High performance BH InAs/InP QD and InGaAsP/InP QW mode-locked lasers as comb and pulse sources

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Abstract: Coherent comb lasers may serve as a source for multiwavelength modulators in short reach transmission, or for phase controlled OFDM channels in long reach. We explore and compare quantum dot (QD) and quantum well (QW) lasers with more than 33 channels in the DWDM 50 GHz grid, thus enabling > 1 Tb/s optical transmission. In addition, the mode-locked devices can be applied as pulse sources with < 500 fs pulses by using a simple SMF. We build QD and QW buried heterostructure (BH) lasers from different epitaxial structures, but sharing an identical mask set.

1. Introduction

Total internet demand continues to grow rapidly with the increase of mobile access usage, 5G applications, new Web 2.0 application developments and emerging technologies such as the internet of things. The growing internet traffic and bandwidth demand requires high capacity transport systems. Comb lasers are of particular interest as sources for terabit optical networking with single laser components. To realize >1 Tb/s transmissions, coherent laser modes with accurate mode spacing and a precise wavelength control are necessary. Additional requirements are low relative intensity noise (RIN) values and a narrow optical linewidth of the individual modes as phase noise impairs the signal to noise ratio in the coherent detection process [1, 2]. In this work, we explore BH C- and L-band free running passively mode locked lasers as comb and pulse sources to meet these requirements and compare the characteristics of QD and QW solutions.

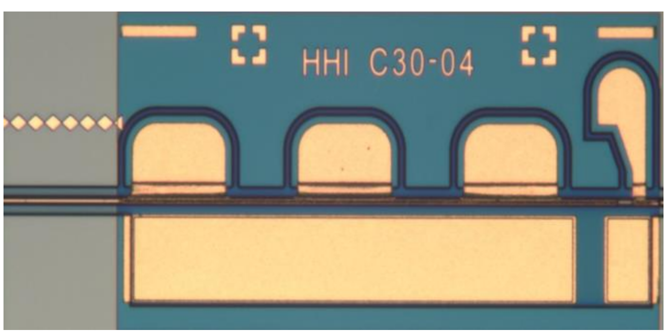

Fig. 1. Top-view photograph of the processed mode locked laser with a total device length of 840 µm including an absorber with the length of 50 µm.

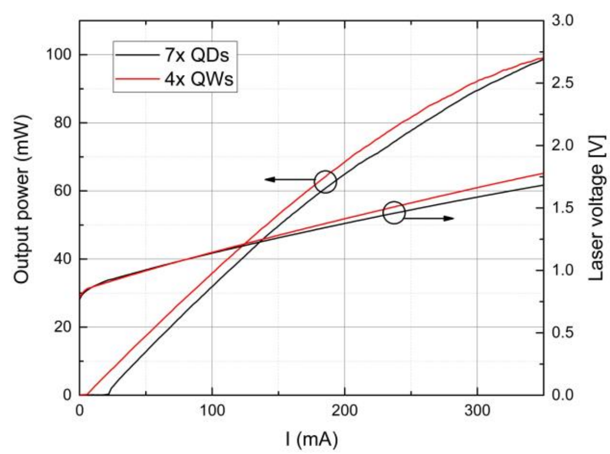

Fig. 2. CW PUI curves of the 7x QD and 4x QW devices.

2. Mode locked laser gain materials, design and measurement setups

All samples have been grown by metal-organic chemical vapor deposition (MOCVD) on (001) oriented n-type InP substrates [3, 4]. In case of the QD devices, the undoped active layers are comprised of 7x stacked layers of InAs QDs with quaternary barriers with 1200 nm bandgap (1.2Q). In case of the QW devices, the active layers are comprised of compressive strained 4x InGaAsP QWs with tensile strained quaternary 1.2Q barriers. The active layers are designed for C- to L-band operation in case of a 10% AR coating at the front facet and a 90% HR coating at the back facet. We then fabricated two-section BH lasers with an active stripe width of 1.4 µm, conventional pn-InP blocking layers and a saturable absorber length of 50 µm [Fig. 1]. The BH structure leads to circular farfields allowing a better coupling into optical fibers as compared to RW structures. The processed wafers were cleaved to form F-P laser cavities with a total length of 840 µm to give a mode spacing of ≈ 50 GHz at operating currents of 50-500 mA and an operation temperature of 20°C. The devices have been mounted on Kyocera heat sinks and measured on an ILX LDT-5910 TEC held at 20°C. Passive mode locking of the devices was characterized using an optical spectrum analyzer (Advantest Q8384), relative intensity noise measurement system (Agilent, HP 70810 B), a self-homodyne interferometer, a PXA electrical signal analyzer (Keysight N9030A), a high frequency u2t IR photodetector, TECOS optical tunable filter and power meters. The pulse duration was measured with a second harmonic generation (SHG) autocorrelator (pulseCheck, APE Berlin).

