2023 IEEE Photonics Conference (IPC) | 979-8-3503-4722-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/IPC57732.2023.10360650

Multi-Mode Interference Reflector for Integrated Photonics

F. T. Albeladi [1, 2], S. Gillgrass [1], J. Nabialek [1], P. Mishra [1], R. Forrest [1], T. R. Albiladi[1,3], C. P. Allford [1], S. Shutts [1] ,
and P. M. Smowton [1]

1. School of Physics and Astronomy, Cardiff University, The Parade, Cardiff. CF24 3AA. UK.
2. Physics Department, Faculty of Science, University of Jeddah, Jeddah 21589, Saudi Arabia
3. Physics and Astronomy Department, Faculty of Science, King Saud University, Riyadh 11451, Saudi Arabia
AlbeladiFT@Cardiff.ac.uk; SmowtonPM@Cardiff.ac.uk

Abstract— **1-port and 2-port InAs-QD MMIR lasers are designed, fabricated, and characterized. MMIRs laser have lower threshold current densities compared to cleaved-cleaved FP lasers with the same cavity length, up to 40% less. They are promising for use in optoelectronic-integrated circuits.**

Keywords—lasers, quantum dots, photonic integration

I. INTRODUCTION

Extremely sophisticated photonic integrated circuits are now reported almost daily, and generic platforms in a variety of materials platforms contain very large numbers of basic building blocks and facilitate sophisticated designs and functionality. Fewer platforms contain on-chip laser sources as a standard offering. Here we examine the Quantum Dot (QD) III-As system grown epitaxially on silicon and specifically examine the value of specific reflective components and the benefits they bring for this potential integration platform. For QD lasers the mirror loss can significantly impact the laser's performance, affecting its threshold current, temperature dependence and overall efficiency so careful selection of reflector type is essential to maximize performance and minimize heat generation on chip. Mminimizing mirror loss in QD lasers can also significantly enhance reliability.

Various reflector types have been proposed to ensure the effectiveness of integrated lasers in monolithic photonic integrated circuits. These include etched facets, distributed feedback (DFB) elements, deep-etched Distributed Bragg Reflectors (DBRs), and loop mirrors. Each option has its advantages and disadvantages. Although deep-etched DBRs and DFB can achieve high reflectivity, integrating them with other building blocks complicates the fabrication process, requiring a high level of process control to achieve the desired reflection/transmission ratio. Furthermore, to reduce bend loss loop mirrors have a considerable chip footprint, usually measured in millimetres.

Here we focus on multimode interference reflectors (MMIR) and will examine their performance using the structures shown in Figure 1. These broadband reflectors work on the same principles as MMIs [1] and have been introduced for the InP integration platform [2]. We will demonstrate the enhanced benefits obtained with QD structures. Devices comprise a multimode imaging section and an angled reflector positioned at single or dual imaging points. In the case of a symmetric structures MMIR reflectivity is about 100% for 1x2MMI (laser A) and 50:50% for 2x2 MMI (Laser B) , providing no extra loss is introduced by the corner reflector (see Figure 1). In this work, we designed, fabricated, and characterised MMIRs integrated with a cleaved facet reflector and compared this to cleaved-cleaved Fabry-Perot lasers (FP laser). MMIRs have a significant advantage in their ease of fabrication. They tolerate variations in device length and width and are made using the same process steps as the waveguide. Additionally, the MMIR device has low waveguide loss and is unaffected by changes in wavelength or polarisation. As a result, MMIRs are an excellent option for on-chip waveguide mirrors used in laser cavities.

