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# AWG-DBR-based WDM Transmitter fabricated in an InP Generic Foundry Platform

**Katarzyna Ławniczuk[1,2], Christophe Kazmierski[3], Mike J. Wale[1,4], Paweł Szczepański[2,5], Ryszard Piramidowicz[2], Meint K. Smit[1], Xaveer J.M. Leijtens[1]**

*1. Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, the Netherlands; 2. Warsaw University of Technology, Koszykowa 75, 00-662 Warsaw, Poland; 3. III-V lab, Common laboratory of Alcatel-Lucent Bell Labs, Route deNozay, 91460 Marcoussis, France; 4. Oclaro Technology Ltd., Caswell, Towcester, Northamptonshire, NN12 8EQ, United Kingdom; 5. National Institute of Telecommunications, Szachowa 1, 04-894 Warsaw, Poland*
*(k.lawniczuk@tue.nl)*

**Abstract:** We report a novel narrow-linewidth WDM transmitter operating at 10 Gbps per transmission channel with 275 kHz optical linewidth. The device, which integrates an AWG-based laser using selective DBR-mirrors with a Mach-Zehnder modulator array, has been fabricated in a multi-project wafer run in a generic InP-based foundry process.
**OCIS codes:** (130.0130) Integrated optics; (130.3120) Integrated optics devices

## 1. Introduction

In this paper we present a novel 8-channel multiwavelength transmitter (MWT) with very narrow linewidth, realized in a generic indium phosphide (InP)-based foundry process [1,2]. The generic foundry approach allows for rapid prototyping at low cost, by participating in so called Multi-Project Wafer runs. These are fabrication runs in a standardized foundry process in which a number of different designs are combined on a single wafer, thus sharing the cost of a run. This approach has been practiced for a few years in silicon photonics, but recently it has become also available for advanced InP-based integration processes [3,4].

The MWT reported here is based on the operational principle of a linear arrayed waveguide grating-based laser (AWGL) [5,6] and is an alternative design to the MWTs presented in [7,8]. The wavelength-selective mirrors, implemented as DBR-based gratings, will prevent lasing of the source in unwanted AWG orders, thus guaranteeing operation in the central free spectral range [6]. The schematic and a photograph of the fabricated circuit are presented in Fig. 1. The cavity of the AWGL is formed between the highly reflective (HR) coated cleaved facet of the chip and the DBR grating. Because the DBR mirrors can be positioned freely on the chip, the length of the laser cavity can be reduced and the longitudinal mode spacing can be controlled. Recently reported on-chip mirrors, multi-mode interference reflectors [9] also provide such flexibility, but are broadband and therefore cannot be used as wavelength selective filters. In our configuration employing DBR gratings, we obtain single mode operation without mode hops and a narrow linewidth thanks to the relatively long extended cavity of the AWGL. The sources are easier to drive, as compared to traditional AWGLs. In addition, the tuning precision can be enhanced by introducing phase elements (PH) within the resonant cavity.

## 2. Design and operation principle

The transmitter integrates the following photonic building blocks available in the generic foundry process: (1) passive waveguide devices: (2) SOAs, (3) phase modulators, (4) detectors, (5) DBR gratings, and (6) spot size converters (SSCs). The device allows for simultaneous transmission of four continuous wave (CW) and four modulated downstream (DS) signals. It was designed using design tools and component libraries developed in the framework of two European projects [10,11], and fabricated in a MPW-run carried out by a foundry partner [11].

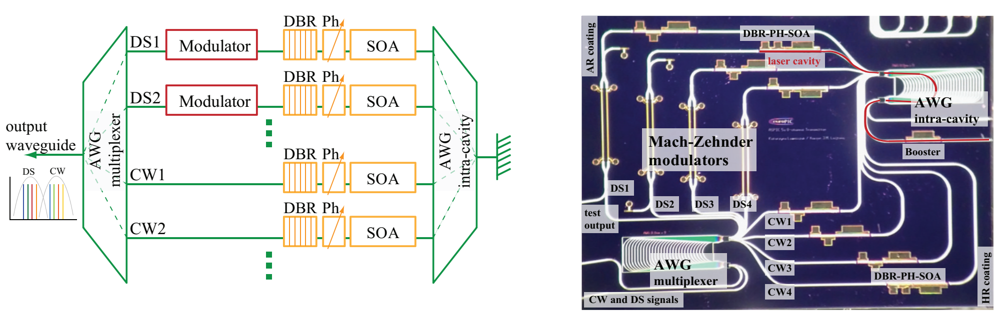

Fig. 1. Schematic (*left*) and photograph (*right*) of the photonic integrated transmitter.

