

Design of photonic integrated transmitter in a multi-project wafer run

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We investigate methods for monolithically integrated multiwavelength transmitters in indium phosphide-based materials. In particular, we focus our interest on two transmitter types. The first uses arrayed waveguide grating as wavelength selective element and the second one takes advantage of DBR lasers that are integrated with electro-optical Mach-Zehnder modulators. In this paper we explain the operation principles and demonstrate the design process of the multiwavelength sources. We also present the mask layouts of the devices that will be fabricated in a multi-project wafer run within the EU NMP programme EuroPIC.

Introduction

The challenge for modern photonic integration is to develop a generic technology that supports a set of elementary components and enables designing and fabricating a variety of different photonic integrated circuits using the same processes. The components, called basic building blocks, can be used for realization of photonic chips with broad functionality [1]. Only three elementary components are sufficient to design the photonic circuits presented in this paper. These components are (1) passive waveguide structures, (2) phase modulators, and (3) semiconductor optical amplifiers. The devices made from these building blocks were studied previously on small scale by the COBRA Research Institute [2]. We investigate the transfer of this generic model to industrial fabs within the EuroPIC programme [3]. Our photonic integrated transmitters would be one of the first devices fabricated and packaged in a commercial foundry according to this generic model. The EuroPIC partners are presently preparing their processes for experimental generic foundry runs.

The multiwavelength transmitters presented here are designed to be fabricated on an indium phosphide (InP) based platform. This is because of the attractive optical properties of InP and related ternary (InGaAs, InAlAs) and quaternary (InGaAsP, AlGaInAs) compounds. They are direct-bandgap materials suitable for light generation and detection, light guiding, and fast phase modulation. Moreover, the platform and related technology enable integration of both passive and active components within single chip.

Multiwavelength lasers based on arrayed waveguide gratings

Multiwavelength lasers and discretely tuneable sources with broad tuning range can be made using arrayed waveguide gratings (AWGs). While AWG-based multiwavelength lasers may be realized in many configurations, the most straightforward one is presented schematically in Figure 1 (left). This AWG laser consists of an array

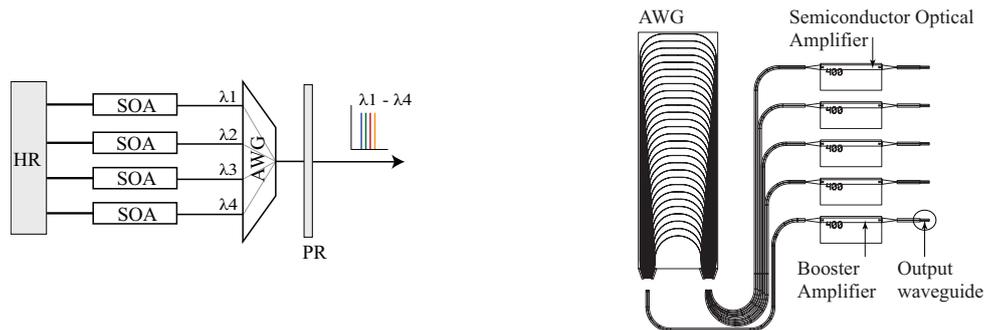


Figure 1. *Left*: schematic of AWG-based laser composed of semiconductor optical amplifiers (SOAs) with an intra-cavity filter (AWG). Optical cavity is formed by the highly-reflective (HR) and partially-reflective (PR) facets of the chip. *Right*: the corresponding mask layout of a four-channel AWG-based laser with booster amplifier. The AWG was designed for a central wavelength $\lambda_c = 1.55 \mu\text{m}$ with a channel spacing $\Delta\lambda = 100 \text{ GHz}$. The size of the device is $2 \times 2 \text{ mm}^2$.

