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Citation for published version (APA):
Olle, V. F., Thompson, M. G., Williams, K. A., Penty, R. V., & White, I. H. (2009). 20GHz picosecond pulse generation by 1300nm mode-locked quantum dot master oscillator power amplifier. In *Proceedings of the 2009 Optical Fiber Communication Conference / National Fiber Optic Engineers Conference (OFC 2009 / NFOEC 2009) 24 - 26 March 2009, San Diego, CA* (pp. OWJ2-1/3). Institute of Electrical and Electronics Engineers.

Document status and date:
Published: 01/01/2009

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

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20 GHz Picosecond Pulse Generation by a 1300nm Mode-Locked Quantum Dot Master Oscillator Power Amplifier

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Abstract: An integrated 1300nm QD mode-locked narrow stripe MOPA is shown to generate 10.5ps Fourier transform limited pulses at 20 GHz. The pulse train has an average power of 46.4mW and peak powers exceeding 0.31W.

OSIC codes: (140.4050) Mode-locked lasers; (230.5590) Quantum-well, -wire and -dot devices

1. Introduction

Short pulse generation in laser diodes remains of great interest for applications in high speed communications and signal processing [1]. Although a range of techniques exists for short pulse generation in laser diodes, mode locking (ML) in monolithic lasers continues to be of great interest, particularly as repetition rates in the range from 10-100 GHz are directly applicable to many communication applications. However, the sources realised to date have relatively narrow operating ranges, and do not allow simple control or pulse amplitude or pulse modulation. Also, conventional mode-locked narrow stripe laser devices can have limited power output due to the onset of saturable absorption, on occasion limiting the operating mode-locking range. For operation at wavelengths where fibre amplifiers are limited, there is growing interest in the use of semiconductor optical amplifiers to increase optical output power.

In this work therefore, we explore the potential of a mode-locked Master Oscillator Power Amplifier (MOPA) device in which the master oscillator is a mode-locked laser. This is not the first demonstration where laser diode MOPA techniques have been used for short pulse generation. For example, Zhu et al. [3] reported an external MOPA where the output signal from a QW bow tie laser was collimated and injected into a separate tapered amplifier section. This resulted in significant pulse energy enhancement from 190 to 580pJ. To the best of our knowledge, however, there has not been a reported demonstration of a monolithically integrated QD ML laser and amplifier (booster) on a single chip. As QD laser diode devices have shown excellent mode-locking performance, this paper seeks to assess the potential of QD ML-MOPA operation.

2. Device description

The device used in this work has an active region of 5 InGaAs QD layers of 5.8nm width separated using 38nm GaAs spacers. This is placed in a transverse separate confinement heterostructure (SCH) GaAs waveguide using a 72nm period superlattice forming a total waveguide height of 120nm. The overall structure is grown on GaAs substrate using MBE. It should be stressed that the lateral waveguide consists of a simple 6µm wide stripe formed using standard photolithography and ICP etching. This allows simple coupling to optical fibre. The length of the total structure is 4600µm (fig.1).

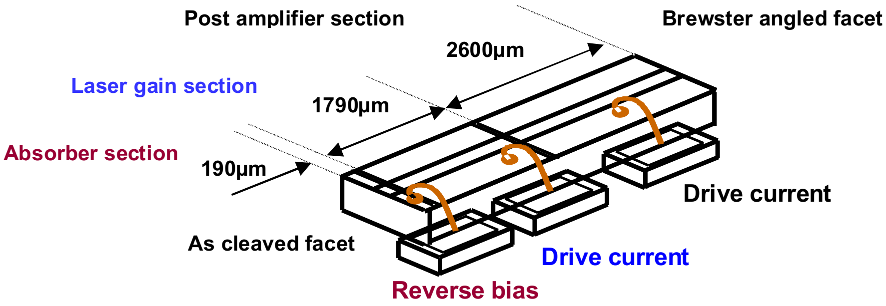

Figure 1. Schematic diagram of MOPA structure.

