InP Wavelength Shifter Designs for Colorless User Terminals in Passive Optical Networks

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Abstract—**Wavelength shifters (WS) are proposed for Rayleigh backscattering mitigation in bidirectional centralized light passive optical networks (PONs). A dual-arm WS is proposed as it requires simpler driving-signals. InP integration allows compact lossless WS design.**

Keywords: electro-optic modulation; frequency conversion; optical fiber communication; Indium Phosphide (InP)

I. Introduction

Providing a broadband access connection to final users has been the objective of telecommunication operators during recent years. Nevertheless, fiber deployment closer to the customer was not considered the most cost-effective option until 2005-2007 [1]. Since then, progress in optical technologies, bringing down the component and system cost, coupled with broad-bandwidth demands from triple-play and new services, have been motivating telecommunication companies and cable system operators to deploy a full set of Fiber-To-The-Home architectures (FTTH). Taking into account also energy consumption trends, telecommunication companies are proposing FTTH architectures with minimized consumption, where, Passive Optical Networks (PON) and especially next generation Wavelength De/Multiplexing (WDM) PONs are showing higher power efficiency [2].

User Terminal subsystems are key for the deployment of future access networks, as they have a significant impact on the CapEx, requiring simplicity and cost and energy efficiency for the ONU of the user terminal equipment. In order to fulfill this requirement, wavelength agnostic Optical Network Units (ONU) have been proposed, so that the same device can be used by all the users in the network, providing mass production cost reductions, even for WDM-PONs. One step beyond this is the use of only one fiber per ONU with the same wavelength for upstream and downstream, as preferred by many operators for deployment and installation cost reduction. However, the Rayleigh Backscattering (RB) effect, caused by the intrinsic inhomogeneity of the fiber, introduces a serious limitation in the link performance [3]. Essentially, the RB generated by the upstream (downstream) propagation of the optical signal along the transmission fiber at the upstream (downstream) optical signal interferes with the downstream (upstream) signal if both downstream and upstream are transmitted at the same wavelength.

Several techniques have been proposed for reducing the impact of the RB, based on reducing the overlap between the RB and the signals as in [4], nevertheless, the overlap present between the RB and the signal is reduced but not completely removed. Alternatively, producing a wavelength shift at the ONU over the received downstream carrier to generate a displaced wavelength for upstream data remodulation reduces the RB interference by avoiding the beating between the upstream signal and the scattering at the OLT receiver. In literature, several implementations have been proposed so far, the best using 4-arm $LiNbO_3$ Mach-Zehnder modulator (MZM) structures [5]. To our knowledge no wavelength shifter (WS) has been implemented in InP for providing a compact ONU compatible with cost and energy consumption requirement in PON networks.

II. Description of the Wavelength Shifter Functionality and Required Drive Signals

A. General description of the functionality

The targeted functionality of the wavelength shifter involves generating a frequency shift of the incoming wavelength by single side band modulation. The simplest configuration from the point of view of the device structure required for producing a wavelength shifting of the incoming signal is just a device having the capability to generate phase modulation. For example, a simple reflective semiconductor optical amplifier (RSOA) has been used for generating a wavelength shifting of 2.5GHz even using a RSOA with 1GHz bandwidth by applying a sawtooth electrical signal of 2.5GHz, thanks to the chirp-induced phase modulation of the RSOA [6]. Though this has achieved a moderate wavelength shifting of 2.5GHz, this displacement is enough for allowing a Rayleigh Backscattering effect mitigation of 5 dB [6].

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The main limitation of this approach using the simplest device structure of a single waveguide able to generate a phase modulation is that it requires a very wideband electrical amplifier with enough output power to achieve twice the voltage V_π for the phase modulator [7]. Thus the simplest optical implementation also has the most stringent electrical requirements. This has motivated a further analysis of more complex structures, but mitigating the requirements for the electrical driving signals, as will be described in the next section.

