A MOVPE Grown Phasar-based Multi-Wavelength Laser with Suppression of Unwanted Orders

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In this paper we present a Multi-Wavelength Laser (MWL) with absolute wavelength control. The device is MOVPE grown on InP and consists of bulk active InGaAsP(1.55) semiconductor optical amplifiers that are monolithically integrated with passive waveguides. The MWL showed a side mode suppression ratio of over 25 dB in all four channels. A very attractive feature of the MWL is that it has been realized in a layer stack that allows for monolithic integration with with other devices in Photonic Integrated Circuits (PICs).

Introduction

A key component in WDM networks is the multi-wavelength laser (MWL), which can be used either as main transmitter or as flexible backup. In Addition, it can be used in more complex devices, for instance as a CW source in a wavelength converter or in optical beam-formers for radar. Two schemes for realizing MWLs have been reported in literature. In the first scheme, an array of DFB or DBR lasers operating at different wavelengths are multiplexed by a phased-array [1] or a combiner [2, 3]. Tuning of each DFB/DBR to the desired wavelength is required. In the second scheme, the multiplexer and the wavelength filter are part of the Fabry-Pérot laser cavity, while an array of semiconductor optical amplifiers (SOAs) is used as optical source. We will focus on this type of MWL, of which the first device, the MAGIC laser, was demonstrated by Mézéno *et al.* [4]. A phased-array based MWL was reported first by Zirngibl *et al.* [5]. The array both multiplexed and filtered the lasing wavelengths with its passbands. A MWL with absolute wavelength control was reported by Doerr *et al.* [6]. He chirped the arm lengths of the array and realized a controllable wide band-pass filter responds that selects one array order only. Later he improved the design of the parabolic chirped phased-array by taking into account the chromatic focal plane displacement [7]. Additionally, Doerr demonstrated a digitally tunable 40 channel MWL [8].
Recently, we demonstrated a MWL laser in which a MQW active layer and passive waveguides were monolithically integrated using a CBE re-growth step [9]. Here we report on a MWL with absolute wavelength control that is realized in an MOVPE grown layer stack in which SOAs have been integrated with passive waveguides. An attractive feature of this stack is its potential in Photonic Integrated Circuits (PICs), because the stack is compatible with devices such as Optical Cross Connects (OXCs) with electro-optical switches that we reported [10, 11]. In addition, the stack allows for the integration of high-contrast and low-contrast waveguides, which combines propagation loss below 1.5 dB/cm with

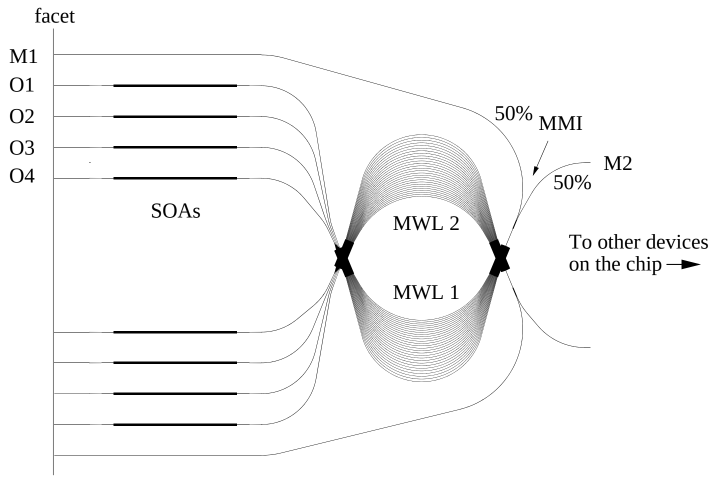

Figure 1: *Two chirped phased-array based MWLs with 4 channels. The SOAs have been integrated monolithically with passive waveguides and can be identified as the thick lines on the left side of device.*

small bending radii of 100 μm by applying a double etch technique. Therefor, this approach allows for monolithic integration of the MWL with components such as filters, phase modulators and SOAs. The MWL demonstrated in this paper can be employed as an on-chip multi-wavelength source in PICs.

Device Fabrication

All epitaxial layers for the SOA 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 InGaAsP (λ_{gap}=1550 nm) layer embedded between two InGaAsP (λ_{gap}=1250 nm) layers. The InGaAsP film layer was cladded by a 200 nm thick p-InP layer. Next, the active layer stack was butt-joint to an InGaAsP (λ_{gap}=1250 nm) layer for the passive sections by the procedure described in [12]. In the third epitaxy step a 1300 nm thick p-InP cladding layer and the p-InGaAs contacting layer were grown.
The waveguide mask layer was defined in 100-nm PECVD-SiN_x using contact photolithography on positive photo resist. The SiN_x-layer was etched using CHF_3 reactive ion etching. The ridge waveguides were etched employing an optimized CH_4/H_2 etching process and an O_2 descumming process [13]. The amplifiers were passivated with a 380-μm-thick SiN_x-layer before metalization.

