Multiwavelength photonic transmitters in a multi-project wafer run

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We present characterization results of monolithically integrated photonic transmitters fabricated in a multi-project wafer run. The devices were realized on an indium-phosphide (InP) platform and combine multiwavelength arrayed waveguide grating (AWG)-based lasers with electro-optical Mach-Zehnder modulators. The 4- and 8-channel sources were realized in two configurations using AWGs both as intra-cavity filter and multiplexers of optical signals. In this paper we present the design of the integrated circuits, the mounting on an aluminum-nitride submount, and the first optical measurements of the transmitters.

Introduction

Modern photonic integrated circuits (PICs) can be realized using a set of elementary components. This approach known as generic technology enables designing and fabricating a variety of different photonic devices from basic building blocks using the same technological processes [1]. Broad class of functionality of photonic chips can be realized just by integrating the following basic building components: (1) passive waveguide structures including waveguide bends, power combiners and splitters, filters, wavelength (de)multiplexers, (2) phase modulators that control the phase of propagating optical signals, (3) semiconductor optical amplifiers (providing amplification and non-linear functions), and (4) polarization converters. Within the EU programme EuroPIC [2] we explore such generic processes and develop photonic building blocks in cooperation with foundry fab partners: Oclaro in the United Kingdom and Fraunhofer Heinrich Hertz Institute in Germany. Additionally, this generic concept enables participation in multi-project wafer (MPW) runs and has the potential to provide a significant reduction in the fabrication and packaging costs of PICs [3]. Devices presented in this paper were fabricated in an industrial fab according to this generic model as one of the first multiwavelength transmitters this kind.

The photonic transmitters presented here were fabricated on an InP-based platform. This is because of the attractive optical properties of InP and related ternary (InGaAs, InAlAs) and quaternary (InGaAsP, AlGaInAs) compounds. These are mainly direct-bandgap materials suitable for light generation and detection, light guiding, and fast phase modulation. Moreover, the InP-based platform and the related advanced technology enable integration of both passive and active components within a single chip, on a single wafer and as a result building of advanced photonic circuits.

Design of the multiwavelength transmitters

Multiwavelength lasers and transmitters can be made using arrayed waveguide gratings (AWGs) acting both as intra-cavity filters and (de)multiplexers of optical signals. Already a number of AWG-based lasers have been demonstrated [4]-[6]. Based on the operating principle of an AWG-based laser and by integrating it with electro-optical modulators we designed the multiwavelength transmitters using the following elementary building blocks: deeply etched passive waveguide structures and phase modulators, shallowly etched semiconductor optical amplifiers (SOAs). Between the shallowly etched and deeply etched elements low-loss deep-shallow transitions were inserted. To maintain laser stability and avoid frequency chirping coming from the SOA, the modulators were placed outside the laser cavity. Figures 1 and 2 show the schematic of two possible configurations with the corresponding mask layouts. For our specific application we designed the multiwavelength sources to generate both continuous wave (CW) signals and modulated downstream (DS) data [7]. Light generated by the AWG-based lasers is coupled out from the cavity using multimode interferometers (MMIs) in Michelson configurations and is subsequently directed to the Mach-Zehnder modulators. In the case of the transmitter presented in Figure 1 only one AWG is used and this AWG acts both as an intra-cavity filter of the laser and as a multiplexer of all optical signals.

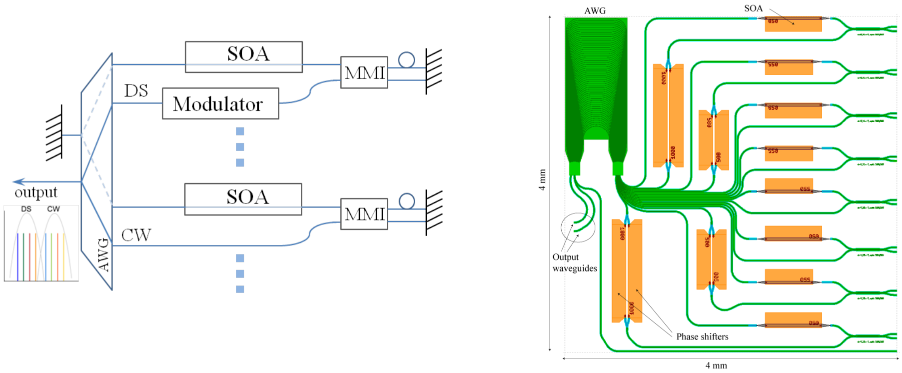

Figure 1. Schematic of the AWG transmitter (*left*) and the corresponding mask layout of 8-channel source integrated with four electro-optical modulators (*right*). Generated light is coupled out from the cavity using Michelson interferometers. This allows the outcoupled fraction of light to be chosen freely, and in principle without loss. The AWG was designed for a central wavelength λ_c = 1.55 µm with a channel spacing $\Delta\lambda$ = 100 GHz. The free spectral range of the AWG is 16 times $\Delta\lambda$.