of semiconductor optical amplifiers (SOAs) integrated with an AWG. The cleaved facets of the chip form a cavity and act as highly-reflective (HR) and partially-reflective (PR) mirrors. The AWG operates as intra-cavity filter and thus determines the generated wavelengths. These lasing wavelengths depend on the passband location of each channel of the AWG. The cavity loss is minimal for the specific wavelength corresponding to the particular passband of the AWG, where the SOA is activated by current injection. For each generated wavelength a separate SOA is dedicated. By biasing more than one SOA, AWG-based lasers can simultaneously generate several wavelengths. These types of sources have good operational stability at a given wavelength because the wavelength selection is dominated by the passive optical component. A number of such devices have already been demonstrated [4]-[6]. Using a principle of the AWG-based laser design shown in Figure 1 (left), we prepared a set of mask layouts of multiwavelength sources. We followed the design rules of the foundry, so these devices can be fabricated in their generic technology process. The mask layout of one of those devices, a four-channel source, is presented in Figure 1 (right). The device integrates an AWG with four SOAs and a booster amplifier that is used to increase the total optical output power. Because each laser emits a continuous-wave signal, we need to integrate the multiwavelength source with radio-frequency modulators to obtain a fully operational multiwavelength transmitter.

Arrayed waveguide grating-based multiwavelength transmitter

AWG-based multiwavelength lasers can be integrated with fast modulators in several ways. To maintain laser stability and avoid frequency chirping coming from the SOA, the modulators should be placed outside the laser cavity. Figure 2 shows a possible configuration with the corresponding mask layout. One common AWG acts both as intra-cavity filter for the laser and as a multiplexer that combines all generated and modulated signals, and then forwards them into the common output waveguide. In this case the larger AWG is required, with doubled number of channels separated by half of channel spacing than $\Delta\lambda$ used to design the AWG-based laser. The cavity is again formed between the cleaved facets. A fraction of the light can be coupled out from the laser cavity using, for instance, multimode interferometer (MMI), as indicated in the Figure 2 (left). Because the MMI is used as a 3dB splitter, it introduces

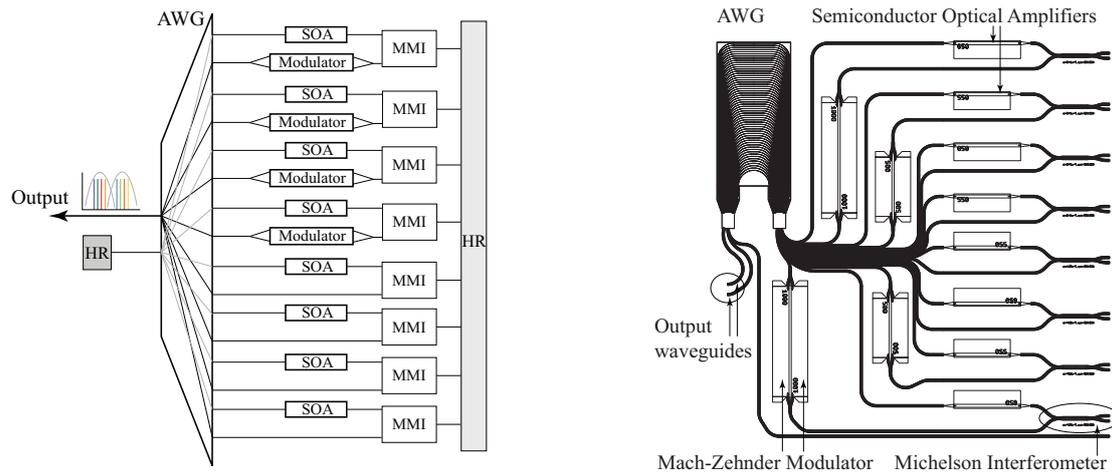


Figure 2. *Left*: schematic of the AWG-based laser integrated with four electro-optical modulators. *Right*: the corresponding mask layout. The AWG was designed for a central wavelength $\lambda_c = 1.55 \mu\text{m}$ with a channel spacing $\Delta\lambda = 100 \text{ GHz}$. The size of the device is $4 \times 4 \text{ mm}^2$.

an additional 3-dB loss, when going from the SOA to the facet. After reflection, the signal is split 50/50% between the SOA branch and the modulator branch. The first 3-dB loss can be prevented by replacing the MMI with a Michelson interferometer. This interferometer is composed of a 2×2 MMI which splits the light in two branches with slightly different length. By choosing this length difference, the splitting ratio of the reflected light can be set anywhere between 0 and 100%, allowing the out-coupled fraction of a light to be chosen freely, and in principle without loss. That light is then routed to the modulator, where it is modulated with the RF signal and then multiplexed by the AWG to the device output waveguide. For the modulation, we use electro-optical Mach-Zehnder modulators. In our transmitter we use both continuous-wave and modulated signals. There are no modulators in the branches generating the continuous-wave signals. This transmitter integrates the following basic components: four modulators (eight phase shifters), eight SOAs, eight interferometers in Michelson configuration, eight 1×2 MMI couplers and eight 2×2 MMI couplers. The device measures $4 \times 4 \text{ mm}^2$. The advantage of this device is that the lasing wavelengths are guaranteed to be aligned, because they are determined by the AWG. The disadvantage is that the lasing cavity is rather long, which makes the longitudinal modes closely spaced which may cause the device to be susceptible to mode hopping.

