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Integrated passively modelocked InGaAsP ringlasers with active-passive integration

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Abstract: Integrated modelocked ring lasers with fundamental repetition rates of 35 and 26GHz were fabricated in InGaAsP using active-passive integration. First measurements shows pulses down to 1.2ps width can be produced.

OCIS codes: (130.3120) Integrated optics devices; (140.5960) Semiconductor lasers; (140.4050) Mode-locked lasers (140.7090) Ultrafast lasers

1. Introduction

In this paper we present the first results from integrated passively modelocked InGaAsP ringlasers that we have fabricated. These devices are, to our knowledge, the first integrated passively modelocked ringlasers realised using an active-passive integration scheme [1]. This work is part of a project in which we are developing an All Optical Clock Recovery (AOCR) device based on an injection seeded passively ModeLocked Laser (MLL). For this application the ring configuration has two advantages. Firstly, the repetition rate of the laser is controlled accurately by photolithography as opposed to a device with cleaved facet mirrors. Secondly the ring laser configuration is more suitable for the injection seeding process that is at the centre of the AOCR. The butt-joint active-passive integration technology we have used makes the laser design suitable for further integration with other devices, e.g. a wavelength converter [2].

2. Design

Fig.1: Optical microscope image of a part of the fabricated chip with a 35GHz MLL.

The different device designs have been realised in the InP/InGaAsP material system with active-passive integration. A picture of a fabricated 35 GHz MLL is given in figure 1; waveguides are visible as dark lines. Light is coupled out from the oval shaped cavity using a Multi-Mode Interferometer (MMI). Opposite to the MMI an active region – a bulk Semiconductor Optical Amplifier (SOA) – is integrated in the passive cavity. The SOA is divided into two sections. Each can be contacted using the two bright metal pads visible in figure 1. The long section is a forward biased amplifier. The short section is a reverse biased saturable absorber. A short non-contacted section isolates the amplifier from the absorber ($R = 600k\Omega$). The Free Spectral Range (FSR) of the cavity corresponds to the required repetition rates of the laser.

The shallowly etched straight waveguides, the amplifier and the absorber in the MLL are $2\mu\text{m}$ wide in order to minimise propagation loss. Curved waveguides with a bending radius of $100\mu\text{m}$ are $1.7\mu\text{m}$ wide and deeply etched. The deep-shallow transition is made gradually using a $50\mu\text{m}$ long taper. An improvement in coupling is obtained by using an extra width of $0.3\mu\text{m}$ between the taper and the shallowly etched waveguide. To reduce facet reflectivity, the output waveguides (not visible in the figure 1) are angled by 7° with respect to the facets normal. Since at this

angle only the reflection from zero-order to zero-order mode is minimal, a mode filter is inserted to suppress the first-order mode [3], which can be guided by the SOA.

3. Fabrication.

Fig.2: Cross-sections of amplifier, isolation, shallowly etched waveguides and deeply etched waveguides

All epitaxial layers for the MLL were grown by Low-Pressure Metal-Organic Vapour Phase Epitaxy (LP-MOVPE) at 625°C. The SOA active layer consists of a 120 nm thick $\lambda = 1.5\mu\text{m}$ InGaAsP layer between two $\lambda = 1.25\mu\text{m}$ InGaAsP layers. The structure was covered by a 200-nm-thick p-InP layer. Next, the active layer stack was butt joint to a $\lambda = 1.25\mu\text{m}$ InGaAsP layer for the passive sections described in [4]. In the third epitaxy step, a 1300-nm thick p-InP cladding layer and the p-InGaAs contacting layer were grown.

A 70 nm thick PECVD-SiN layer served as an etching mask for the waveguides. The pattern was defined using contact photolithography with positive photoresist and transferred to the SiN_x layer by CHF₃ Reactive Ion Etching (RIE). Waveguides were etched in three steps employing an optimised CH₄-H₂ etching process (RIE). The isolation between the amplifier and the absorber in the SOA structure was realised wet chemical etching. The amplifier and the absorber were passivated with a 350 nm thick PECVD-SiN layer before the metalisation step. A further description of the fabrication can be found in [5].

4. Experimental setup and first measurements

The chip was soldered on a temperature controlled copper mount. The current and the reverse bias voltage were applied through two probes. Light from the two laser output waveguides was collected using lensed fibres and led to a spectrum analyser, power meters or an optical autocorrelator. In order to obtain autocorrelator traces, the signal needed to be amplified using an EDFA. The first results of two of our new devices are presented here. The devices are switched on by first turning up the current in the amplifier when the absorber is not connected. Then when the laser is above threshold the absorber is connected and a voltage is applied.

The first device has amplifier that is 670 μm long; the absorber is 50 μm long and the isolation section is 30 μm long. The device was operated at 15°C. The threshold current is around 90 mA. The device is truly bi-directional and outputs powers, from the lensed fibres (4-5dB coupling loss), go up to -5 dBm at 120 mA. The details in the output of the laser are highly dependent on the amplifier current. An example of a spectrum at 133 mA current in the amplifier is plotted in figure 3. There are two groups of four modes spaced by 8 FSR, other modes in the spectrum contain less power. The laser produces more than one pulse per roundtrip as can be seen from the autocorrelator trace (Fig. 5a). Pulses of 1.2ps duration at 26Ghz are generated together with less intense pulses in between. Using the recorded output spectrum we have calculated the field and the autocorrelation signal, assuming locked phases between modes. The calculated autocorrelation trace is plotted in figure 5b. The good matching between the measured and calculated autocorrelator traces shows that the system is stable with many pulses and does not switch between two frequencies. The mode structure of the cavity is under investigation, taking into account the small reflections at the different interfaces, e.g. the active-passive interfaces.

Fig. 3 Spectrum of a 26GHz device $I = 133$ mA $V = -0.3$ V.

Fig. 4 Spectrum of a 35GHz device $I = 111$ mA $V = -0.8$ V.

Fig. 5 (a) Measured autocorrelator trace at 26GHz.
(b) Calculated autocorrelator signal.

Fig. 6 (a) Measured autocorrelator trace at 35GHz.
(b) Calculated autocorrelator signal.

The second device reported here has a 440 μ m long forward biased amplifier, a 30 μ m long reverse biased saturable absorber and a 30 μ m long non-biased isolation section. Its repetition rate is 35 GHz. Due to the shorter amplifier in this device, it needs to be cooled down to 8°C in order to have sufficient gain to bleach the absorber. The threshold current is around 100 mA. The device also operates bi-directionally and outputs power levels recorded in the fibres go up to -6dBm at 110 mA. The spectrum at 111mA is plotted in figure 4. There is one group of 4 modes and a second group of 2 modes with the same mode spacing of 7 FSR. These two groups of modes are spaced by 1 FSR. The recorded autocorrelator trace is plotted in figure 6a. Five pulses of 1.5ps width can be clearly observed in the 28ps roundtrip time. The recorded and calculated autocorrelation signals are presented in figure 6(a) and 6(b). Again these are matching well, which demonstrates the stable phase relation between the modes.

5. Conclusion

We have fabricated integrated modelocked ring lasers with active-passive integration. First experiments show that pulses down to 1.2ps width can be produced in bi-directional operation of the ringlaser with a fundamental repetition rate of 26 and 35GHz. The autocorrelation traces of the output of the devices have been simulated using the output spectral data, demonstrating the locked phases of the modes. The investigation of these devices is ongoing and is focussing on the explanation of the observed mode structure, the achievement of operation at the fundamental repetition rate and on the behaviour of the device when injection seeded.

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6. References

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