3. Device characteristics, analysis and discussion

We first explored the continuous wave (CW) PUI and passive mode locking behavior for both active layer designs. Fig. 2 shows the CW optical power / laser voltage vs. gain current (PUI) curves for both designs at an absorber voltage V_{ab} = 0V. Both devices have comparable slope efficiencies of 0.33 W/A and 0.35 W/A. Figures 3a and 3b show optical spectra of the passively mode-locked QD and the QW devices at I_{gain} = 300 mA, equivalent to about 90 mW output power, and an absorber voltage V_{ab} = -0.2 V. The spectra show comparable bandwidths and are comprised of 33 and 34 lines > -3 dBm with a central wavelength of 1553 nm in case of the QD device and 1573 nm in case of the QW device. The spectra differ in their uniformities: Due to the reduced mode competition in QDs the spectrum of the QD device is flatter with a standard deviation of 1.42 dB between the lines, while the QW device lines show a deviation of 1.62 dB. The free spectral range between the modes is approximately 50 GHz corresponding to the FP resonator length of 840 µm.

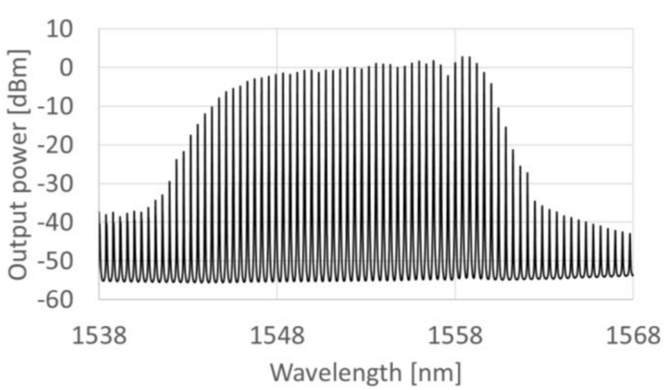

Fig. 3a. Optical spectrum of the 7x QD device with I_{gain} = 300 mA and V_{ab} = -0.2 V.

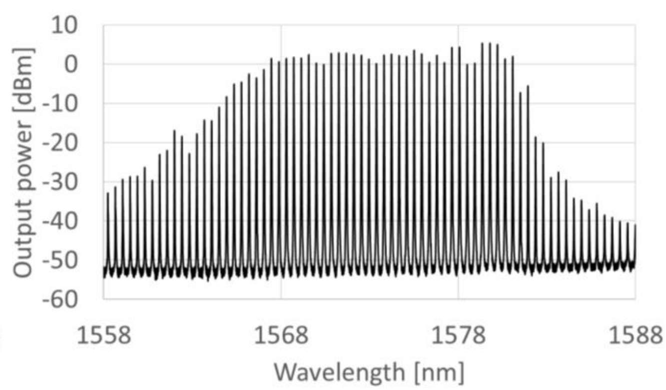

Fig. 3b. Optical spectrum of the 4x QW device with I_{gain} = 300 mA and V_{ab} = -0.2 V.

We investigated whether there is a beat signal generated at this frequency of 50 GHz in the RF domain. At I_{gain} = 300 mA and V_{ab} = -0.2 V we recorded peaks at 50.17 GHz in case of the QD device and at 51.41 GHz in case of the QW device. The measured data points were fitted with a Lorentzian shape, and -3 dB linewidths of ≈ 50 kHz were derived from the widths of the fitted curves for both designs at this working condition.

To use the devices in >1 Tb/s transmission schemes low relative intensity noise (RIN) values and a narrow optical linewidth of the individual modes are required [1, 2]. In case of the combined laser combs, the corresponding integrated average RIN values are -155 dB/Hz and -147 dB/Hz across the frequency range 10 MHz to 10 GHz for the QD and the QW device, respectively. When looking at the RIN spectra of the individual central modes, the RIN value is slightly better for the QW device with -132 dB/Hz as compared to -129 dB/Hz for the QD device. In both cases the RIN values of the individual modes are suitable for 28Gb/s PAM-4 modulation [5].

