

InP monolithically integrated label swapper device for spectral amplitude coded optical packet networks

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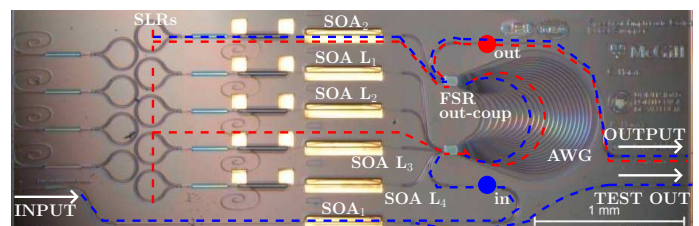
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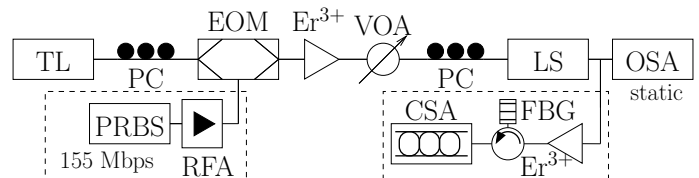
Abstract—In this paper a label swapping device, for spectral amplitude coded optical packet networks, fully integrated using InP technology is presented. Compared to previous demonstrations using discrete component assembly, the device footprint is reduced by a factor of 10^5 and the operation speed is increased by a factor of 10^3 . This is, to the best of our knowledge, the first demonstration of a totally integrated label swapping device.

I. INTRODUCTION

The actual optical network infrastructure is based in connection oriented (circuit) networks. However most of the traffic since nearly 15 years ago is data (packet/burst) traffic. One of the major drivers for a change from circuit to packet optical networks will be the availability of cheap and power efficient components, able to perform the different network functions over data packets. Amongst these functions, operations over the packet headers (labels) is crucial for packet optical networks to succeed. One approach is optical code multiprotocol label switching (OC-MPLS). Several labeling implementations have been subject of research; a simple but yet effective approach is the Spectral Amplitude Coded (SAC) label swapping [1]: a spectral band is reserved for labels, and divided into N wavelength slots, therefore enabling 2^{N-1} labels. A key component in a OC-MPLS network node is the label swapper (LS), which strips the incoming label, attaches a new label, and reinserts it with the payload. Devices using cross-gain modulation (XGM) in ring cavities have previously been demonstrated with high extinction and contrast ratios [2]. In particular, a proof-of-concept tabletop ($2 \times 1 \text{ m}^2$) label-swapper using a two stage XGM-based fiber-ring laser has been demonstrated in [3]. The main drawbacks of this device were cost and low operating frequency (80 kHz) due to a lengthy cavity (8.9 m). In [4] a different label swapper implementation using a Semiconductor Optical Amplifier-Mach Zehnder Interferometer (SOA-MZI) was demonstrated at a label rate of 4 MHz, according to the packet payload duration (256 ns, payload rate 160 Gbps). In this paper, we present a label swapper device based on a linear multi-wavelength laser configuration, built using Sagnac Loop Reflectors (SLR), an Arrayed Waveguide Grating (AWG) and SOAs on a single InP chip. The device footprint is $4.5 \times 2 \text{ mm}^2$ and error-free operation at a label rate of 155 Mbps is performed.



(a) Label Swapper (LS) chip micro graph



(b) Characterization setup

Fig. 1. Device micro graph, input, output and SOA's labeled (a) and characterization setup (b) (TL Tunable Laser, PC Polarization Controller, EOM Electro-Optic Modulator, RFA Radio-Frequency Amplifier, PRBS Pseudo Random Bit Sequence generator, Er^{3+} Erbium doped fiber amplifier, VOA Variable Optical Attenuator, LS Label Swapper chip, OSA Optical Spectrum Analyzer, FBG Fiber Bragg Grating, CSA Communications Signal Analyzer).

II. RESULTS

A micro-graph of the device is presented in Fig. 1-(a). The device is a linear laser between the SLRs enclosing SOA_2 -AWG- $\text{SOA} L_i$ $i=1\dots 4$, where the SOA_2 acts a common cavity gain medium, and the AWG and $\text{SOA} L_i$ combination enable the different output wavelengths/labels. The light is out-coupled from the laser cavity using a side diffraction order of the AWG ('FSR out coup' in the figure). The device design, fabrication and multi-wavelength operation details are fully described in [5]. An additional waveguide at the $\text{SOA} L_i$ side is laid out as input for the incoming labels, through SOA_1 that can be used as booster amplifier. The label swapper device operation is as follows: referring to Fig. 1-(a), one output lasing wavelength is enabled by biasing SOA_2 and one of the L_i SOAs (dashed red line); next, an external laser signal with proper wavelength to reach SOA_2 through the AWG is used as input (dashed blue line); the SOAs biases are adjusted to allow switching on and off the laser by turning off and on the

