Design of multi-wavelength transmitters using on-chip MMI reflectors

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Multi-wavelength lasers (MWLs) play an important role in wavelength division multiplexing networks, and also in photonic radar beam steering applications. In this paper we present the design of multi-wavelength transmitters, with multi-wavelength lasers and modulators monolithically integrated on an InP chip. We use novel on-chip MMI reflectors to form an array of Fabry-Perot lasers, which is frequency-locked by feedback from an AWG filter. The multi-wavelength laser is integrated with a Mach-Zehnder modulator array on a single chip, fabricated in a standard InP active-passive technology.

I. Introduction

With the increase of the demand for telecommunication bandwidth, wavelength-division multiplexing (WDM) has been regarded as a very efficient way to increase the capacity of the existing optical fiber system. It is highly desirable to have an integrated multi-wavelength transmitter to support WDM applications. This transmitter should have a laser with a stable and accurate wavelength comb and separate modulators to modulate each wavelength signal. Previously, we studied the design of such multi-wavelength transmitters[1], which consisted of an array of Fabry-Perot (FP) lasers formed by on-chip deeply etched Bragg grating reflectors (DBR)[2], a modulator array and an arrayed waveguide grating (AWG) filter to provide feedback for selecting the wavelength for each laser. The DBR FP laser was a good choice to have a short laser and to keep the AWG filter outside the cavity. However, the fabrication of DBR reflectors requires e-beam lithography and additional non-trivial processing steps[2]. Here we propose to replace DBR reflectors with the novel on-chip multi-mode interference (MMI) reflectors. These MMI reflectors are almost as compact as the DBR reflectors and they can be fabricated with the same lithography and etching steps used for fabricating deeply-etched waveguides and keep all other advantages of on-chip broadband reflectors, such as accurate positioning and keeping the light on-chip for futher use.

This paper describes the MMI reflectors and the FP lasers (section II), and the design of the multi-wavelength transmitter circuit (section III).

II. Fabry-Perot Lasers with MMI Reflectors

The 1-port MMI reflector is based on a 1×2 multi-mode interference(MMI) power splitter[3]. In 1×2 MMI power splitters, two images of the input light will appear at the output side, Fig. 1(a). To form a 1-port MMI reflector, two deeply etched 45 degree mirrors are placed on the output side in such a way that the two images will be directed towards the MMI axis, as shown in Fig. 1(b), causing the light to be reflected back at the input. This makes a full reflector, where in principle 100% of the light is reflected[4]. In a similar way, by using a 2×2 MMI power splitter with an equal splitting ratio, a 2-port 50%/50% MMI reflector can be obtained (see Fig. 1(d)). The two ports are identified respectively as a reflection and a transmission port. The reflection port is the one used for both input

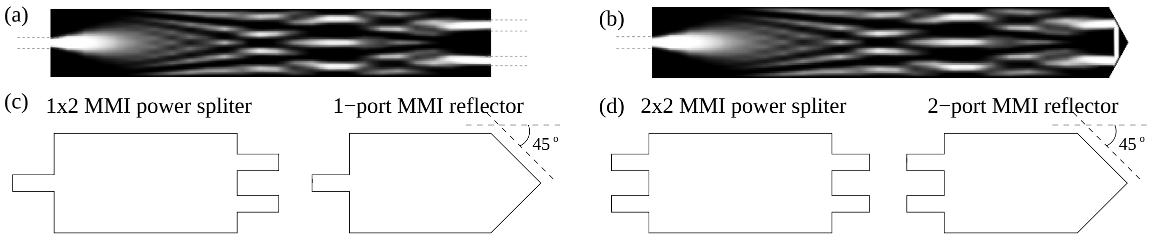

Figure 1: Illustration of MMI reflectors. (a) Field distributions in an original 1x2 MMI power splitter; (b) Field distributions in a MMI reflector after introducing two 45°mirrors from [4]. (c) and (d) Layout of MMI power splitters and the corresponding reflectors adapted from the power splitters.

and output, while the transmission port is only operated as an output. MMI reflectors can have different reflection/transmission ratios by tapering the multi-mode section. Here, the equal ratio reflectors are used.