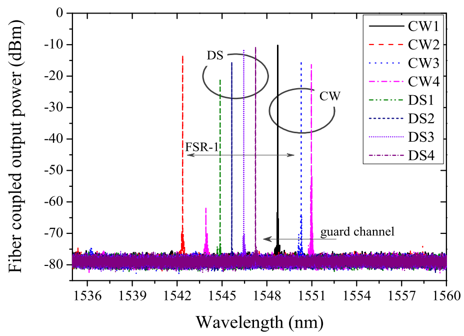


**Fig. 2.** Spectra of the MWT while activating each channel one by one. The SMSR is better than 40 dB.

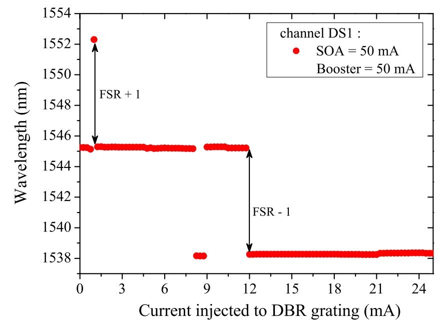


**Fig. 3.** Tuning the DBR mirror via current injection: laser operation is dependent on the position of the DBR passband.

The modulators are placed outside the laser cavity and are realized as electro-optical Mach-Zehnder modulators (MZMs), composed of two identical electro-optical phase shifters and an optical splitter/combiner pair. The facet of the chip, where the optical outputs were positioned, is anti-reflection (AR) coated. All generated signals, CW and DS, are combined to the common optical output through the multiplexing AWG. Both AWGs (the intra-cavity filter and the multiplexer) have identical design, with a centre wavelength $\lambda_c$ = 1550 nm, a channel spacing of 100 GHz, and FSR of 900 GHz. The length of the DBR grating section is 150 µm giving 40% reflection for a coupling coefficient κ = 50 $cm^{-1}$. The pitch of each of the DBR gratings was chosen to match the appropriate passband of the AWG. The phase sections are 200 µm long and all SOAs are 500 µm long. The length of the phase modulators used for the MZM implementation was chosen to be 1000 µm. The optical outputs are terminated with waveguide SSCs placed at an angle of 7° with respect to the cleaved facet. The whole device measures 4.3 mm × 6.0 mm.

## 3. Measurements

The measurements were done at room temperature using a lensed fiber-tip to couple the light out from the chip. To obtain spectral characteristics, we used needle probes to bias the SOA-, DBR- and PH-components. A high resolution (0.16 pm) Optical Spectrum Analyzer, APEX P2041A, was used to record the spectra of the transmitters, as well as to determine the single mode (SM) operation of the AWG-DBR laser and the side-mode suppression ratio (SMSR). The transmission experiments required wire-bonding of the device. Therefore we used a high frequency submount to fix the chip. The modulators were wire bonded to RF transmission lines and to 50 Ω terminations.

The threshold currents of the individual channels of the AWG-DBR-laser depend on the bias conditions set to the booster amplifier placed in the common waveguide within the laser cavity. The detected threshold current decreases from 46 mA to 20 mA, while we increase the bias current of the booster from 20 mA to 80 mA.

The spectral characteristics of the device detected for all channels biased one by one are presented in Fig. 2. The measurements were performed while biasing the booster between 50 mA and 100 mA, and activating SOAs between 90 mA and 160 mA. For our application we designed the multiwavelength source with a guard channel, which can be observed in the spectra as a missing wavelength channel between the CW and DS channels. The implementation of the on-chip selective DBR mirrors resulted in stable SM operation of the laser on the FSR determined by the gratings bandwidth. In the case of channel CW2, we believe that the Bragg wavelength of the grating, and thus the grating pitch, encountered shifting from the designed value (this is found within the process tolerances and variations), and resulted in operation at the lower FSR order. The tuneability of the DBR through current injection allowed for operation of the laser up to three FSR orders, as presented in Fig. 3 for DS1

