Design of an Integrated Electro-optically Tunable Filter for Tunable Laser purposes

B.W. Tilma, E.A.J.M. Bente, X.J.M. Leijtens, R. Nötzel and M.K. Smit

TU Eindhoven, Eindhoven, the Netherlands
b.w.tilma@tue.nl

Abstract. *We present the design of a monolithic integrated electro-optically tunable filter based on two cascaded tunable arrayed waveguide gratings. The filter is designed to be used in a fully integrated single mode InAs/InGaAsP/InP quantum dot tunable ring-laser with a tuning range of 100nm to 200nm and a linewidth under 0.07nm.*

Introduction

Lasers that can make wavelength scans over wide ranges are useful tools for e.g. spectroscopy, gas detection and frequency domain optical coherence tomography (FD-OCT) [1]. Such laser systems are typically bulk solid-state laser systems that are scanned opto-mechanically or opto-acoustically. These systems are however limited in scanning speed due to their size. Besides that they are bulky and costly to operate. In this project we are developing monolithically integrated InAs/InGaAsP/InP (100) quantum dot semiconductor laser systems that can make continuous sweeps of 100nm up to 200nm in the 1600 to 1800nm wavelength range, at repetition rates of 20 kHz to 50 kHz and a linewidth better than 0.07nm. Such properties are desirable for the applications listed above and surpass the capabilities of available tunable semiconductor lasers [2]. To realize a laser for these applications we want to make a monolithically integrated ring-laser with a continuously scanning intra-cavity tunable filter based on electro-optically tunable arrayed waveguide gratings (AWGs). Combinations of tunable AWGs that have the 100 to 200nm scanning range can be realised in our active-passive integration technique and thus be used in a fully integrated tunable laser. Significant advantages of such filters are: full configurability through control voltages; continuous scan capability over the full range; no heating effects in the filter (only tens of nA current flow through the modulators, in contrast to injection current controlled gratings).

The laser gain medium will be InAs/InGaAsP/InP (100) quantum dots layers [3]. This medium can provide gain in the 1600-1800nm wavelength range. The output spectrum of a monolithic ring laser operating around 1700nm is presented in figure 1.

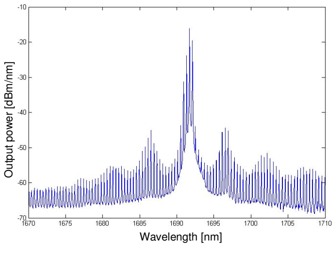

Figure 1: *Laser output spectrum of a monolithic quantum dot ringlaser with a 4mm long cavity.*

In this paper we present the design of a monolithic integrated electro-optically tunable filter based on tunable AWGs. First of all, we will discuss the requirements on the tunable filter and secondly we will present the design of the filter.

Filter specifications

Assuming a ring-laser configuration with an intra-cavity tunable AWG, we expect that the total length of the cavity will be approximately 15mm. The mode spacing of such a laser in this case will be 0.05nm. This means that the ring-laser must be near single mode to achieve a linewidth of 0.07nm. To scan the laser over 100nm in 1000 steps and with a scanning frequency of 20kHz the filter must be able to change in 50ns from 1 wavelength to the next wavelength. To determine the requirements on the filter characteristics we have simulated the ring-laser structure with a simple time dependent multimode laser model. The parameters in the model are typical for a bulk amplifier structure. The losses for the different modes are the calculated values for the tunable AWG. The dynamical and CW behavior of the laser can then be simulated for various filter properties. From the CW state simulations one can find a set of minimum required loss values for the unwanted laser modes. When the filter is scanned the situation becomes more involved. As the filter will be scanned the laser must change from one mode to the next. To study the speed at which the laser mode intensities can follow the filter tuning one also has to consider the relative losses of the modes, the cavity length, the laser pump level, overall cavity losses and the spontaneous emission intensity. The multimode dynamics in the laser and the SOA and the limits on the switching speed are still under investigation. Two results from simulations are given in figure 2. On the left hand side the evaluation of the output power is shown when the laser starts up and reaches the CW state. All modes are building up, but the mode with the smallest loss in the filter (wl3) will win the competition and suppress the other modes. On the right hand side the evaluation of the output power is depicted when the laser is already on and the filter is switched from wl3 to wl2. In this case wl3 will decrease and wl2 will increase. In these figures we immediately see that the laser can switch from one wavelength to another within 50ns. In our first design we have chosen to make a tunable filter with a loss difference of at least 0.06dB at 0.05nm (the modespacing) from the center wavelength. This choice is based on the modeling results.

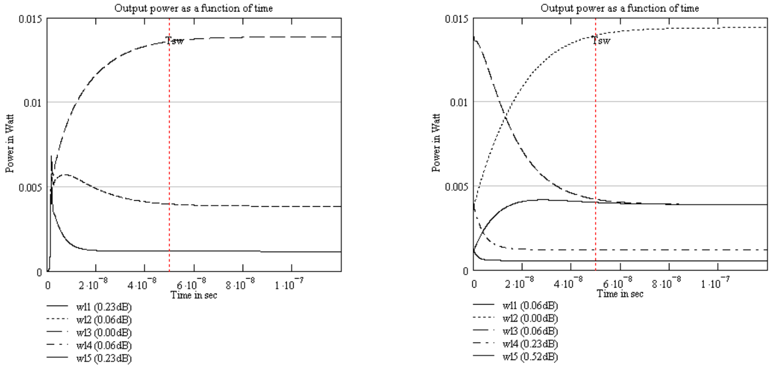

Figure 2: *Simulated output power levels for the different laser modes. In the figure on the left, the laser starts up with the filter at its center wavelength at wl3. The figure on the right depicts the evolution of the modes when the filter switches from wl3 to wl2 at t=0. The legend gives the relative loss values for the different modes. The vertical line marks the 50ns switching time.*