A basic Fabry-Perot laser needs two mirrors, one on each side of the semiconductor optical amplifier (SOA) to form the oscillation cavity. At least one of these two mirrors should be a partial reflector that is able to tap the laser light out of the cavity. Common FP lasers use cleaved facets as mirrors, for which the laser cavity has to be extended to the cleaved edge of the chip. The laser light will be emitted from the facet, outside the chip and will not be available for further on-chip processing, Fig. 2(a). For the FP lasers with MMI reflectors, the cavity length can be precisely defined by the lithography. In this case, if the passive and active group index as well as its current dependency are known, the laser mode spacing can be designed and slightly tuned by changing the SOA injection current.

By having combinations of 1-port and 2-port MMI reflectors on either side of the SOA, the MMI reflector FP lasers make the laser light available on the chip. As shown in Fig2(b), the FP laser cavity is free from the restriction of the facets, and it is formed on one side with a 1-port MMI reflector, and on the other side wiht a 2-port MMI reflector acting as a partial reflector to tap the light out of the cavity. The transmission of the 50%/50% 2-port MMI reflector can be routed to other components of the circuit which needs a laser input, or to the edge of the chip for characterization, as is shown here, with an angled waveguide to suppress possible reflections. For application in our multi-wavelength transmitter circuit, we use two 2-port MMI reflectors, to obtain the light transmission from both sides of the laser cavity, see Fig. 2(c). In the next section this FP laser will be explained in more detail when used as a building block for the multi-wavelength transmitter.

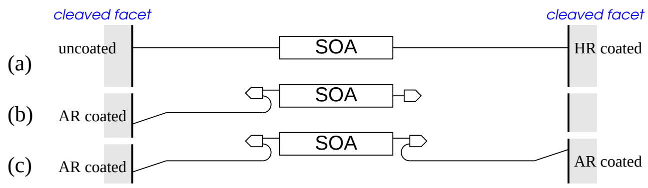

Figure 2: Schematic picture of (a) an extended cavity FP laser with cleaved facets as mirrors; (b) a FP laser with its cavity formed by 1-port and 2-port MMI reflectors; (c) a FP laser with two 2-port MMI reflectors.

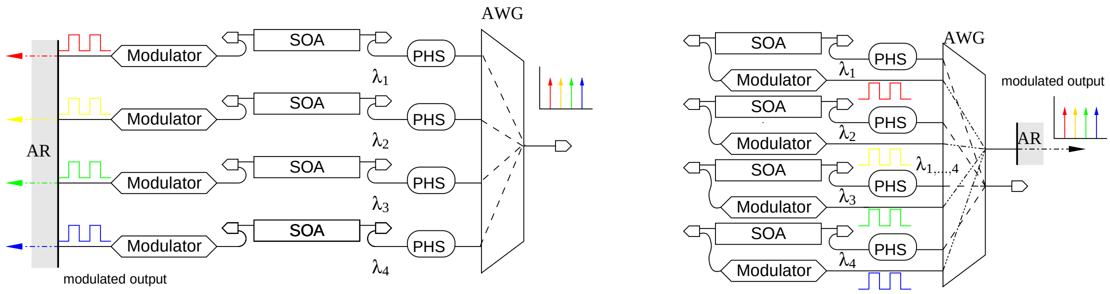

Figure 3: Schematic drawing of AWG based filtered feedback multi-wavelength transmitters: with separate output (left), and with multiplexed output (right).

