Multi-mode Interference Reflector based InAs-QD Laser

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Abstract – InAs quantum dot multi-mode-interference-reflector (MMIR) lasers, based on a 1-port MMIR and a single cleaved reflector, are designed, fabricated, and characterized to demonstrate capability for optoelectronic-integrated-circuits. Threshold current densities are less than 40% of those in cleaved-cleaved ridge waveguide lasers of the same cavity length.

I. Introduction

In photonic integrated circuits, reflective component are an important element, being essential in lasers. In III-V photonic integrated circuits they are often created by cleaved facets, deep etched Distributed Bragg Reflectors (DBRs) or loop mirrors. Each of these reflector types has its merits and drawbacks. For cleaved facets, the inaccuracy of cleaving position (±10 µm) causes uncertainty in the cavity length and to obtain high reflectivity the facet must be coated, which introduces extra non-trivial process steps. Of course, cleaving is generally not compatible with large monolithic optoelectronic integrated circuits. Deep-etched DBRs can be used, with only a few grating periods to achieve high reflectivity, but generally require e-beam lithography. Integrating DBRs with other components also adds complexity to fabrication, requiring a high level of process control to achieve the desired reflection/transmission ratio in the DBRs while maintaining the performance of other components.

The 1-port multi-mode-interference reflector (MMIR), shown in Fig 1 [1], has in principle low loss (~ 0.1 dB) and is relatively insensitive to wavelength and polarization [1]. The device is based on a 1 x 2 multi-mode-interference (MMI) coupler, but instead of output waveguides it has two 45° mirrors forming the MMIR, whereby total internal reflection occurs and the light is imaged back on the input waveguide. Similar to MMIs, MMIRs show high fabrication tolerances, polarization insensitivity and operation over large wavelength ranges. Furthermore, they are relatively easy to fabricate as the technology only has to support deep-etched waveguides with reasonably vertical sidewalls.

In this work we describe the modelling and design, fabrication and characterization of MMIR lasers based on InAs QDs grown on GaAs as a means to qualify the performance of these reflectors.

(a) (b)

Figure 1: operation principle: (a) field distributions simulation of a 1×2 MMI (b) the light reflectivity to the input waveguide due to positioning 45° mirrors[1]

II. Results

Due to the reflector element in MMIRs, the propagation inside the devices is omnidirectional. As a result, some of the simulation methods suitable for MMIs cannot be directly applied. If the mirrors are assumed to be perfect, then an equivalent geometry can be found that can be simulated using bidirectional and unidirectional methods.

By dividing the MMIR into parts and selectively applying either the Eigenmode expansion (EME) or Finite Difference Time Domain (FDTD), both the speed of EME and the omnidirectionality of FDTD are exploited using the commercially available Photon Design software. Fig 2 illustrates how the device is partitioned.

This approach was used to optimize an InAs QD laser with a deep etched waveguide, the MMI length optimized at 45.75um as shown in Fig 2 (b), then by using FDTD (OmniSim software) the mirror reflectivity has been simulated as a function of mirror angle and wavelength, as shown in Fig 2 (c). The mirror has maximum reflectivity at 50° at a desired operating wavelength of 1.31 um. High reflectivity (>85%) is obtained over a wide wavelength range between 1.26-1.38um.

To fabricate InGaAs-InAs QD MMIR lasers we used a 6um MMI width terminated with etched faces at either 45° or 50° to the normal and integrated with a single cleaved edge reflector with 3um waveguide width. One of the fabricated devices is pictured in Fig 3a, with a plan view SEM image showing a section of the 3um wide ridge covered in metal and the relatively short and slightly wider MMIR section. The angled end section of the MMIR is shown in Fig 3b. The MMIR lasers typically show more than 40% lower threshold current for the same cavity length compared with FP lasers (see Fig 3 (c)). The single facet laser differential efficiency is improved by around 75% (to 60%) for 0.5 (1mm) cavity length at room temperature.

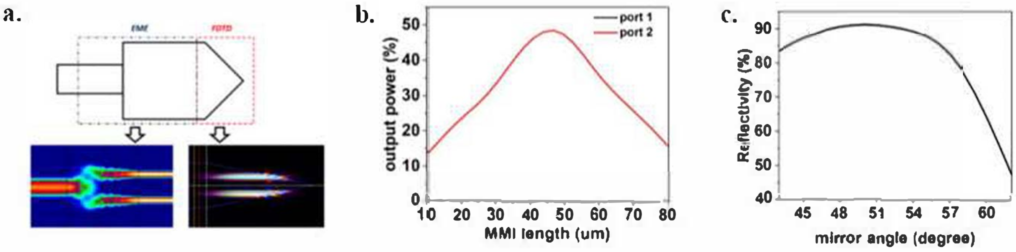

Figure 2: a. The MMIR is divided into two parts: The first part is simulated using EME. The field is then stored and launched into an FDTD simulation, the output field of the FDTD is launched in a EME simulation. The overlaps with the access waveguide modes are then calculated to obtain device reflection and transmission coefficients b. MMI output power as a function of MMI length, c. MMIR reflectivity as function of mirror angle.