Filter design

The filter we will use is based on the interference principle in an arrayed waveguide grating (AWG) [4]. Including electro-optical phase shifters in the arms of the AWG makes it possible to tune the AWG [5]. An AWG without phase shifters is designed to have a linear length difference between the arms of the waveguide array. This length difference in the waveguide array acts as a dispersive element. Waves at different wavelengths will have a differently oriented phase front at the end of the waveguide array and will focus on separate positions on the image plane of the output free propagation region (FPR). The central wavelength will have his focal point exactly in the middle of the image plane where the output waveguide is located. Adding phase shifters in the arms of the waveguide array will allow electro-optic tuning of the AWG. By applying a combination of voltages on the phase shifters, the orientation of the phase front at the end of the waveguide array can be changed. The focal point of the central wavelength of the AWG can thus be tilted away from the output waveguide and another wavelength will be focused on the output waveguide. The refractive index change in the phase shifters is due to field induced electro-optical effects and free carrier depletion based electro-optical effects [6].

The filter also must be tunable over at least 100nm. In theory it is possible to design a filter with one AWG which fulfils these requirements. However this would become a large AWG with more than 200 arms and phase shifters, which is impractical. In our design we have cascaded two different AWGs, the first one is a high resolution AWG with 28 arms that selects a single laser cavity mode and suppresses the other modes with at least 0.06dB (figure 3B). Since this filter needs to have a sufficiently narrow bandwidth to suppress the neighboring laser modes, it will also have a free spectral range (FSR) of approximately 10nm. The second AWG with 11 arms selects a single peak of the high resolution AWG transmission and suppresses the other peaks with at least 1dB (figure 3A). The combination is optimized to be tuned over 200nm between 1600nm and 1800nm.

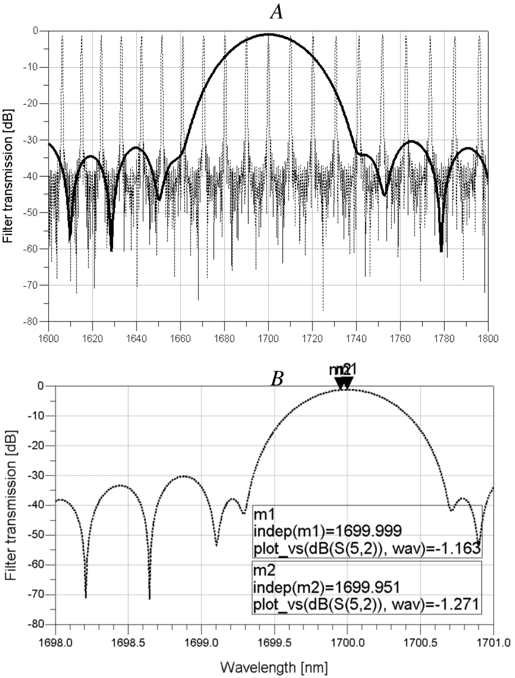

Figure 3: *Transmission spectra of the high resolution AWG (dot) and the low resolution AWG (solid). Figure B is a zoom in on the high resolution AWG at 1700nm and has two markers on laser mode positions.*

Figure 4 depicts the mask layout of the tunable filter and some test structures. It contains a high resolution tunable AWG filter with 28 phase shifters in the arms and a low resolution tunable AWG filter with 11 phase shifters in the arms. These filters can be measured separately but also in sequence. Furthermore it contains a low resolution tunable MMI filter which possibly can replace the low resolution AWG filter. To measure only the passive waveguide characteristics and the passive filter characteristics we included some passive AWGs and other test structures. Both AWGs designs are standard orthogonal AWG designs that are modified to have equal spacings between the phase modulators in the arms. This has been done in order to increase the reliability of the fabrication of the electrical contacts. In the low order AWG the path length difference between the arms need to be only eight wavelengths. This was achieved by designing this AWG in an S-shape to cancel out all path length differences and changed one side to include the small path length differences.

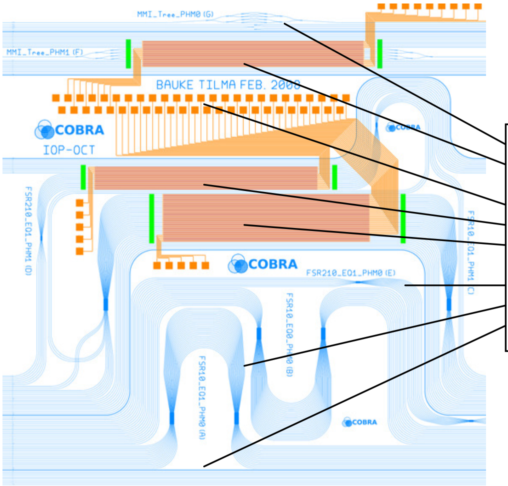

***Figure 4**: Mask layout of the tunable AWGs and some test structures. The tunable AWGs can be controlled by the electrical contact pads*

Conclusion

We present the design of a monolithic integrated electro-optically tunable filter based on two cascaded AWGs with phase shifters as tuning mechanism. The first AWG is a high resolution filter with a suppression of 0.06dB at 0.05nm from its center wavelength and the second AWG is a low resolution filter with a suppression of 1dB at 10nm from its center wavelength to select one peak from the first AWG. The filter is designed to make a fully integrated single mode tunable ring-laser with a tuning range over 100nm and a linewidth beneath 0.07nm.

Acknowledgement

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