12.5-GHz InP Quantum Dot Monolithically Mode-Locked Lasers Emitting at 740 nm

Zhibo Li[1], Samuel Shutts[1], Craig P. Allford[1], Andrey B. Krysa[2], Peter M. Smowton[1]

[1]*EPSRC Future Compound Semiconductor Manufacturing Hub, School of Physics and Astronomy, Cardiff University, Queen's Building, The Parade, Cardiff, UK, CF24 3AA*

[2]*EPSRC National Centre for III-V Technologies, University of Sheffield, Sheffield, S1* 3JD

LiZ74@cardiff.ac.uk

Abstract: Monolithic InP/GaInP quantum dot passively mode-locked lasers, designed using gain and absorption measurements, are realised for the first time, emitting at 740 nm with 12.5 GHz repetition frequency.

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Semiconductor monolithic mode-locked lasers (MLL) emitting in the visible to near infrared region are required for small footprint, low cost alternatives to the Ti: Sapphire laser and specifically for applications in biomedical imaging and fluorescence studies.

Here we demonstrate mode-locking in monolithic structure using InP quantum dots (QD) as the active region in an epitaxial structure that can be extended to cover the 630 – 780nm wavelength range and beyond [1,2] and that can be used in integrated lab-on-a-chip configurations [3]. QD materials with their broad optical gain feature are promising to achieve ultrashort pulses mode-locking. [4]

We demonstrate, for the first time, the InP/GaInP DWELL structure to achieve monolithic mode-locked lasers. Figure 1 (A) gives the structure which was grown by MOCVD on n-GaAs (100) substrates oriented 10° off toward <111>. Self-assembled InP QDs were covered by lattice-matched GaInP quantum wells to form each DWELL layer which is then separated by AlGaInP barriers. Top and bottom waveguide and cladding layers were formed by AlGaInP, and a heavily doped GaAs cap for the p-contact.

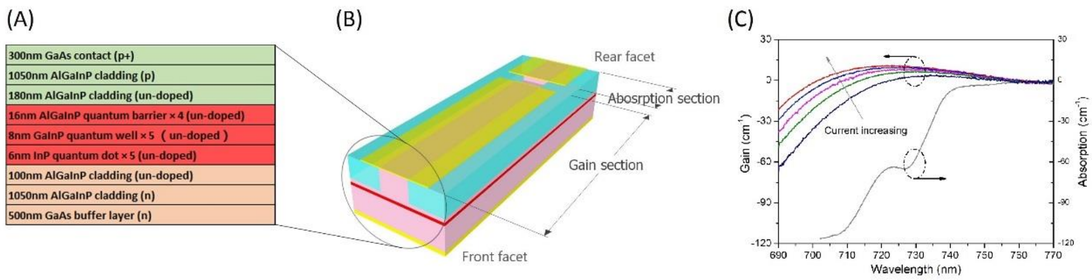

Figure 1, (A) InP/GaInP DWELL laser structure, (B) Diagram of passively mode-locked lasers, (C) Optical gain and absorption spectra measured on this material.

Figure 1 (B) shows the diagram of the mode-locked lasers. The wafer was patterned with 2 µm wide shallow-etched ridges, followed by Benzocyclobutene (BCB) planarisation. P-type contacts were defined after BCB back-etching, with a gap between gain and SA section of 20 µm which is wet-etched through the p-GaAs layer to increase electrical isolation. After lapping to 100 µm the backside n-type contact was formed by thermal evaporation. Figure 1 (C) shows the optical gain and absorption curves measured, using the segmented contact method, on broad area test structures. At high current the optical gain spectra are relatively flat topped and reach 60 nm width (red curve).

We utilized the gain and absorption measurements to design the lengths and length ratio of absorber and gain sections using the approach described in [5] and fabricated samples with different total cavity lengths and SA section ratios around this central design. We did not employ facet coatings. Light-current (L-I) measurements were carried out with a pulsed current source (1 μs pulse width and 5 kHz duty cycle). Figure 2 (A) shows the L-I curves of a mode-locked laser with 3 mm total cavity length and ~19% SA section ratio, namely, 2.4 mm gain and 0.58 mm SA section. When driving both sections in forward bias, the ridge laser gave a threshold current at 8 mA. For samples where the absorber section was floating or reverse biased, a kink characteristic of saturable absorption was observed to a greater or lesser degree in the different devices. The lasing spectrum of this MLL driven at 60 mA gain current and 1.7 V reverse bias is inserted in Fig.2 (A). To measure the repetition frequency, a constant current source was used. The front facet emission was coupled into a fast-photodetector connected to a radio-frequency (RF) spectrum analyzer and the result is shown in Figure 2 (B), with the insert showing an expanded range of frequency to observe the fundamental and 2nd harmonic frequencies. The measured repetition frequency of this MLL was 12.5 GHz which corresponded to its cavity length of 3 mm with a fundamental RF signal linewidth of 480 kHz. This linewidth is probably limited by the properties of our current source. We map out regimes of stable mode-locking and autocorrelator measured minimum pulse lengths.

In summary, we have designed InP/GaInP QD mode-locked lasers using gain and absorption measurements and achieved the first reported monolithic MLLs with a 12.5 GHz repetition frequency using this material system. We will explain the importance of this result in the context of the full wavelength spectrum that can be achieved using this material system.

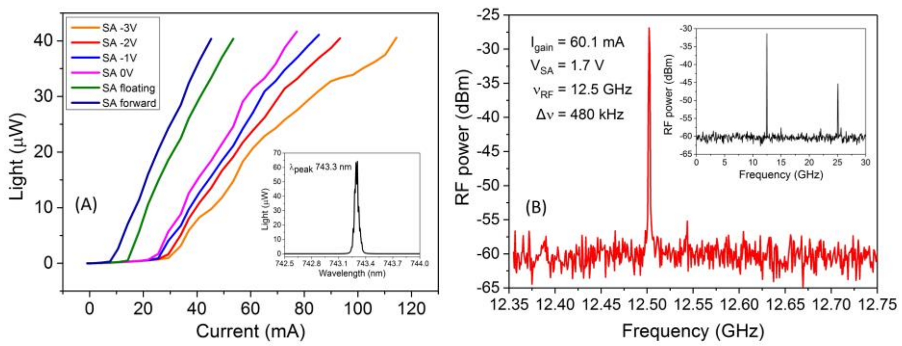

Figure 2, (A) Light-current measurements of 3 mm length MLLs with 19% SA section ratio, insert shows the spectrum (I_{gain} = 60 mA and V_{SA} = 1.7 V), (B) RF signal obtained at I_{gain} 60 mA and V_{SA} 1.7 V, Insert 0-30 GHz.

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