OPTICAL SWITCHING OF CLOCKWISE/ANTI-CLOCKWISE LASING IN BUS COUPLED MICRORINGS

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Abstract

Clockwise / anti-clockwise switching of InP based bus-coupled microring lasers induced by external light injection has been measured and simulated. Device design and injection parameters of bistability and pre-selected unidirectional operation are discussed.

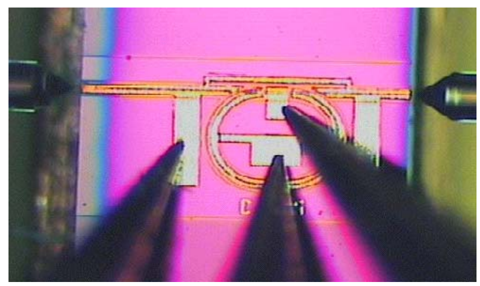
I. Introduction

Integrated passive and active microring cavities are attractive candidates for application in various photonic devices (e.g. [1,2,3]). Operation regimes like wavelength filters, dispersion compensators, wavelength converters and all optical switching elements have been demonstrated in passive ring resonator structures. Microring cavity lasers offer novel architectures of compact single mode devices and the feature of low threshold lasing. Part of recent investigation focuses on bistability phenomena related to the coupling of clockwise (CW) and anti-clockwise (ACW) propagating ring laser modes [4,5]. This work focuses on the capability of switching the ring laser output direction by external optical injection.

II. Experimental

The semiconductor microring lasers investigated here consist of an GaInAsP strained layer multi-quantum well (MQW) gain structure grown on InP. The layer structure was designed for operation at 1.5 µm wavelength and supports preferably TE polarisation. A deeply etched bent ridge was chosen to assure a sufficient index step necessary to keep the radiation losses in the ring cavity at low level. The Free Spectral Ranges (FSRs) of the microring cavities were in the range between 100 and 200 GHz.

The investigated single stage laser device (shown in **Fig. 1**) includes one microring coupled to one bus waveguide. In our case the bus waveguide consists of the same layer stack as the ring ridge which facilitates the fabrication and minimises the number of processing steps. Hence, the waveguides and the waveguide couplers (multimode interference couplers as well as co-directional couplers, power coupling strength K = 0.2 – 0.7) have to be electrically driven and may act as semiconductor amplifier (SOA) sections too.



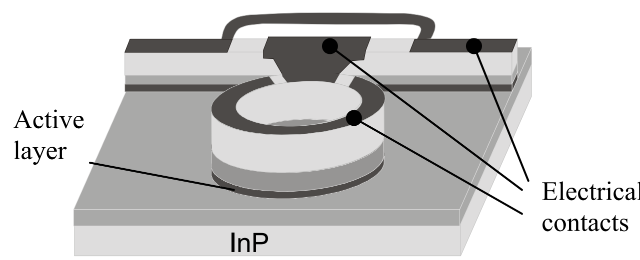


Fig. 1: *All-active microring device inGaInAsP/InP under test (top: photograph of investigated device, bottom: schematic view).*

The waveguides are designed to support only one lateral mode; facets for power input and output are anti-reflection coated. More details of the design are summarised in [6].

III. Results

The investigation of ring lasers described here was focused on the spatial distribution of longitudinal counter-propagating ring laser modes. In order to reduce the influence of parasitic cavities the driving current of the straight waveguide was kept at a current density slightly lower than the transparency value.

This causes moderate absorption losses outside the ring and minimises back reflections. Under such conditions the ring cavity can be decoupled from the straight waveguide cavity and the observed emission spectrum is mainly controlled by the microring.

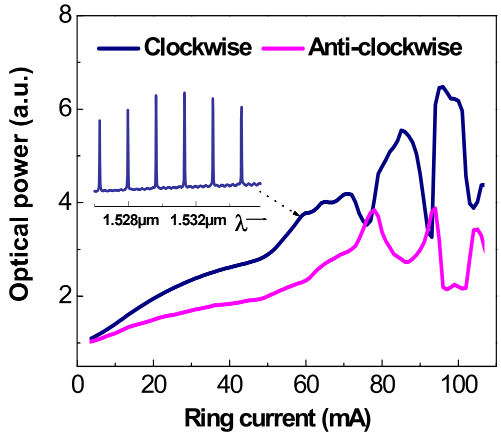


Fig. 2: Power of counter-propagating modes in all-active microring laser structure, inset: emission spectrum (FSR: 215 GHz, K= 0.7, threshold @45 mA).

Typical PI curves are shown in **Fig. 2**. The curves demonstrate oscillations of the power on one facet which are accompanied by diametrical power changes at the opposite site. This behaviour indicates a strong coupling of CW and ACW ring modes similar to the observations in ring lasers with larger radius [7] or triangular laser configurations [8]. The results are reproducible. No explicit hysteresis has been found.

The observed chaotic-like switching of the lasing direction causes instabilities in terms of output power and crosstalk and must be controlled in integrated ring laser devices.