input wavelength, so the output label is an inverted version of the input. To test the device static and dynamic operation, the setup of Fig. 1-(b) was assembled. First, the static operation of the LS was measured using a CW input signal from a TL, set at 1561.5 nm to reach SOA₂ through the AWG. Before the LS, and the VOA set to 0 dB, the power was 20 dBm. Lensed fibers were used to couple in/out to/from the chip. The static operation curves, Fig. 2, correspond to the estimated on-chip input and output power, at the points marked in Fig. 1-(a). The estimation was obtained through measurements of the propagation (5 dB/cm) and in/out coupling losses (5 dB), using auxiliary test structures. To measure the AWG losses the SOA₁ was not biased, and a value of 8 dB was obtained (5 dB insertion losses, 3 dB side order out coupling). Afterwards, spectrum traces were recorded with an OSA at the output, for different input powers tuned using the VOA. The peak power within 0.1 nm was recorded for the input and output (L₄ 1563.25 nm and L₃ 1564.81 nm) wavelengths. The laser operation with L₁ and L₂ exhibited mode hopping to side AWG resonances (FSR 8.1 nm). The static results shown in Fig. 2 are labeled as 'S-L4' and 'S-L3'. The contrast ratios are 28 dB and 33 dB respectively, and the on-off happens within an input power range of approximately 10 dB in both cases. Second, the dynamic operation of the device was assessed, using the setup in Fig. 1-(b) where the hardware enclosed in dashed lines was added. A PRBS generator operating at 155 Mbps followed by an RFA were used to drive the EOM. The output wavelengths were amplified, and subsequently filtered with a circulator and a FBG. In Fig. 2, a set of points labeled 'D-L4' and 'D-L3' overlay the static curves, corresponding to average input powers for which dynamic measurements were performed. The dynamic metrics, extinction ratio and Q factor, where acquired with a CSA, and are compared to the equivalent input power extinction ratio and Q factor measured back-to-back. The results are shown in the right panel of Fig. 2. The eye patterns for both output wavelengths are also shown at the bottom of the figure. In both cases the extinction ratio and Q factor trends agree with the static behavior. The rise and fall times, which correspond to the turn on and turn off times for the integrated laser, support the operation at 155 Mbps. The kHz limited operation in [3] was due to the long turn on and turn off times of the laser long cavity. The integrated LS provides shorter turn on/off times and avoids using guard bit slots, needed otherwise to prevent data loss. Significant extinction ratio and Q factor penalties, right panel of Fig. 2, occur due to the fact the device is operated near threshold, but this can be overcome with post-amplification, as in the experiments. The differences between L₄ and L₃ operation in the extinction ratio and Q factor arise from the different slope in the static curves. Although the extinction ratio is always higher for L₄, because the operation points are inside the static curve on-off transition, the Q factor is always higher for L₃, for which the operation is always started from the unsaturated 'on' side. This is in agreement with the eye patterns shown in the figure (note the different vertical $\mu\text{W}/\text{div}$) where cleaner patterns occur for L₃, with wider eyes

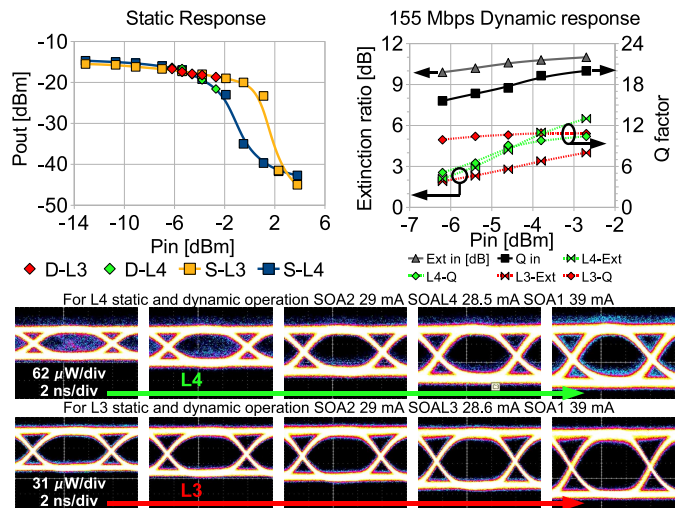


Fig. 2. Static operation (left) and dynamic (right) operation results.

(note the same horizontal scale in the graphs, 2 ns/div). A close look to the patterns also reveals slight differences between the rise (input fall) and fall (input rise) behavior in all the cases. The former corresponds to SOA slow recovery from carrier depletion, whilst the latter is due to fast dynamics. Hence, the traces are wider during the output rise than during the fall.

III. CONCLUSION

In this paper, a label swapping device monolithically integrated on InP has been presented. Static and error-free dynamic operation were demonstrated at a label rate of 155 Mbps for two output wavelengths. Compared to previous discrete component assembly implementations based on XGM switched lasers, the device is 10^5 smaller and operates 10^3 faster.

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