Multi-wavelength Laser Based on Filtered-feedback

Jing Zhao[1], Peter J. Williams[2], Meint K. Smit[1], Xaveer J.M. Leijtens[1]
[1]Eindhoven University of Technology, COBRA, P.O. Box 513, 5600MB Eindhoven, the Netherlands
[2]Oclaro, Caswell, Towcester, Northamptonshire, NN12 8EQ, U.K.

We present a novel multi-wavelength laser based on on-chip filtered optical feedback. The monolithically integrated device consists of four Fabry–Pérot (FP) lasers that are wavelength-locked by an on-chip filtered-feedback section. The FP mirrors are formed by two on-chip multimode interference reflectors (MIRs), and the feedback section contains four phase shifters and a reflective arrayed waveguide grating to provide the filtered-feedback. By controlling the current injection to the lasers, single mode operation in each channel can be achieved. In this paper the design, fabrication and the first measurement are presented.

I. Introduction

The progress in the wavelength-division-multiplexing (WDM) technologies for broadband optical communication systems has called for multi-wavelength light sources. A monolithically integrated multi-wavelength laser is particularly in demand due to its economy and efficiency in increasing the flexibility of the WDM system. Different integrated MWLs have been realized. For example, tunable distributed Bragg reflector (DBR) laser arrays [1], micro-disk laser arrays [2] or MWL made by integrating a semiconductor optical amplifier (SOA) array with a multiplexer in one cavity [3-5] in a linear or ring configuration.

Here we present a novel multi-wavelength laser based on on-chip filtered optical feedback. The filtered-feedback scheme has been demonstrated in a fast tunable laser device [6]. Here we implement it to realize a multi-wavelength laser. The monolithically integrated device consists of four Fabry–Pérot (FP) lasers that are wavelength-locked by an on-chip filtered-feedback section. The FP cavities are formed by two on-chip broadband multimode interference reflectors (MIRs) [7], and a feedback section containing phase shifters and a reflective arrayed waveguide grating (AWG) to provide the filtered-feedback. Because the AWG that is used for wavelength selection is outside the main laser cavity, in contrast to conventional AWG based MWLs [3-5], the gain from the laser cavity does not need to compensate the loss from the AWG, and the main cavity can be much shorter. This configuration makes the laser have a lower threshold current, a higher output power and allows for accurate wavelength selection. In this paper the design and fabrication (section II) and the first measurement of the integrated device (section III), are presented.

II. Design and fabrication

The operating principle of the multi-wavelength laser can be understood from its schematic representation in Fig. 1a. This device consists of an array of FP lasers, each of which is formed by an SOA and two on-chip broadband reflectors that form the FP-cavity. The reflectors also provide some transmission to and from the laser cavity. One side of each FP laser is coupled to an AWG filter through a phase shifter. These FP lasers generate a broad spectrum of longitudinal modes, of which the spacing is determined by the cavity length. The AWG multiplexes the light of the FP laser channels to a common output, which is connected to another on-chip broadband reflector. This reflector will reflect the light and subsequently, the AWG will demultiplex and route the reflected signals back to each FP laser. Only the FP modes that match in wavelength with the AWG passbands are selected and fed back to the laser cavity. The filtered-feedback mode with the highest power will enhance this particular longitudinal mode inside the cavity and the laser will lock on that wavelength, thus achieving single-mode operation. The phase shifting sections (PHS, see Fig 1a) can adjust the feedback phase with the FP-cavity modes.

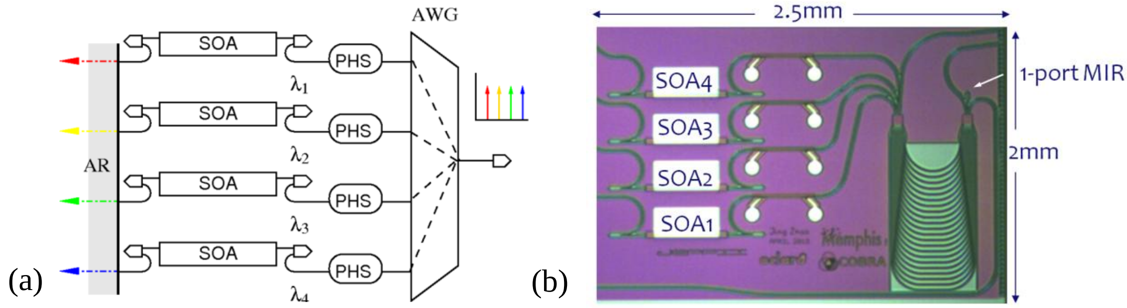

Figure 1 (a) Schematic of the device and (b) Microscopy photograph of the realized device. The chip dimensions are approximately 2 × 2.5 mm.

