Advantages of generic technology for academic research

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The generic foundry model is generally thought to be important for industrial users, but it also offers excellent opportunities for academic research at an affordable cost. It allows for integration of complex sub-circuits with lower component coupling losses and a better stability and phase control than would be possible on an optical table. Further the researcher can tailor the component properties to his own requirements, which is usually not possible with commercially purchased components. In the paper we explain this novel way of working using an example in which four-wave mixing was studied in a multiwavelength laser.

Generic foundry model

Generic foundry model originates from microelectronics and CMOS (Complementary Metal Oxide Semiconductor) processes, and allows for the realization of a number of different functionalities using a small set of basic components, called building blocks. By connecting these components in different numbers and topologies, a huge variety of circuits and systems is feasible, with very high complexities and up to hundreds components. In photonics, these building blocks are: passive waveguides, phase modulators and semiconductor optical amplifiers (SOAs) [1].

The generic approach allows for shared development costs, facilitates prototyping of photonic ICs and accelerates the design-fabrication cycle. This is due to re-use of well characterized, verified and parameterized photonic building blocks. The low cost fabrication and small scale prototyping is enabled via multi-project wafer (MPW) runs, where different users share space on the same wafer, and thus share the manufacturing

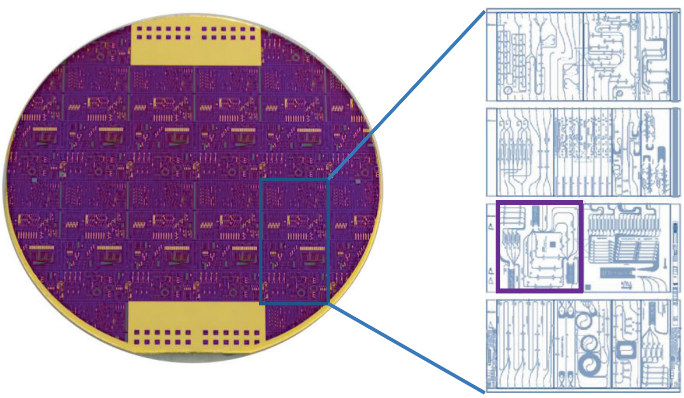

Figure 1. Multi project InP 3” wafer filled with application specific photonic ICs, processed at Oclaro. Versatile photonic devices can be fabricated in single technological processes.

costs (Figure 1). The design of photonic integrated circuits is done through advanced process design kits (PDK), implemented in the software for circuit simulation [2]-[3] and mask layout design [4]. The PDK is elaborated with the fabs, for a certain MPW process. Typically, allocation of the space in the MPW run and distribution of the relevant PDK is done by the broker. In particular, for the InP-based technology platforms of Fraunhofer HHI [5], Oclaro [6] and SMART Photonics [7] and TriPleX technology of LioniX [8], the brokering activity is provided by JePPIX [9].

From the academic-research perspective, the generic foundry model offers excellent opportunities for novel circuit development, at lower and affordable manufacturing costs. The generic approach allows for integration of complex sub-circuits and multiple photonic components with lower coupling losses and enhanced stability, tailoring the component properties to own requirements. As an example we studied a four-wave mixing (FWM) effect in an arrayed waveguide grating (AWG)-based laser with single contact double-waveguide SOAs, fabricated at Oclaro MPW run, InP-based platform.

Four-wave mixing

The FWM effect is a phenomenon in a nonlinear medium, where different frequencies interact coherently leading to creation of symmetrically (in frequency) disposed side waves, as schematically shown in Figure 2. In this paper, we focus on the two channel system, where a signal at frequency $\omega 1$ mixes with a signal at frequency $\omega 2$. The nonlinear medium is a semiconductor optical amplifier. As a result two new signals at frequency $2\omega 1-\omega 2$ and $2\omega 2-\omega 1$ are produced. The observation is reported for the 4-channel AWG-based laser shown in Figure 3. The device integrates two single-contact

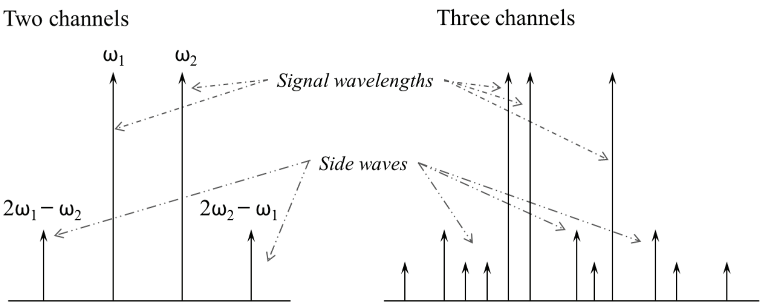

Fig. 2. Four-wave mixing effect in two and three channels systems. The interaction between signal wavelengths in a nonlinear medium results in creation of side waves.

