InP Quantum Dot Monolithic Mode-Locked Lasers for Ultrashort Pulse Generation at 735 nm

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Abstract: Monolithic InP/GaInP quantum dot passively mode-locked lasers are realised for the first time, emitting in the 730 nm waveband. Devices with total cavity length between 2 mm and 3.5 mm, with uncoated cleaved facets, and saturable absorber (SA) sections representing approximately 20% of the total cavity length have been found to Q-switch, mode-lock or both, depending on operating regime. The influence of bias conditions on the characteristics of lasers with a 3 mm cavity length have been explored, resulting in generation of pulses at 734.7 nm with pulse repetition rates of 12.55 GHz and pulse durations down to ≈6 ps.

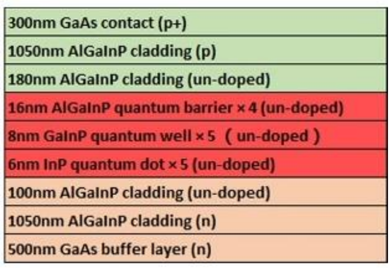
1. Introduction

Semiconductor monolithic ultrashort pulse mode-locked lasers (MLLs) which emit in the visible to near infrared regions are promising candidates to provide low cost, efficient and small footprint alternatives to the Ti:Sapphire laser, specifically in biomedical imaging and fluorescence studies, and for 'lab-on-a-chip' integrated applications.

Due to the broad optical gain features exhibited by quantum dot (QD) materials, there is excellent potential to achieve ultrashort pulses [1] in these material systems. However, much of the work in similar wavelength ranges, has, to-date, been focused on quantum well (QW) materials [2], rather than QDs. Here we demonstrate mode-locking in simple two-section monolithic structures using InP QDs as the active region, in an epitaxial structure that can be extended to cover the 630-780 nm wavelength range [3, 4, 5]. We report on the first measurements of ultrashort pulses from InP QD mode-locked lasers and explore the range of bias conditions and cavity lengths over which mode-locking has been achieved.

2. Experimental Setup

The InP QD laser structures were grown by MOVPE on n-GaAs (100) substrates, orientated 10° off toward <111>. Self-assembled InP QDs were covered by slightly tensile trained GaInP QWs and separated by AlGaInP barriers, with AlInP cladding lasers forming the remainder of the waveguide (Figure 1). Figure 2 shows a schematic diagram of simple two-section mode-locked lasers, where 2 μm wide shallow-etched ridge waveguides were fabricated, followed by planarization using Benzocyclobutene (BCB). Two section P-type contacts were defined across the ridgetops after BCB back-etching, with a 20 μm gap between the gain and saturable absorber (SA) sections. A wet etch was used to remove the highly conductive p-GaAs layer between the gain and SA contacts to improve electrical isolation. Lasers with total cavity lengths between 2.0 mm and 3.5 mm, with cleaved facets and saturable absorber sections representing approximately 20% of the total cavity length were examined. Broad-area oxide-stripe non-lasing segmented contact devices were also fabricated to measure the material optical gain and modal absorption spectra, via the segmented contact method.



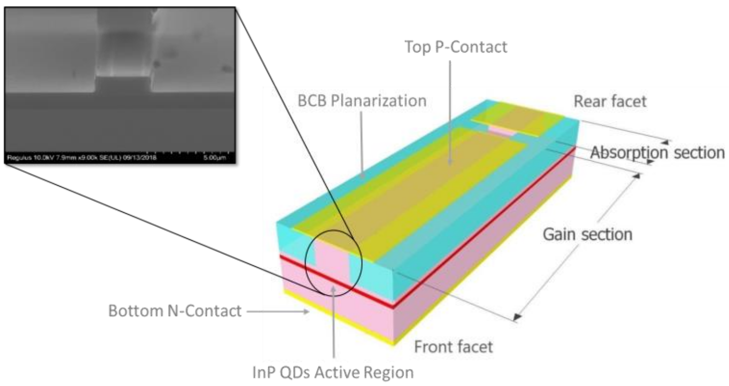


Figure 1: InP/GaInP DWELL laser structure.

Figure 2: Diagram of passively mode-locked laser, with SEM image (inset).

The mode-locking properties of the lasers were measured under continuous-wave current conditions, with reverse DC bias applied across the saturable absorber. The heatsink temperature of the device was maintained at ≈10 °C. To examine the device behaviour under identical bias conditions, the front-facet emission was free-space coupled into an autocorrelator operating in non-collinear mode and a flip-mirror used to fibre-couple the emission into an optical spectrum analyser and a fast-photodetector connected to an electrical spectrum analyser.