Multi-wavelength laser design

The chip layout in figure 1 shows two similar chirped 4-channel MWLs in which 1000-μm-long SOAs have been monolithically integrated with passive waveguides. All waveguides are ridge waveguides. The SOAs in the MWL are filtered and multiplexed by an phased-array with parabolic chirp for absolute wavelength control [7]. The chirping suppresses transmission in orders of the array that lie outside the central one at 1550 nm. The phased-array is designed with a channel spacing of 3.2 nm, a central wavelength for TE of 1.55 μm and a FSR of 19.2 nm. In order to integrate the MWL monolithically with

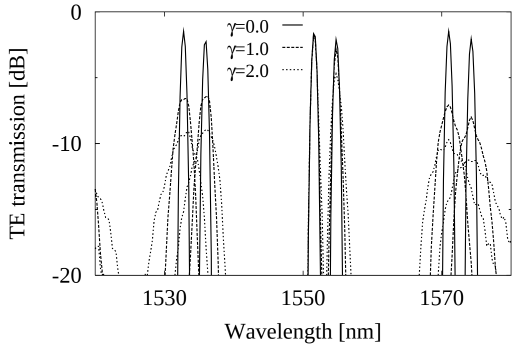

Figure 2: *Simulated transmission spectra of the chirped phased-array for three chirp factors γ.*

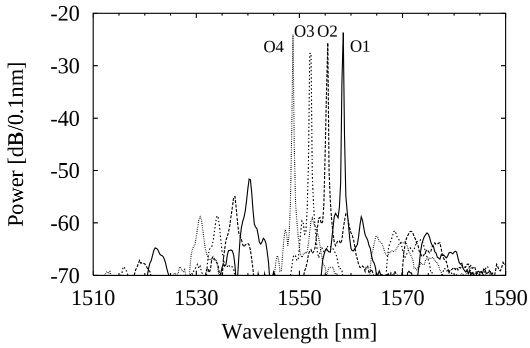

Figure 3: *Spectra from the multiplexed output of the separately biased channels of the chirped MWL.*

other devices, power is tapped from the laser cavity by employing an MMI. The MMI splits the power in the multiplexed output of the array in a 50%:50% ratio to outputs M1 and M2. Output M1 is part of the laser cavity and ends at a reflective facet. Output M2 is fed into other devices on the chip.

Simulations of the TE transmission of the array for chirp factors [7] $\gamma = 0$ un-chirped, $\gamma = 1$, and $\gamma = 2$ are displayed in figure 2, in which only two channels are shown for clarity. The suppression of the adjacent orders near $\lambda = 1530$ nm and 1570 nm is clearly visible. The simulated transmission peaks in the central order of the outer channels show some chirping-induced loss as well. This is because in the simulations a fixed FPR length was used, but chirping changes the focal length for all wavelengths and as a result it changes the optimal length of the FPR for each output port. In contrast, in the fabricated devices the FPR length has been optimized.

Measurement results

Measurements on the MWL were made without applying any coating to the facets of the chip. Output M2 was leading to amplifiers that were not pumped and absorbed all the light. Therefore, M2 had no influence on the laser operation. The output from the chip was fiber coupled using a tapered lensed fiber tip. Output spectra are shown in figure 3, where it can be seen that the MWL operates in the single order around 1550 nm, as it was designed to do. All channels show a SMSR of over 25 dB. The peaks visible next to the laser peaks are caused by Amplified Spontaneous Emission (ASE) noise that is filtered by adjacent orders of the array. The decreasing power in wavelengths at increasing distance from the central order is due to both the chirping of the array and the gain spectrum profile. Loss in the phased-array itself was measured on a copy of the phased-array using transmission measurements. The loss in the central order of the phased-array was measured to be less the 4 dB. In the side orders the suppression in the transmission due to the chirping was around 5 dB. The output power of the laser was measured as a function of the injection current for all channels on the multiplexed output M1. The threshold currents are between 127 mA and 135 mA, which equals a current density around 6.5 kA/cm^2. The differential efficiency was $\eta = 6 \times 10^{-3}$ W/A.

The output power available at the multiplexed output on-chip output M2 was measured to be 1 mW at 150 mA bias. This power is sufficient for the using the MWL as on-chip source and the power can be increased by optimizing the amplifier length and by applying a High-Reflection (HR) coating to the facet with outputs O1, ...,O4 and M1.

Conclusions

We realized a chirped 4-channel phased-array based MWL in a layer stack that is suitable for the fabrication of PICs. All channels operated in the central order and had a SMSR of over 25 dB. The phased-array itself showed excess transmission loss below 4 dB in the central order and a suppression over 5 dB compared with the central order in the adjacent orders. The on-chip power tapped from the laser cavity for use in monolithic integrated devices was 1 mW at 150 mA injection current.

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