We investigated the pre-selection of ring lasing direction under optical injections. In the experimental investigations we used a setup shown in **Fig. 3**. The current density of the bus waveguides is kept near transparency, the output powers at left and right hand side are measured by an optical power meter. Light of the external cavity laser (ECL) was launched into the single ring device via a circulator. For a good fibre chip coupling lensed fibres have been used, placed at left and right side of the waveguide facets.

Without external injection the devices showed a comparable output power level for the CW and ACW lasing direction.

The situation is changed by optical power injection. When the power is launched into the device at wavelengths close to the ring laser modes from left hand side into the CW ring laser mode the ACW output power of left facets is strongly decreased (cf. **Fig. 3**). Simultaneously, the corresponding CW power output of the ring laser at the right facet is increased. The output power distribution of the facets remains unaffected when the injection is done at non-resonant wavelength.

The pronounced decrease of the ACW propagating wave was observed in ring devices with different FSRs and bus waveguide / ring coupling ratios. The bandwidth of the off-switching state decreases with lower coupling ratios. In addition, at high ring currents or increased bus waveguide amplification the extinction ratio decreases. Latter is attributed to the influence of the coupled bus-waveguide cavity for non-vanishing facet reflectivities R.

The obtained suppression of ACW wave propagation was of about 15 dB, indicating the induced unidirectional CW lasing under external injection. It provides the advantage of reduced optical feedback which is of interest for the application of integrated ring laser devices for WDM sources, resonant amplifiers and wavelength converters.

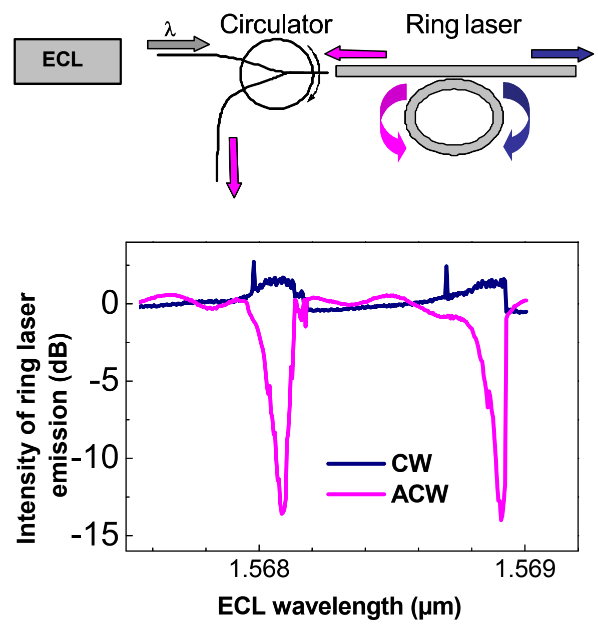


Fig. 3: Off-switching of ACW emission by external injection at CW ring laser modes, FSR: 100 GHz (top: scheme of the experimental setup, bottom: CW/ACW output power as a function of wavelength).

IV. Modelling

In order to evaluate the potential of bidirectional operation for all optical switching devices, simulation of lasing behaviour under different conditions of optical injection have been performed. To describe the dynamics of the devices we used the Traveling Wave (TW) model [9]. It supposes, that within each part of the device the spatiotemporal dynamics of the optical fields and the carrier densities can be described by a hyperbolic system of the first order partial differential equations which is nonlinearly coupled to the system of ordinary differential equations. The ring geometry of our laser is represented by the properly imposed field reflectivity and transmission conditions at the edges of different parts of the device. Namely we assume that at the position where the ring is connected to the straight waveguide, the forward or backward propagating complex fields along the ring ($E_r^{\pm}$) and along the straight waveguide ($E_s^{\pm}$) are related according to the following rule:

$$\begin{cases} E_{s,out}^{\pm} = \sqrt{1-K}E_{s,in}^{\pm} + i\sqrt{K}E_{r,in}^{\pm} \\ E_{r,out}^{\pm} = \sqrt{1-K}E_{r,in}^{\pm} + i\sqrt{K}E_{s,in}^{\pm} \end{cases}.$$

For numerical integration of model equations and simulation of the device behaviour we have used the software package LDSL-tool (abbreviation for Longitudinal Dynamics in Semiconductor Lasers) [10].

Simulations of the ring laser structure confirmed well our experimental findings. The bistability of CW and ACW lasing direction has been verified for different biasing of the ring laser. The off-switching of one lasing direction by external light injection has been approved as well. In order to illustrate the operation of our ring laser the power distributions of CW and ACW modes along the straight and the ring sections are shown in **Fig. 4**. It shows the dominant CW lasing mode where the ACW mode is almost completely suppressed.