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To form the MOPA structure, focussed ion beam etching is used to define a mirror, thereby creating a 2000µm long laser section and a 2600µm long amplifier. Modelling predicts that the optimum mirror etch is 520 nm wide (fig.2a), so that a combination of good coupling (with 4 dB loss) exists between the laser and amplifier sections, along with a strong laser facet reflectivity (40% is observed). A second etch is used to form a split contact for the mode-locked laser, resulting in a saturable absorber length of 190µm, a contact gap of 20µm, and a laser gain section length of 1790µm. A third and final etch is used to created a 7 degree Brewster angled facet at the amplifier output (fig. 2b). This is intended to prevent previously observed back reflections and to minimize output signal degradation as a result of coupled cavity effects between the waveguide cavity and a lensed fibre.

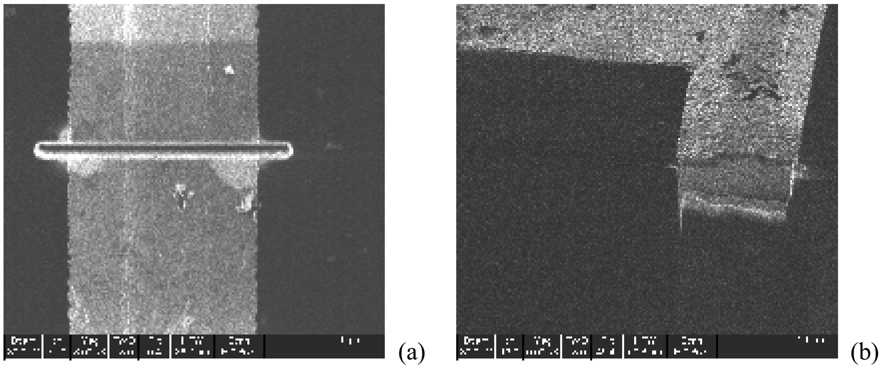

Figure 2 (a) Device waveguide with mirror etch and (b) Brewster angled amplifier output facet

3. Assessment of the ML-MOPA Performance

Continuous wave measurements are carried out at room temperature on the ML- MOPA with both the saturable absorber and laser gain section being electrically connected and biased together while the 2.6mm long amplifier section is biased separately. As shown in fig. 3, the laser threshold is ~50mA and an amplifier output power in excess of 60mW is achieved. There is evidence of a small amount of coupling from the amplifier into the laser, as the laser threshold current gradually decreases with increasing amplifier current.

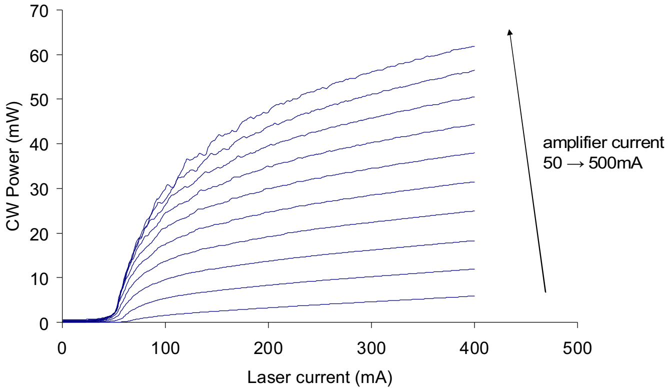

Figure 3: LI characteristic (laser absorber and gain sections connected) as a function of amplifier current in 50mA steps.