The threshold current density for different cavity lengths is plotted in Fig 3d as a function of temperature and the lower mirror loss afforded by the MMIR leads to a lower threshold current temperature dependence for the MMIR lasers as compared to ridges of equivalent length as well as the lower absolute threshold.

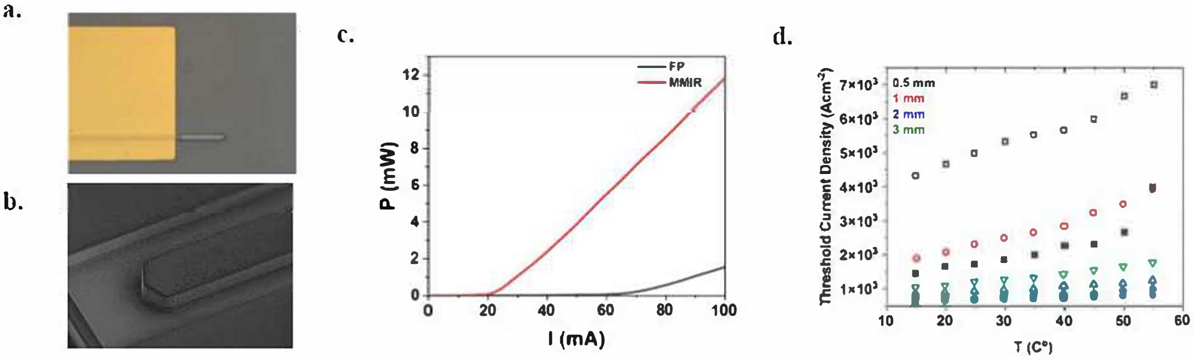

Figure 3: a. Optical microscopic image of InAs QDs based MMIR laser, b. FESEM of zoomed area of MIR c. P-I curves for MMIR and Fabry Perot 1 mm cavity length Lasers, d. current density for MMIR and FP laser for 0.5, 1, 2 and 3mm cavity length as function of temperature (open dots is FP and full dots is MMIR)

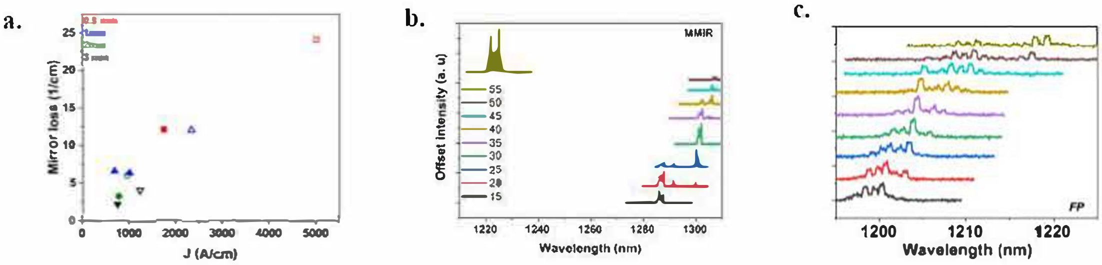

Figure 4. a) calculated mirror loss as a function of measured threshold current density; (open dots is FP and full dots is MMIR) b) Lasing spectra for MMIR and c) FP RWG lasers as a function in temperature for 0.5 mm cavity length.

In Fig 4a we plot the mirror loss calculated for each MMI and RWG laser as a function of threshold current density, which if the internal optical loss is the same for the two mirror types should result in a single gain-current like curve. This is broadly true within the measurement uncertainties with, if anything, the MMIR lasers outperforming expectations. In figure 4b and 4c we compared the measured spectra for 0.5mm MMIR and RWG lasers demonstrating the MMIR laser operating on the QD ground state (around 1.3um) for temperatures up to 50°C whereas the FP-RWG lasers of similar length operate on the excited state of the dot distribution in the range of 1.200 um,

In summary, we achieved high reflectivity on-chip reflectors with a single waveguide etch step, which can be flexibly positioned anywhere in the circuit and with high fabrication tolerances with respect to the length and width. To avoid ambiguity the reflectors were demonstrated here in lasers where the other mirror is a cleaved facet and will be used with simple etched facets or other reflector elements in integrated circuits. Lasers outperformed simple FP-RWG devices with operation on the quantum dot ground state up to 50° C.

III. References

[1] L. Xu et al., "MMI-reflector: A novel on-chip reflector for photonic integrated circuits," in 2009 35th European Conference on Optical Communication, 20-24 Sept. 2009 2009, pp. 1-2.