B. Dual-arm modulator based wavelength shifter

The next step in complexity for the wavelength shifter device was considering a dual-arm modulator application-specific optical integrated circuit (ASPIC) as shown in Fig 1.

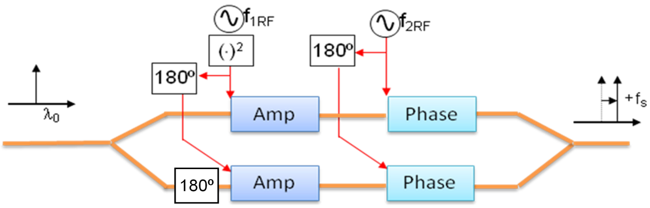

Fig 1: Functional description of the application-specific optical integrated circuit for wavelength shifting based in a Mach-Zehnder modulator, also showing the driving signals for the phase and amplitude (Amp) modulators.

A previous publication [8] analyzes best trade-off considering the performance of the wavelength shifter, measured as spurious free dynamic range (SFDR), and the required electro-optical bandwidth, showing that theoretically a SFDR higher than 35 dB can be obtained by proper synchronization of a tone and its harmonic [8].

C. Triple-arm based wavelength shifter

The requirements for the driving signals can be further

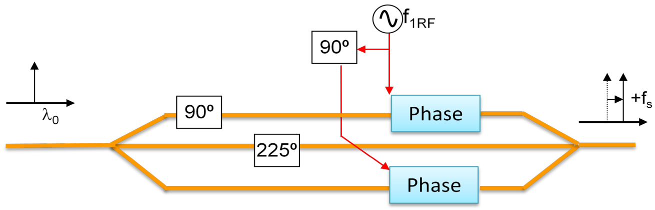

Fig 2: Functional description of the ASPIC for wavelength shifting based in a 3 arms structure, and required driving signals.

reduced by using a slightly more complex ASPIC based on a 3-arm structure as shown in Fig 2. In this case a single tone and appropriate adjustment of electrical and optical phases can also provide a proper wavelength shift of the incoming wavelength.

The triple-arm based wavelength shifter shown in Fig 2 does not include the extra elements that could be required as a variable attenuator driven by a bias current for adjusting the appropriate splitting ratio of the input signal into the 3 arms.

III. ASPIC DESIGN IN INP TECHNOLOGY

The specific ASPIC design depends strongly on the technology platform. We will describe the specific design achieved using the design manual developed by the European project "Photonic Advanced Research And Development for Integrated Generic Manufacturing" (PARADIGM). As described by the title of the project, it aims to provide a generic platform technology for reducing the cost of design, development and manufacturing of ASPICs. In order to do this, a set of basic generic modules are provided. Making use of these building blocks a specific design of the double-arm wavelength shifter is shown in Fig 3, including: strong confinement passive waveguides for input/output and S-bends; SOA weak waveguides; electro-optical phase modulator (φ-mod in Fig 3), several multi-mode interference (MMI) structures as 2:1 and 1:2 power splitters and input/output spot

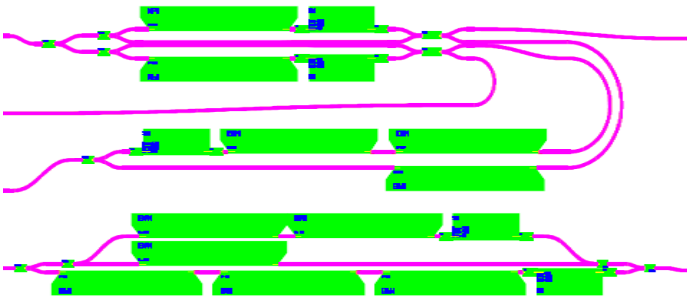

Fig 3: GDS view of the dual-arm (top) and triple-arm (bottom) wavelength shifter corresponding to the functional descriptions of Fig 1 and Fig 2.

size converters for improved coupling.

The layout shown in Fig 3 shows that the implementation of the triple-arm wavelength shifter, though initially more complex, leads finally to a more compact final design.

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