Integrated ‘all-optical’ Transmodulator Circuits with non-linear Gain elements and tunable Optical Filters

with design, realization & testing in generic InP technology

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***Abstract*—We characterize integrated InP circuits for high speed ‘all-optical’ signal processing. Single chip circuits act as optical transistors. Transmodulation is performed by non-linear gain sections. Integrated tunable filters give signal equalization in time domain.**

Keywords: transmodulator; ‘all-optical’ signal processing; generic InP technology;integrated tunable filters

I. Introduction

All-optical signal processing, like any other signal processing, can be performed in the time domain as well as in the frequency (wavelength) domain.

Wavelength domain, ‘all-optical’ signal processing is common practice in today’s high speed WDM optical communication systems. The smallest granule in these systems is obviously the individual WDM channel. On the device and component level such WDM system use e.g. multi-wavelength sources, wavelength combiners and splitters, wavelength-selective switches and routers, ROADM’s etc. On the component technology level both integrated and free space optics are being used.

The main *time domain ‘all optical’ signal processing* in today’s communication systems is optical amplification, mainly by EDFA’s but also with SOA’s. Next to the ability to amplify many WDM channels simultaneously, a key advantage of optical amplification is the absence of a high speed roll-off. This is in contrast with electronic amplification, which always rolls off at high frequency. Figures of merit in this respect are f_T (for unity current gain) and f_{MAX} (for unity power gain).

Time domain ‘all optical’ signal processing also comprises trans modulating data from one wavelength to another. Functionally this is equivalent to optical transistor action. Often this process is called wavelength conversion. Trans modulation of more than one input to a single output is called trans multiplexing. Despite its ‘all optical’ character, and in contrast with amplification, this process shows a roll off at high signal frequencies, e.g. when cross-gain/cross-phase modulation in SOA’s is used. However by differential linear filtering of the trans modulated output (or the input), the output roll off can be equalized optically, up to (very high) frequencies not accessible by electronics or by opto-electronic modulators.

In this paper we describe the design and experimental characterization of InP circuits in which the ‘all optical’ trans modulator function and the ‘all optical’ equalization in the time domain are realized in single chips. Since all signal processing is optically only, there are no high speed electrical contacts to the chips. All electrical contacts are dc and provide the necessary control of gain and of phase of the optical waves at various stages in the chip.

InP is chosen as the materials system for the chips, because of its unique ability to combine “actives” (gain sections, but also phase shift sections) with “passives” (waveguides, MMI’s)

II. Design, Manufacturing and Testing of Transmodulator Circuits

A. *The operating principle*

The circuits combine three well defined functions

- Transcription of the optical base input data to a new carrier wavelength at the collector output, The collector field strength modulation index is:

  $\Delta E/E_0 = (-1/2)\,(1+j\alpha)\,\Gamma\,(dg/dN)\,(G-1)\,\Delta P_{in,\,base} / (j\omega+\tau^{-1})$

  where τ is the gain recovery time.

- Separation of the input wavelength (base → drain) and the output wavelength (emitter → collector), by using a parallel matched pair of gain sections in a phase tunable equal arm length MZ configuration.

- Optical equalization of the slow gain recovery and suppression of the carrier, with tunable unequal arm length MZ filters acting as differential filter and additionally as FM→AM converter. Periodicity, and 360 degree tuning of phase differences, gives proper (and electrically tunable) filter operation, with full C-band (from 1535 to 1565 nm) coverage.

B. Manufacturing at OCLARO

The chips were manufactured in a generic InP technology at OCLARO in Caswell/UK while using well established, standard building blocks and process modules. As shown in fig.1, typically 5 or 6 trans modulator circuits (with a total area of 4x4 mm^2) were realized together with very different circuits from other designers on a 12 x 12 mm^2 reticle.

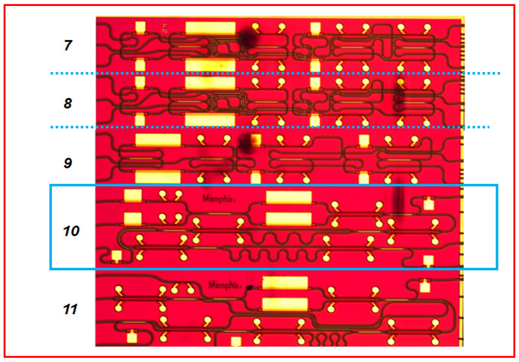


Figure 1. Optical microscope picture of 4x4 mm^2 die, prior to dicing into five transmodulators chips (#7-11). Rectangular bondpads contact gain sections, while small circular bondpads contact deep ridge phase shifters

The "actives" building blocks available and used in the present designs were *a) shallow etched gain sections* and *b) deeply etched phase shifter waveguides* with low capacity electrical contacts, to be used under forward bias. A full description of these modules in terms of "compact models" was not (yet) available at the time of the chip design. In fact some of the properties of the gain- or the phase shift- sections which are of specific interest to the chip designer, could only be determined,(= measured), after realization of the chips.

