All-Optical InP Monolithically Integrated WDM Regenerator for PolSK Signals

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***Abstract*—A monolithically integrated Indium Phosphide optical circuit performing WDM regeneration of Polarization Shift Keying signals is presented. The scheme is based on hard-limiting amplification in a saturated Semiconductor Optical Amplifier. A Q-factor improvement of around 2 is reported on two different wavelengths.**

***Keywords*—All-optical regeneration, polarization shift keying.**

All-optical regeneration has been widely investigated with the aim of improving the quality of the optical signals without recurring to expensive and power-hungry optoelectronic regenerators. Studies mainly focused on conventional non-return-to-zero (NRZ) or return-to-zero (RZ) on-off-keying (OOK) modulation formats [1]. Recently, the research on all-optical regenerators also included the application to alternative modulation formats and multi-wavelength operation [2]. Indeed, the simultaneous regeneration of many optical signals at different wavelengths could represent a significant step toward the commercial viability of all-optical regeneration solutions, since a number of optoelectronic regenerators can be replaced in a single shot.

In this work we present an Indium Phosphide-based photonic integrated circuit (PIC) performing all-optical regeneration of wavelength division multiplexed (WDM) Polarization Shift Keying (PolSK) signals. The device has been fabricated exploiting JePPIX [3], the European platform for the manufacturing of Indium Phosphide-based PICs. Such platform pushes a generic integration technology, where standardized building blocks and foundry process are enforced, without technologies specifically developed or optimized for a given application. The actual PIC is here demonstrated performing all-optical regeneration of 10 Gb/s PolSK signals at different wavelengths, achieving a Q-factor improvement of around 2.

The realized device implements the scheme sketched in Fig. 1(a), presented in [2] to realize simultaneous all-optical regeneration of constant-envelope (CE) WDM signals. For these signals the regenerator should be placed in a WDM amplification site, preceded by an Erbium-doped fiber amplifier (EDFA) to pre-amplify the signals and by a dispersion compensating fiber (DCF) to recover the CE property. Then the WDM comb enters the regeneration block, where the component signals are demultiplexed by means of an arrayed waveguide grating (AWG). Each signal travels in and saturates a Semiconductor Optical Amplifier (SOA) so that it is regenerated thanks to the hard-limiting effect on the noise. Moreover, there is no pattern effect since the signals are all CE. Before the second AWG multiplexes all channels, an optical attenuator can be used on each path to provide power equalization. Finally a second EDFA can be used as a booster. The functions in the highlighted box of Fig. 1(a) have been implemented on a Indium Phosphide PIC fabricated in a multi-project wafer run of JePPIX Indium Phosphide platform [3] at the COBRA research institute of the Eindhoven University of Technology. This platform enables a generic foundry model, where the process is application blind and a small set of building blocks are used as basic elements for more complex photonic circuits. The layout and a picture of the realized PIC are shown in Fig. 1(b) and (c), respectively. Differently from the scheme in Fig. 1(a), the same AWG has been used both as a mux and a demux, in order to ensure consistent pass-band characteristics. The AWG has been designed to have a central frequency of 1534 nm and a free spectral range (FSR) of 19.5 nm. The ASE spectrum of one of the SOAs in the PIC measured at OUT1 is shown in Fig. 2(a). Each of the four AWG paths, destined to a specific wavelength channel, connects two different SOAs: the currents can be properly tuned to saturate the first SOA, and set the second SOA to

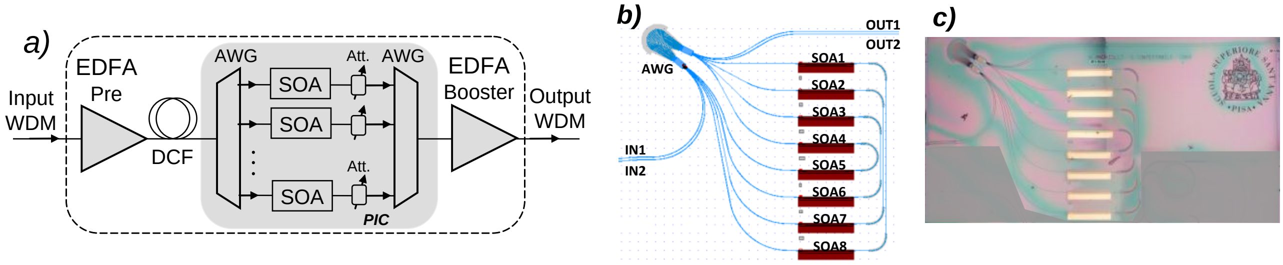

Fig. 1. (a): Scheme of the WDM regenerator of constant-envelope signals; (b): layout of the designed PIC; (c): picture of the fabricated PIC.

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transparency. Input and output waveguides have been duplicated, to ensure proper operation even in case of device realization problems. All the SOAs in the PIC have a fixed length of 500 µm, the same gain (a small signal gain of 10 dB has been measured) and saturation current (around 70 mA) [4]. To determine the proper input optical power to ensure SOA saturation, an input/output power characteristic has been measured on a test SOA identical to the previous ones fed with a current of 80 mA: the results, measured fiber-to-fiber are presented in Fig. 2(b), showing that a fiber input power of 15-to-20 dBm is required to have strong SOA saturation.