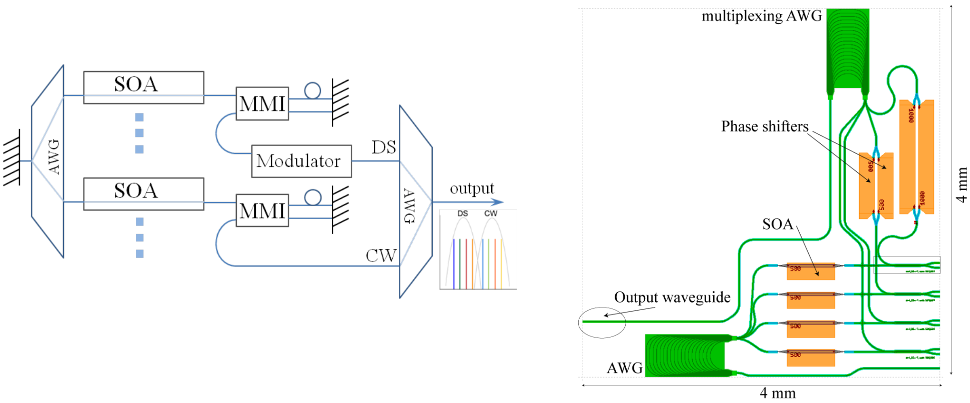

Figure 2. Schematic of the AWG transmitter (*left*) and the corresponding mask layout of 4-channel source (*right*). Both AWGs were designed for central wavelength λ_c = 1.55 µm, channel spacing $\Delta\lambda$ = 200 GHz and free spectral range 4 times $\Delta\lambda$. The length of the SOA is 500 µm. One AWG is used as intra-cavity filter of the laser, the other AWG multiplexes all signals into the common output.

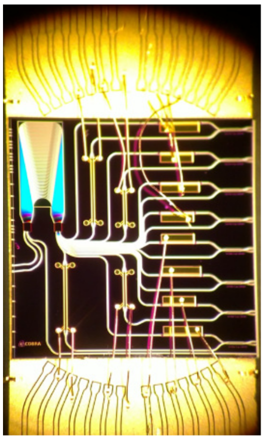

Figure 3. Picture of the submounted 8-channel AWG transmitter.

Submounting of the multiwavelength transmitters and measurements

The devices were mounted on an aluminium nitride submount and the contacts were wire bonded to DC and RF tracks on the submount (Figure 3). For characterization we used needle probes to bias the SOAs and modulators. A lensed fiber-tip was used to couple the light out from the chip. The devices were measured at room temperature. A high resolution (0.16 pm) Optical Spectrum Analyzer, APEX P2041A, was used to detect the spectra of the transmitters.

The measurements of the threshold current and the emission spectrum of the 4-channel source are presented in Figure 4 and Figure 5. The measured threshold current of the laser is below 40 mA for each channel with the output power above 1 mW. Figure 5 shows the emission spectrum of one of the channels of the AWG source. After analysis of the spectra we noticed that two laser cavities are formed within the device: one, as intended, between cleaved facet of the structure (between *out-top*, *out-bot* and *cout* waveguide) with wavelengths matching to the AWG passband; and a second one, a parasitic cavity, formed between the cleaved facets (*out-top* and *out-bot*) and the free propagation region (FPR) of the AWG where the trench of the deeply etched waveguide forms a competitive mirror. This type of behaviour can be eliminated in several ways: (1) by redesigning the FPR regions of the AWG; (2) introducing the HR coating