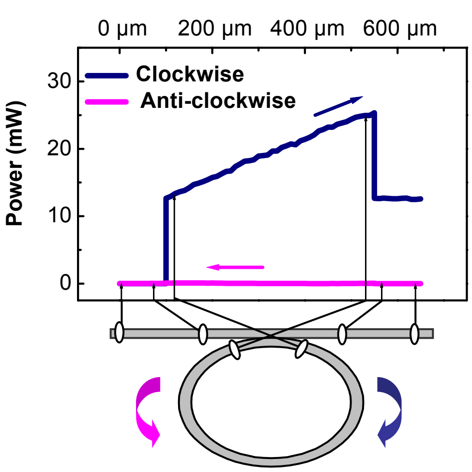


Fig. 4: *Longitudinal power distribution of a three section ring laser with CW lasing direction (FSR: 200 GHz, K = 0.5, @60 mA, passive bus waveguide sections, top: simulation results, bottom: schema of mapping the local power).*

We have used the experimentally approved ring laser model in order to evaluate further characteristics of the directional bistability. The potential of switching by optical pulses was analysed for ring laser devices with an FSR of 200 GHz and ring biasing at 60 mA.

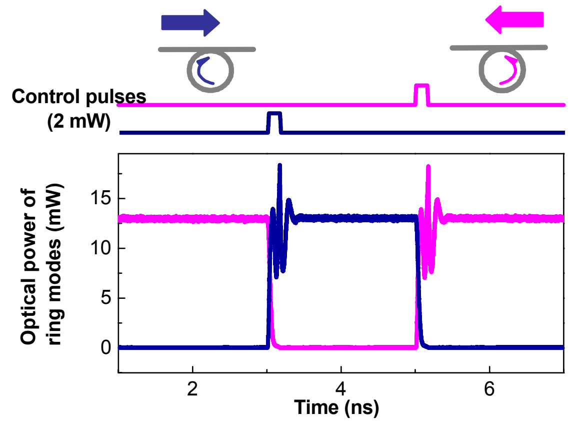


Fig. 5: *Simulation of optical switching by optical pulse injection @ lasing wavelength and zero power facet reflectivites (FSR: 200 GHz, ring laser @100 mA, K = 0.5).*

The situation is examined for a device with zero power reflectivity (R = 0) at both facets. The response of the ring device is calculated for external pulses of 0.15 ns length. At a wavelength matching the laser mode emission, the typical switching behaviour is shown in **Fig. 5**. In the beginning, the system is in a stationary state controlled by ACW lasing direction. After applying the short pulse in CW direction, the laser switches to a stable operation in a CW mode. When again an external pulse is injected, but now in the opposite ACW direction, the ring laser system switches back to ACW lasing.

The switching characteristic shown here could be confirmed also for rings with higher FSRs (up to 500 GHz) and other coupler parameters (K=0.3, 0.2).

Parasitic cavities may affect the switching performance of the ring laser device and have to be taken into account for real photonic devices. In particular, even small reflectivities at the facets may interfere the ring the mode propagation. If these effects are involved in the model, the simulation results are slightly modified. **Fig. 6** gives an idea about the stability of the CW/ACW switching under the influence of facet reflections. For values of $R = 1*10^{-4}$ at both facets, the long time stability of the induced unidirectional lasing is reduced.

Further investigations are necessary in order to identify the characteristics of the directional bistability in ring lasers and its potential for application in photonic circuits. Besides the knowledge on the optimised design parameters a better understanding of the dynamic determining the physical processes of CW/ACW ring mode coupling and selection has to be developed.

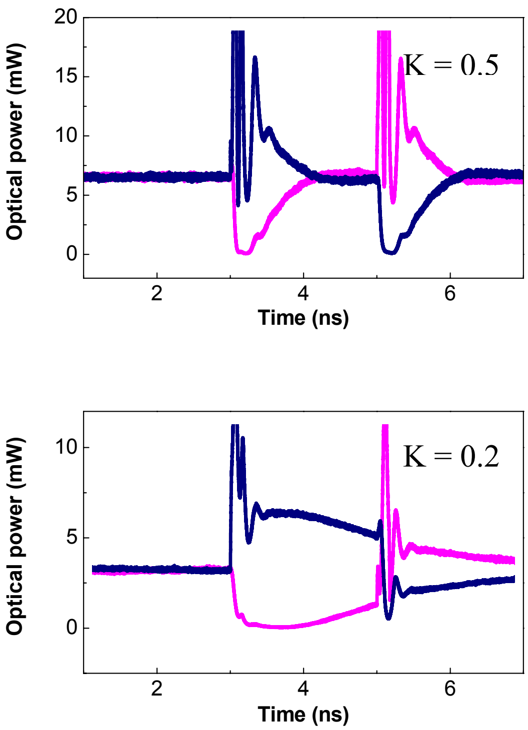


***Fig. 6:** : Quality of switching between CW and ACW degrades for non-zero facet reflectivities (R =1*10^{-4}; FSR: 200 GHz, ring laser @60 mA).*

V. Summary

Semiconductor microring lasers show an induced unidirectional lasing as well as the ability of switching the lasing direction under the influence of external optical injection at ring laser wavelength at well performed suppression of facet reflectivities.

It was experimentally shown that the counter-propagating ring laser modes are well suppressed by injection of optical power at wavelengths close to the ring cavity modes, accompanied by strongly dominant co-propagating laser modes.

Simulations of the dynamics of the ring laser device reveal that the induced directionality is expected to allow spatial laser port switching by pulsed injection. The pre-selection of the optical output keeps stable over time for pulse injection at lasing wavelength.

Acknowledgement

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