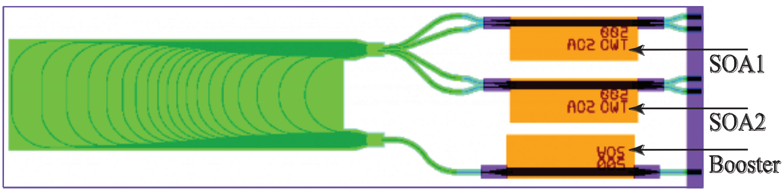

Fig. 3. Mask layout of 0.65 mm × 2.75 mm 4-channel AWG-based laser. This device has two SOAs: SOA1 and SOA2, each of which has two parallel waveguides connected to different ports (channels) of the AWG. Four different wavelengths can be generated using just two SOAs. Note that the booster amplifier is inside the FP-cavity. The cavity is formed between the cleaved facet.

double waveguide SOAs with an AWG and a booster amplifier. The booster is placed in the laser cavity. The cavity is formed between the cleaved facets. The operation principle of the sources is similar to a linear AWG-based laser [10]. The difference in the presented laser is that each single contact double-waveguide SOA guides two waveguides, corresponding to two different AWG passbands. By biasing one double-waveguide SOA we achieved double AWG channel operation of the lasers [11]. The FWM effect is observed in the booster amplifier, where two generated wavelengths interact. These interacting wavelengths correspond to two AWG passbands after biasing one of the SOAs (the effect is observed for both SOA1 and SOA2).

Measurements

The measurements were done at room temperature using a high resolution (0.16 pm) Optical Spectrum Analyzer, APEX P2041A. We biased simultaneously the booster amplifier and SOA1 or SOA2. The initial measurements of the device, the threshold current and the optical output power were reported in [10]. The spectral characteristics were detected at the common optical output, at the booster side.

In Figure 4 we demonstrate the FWM effect while biasing the SOA2 with 160 mA and the booster with 80 mA. The peaks ω1 and ω2 correspond to the AWG passbands and correspond to the modes of the laser cavity. The peaks 2ω1-ω2 and 2ω2-ω1 are the effect of FWM. This can be confirmed by analyzing the position of 2ω1-ω2 and 2ω2-ω1 with respect to the longitudinal Fabry-Pérot (FP) modes (inset in Figure 4): the side peak is positioned in between two FP-cavity modes, hence could not build up as longitudinal FP-modes. Note the asymmetry in the side peaks, with the wavelength up converted being significantly smaller than the down converted one, as discussed in [12],

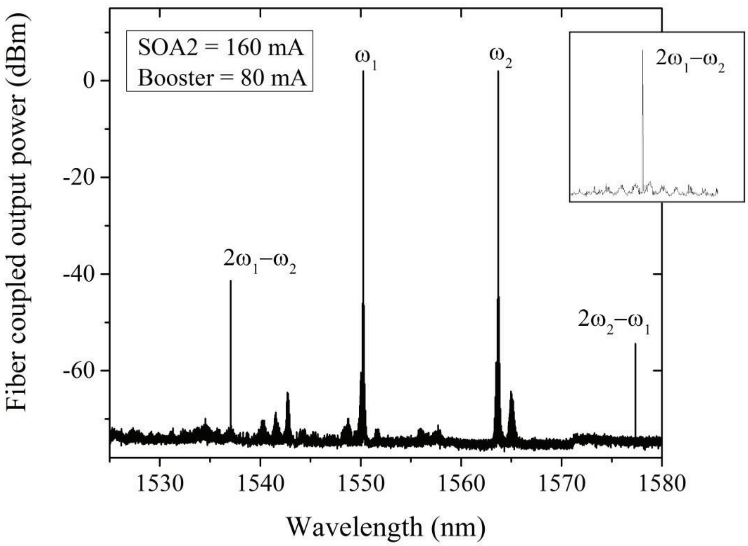

Fig. 4. FWM effect observed in the booster amplifier of the 4-channel AWG-based laser. The peaks corresponding to the ω1 and ω2 were generated by the SOA2, and correspond to two different AWG channels, spaced by two free spectral ranges of AWG. The two side peaks, 2ω1-ω2 and 2ω2-ω1, are the effect of FWM, with the output power more than 40 dB lower than the signal wavelengths.

with the relative FWM conversion efficiency between 40 dB – 55 dB. We observed stronger FWM effect for higher currents injected into the booster. The FWM effect is present while changing the current injected into the SOA2. The low experimental complexity enables further investigation of the FWM effect, and its impact on the performance of the whole circuit.

Conclusions

Generic technology through open access Multi-Project Wafer runs facilitates prototyping of novel photonic ICs at lowered costs. It also enables a fabless model for photonic IC research which can be beneficial academic study without the need for investment in the expensive manufacturing facilities or process development. The generic approach, offering mature technology platforms supported by advanced PDK tools, reduces the development time of new devices and allows investigation of complex photonic phenomena at the circuit level. As an academic example, we demonstrated four-wave mixing effect within a single chip: an experiment which would have previously required multiple photonic components on moderately sized optical bench.

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