely affecting the DFB performance.

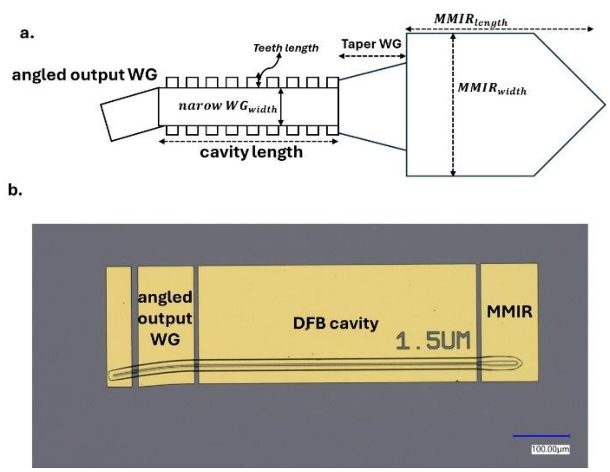

Fig. 1: a. Schematic of the MMIR-integrated DFB laser design. b. Microscope image of the fabricated device structure.

II. LASER DESIGN

The epitaxial structure is grown on a GaAs substrate and comprises multiple layers of InAs QD embedded within InGaAs quantum wells (7xDWELL structure), offering strong carrier confinement and efficient optical gain around 1.3 µm. This active region is enclosed by n-type and p-type AlGaAs cladding layers for effective electrical and optical confinement.

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The device design is based on the conventional κ-method [2] and was simulated using FIMMWAVE software from Photon Design. As illustrated in Fig. 1(a), the structure incorporates a monolithically integrated deep-etched MMIR with over 90% reflectivity on one facet. A tapered waveguide is implemented between the MMIR and the DFB cavity to minimize back-reflection and facilitate smooth mode transition. We explored DFB designs with various cavity lengths and ridge widths of 1.5, 2, and 2.5 μm, resulting in κ·L values between 1.6 and 28. Results here are for a 1 mm-long cavity with a 1.5 μm-wide waveguide. High κ·L leads to an increased threshold current but with improved mode selectivity and the range of values was chosen to explore the trade-off in compensating for potential optical losses caused by sidewall roughness in the deeply etched waveguide. A third-order grating with a 200 nm tooth length (0.75 μm pitch for a central wavelength of 1.31 μm) was used across all devices to suppress higher-order modes and improve fabrication uniformity. A reduction on the tooth length helps improve the etch depth uniformity by reducing aspect ratio dependent etching effects in typically high aspect ratio structures. The output facet is angled at 10° to reduce reflections, as shown in the scanning electron microscope (SEM) image in Fig. 2, which also highlights the DFB grating structure.

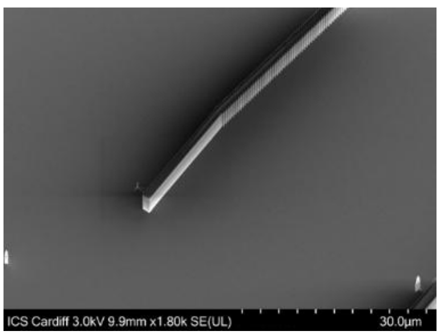

Fig. 2: Scanning electron microscope (SEM) image of the fabricated device, showing the 10°-angled output facet designed to minimize back-reflections, along with the etched DFB grating structure.

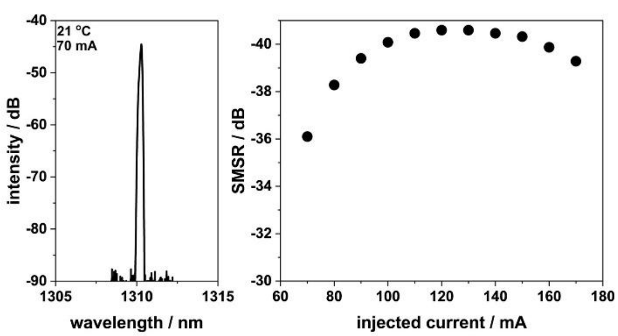

Fig. 3: (Left) Optical spectrum of the MMIR-DFB laser at 21 °C near threshold, showing a lasing wavelength at 1310 nm with an SMSR of 46 dB. (Right) SMSR as a function of injection current measured at 25 °C, demonstrating stable single-mode operation

III. RESULTS

The fabricated MMIR-DFB laser was characterized using pulsed current injection with a 0.5% duty cycle. All measurements were performed under controlled temperature conditions.

At a substrate temperature of 21 °C, the laser demonstrated a threshold current of 66 mA. The corresponding emission spectrum, shown in Fig. 3 (left), reveals a lasing peak at 1310 nm with a side-mode suppression ratio (SMSR) of 46 dB, confirming stable single longitudinal mode operation. The narrow linewidth and strong mode selectivity are attributed to a relatively high κ·L value and effective unidirectional feedback provided by the integrated MMIR.

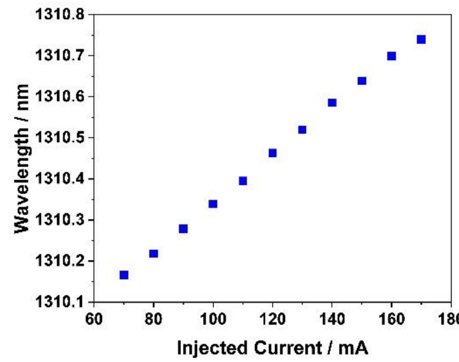

Fig. 4: Peak lasing wavelength as a function of injection current measured at 25 °C.

To evaluate spectral purity across different operating currents, SMSR was measured as a function of drive current at 25 °C. As shown in Fig. 3 (right), the SMSR remains consistently high, with values in the range of 41 dB from threshold up to 170 mA.

The wavelength tuning characteristics were also investigated by measuring the peak lasing wavelength as a function of injection current. Fig. 4 shows a total wavelength shift of approximately 0.57 nm across the current range of 70 mA to 170 mA.

To summarize, the results presented here and similar results on devices of the same design confirm that the proposed MMIR-DFB structure achieves efficient single-facet emission, high spectral purity, and stable lasing performance, meeting key requirements for scalable integration in photonic integrated circuits. Results for the other design variations and further characterisation of the MMIR-DFB lasers will be presented at the conference.

ACKNOWLEDGMENT

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