Injection Locking Properties of 1.55 µm InAs/InP (100) Quantum Dot Ring Lasers

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We report on results of injection locking experiments with InAs/InP (100) Quantum Dot ring lasers, lasing in the 1.55µm wavelength region. Single mode operation (under external injection) with suppression of longitudinal modes of more than 35dB was shown on lasing direction agreeing with the injected signal. Counter propagating lasing is shown to be suppressed by as much as 18dB with measured power limited mostly by isolation of components rather than actual power. In addition, as expected from an injection locked laser, linewidth narrowing of 20 times was observed depending on the quality of the external laser used as the injection seed.

Introduction

Ring lasers are a favorable choice of light sources for integrated active optical circuits as they do not require mirrors or periodic structures to create cavities, required for lasing [1]. Moreover, since ring cavities modes are highly dependent on the phase inside the ring, tuning of the lasing mode can be easily accomplished by thermal or current injection variations [1].

Ring Laser (RL) and Fabry-Perot Lasers (FBL) have natural linewidths which stem from the Q-factor of the resonator and the physical properties of the active material. In addition, due to the large size of the ring (2mm), the Free Spectral Range (FSR) is much smaller than the gain bandwidth, leading to multimode operation [2]. Such multimode lasers cannot support high-speed optical data transmission due to modal dispersion [3].

In order to improve the performance of these lasers it has been suggested to use a low power injection-seed to stimulate uni-directional and single mode operation [4]. This way the resulting laser signal can be much stronger than the original seed while retaining its good noise properties and linewidth [4]. Also, for complicated integrated optical circuits, where attenuation can reach several tens of dBs (including coupling losses into the chip), an injection seeded RL can be used as a regenerator for the laser light as the required injection seed power is low [5].

Injection locking properties of Semiconductor RLs (SRLs) have been demonstrated for quantum well gain material [6], showing how both uni-directionality and single mode operations can be achieved by low power injection seeding. For such devices it has been shown that uni-directional operation is also possible for a free running RL and that the lasing direction can be switched using injection seeding [6]. Such RL can be used as memory elements [6].

The use of Quantum Dot (QD) material as a gain medium in SRL has several advantages over bulk or quantum well semiconductor. Due to the concentration of gain at certain energy levels (due to quantum restrictions on electron distribution), lasers using QD materials should have lower threshold currents, higher modulation speeds with lower chirping and narrower spectral line widths [7]. Also, as gain in QD material is spatially localized, surface recombination is a minor phenomenon and deeply etched small diameter rings are easier to fabricate.

In this paper we report on injection locking experiments carried out on QDRLs . These QDRLs, have a steady state lasing spectrum in the 1.57-1.58μm window, with longitudinal mode separation of 40GHz [8]. We show that when injected with low power seed, longitudinal modes are strongly suppressed (up to 40dB) and counter propagating lasing is also suppressed by at least 10dB. Using a high resolution optical spectrum analyzer we are able to measure a 20 fold reduction in linewidth of the injection locked ring laser.

QD material details and Mask Layout

The QD laser structure was grown on n-type InP (100) substrates by metal–organic vapor-phase epitaxy. In the active region, five-fold stacked InAs QD layers separated by 40-nm-thick InGaAsP (λ_Q = 1.25μm; Q1.25) were placed in the center of a 500-nm-thick lattice-matched Q1.25 waveguide core. The choice of the Q1.25 waveguide core is the result of an optimization made with regards to the application of this material in active–passive photonic integration using selective area regrowth [8]. The nominal InAs amount for QD formation was 3.5 monolayers (MLs). One ML GaAs interlayer was inserted underneath each QD layer to suppress unwanted As–P exchange reactions during QD growth to tune the QD emission wavelength into the 1.55μm region [9]. Bottom and top claddings of the laser structure are 500nm n-InP buffer and 1.5μm p-InP completed by a compositionally graded 75-nm p-InGaAsP contact layer.

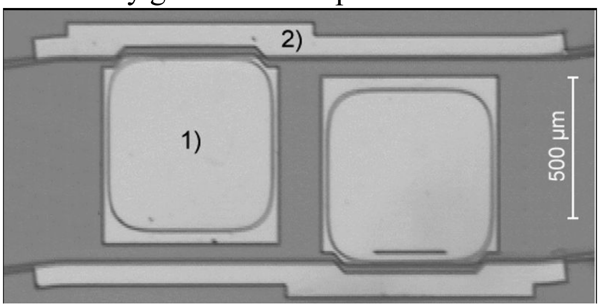

Figure 1 - Top view of two QD ring lasers with two separate electrical contacts;
1) For the ring and the directional couplers and 2) For the output waveguides.