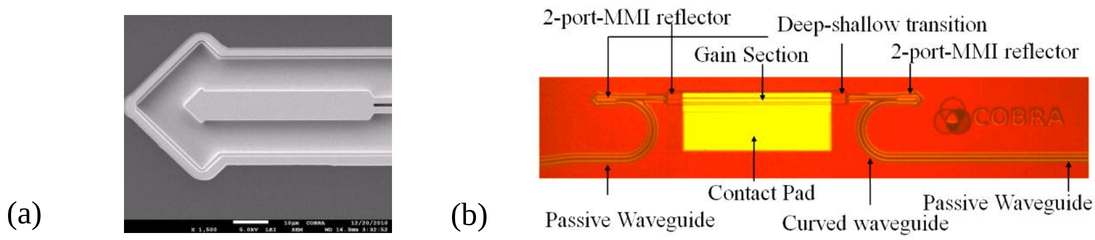

Figure 2 (a) SEM photograph of the 2-port MIR measuring 9×57 μm^2; (b) Microscope photograph of one FP laser channel with the laser based on two MIRs. Each part of the device is labelled in the figure.

Our devices were designed and fabricated on a mature and stable surface ridge active/passive InP-based integration technology [8]. The chips are fabricated in a generic multi-project wafer (MPW) run, carried out in the fab of Oclaro (UK), based on the framework of the JePPIX platform [9]. The Oclaro platform offers a set of standard photonic building blocks such as waveguides, optical amplifiers/gain sections and phase shifters on a 3” InP wafer.

Fig. 1b is a microscope photograph of the fabricated multi-wavelength laser. Here we use two-port MIRs [7] as the broadband on-chip reflectors to form the four FP laser cavities(Fig. 2), as the simple fabrication of the MIRs makes the whole device compatible with the standard active/passive integration process of the fab. The laser gain sections are 320 μm long. This length is chosen to provide sufficient gain and aims to ensure a 50 GHz longitudinal mode spacing in the FP laser cavity, of which the physical length can be accurately designed because the elements are made with lithographic precision. The optical length of the cavity is $L_{ocav} = 2 \times L_{reflector} \times N_{g\_p} + (L_{gain}+2\times L_{d,s})\times N_{g\_a}$, where $L_{reflector}$ and $L_{d,s}$ are the length of the reflector component and the deep-shallow transition with fixed design values, L_{gain} is the length of gain section, and $N_{p\_g}\approx 3.69$, $N_{a\_g}\approx 3.55$ are the group indices of the passive and active waveguide. Since the mode spacing $\Delta f = c/(2\times L_{ocav})$, where c is the speed of light in vacuum, the gain section length of 320 μm therefore corresponds to a mode spacing of 50 GHz (0.4 nm). In the filtered-feedback section, the AWG was designed with a central wavelength of

λ_0=1550 nm, with 5 inputs and 3 outputs. Four of the inputs are connected to the four FP lasers and the other one is used as test port. The AWG has spectral channels spaced at Δf=200GHz (1.6 nm), such that there are four FP modes in each AWG channel. The Free Spectral Range (FSR) of the AWG is six times its channel spacing, FSR= 6×1.6 nm=9.6 nm. On the output side of the AWG, the central port is connected to a one-port MIR to provide a common reflector, with approximately 80% reflection [10]. The other output ports are left as test waveguides. Additionally, 250 µm long forward-biased phase shifting sections (PHS) are placed between each FP laser and the AWG wavelength selection section to optimize the phase of the feedback signal. On the left side of the FP laser arrays there are the separate outputs of the multi-wavelength lasers.

III. Characterization and Discussion

The device was mounted on a copper chuck and its temperature was kept at 20 ºC during the measurements. A lensed fibre mounted on a nano-positioning stage is used to collect the light. The light is coupled out from an angled facet which is not shown in Fig. 1b. In this first measurement, the gain sections are biased consecutively.