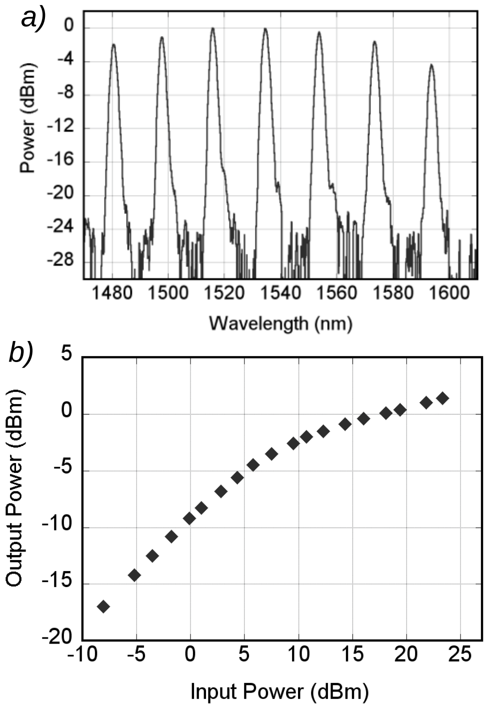

Fig. 2. (a) SOA8 ASE spectrum measured at OUT1; (b) optical input/output power characteristics of a test SOA at 80 mA on the same chip.

The experimental setup is sketched in Fig. 3(a). A 10 Gb/s PolSK signal is generated by using a tunable laser (at 1534 and 1553.5 nm, corresponding to two AWG pass bandwidth peaks) whose output lightwave is rotated and injected at $\pi/4$ in respect of the axes of a $LiNbO_3$ phase modulator driven by a 2^{31}-1 long Pseudo Random Bit Sequence (PRBS). This PolSK signal is combined with ASE noise from an EDFA source, after crossing a tunable optical bandpass filter (TBPF) centered at the signal wavelength. To properly set the optical power and the polarization into the PIC, an EDFA, another TBPF, a variable optical attenuator (VOA), and a polarization controller (PC) are utilized. Tapered fibers are used to couple light to and from the PIC. For each experiment the two SOAs on the optical path are fed with a current of 80mA and 20mA, respectively, to obtain the maximum available gain from the first one and to set to transparency the second one. PolSK demodulation is obtained by using a PC and a polarization beam splitter (PBS). The signal is thus detected by means of a pre-amplified receiver, composed of an EDFA, a TBPF, and a 10 dB optical attenuator (OA) connected to a sampling oscilloscope equipped with a 30 GHz optical head used for eye diagram acquisition and Q-factor measurement.

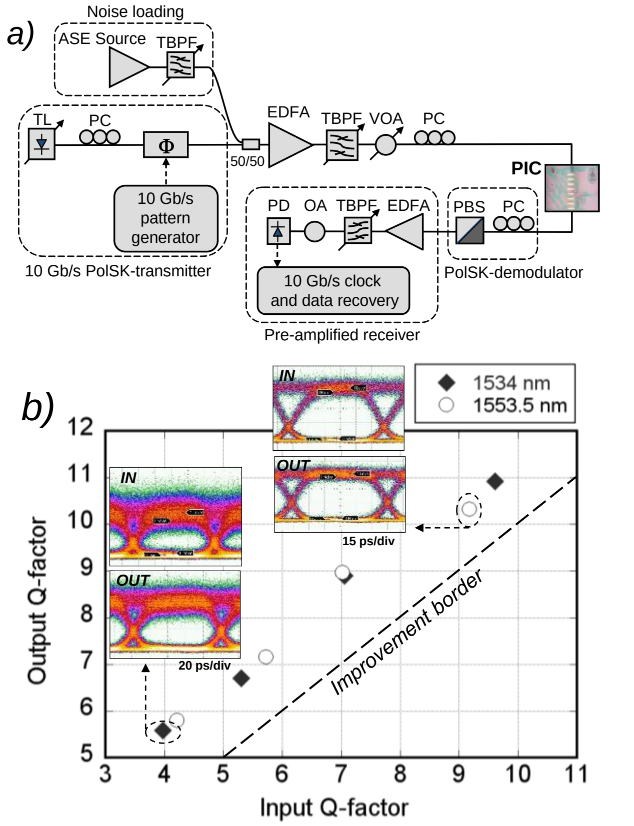

Fig. 3. (a) Experimental setup; (b) Input-output Q-factor evolution and example of input-output eye diagrams.

Fig. 3(b) shows the output Q-factor as a function of the input Q-factor for two tested wavelengths, as well as two examples of input and output eye diagrams. Thanks to the limiting amplification in the PIC, a Q-factor improvement up to 2 can be observed for every signal. This is slightly larger at 1534 nm compared to 1553.5 nm, since the former wavelength is closer to the SOA gain peak. A clear eye opening confirms the Q-factor results showing a significant noise compression. The PBS demodulator actually selects one polarization state so that the "ones" level is clearly compressed while the "zeros" level is mainly determined by the PBS contrast ratio.

In this paper an Indium Phosphide PIC realized through JePPIX platform is shown to perform WDM regeneration of 10 Gb/s PolSK signals. A Q-factor improvement of around 2 and a clear eye-opening are reported on two different channels.

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