The waveguides have been processed using reactive ion etching and have a 7^o angle at the chip's output to reduce reflections. Additionally anti reflection coating was also used to reduce reflection even more.

For electrical isolation between contacted waveguides, the contact layer and part of the top cladding were removed. Before contacting, the waveguides have been planarized by polyimide. An image of two such ring lasers is given in Fig. 1.

Measurement results

A. Ring Laser Operation

The chip was cooled to 14°C and the output waveguide was pumped with 8mAto ensure transparency. Output powers for both Clock Wise (CW) and Counter CW (CCW) directions were measured simultaneously as a function of injection current. We estimate that coupling losses to the outside lensed fibers collecting the light are around 5-10dB. In Fig. 2 we see that for the selected temperature, threshold is at around 130mAmps. From threshold the power grows linearly with current and with equal magnitude on both lasing directions of the ring. At 170mAmp there is a break in symmetry between lasing directions, as the CCW power becomes stronger, although the CW power continues to grow. However for higher injection currents the optical power on the CW reaches a maxima and then proceeds to drop in power, while the CCW shows improved efficiency.

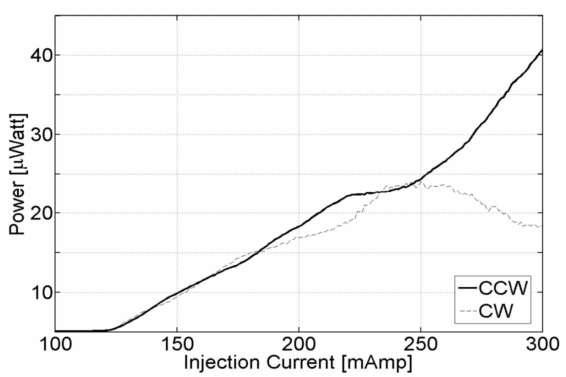

Figure 2 - Output Power of both counter propagating modes in the ring as a function of current injection

The above-threshold operation of the injection-free device is characterized by multi-mode operation, with strong mode competition and almost no single dominant mode operation (see Fig. 3). The kinks in the P-I curves of Fig.2 correspond to changes in the wavelength of the dominant mode or to repartitioning of optical power among different modes.

B. Injection Locking results

Once a threshold value for lasing was established, injection locking for several biasing values and with several wavelengths was performed. Optical power injected into the ring varied between 0 - 8 dBm in the fiber, or -5 – 3dBm into the InP waveguide (assuming a minimal coupling loss of 5dB). Different power levels were required to obtain stable injection locking characteristics based on biasing and choice of injection wavelength compared to the natural lasing spectrum of the ring.

Overall, for all choices of biasing and input wavelength, strong single mode operation of the laser in the rotational lasing mode supported by the injection seed was observed. Side mode suppression of more than 35dB was obtained and suppression of the counter propagating ring lasing mode of at least 10dB, with a top suppression of 18dB achievable for higher bias currents. The last important attribute of injection locking is the linewidth narrowing. Using a high resolution optical spectrum analyzer (20MHz resolution band width) we were able to estimate that the linewidth is reduced from ~5pm (or 600MHz) for the free running ring laser to around 0.2pm (or 25MHz) or about 20 times narrower. Figure 3 shows the optical spectrum with and without injection, for a biasing condition of 146mA (only 10% above threshold).

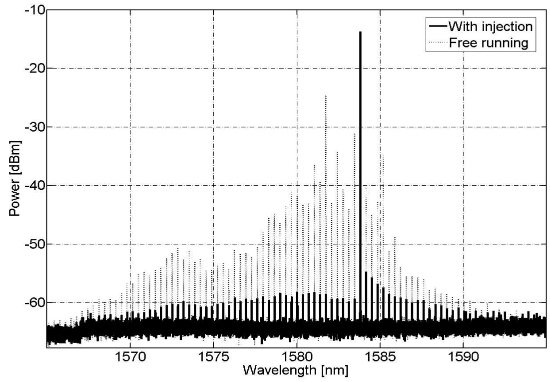

Figure 3 – Optical spectrum of the ring laser with and without co-propagating injection seed showing single mode operation with 40dB side mode suppression

Discussion and Conclusions

Using an external optical source, a QD ring laser was injection locked to give narrow linewidth lasing and single mode operation with high rejection of side modes, and strong suppression of counter propagating mode. This performance was easily replicated across the lasing bandwidth of the QD gain material from 1572-1583nm with similar performance. While it is estimated that the QD material has homogeneous broadening of around 10nm, full suppression of all modes was observed throughout the lasing spectrum with limited significance to choice of injection signal frequency. This leads us to believe that for CW injection, there is interaction between the groups of QDs, possibly through the wetting layer or overlapping homogeneous linewidths.

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