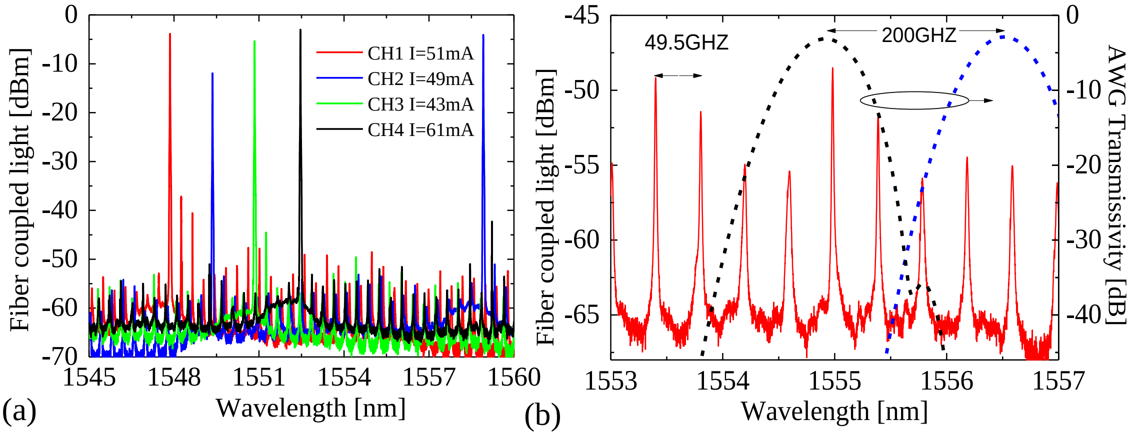

Figure 3 (a) Superimposed lasing spectra of the four channels while forward biasing the different channels. The injection currents on the different channels are shown in the graph; (b) part of channel 1 spectra showing the subthreshold sidemodes and two simulated AWG passbands.

The lasing threshold current for each channel is around 16 mA. By controlling the current injection to the lasers, we select the position of the longitudinal modes. Single mode lasing of 3 out of 4 wavelengths was obtained within the same AWG FSR. The measured spectra are shown in Fig. 3a. The four lasing peaks correspond to the laser channels labeled 1 to 4 in Fig. 1b. The pumping current and lasing wavelengths are indicated in the figure. The wavelength distance of the lasing channels is around 1.55 nm, which is close to the designed AWG channel spacing of 200 GHz. The highest sidemode suppression ratio (SMSR) is more than 40 dB. Only channel 2 has two lasing modes, which are 9.56 nm away from each other. This spacing matches the designed FSR of the AWG. The present device has not been designed to suppress higher order passbands of the AWG (e.g. through chirping of the waveguide array [11]), so lasing operation in a single order of the AWG is not guaranteed. Fine tuning of the filtered-feedback can be obtained by biasing the phase section, but the measurement has not been performed yet.

In Fig. 3b, a zoom of spectra from channel 1 is plotted. This graph shows the subthreshold sidemodes that originate from the longitudinal modes of the FP cavity, which are spaced by 0.39(1) nm. This corresponds to a frequency spacing of 49.5 GHz, 1% deviation from the ITU spacing which we designed it for. The dashed lines in Fig. 3b show the simulated AWG transmission with a channel spacing of 200 GHz. When the FP modes align with the peak transmission of the AWG, single mode lasing of the proper wavelength will occur. In our present design the FP mode can be shifted by changing the injection current, but only approximately 30% of the mode spacing, which is not sufficient to optimize the lasing operation for each channel. For precise alignment with the AWG passband, full control of the phase inside the FP laser cavity is necessary. This can be achieved by adding a phase shifting section in the FP cavity.

IV. Conclusion and acknowledgement

A four channel multi-wavelength laser based on AWG filtered-feedback, monolithically integrated on InP is reported for the first time. The chip was realized in a Multi-Project Wafer run in an active/passive integration process from a combination of amplifiers, multimode interference reflectors (MIRs) and an AWG-based filtered feedback section. This concept can be easily extended to a larger number of wavelengths by increasing the number of AWG channels and the number of lasers in the array. With the short laser cavity formed by the MIRs and the filtered-feedback scheme, the laser threshold current is lower and the output power is higher compared to the AWG-based lasers with AWG filter inside the main lasing cavity.

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