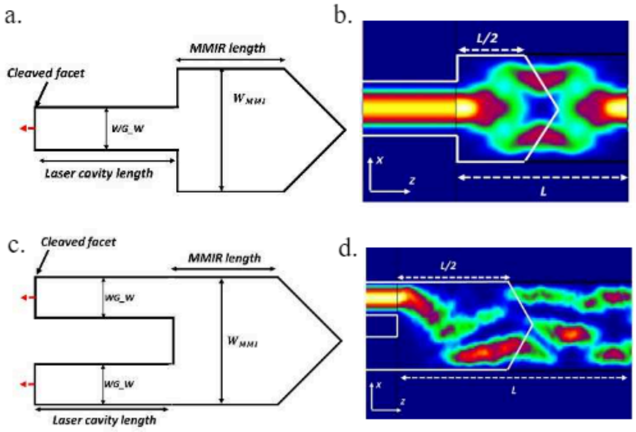

Figure 1: Schema of the MMIR laser a.1xMMIR laser (Laser A) and c. is 2xMMIR laser (laser B), b and d. Operation principle: field distributions simulation of 1x2 MMI and 2x2MMI with the position of two superimposed angled facets marked. We implement with one cleaved facet to simplify analysis of the performance of the MMIR reflector, but this would not be used in the integrated structures.

II. RESULTS

MMIR reflector elements pose a challenge for simulation due to omnidirectional propagation. However, using perfect mirrors, simulating equivalent geometry becomes possible through bidirectional and unidirectional methods. The simulation method is fully explained in [3], which also reports simulation and basic device results. By optimising the size of the multimode interference section (MMI), we achieved a mirror reflectivity of over 85% at a desired operating wavelength of

979-8-3503-4722-7/23/$31.00 ©2023 IEEE

1310 nm at 45° mirror angle. This high reflectivity was maintained within a wavelength range, from 1260 to 1380 nm.

InGaAs-InAs QD MMIR 3 um wide Ridge Waveguide (RWG) lasers have been fabricated using a 6 and 8-µm MMI section width for laser A and B respectively; both had etched faces mirror at a 45° angle to the normal and cleaved facet mirrors at the opposite end of the device. Figure 2 a. illustrates the fabricated MMIR laser, with a plan view SEM image depicting a section of the 3um ridge covered in metal and the short and slightly wider MMIR section; the angled mirror section of the MMIR is pictured in Figure 2 b.

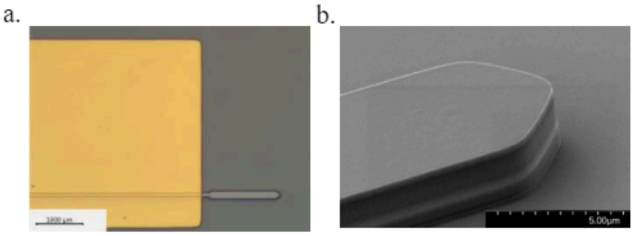

Figure 2: a. Optical microscopic image of InAs QDs based MMIR laser, b. FE-SEM micrograph of zoomed area of MMIR.

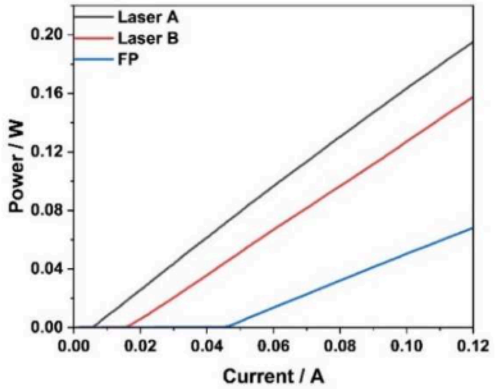

Figure 4: Pulsed P-I curves for 1-port (A), 2-port (B) MMIR lasers and a 1mm long two-cleaved-facet FP laser at 25°C, (Laser B's cavity length is split into two 0.5 mm output waveguides, totaling 1 mm.)

According to Figure 3, MMIR lasers exhibit a more than 40% decrease in threshold current compared to FP lasers of equal cavity length. The differential efficiency of the single-facet laser for Laser A has been enhanced by approximately 1.9 times that of an FP laser at room temperature.

