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Multi-Mode Interference Reflector InAs-QD Mode-Locked Laser for Integrated Photonics

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***Abstract*—We demonstrate on-chip colliding pulse mode-locked lasers that integrate high-reflectivity MMIRs on an InAs-QD platform. Such lasers offer benefits such as improved mode locking with simplified device fabrication through a single-step deep-etch waveguide process, suitable as on chip short pulse sources.**

Keywords—Mode lock, QD, MMIR, Integrated Photonics

I. INTRODUCTION

Mode-locked lasers (MLLs) are sources of ultra-short, stable optical pulses that have a wide range of scientific and technological applications, such as optical clocks, medical diagnostics, environmental monitoring, and advanced optical communication systems. MLLs can also generate frequency combs, which are sets of equally spaced spectral lines that can be used for precise measurements. However, the integration of MLLs as sources for more complex photonic integrated circuits is limited by conventional narrow-band mirrors such as distributed Bragg reflectors (DBR) and loop mirrors. These mirrors, while providing high reflectivity, suffer from constraints in bandwidth and integration complexity and performance is limited compared to cleaved mirror FP- MLLs [1]. This work addresses these challenges by focusing on the use of Multi-Mode-Interference Reflectors (MMIRs) as wide-band mirrors.

The use of MMIRs offers the promise of improved on-chip MLL sources by minimizing cavity loss and maximizing intracavity power to enhance MLL efficiency and stability. By combining high reflectivity MMIRs with Quantum Dot (QD) material, the interplay between gain and Saturable Absorption (SA) in generating MLL pulses benefits from the advantageous properties of QD media, such as gain bandwidth, gain and absorption recovery time, saturation fluence of the absorber section, and a low threshold current. Simulations of QD-MLL indicate that a broader gain spectrum can result in shorter pulses, even in cases where the gain spectrum is not the primary factor affecting pulse duration [2].

In this work we investigate MMIRs [3-5] as wideband mirrors for on-chip QD-MLL sources, which require only a single deep etch fabrication step [3-5]. We demonstrate InAs-QD MMIR lasers, where the high reflectivity is particularly advantageous, with lower threshold current than FP ridge lasers with the same cavity length e.g. 6-mA compared to 46-mA. The threshold current density of the 1-mm MMIR laser is equivalent to the FP-laser with a 3-mm cavity length [5].

We choose to use two types of MMIRs, where the single-port 100% reflective MMIR acts as a transverse mode filter to maintain a single spatial mode and the 50:50 reflective two-port MMIR provides the output signal. The MMIR laser structure is illustrated in Figure 1. The MMIRs are designed with different spectral reflectance (see Figure 1b) so that they produce a broad reflectivity bandwidth for the cavity when combined.

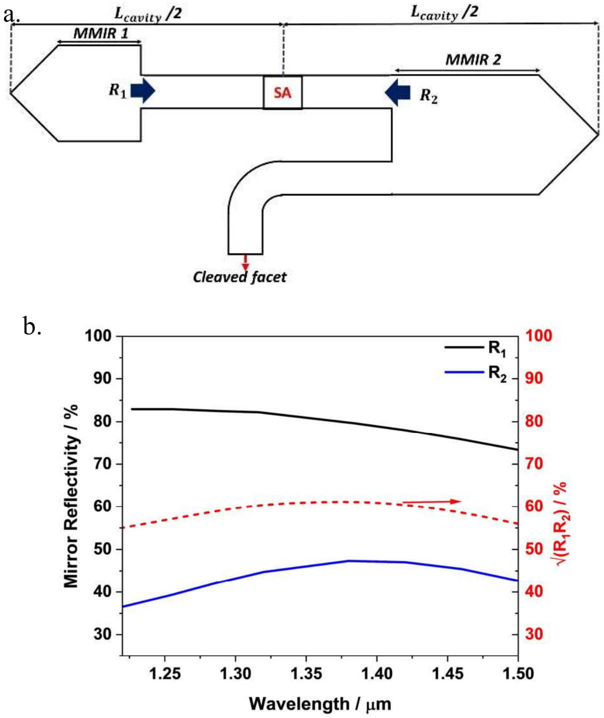

Figure 1: a. Schema of colliding pulse QD-MMIR MLL with a combination of one-port and two-port MMIRs. The cleaved output facet is used here to measure performance. b. The reflectivity of the InAs-QD MMIRs and the resulting cavity reflectivity. The cavity reflectivity is calculated using the formula: $R_{cavity} = \sqrt{R_1R_2}$, where R_1 and R_2 are the reflectivities of the MMIRs.