Passive mode locking (PML) is demonstrated by reverse biasing of the saturable absorber whilst both the laser gain and amplifier sections are forward biased. Illustrative low power PML results are presented in fig. 4 at an amplifier current of 75mA, laser current of 227 mA and absorber voltage of -5.0V. A clear resonance at 20.18GHz is accompanied by a signal to noise ratio of greater than 30dB (fig. 4a). In fig. 4b stable asymmetric optical spectra are plotted with a peak wavelength of 1286.5nm and -3dB spectral width of 0.15nm. Finally fig. 4c shows a clear 3:1 SHG ratio autocorrelation trace indicating a pulse duration of 10.5 ps and a near-bandwidth limited time-bandwidth product (TBP) of 0.32 (typical of a sech^2 pulse profile). For these driving conditions, an average power of 5.1mW was measured, corresponding to a pulse peak power of 27.3mW and pulse energy of 0.25pJ

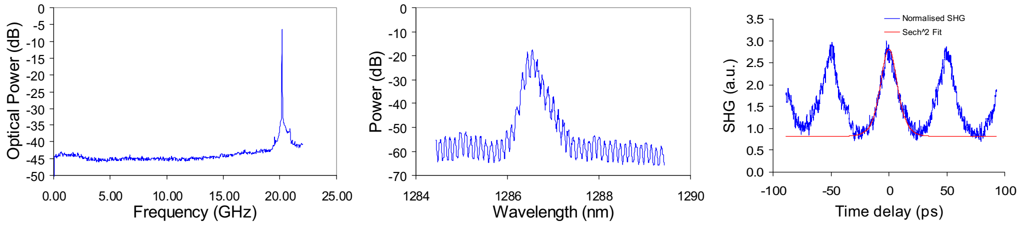

Figure 4: TBP limited PML results with corresponding RF spectra (a), optical spectra (b) and autocorrelation trace (c).

At a laser current of 376mA, a saturable absorber voltage of -7.3V and amplifier bias of 500mA, an average power 46.4mW, corresponding to a pulse energy of 2.3pJ broadened pulse width of 8.33ps and peak power of 0.31W is achieved. However, this improvement in operating power has been achieved at the expense of a chirp induced pulse and spectral broadening as the TBP increases to 2.15.

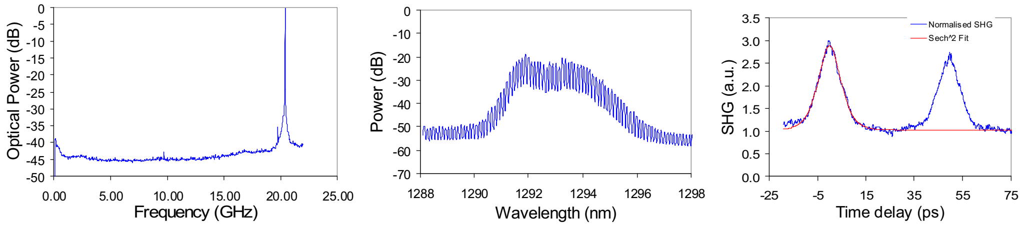

Figure 5.PML results at high powers with corresponding RF spectra (a), optical spectra (b) and autocorrelation trace (c).

The mode-locking operation is found to be stable over a broad range of amplifier currents up to 500mA and laser currents as high as 480mA. This gives a strong potential for further optimisation of the driving conditions over which Fourier limited pulses can be generated. A clear understanding of effects at higher amplifier currents as well as possible ways for reducing back reflections into the laser cavity is required for further improvements in the performance.

5. Conclusion

The first monolithically integrated QD passively mode-locked MOPA is reported. Here a 2000µm long QD ML laser is integrated with a 2600µm long SOA post-amplifier. At low bias currents, a 20.18GHz repetition rate of pulse train is observed with Fourier transform limited pulses of 10.5ps duration. At higher bias currents, despite the device being narrow stripe, a high 46.4mW average power, corresponding to a pulse energy of 2.3pJ and 0.31W peak power, is observed though at the expense of an increase in TBP to 2.15.

6. Acknowledgements

The authors would like to acknowledge funding from the UK EPSRC via the MUSIC project and from the EU FP NoE EPIXNet.

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