The "passives" building blocks available and used were *c) straight waveguides* and *d) curved waveguides*, *e) shallow-deep ridge transitions, f) 1x2 MMI's and g) 2x2 MMI's.*

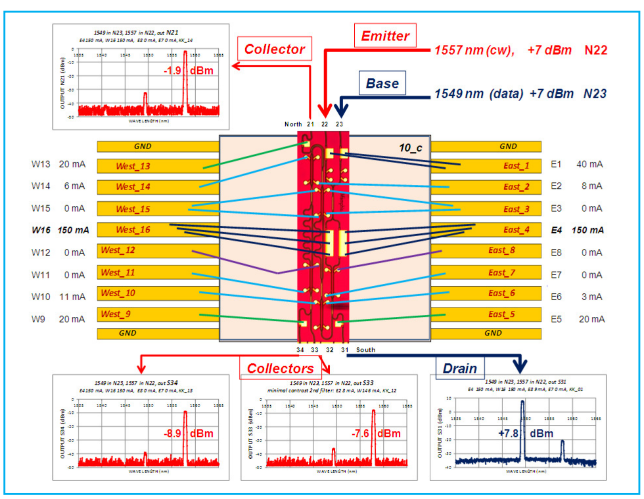


Figure 2. Electrical and optical connections to design #10. And an experimental demonstration of upto 30 dB spatial filtering efficiency in the collector outputs by using the matched SOA pair

C. Circuit design, Mask Layout, Mounting, Testing and Characterization of the chips at the TU/e

Trans modulator circuit design, mask layout, mounting and testing were all carried out at the TU/e in Eindhoven/NL. As illustrated in fig.2, 3 and 4, we developed for the characterization dedicated (but universal) carriers, test fixture, electrical drive/measurement equipment (hard & software) and an optical-mechanical test station. Lensed multi (~4) fiber array are coupled to the North, and simultaneously to the South side of the chip. The electrical connections to the chips are made at the East and West side. On the carriers the (~16) bond contacts from the chip are fed into a standard flexible print connectors.

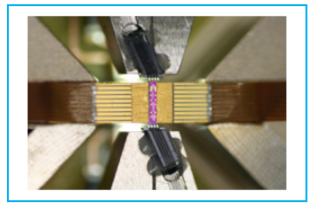


Figure 3. Dedicated carrier with lensed fiber arrays, angled at 24.6 degree

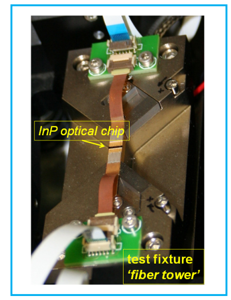
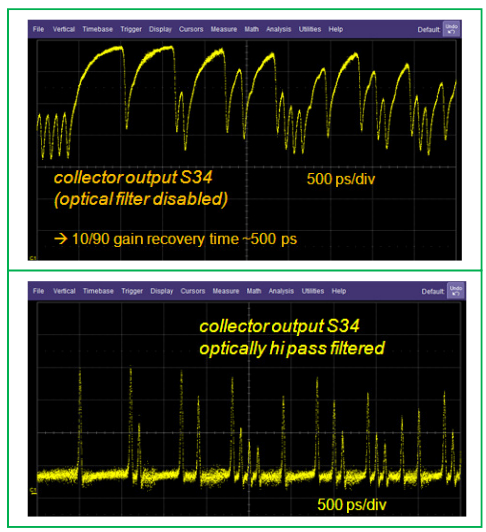


Figure 4. FiberTower test fixture

III. TEST RESULTS, AT 10 GB/SEC BIT RATE

Both testing of the on-chip components and of the fully integrated device (#10) was done. Examples of trans modulated collector outputs at 10Gb/s, before and after differential filtering, are shown below in fig. 5a and fig. 5b.



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