The optical linewidths of the individual central modes [Fig. 4] of the QD and QW devices differ significantly. While the QW device has a linewidth of around 0.6 MHz the QD device with the same resonator quality has a linewidth of around 14 MHz. To understand the difference in the optical linewidths and the threshold currents for both active layer designs we determined the internal losses for both active layer types. The internal losses account to -14.33 cm^{-1} and -13.03 cm^{-1} for the 7x QD and the 4x QW stack, respectively. These values are typical for BH

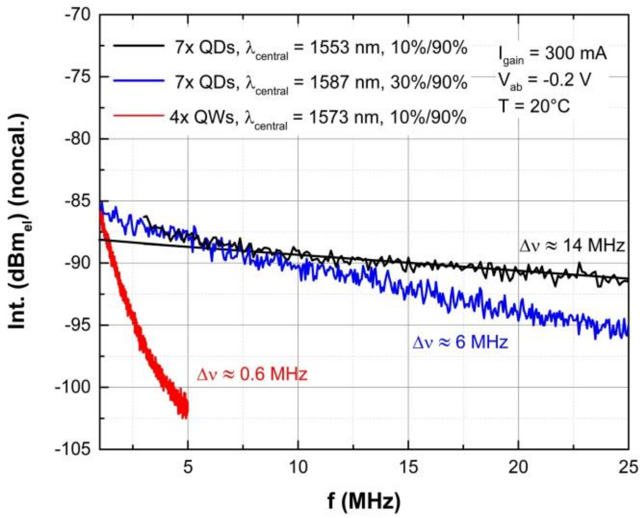

Fig. 4. Linewidths of respective individual modes.

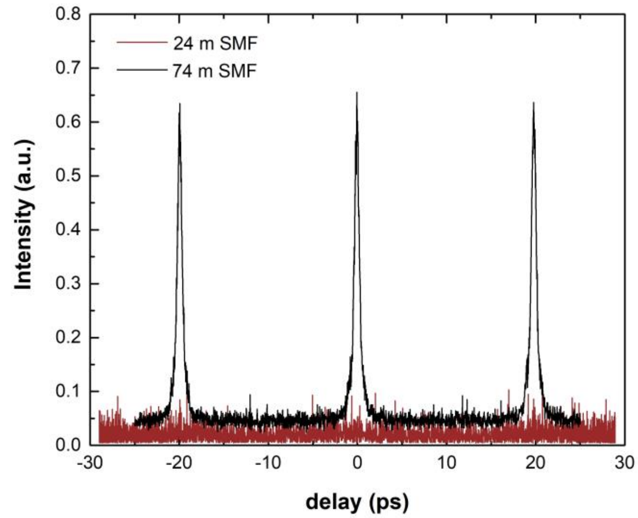

Fig. 5. SHG ACF at Igain = 500mA for the 7x QD device.

structures and indicate a good epitaxial quality of the QD and the QW active layers. We therefore explain the difference in the threshold current and the larger linewidth in case of the QD stack with a higher leakage current through the matrix layers in between the QDs.

Fig. 5 shows the SHG autocorrelation at I_{gain} = 500mA of the 7x QD device after propagation through two fibers with different lengths. After traveling through 24 m of standard single-mode fiber, no pulses are visible (red line). After 74 m, three sharp pulses with a temporal spacing of 20 ps become visible in accordance to the repetion rate of 50 GHz. The measured pulse duration is in the order of 480 fs at 20°C, whereas the simulated minimal possible pulse duration for the structure is 430 fs. This proves the excellent mode-locking behavior for our C-band laser with strongly linearly chirped pulses directly emitted from the device. This linear chirp can be compensated by the anomalous dispersion of a simple single-mode fiber at 1550 nm. Similar autocorrelation measurements are currently carried out for the 4x QW device. The respective results will be presented at the conference.

In summary, we compared two different active layers, composed of 7x InAs QD stacks and 4x InGaAsP QWs, respectively, to realize BH C-band and L-band coherent comb and pulse lasers for > 1 Tb/s optical networking and for applications in DWDM networks. QD devices show a better uniformity of the comb spectrum and a lower RIN value of the combined laser modes, while QW devices show one order of magnitude lower optical linewidths of the individual modes and higher internal quantum efficiencies. In addition, AFC measurements of our QD CCL indicated excellent mode-locking behavior. Both types proofed to be suitable for DWDM comb and pulse sources and are very promising for > 1 Tb/s optical data transmission.

4. References

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