Multiwavelength transmitter based on array of DBR lasers

Multiwavelength transmitters can also be realized by generating each wavelength separately and using an AWG just for the multiplexing. We study this concept as well, using an array of integrated tuneable distributed Bragg reflector (DBR) lasers combined with modulators. The schematic of the structure and corresponding mask layout of the eight-channel device, generating four continuous-wave and four modulated signals, is given in Figure 3. The light is multiplexed and coupled into a single output waveguide using an AWG. In this design we use the electro-optical modulators in Mach-Zehnder configuration that were described above. The device integrates eight DBR lasers, four Mach-Zehnder modulators (eight phase shifters) and the AWG. The DBR laser consists of four sections: (1) a front grating providing the partial reflection, (2) a rear grating giving near 100% reflection, (3) a phase control section

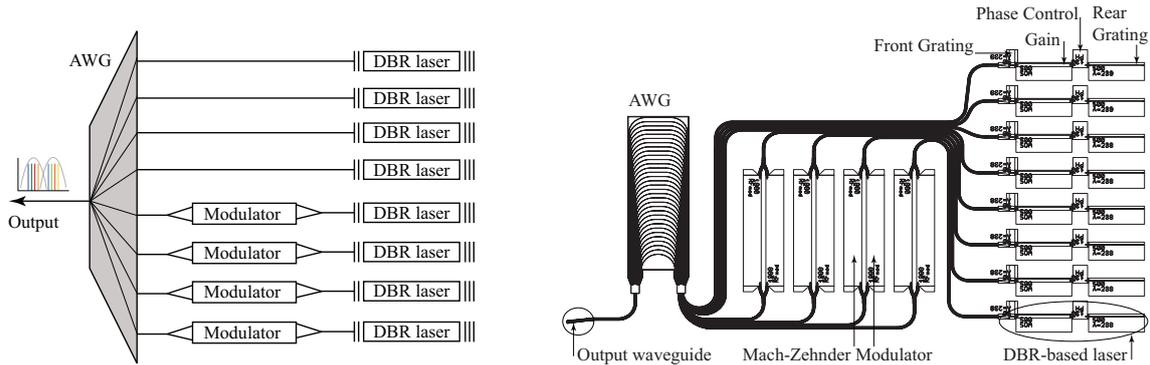


Figure 3. *Left*: schematic of multiwavelength transmitter that integrates eight DBR lasers with four electro-optical modulators. *Right*: the corresponding mask layout. The AWG was designed for a central wavelength $\lambda_c = 1.55 \mu\text{m}$ with a channel spacing $\Delta\lambda = 100 \text{ GHz}$. The size of the device is $5 \times 2.5 \text{ mm}^2$.

to tune the phase of the reflected signal, and (4) a semiconductor optical amplifier for providing the gain within the structure. The wavelength selection is done by design of the grating period of the DBR gratings and this can be fine-tuned by current injection in each of the gratings. We aim to achieve 10 Gb/s data rate from each of our electro-optical modulators. The tuning range of the DBR laser is around 10 nm, which is sufficient to tune each laser to the proper AWG passband.

Summary and acknowledgement

In this paper we discussed two concepts of multiwavelength transmitters, presented designs and mask layouts of integrated sources and gave account of the operating principles of the AWG- and DBR-based transmitters. The structures were designed and prepared to test the generic fabrication concept in the framework of the EuroPIC programme. The devices will be fabricated at the facilities of one of the EuroPIC partners this year.

We acknowledge the support of the EU through the FP7 NMP programme, grant agreement no.: CP-TP 228839-2 EuroPIC: European manufacturing platform for Photonic Integrated Circuits.

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