3. Results and Discussion

The repetition rates for the 2.0 mm, 2.5 mm and 3.5 mm cavity length lasers operating in mode-locked regimes were found to be 18.89 GHz, 14.98 GHz and 10.74 GHz respectively, which follows the expected repetition rates from cavity round-trip calculations.

The mode-locking properties of lasers with a 3.0 mm total cavity length have been explored over a range of gain and saturable absorber bias conditions. Regions of Q-Switching, unstable mode-locking and stable mode-locking have been observed in both RF and pulse duration measurements, with optimal bias conditions for the 3.0 mm total cavity length devices found to be a gain current, I_{gain} = 80 mA and saturable absorber reverse bias, V_{SA} = 2.74 V. Figure 3 shows the RF signal measured under optimal bias conditions, demonstrating strong mode-locking with a signal strength ≈ 50 dB above the noise floor, and a strong second harmonic signal (inset). The repetition frequency for the 3.0 mm cavity length was found to be ≈ 12.549 GHz with a 3 dB linewidth of ≈ 21.3 KHz. The pulse duration under optimal bias conditions was measured to be ≈ 6 ps, using a $Sech^2$ fit, and is shown in Figure 4, with the lasing spectrum showing emission at 734.7 nm (inset). The average power emitted from the front facet of the laser under optimal conditions was found to exceed 1.74 mW, with a peak power greater than 23.11 mW.

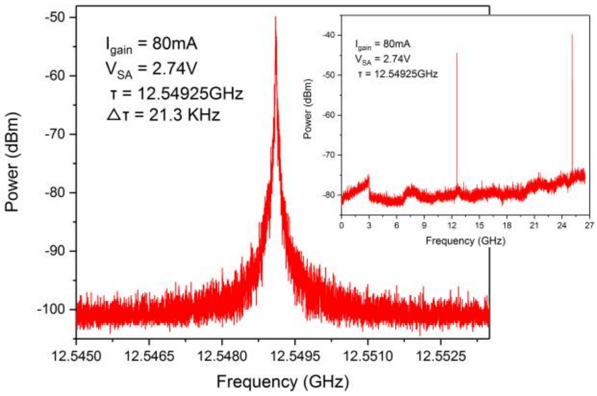


Figure 3: RF spectrum of 3 mm cavity length laser, with repetition frequency of 12.549 GHz and 3 dB bandwidth of 21.3 KHz. A wider frequency range is also shown (inset), with the fundamental frequency and second harmonic clearly visible.

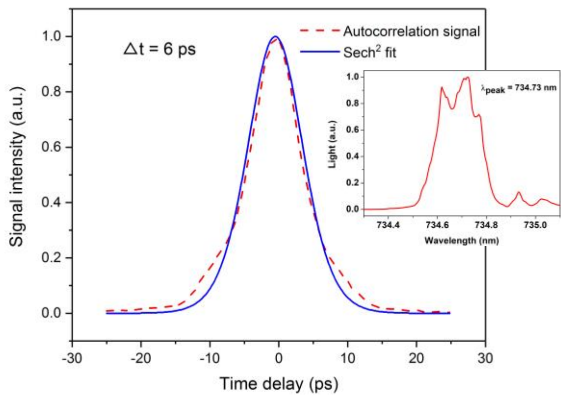


Figure 4: Autocorrelation signal (dashed) and $Sech^2$ fit (solid), resulting in a calculated pulse duration of ≈ 6 ps. The optical spectrum is also shown inset, with a lasing wavelength 734.7 nm and spectral bandwidth of ≈110 GHz (0.2 nm).

4. Conclusion

We present the first report of ultrashort pulse generation in monolithic InP/GaInP QD passively mode-locked lasers in the 730 nm waveband. The influence of bias conditions on the characteristics of lasers with a 3 mm cavity length have been explored and resulted in generation of pulses at 734.7 nm with pulse repetition rates of 12.55 GHz, with a 3 dB bandwidth of 21.3 KHz and pulse durations down to ≈6 ps under optimal bias conditions. InP QD mode-locked lasers operating in this regime have therefore been shown to be promising candidates for low cost, small footprint and efficient alternatives to the Ti:Sapphire laser.

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5. References

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