III. Multi-wavelength Transmitter with MMI FP Lasers

Fig. 3 shows the layout of two types of multi-wavelength transmitters, with separated and with multiplexed outputs, respectively. Both transmitters use FP lasers with 2-port MMI reflectors to form a four-channel laser. The laser shown in Fig. 3 (left) has four outputs. On the right side of the FP laser, the feedback through the AWG locks the wavelength of each FP laser and the phase of the feedback light is tuned by the phase shifter (PHS). This laser can emit simultaneous at four channels, of which the lasing wavelength is determined by the AWG. At the left side of each FP laser, the light is routed to a modulator, which can be an electro-opto Mach-Zehnder (MZ) modulator or an electroabsorption modulator. After modulation, the four channels are each output from the anti-reflective coated facet, as is shown in the left figure. Alternatively they can be guided to an AWG multiplexer to create a single multiplexed output. This AWG may even be the same that was used for the filtered feedback, as is shown in the right figure. This has the advantage that the passbands of the multiplexer are guaranteed to be aligned with the lasing wavelengths, but has the disadvantage of a larger AWG size. Because of the use of the MMI reflectors, the laser cavity length can be designed in such a way that the AWG channel spacing is several multiples of the longitudinal mode spacing of the FP laser, as is shown schematically in Fig. 4(b).

Fig. 4(a) shows the mask layout corresponding to the separate output transmitter. The four-channel device uses an AWG with 5×3 channels, at a spacing of 100 GHz (0.8nm), for a central wavelength of 1550nm, to match the ITU-grid standard. The extra ports are used for characterization. On one side of the AWG, the central channel of the 3 outputs ends in a 1-port MMI reflector to produce the feedback. On the other side of the AWG, 4 outputs are connected first to phase shifters. With the curved waveguides the FP lasers are coupled the the phase shifters and to the MZ modulators, of which each interferometer branch has a phase shifter. The outputs of the modulators are routed to the angled waveguides at the facet. The footprint of the whole transmitter chip is $2 \times 4\text{mm}^2$. As indicated in Fig.4(a), all the contacts are electrically isolated from each other to prevent electrical crosstalk.

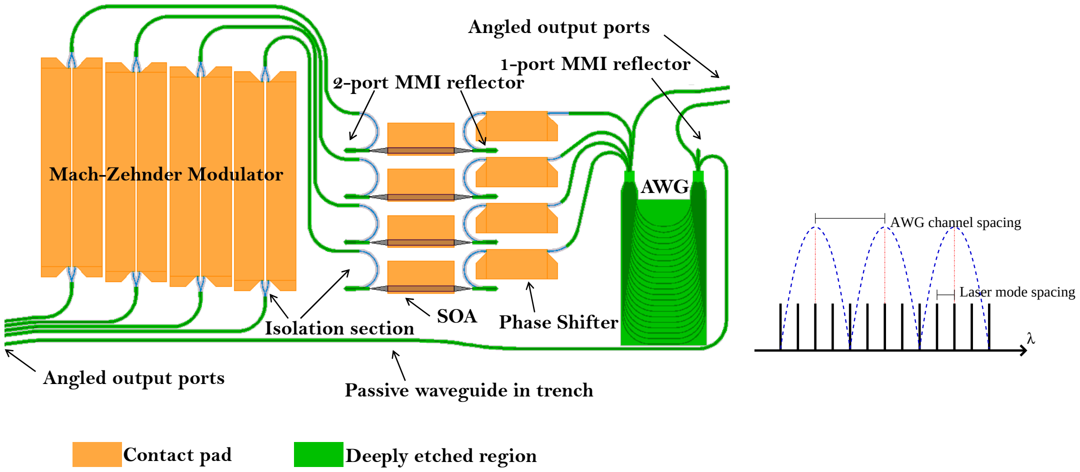

Figure 4: (a) Mask layout of a multi-wavelength transmitter with separate outputs; (b) A diagram example of a FP laser mode spacing matching with the AWG channel spacing.

IV. Conclusion and acknowledgment

Novel on-chip MMI reflectors have been introduced for use in an AWG filtered-feedback based multi-wavelength transmitter circuit. We presented the concept and mask design of this kind of multi-wavelength transmitter which uses the MMI reflectors to form a FP laser building block. The fabrication of the transmitter chip is much simplified because no additional process steps are required for these MMI reflectors.

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