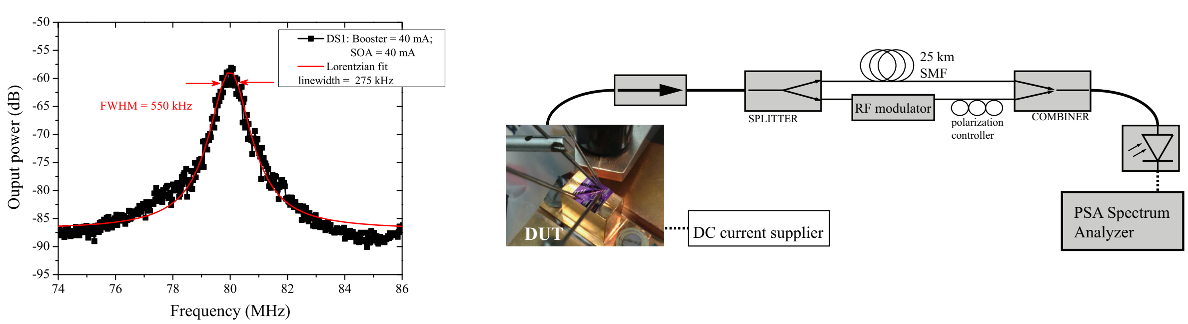


**Fig. 4.** Measured linewidth of AWG-DBR-laser (*left*) and the used setup (*right*).

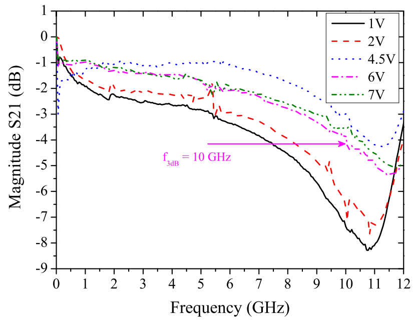


**Fig. 5.** Normalized (at 0 GHz) $S_{21}$ frequency response of the MZM for various bias voltages.

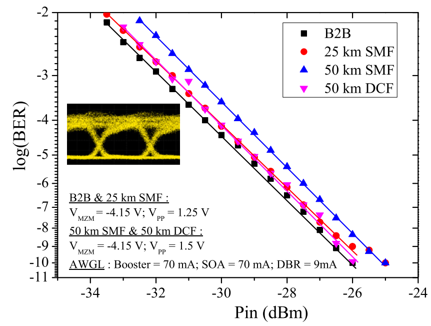


**Fig. 6.** 10 Gbps BER detected in B2B setup and after transmission through 25 km, 50 km SMF, and 50 km DCF.

while biasing the amplifiers with 50 mA, and typically provides tuning to the shorter wavelength range. The phase section allows to fine-tune the source within the AWG passband in a range of 0.04 nm (experimentally verified).

Optical linewidth measurements of the individual channels of the AWGL were performed using a self-heterodyne setup. We used an 80-MHz RF modulator and 25-km-long SMF with polarization controller. The laser linewidth was found at the full width at half maximum (FWHM), after fitting the RF spectrum with a Lorentzian profile, resulting in 275 kHz linewidth (Fig. 4).

The implementation of the AWGL with the on-chip selective DBR mirrors resulted in stable SM operation of the laser in the FSR determined by the grating bandwidth. The extended cavity configuration of the laser allowed for narrow linewidth operation, which is good for utilization of the MWT in both short and longer-distance optical transmission systems possibly using advanced data modulation schemes.

The measured static extinction ratio of MZMs is better than 25 dB, and the obtained $V_\pi$ is 1.4 V (reverse biased). The detected small signal -3 dB bandwidth response ($S_{21}$) of MZM is more than 10 GHz, as demonstrated in Fig. 5. The transmission experiments concerned detecting the BER and recording eye-diagrams at 10 Gbps, both in back-to-back (B2B) configuration as well as when introducing 25-km and 50-km-long SMFs. The experimental results are shown in Fig. 6. The modulator settings were as follows: bias voltage of $V_{MZM}$ = –4.15 V, optimized for transmission with a voltage swing $V_{PP}$ of 1.25 V and 1.5 V. The BER measurements revealed error-free operation of the MWT for the input power of –26.5 dBm with a penalty of only 0.25 dB after introducing 50 km long SMF with dispersion compensating fiber (DCF).

## 4. Conclusions

We demonstrated operation of a novel 8-channel monolithically integrated photonic transmitter that was fabricated in an MPW run in a generic foundry process. The device integrated 46 photonic building blocks in an AWG-based laser configuration with DBR mirrors and Mach-Zehnder modulators. The characterization results show a very good performance allowing for error-free transmission at 10 Gbps per channel at a distance of 50 km. The reported transmitter demonstrates the potential of generic integration processes to develop high performance devices in low-cost MPW-runs.

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