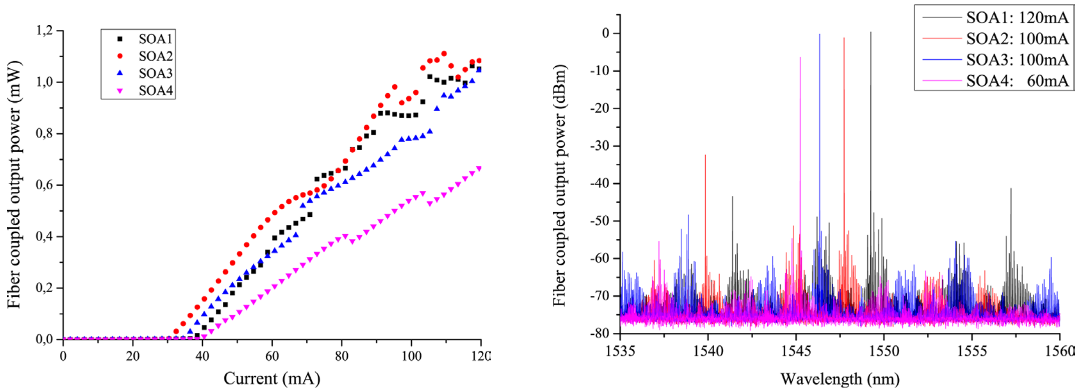

Figure 4. *Left*: *LI* curves of the 4-channel AWG-based transmitter. The threshold current is below 40mA for all channels. *Right*: emission spectra from all SOAs of the 4-channel AWG transmitter.

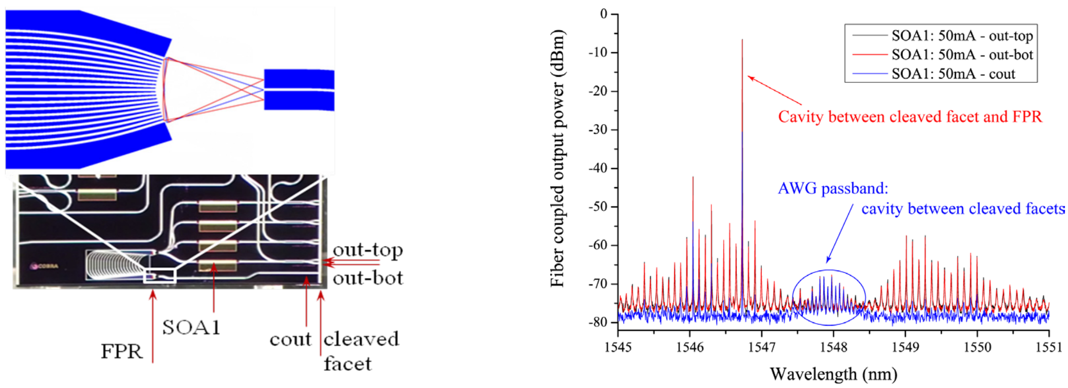

Figure 5. *Left:* 4-channel AWG-based source with indicated reflection point from the FPR of the AWG. *Right:* the emission spectra from the SOA1 measured at different outputs. Basing on FFT analysis and spacing of the longitudinal modes we identified two laser cavities formed in the source.

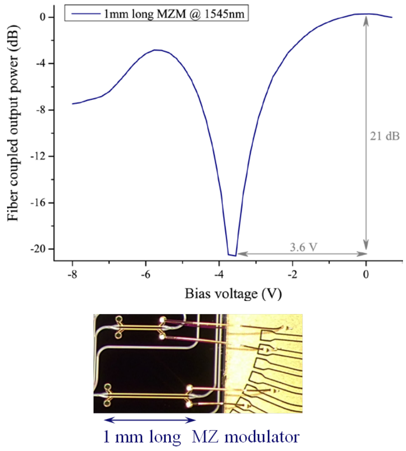

Figure 6. Measured extinction ratio of 1 mm long Mach-Zehnder modulator (*top*) and the photograph of the mounted device (*bottom*).

at the cleaved facet to enhance the reflection from this type of mirror; (3) by placing optical amplifier at the output waveguide that introduces extra amplification to the preferred cavity.

We also measured first static characteristics of electro-optical modulators in Mach-Zehnder configuration by using the submounted 8-channel transmitter. The extinction ratio of 1 mm long component is more than 21 dB with V_π of 3.6 V for 1545 nm wavelength, as is presented in Figure 6.

Summary

AWG-based multiwavelength transmitters were realized within the framework of the generic foundry model and by participating in the MPW run. The results show that complex photonic integrated circuits can be realized using a set of building block components provided by the foundry's platform and can be fabricated through standardized MPW runs. First characterization results of the devices show promising performance of this type of photonic integrated circuits.

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