In Figure 4 a, the threshold current density of lasers A and B are compared to FP laser at different temperatures. The MMIR lasers (A and B) exhibit a lower threshold current temperature dependence than ridges of the same length, thanks to the lower mirror loss they provide. Furthermore, the MMIR lasers have a significantly lower absolute threshold than the FP laser with the same cavity length.

According to Figure 4 b, MMIR lasers A and B operate on the QD ground state, which has a wavelength of approximately 1300 nm, using a cavity length of 0.5 mm. On the other hand, FP lasers require a longer cavity length of 1 mm and operate on the excited state, which has a wavelength of approximately 1200 nm, even under low-temperature conditions of 15°C.

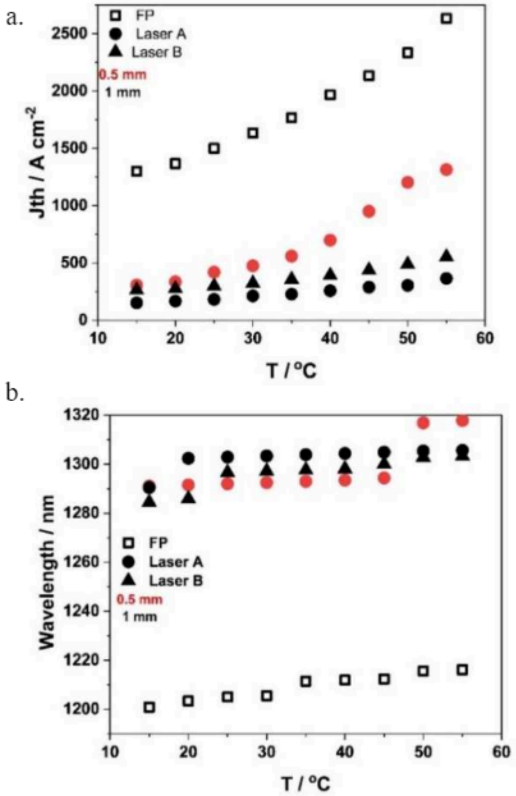

Figure 3: a. Current density for MMIR (A and B) and FP lasers as function of temperature, b. Lasing wavelength at 1.1xIth for MMIR and FP-RWG lasers, for 0.5 mm (red) and 1mm (black) length

To summarise, the reduced optical loss of MMIR structures are particularly effective in QD lasers in reducing threshold current density and maintaining operation at the ground state. We also discuss the lateral mode filtering effect in MMIR lasers which means slightly wider ridges can be used while maintaining single mode operation. We examine MMIRs used as simple reflectors (laser A) and as the reflectors/splitter (laser B). We demonstrated their effectiveness in lasers, which can be paired with simple etched facets or other reflector elements in integrated circuits for use as on-chip mirrors. The compact format lasers perform better than simple FP-RWG devices.

REFERENCES

[1] Soldano LB, Pennings ECM (1995) Optical multi-mode interference devices based on self-imaging: principles and applications. Journal of Lightwave Technology 13:615-627 doi: 10.1109/50.372474J.

[2] E. Kleijn, M. K. Smit and X. J. M. Leijtens, "Multimode Interference Reflectors: A New Class of Components for Photonic Integrated Circuits," in Journal of Lightwave Technology, vol. 31, no. 18, pp. 3055-3063, Sept.15, 2013, doi: 10.1109/JLT.2013.2278187.

[3] Albeladi, F., Gillgrass, S.J., Nabialek, J., Mishra, P., Forrest, R., Albiladi, T., Allford, C.P., Deng, H., Tang, M., Liu, H. Shutts, S., and Smowton, P.M., 2023. Design and Characterisation of Multi-Mode Interference Reflector Lasers for Integrated Photonics. Journal of Physics D: Applied Physic.

Device fabrication was carried out in the cleanroom of the European Regional Development Fund (ERDF)-funded Institute for Compound Semiconductors (ICS) at Cardiff University. EPSRC funded Future Compound Semiconductor Manufacturing Hub: reference EP/P006973/1 and EPSRC funded QUDOS Programme Grant EP/T028475/1 provided essential resources for this study.