II. RESULT

The InAs-QD MLL, shown in Figure 1a, has a total cavity length of 6 mm, with a 600 µm long SA section. The total cavity length of 6 mm resulting in an expected fundamental cavity-free spectral range (FSR) of approximately 6.6 GHz. Configuring the MLL with the SA section positioned at the center of the cavity allows for the possibility of achieving colliding pulse mode-locking, effectively doubling the repetition frequency to 13.2 GHz.

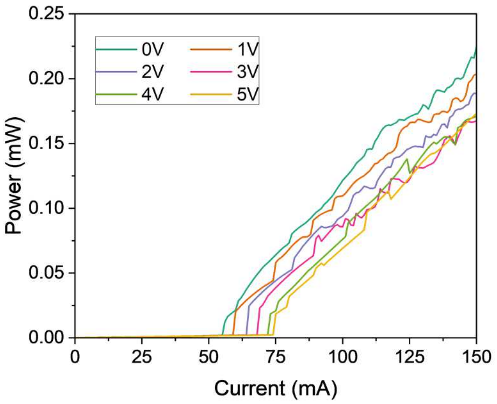

Figure 2: Light-Current characteristics of the colliding pulse MLL with varying SA reverse bias.

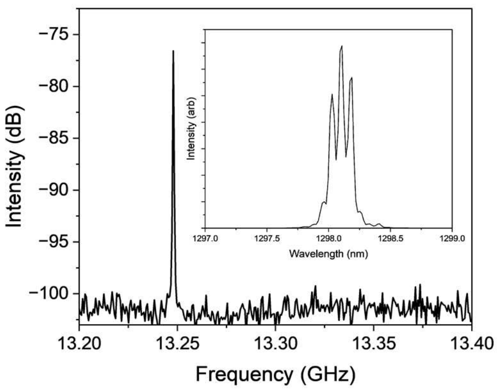

Figure 3: MLL electrical spectrum showing colliding pulse mode-locking repetition rate of 13.248 GHz and optical spectrum of mode-locked pulse (inset) at a gain current of 95 mA and a SA reverse bias of 3V.

The light-current-voltage (LIV) characteristics of the MLL were measured with the gain sections under forward bias continuous-wave (CW) conditions, whilst the SA section was either driven with a forward bias, or under varying reverse bias conditions between 0V and 5V, shown in Figure 2. The MLL heatsink temperature was maintained at 21°C.

To characterise the mode-locking performance, light emission was collimated from the cleaved facet at the termination of the passive waveguide output of the 2-port MMIR and coupled, via a focussing lens, into a 1 × 2 single-mode fibre splitter. The output ports of the fibre splitter were connected to a fast photodetector and an optical spectrum analyser for simultaneous measurement of optical and electrical spectrum under identical bias conditions.

Figure 3 shows the measured electrical spectrum and optical spectrum at 95 mA gain current and -3 V applied to the SA section. The observed repetition frequency corresponds to that expected for colliding pulse mode-locking of 13.248 GHz with no observable signal measured corresponding to the full cavity round trip frequency of 6.624 GHz. The optical spectrum shows lasing occurs across multiple modes with a center wavelength of 1298.10 nm, the Full-Width Half-Maximum (FWHM) is found to be 0.21 nm. Stable mode-locking behaviour is observed across a wide-range of gain current and SA reverse bias, where the measured repetition frequency is plotted in Figure 4.

Results from a variety of device geometries will be presented at the conference indicting the range of pulse length and repetition frequencies that can be achieved.

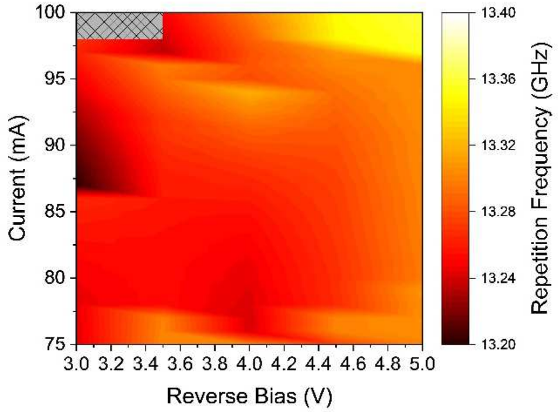

Figure 4: Colour map of measured mode-locking repetition frequency against gain current and SA reverse bias. (No data taken at the gray color)

III. ACKNOWLEDGMENT

Device fabrication was carried out in the cleanroom of the Institute for Compound Semiconductors (ICS) at Cardiff University. The EPSRC funded Future Compound Semiconductor Manufacturing Hub: reference EP/P006973/1 provided essential resources for this study.

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