Optical characterization of a monolithically integrated photonic Remote Access Unit for 60 GHz wireless communication

K. Rylander,[1] A. Sosa,[2] S. Latkowski,[3] E. Bente,[3] R. Broeke,[4] D. Tsiokos,[5]
N. Pleros,[5] A. Bakker[1] and T. Tekin[1]

[1] PhoeniX Software, Hengelosestraat 705, 7521 PA Enschede, The Netherlands
[2] Technische Universitat Berlin, Research Center of Microperipheric Technologies,
Gustav-Meyer-Allee 25, 13355 Berlin, Germany
[3] COBRA Research Institute, Electrical Engineering, Eindhoven University of Technology Eindhoven,
Den Dolech 2, 5612AZ Eindhoven, The Netherlands
[4] Bright Photonics, Burgemeester van den Helmlaan 67, 3604 CE Maarssen, The Netherlands
[5] Aristotle University of Thessaloniki, Information Technologies Institute - Center for Research and
Technology Hellas, P.O. Box 114, 54124 Thessaloniki, Greece

We present the optical characterization of a Remote Access Unit (RAU) that integrates Radio-Over-Fiber (RoF) with 60 GHz wireless (10-20 GHz on-chip) and Fiber to the Home (FTTH) services. We investigate the DC performance of the sub-circuits of the device, such as tunable radio frequency transmitters and receivers which were integrated on a single Indium phosphide chip.

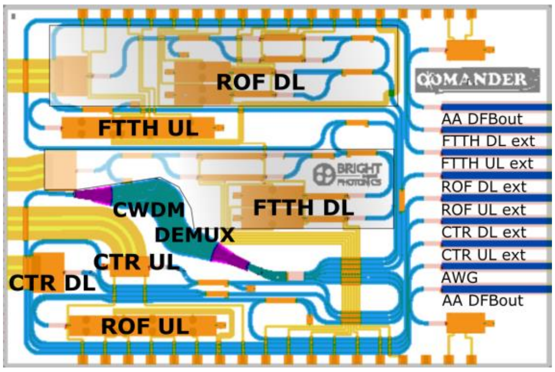
1 Introduction

Growing capacity and coverage demand for wireless services make the mobile operators explore emerging 5 G solutions [1]. Simultaneously, Passive Optical Network (PON) architectures are a dominant infrastructure that provides broadband Fiber-To-The-Home (FTTH) services. It seems that the most natural solution towards equipping end-users with broadband wireless services is to merge the optical and wireless infrastructures. Such a novel network architecture, which builds upon Radio over Fiber (RoF) and PON paradigm, was proposed by the COMANDER project [2]. One of the key components of this architecture is a Remote Access Unit (RAU) that was designed as a photonic integrated circuit (PIC) on the Indium Phosphide platform [3]. Here we report on the initial measurements of all subsystems on chip, covering mainly DC characterization.

2 Remote Access Unit design and fabrication

The layout of the RAU has been designed in OptoDesigner5, using foundry provided Photonic Design Kit (PDK) and an AWG IP Block. The chip has been fabricated in a shared, multi-project wafer (MPW) run offered by the PARADIGM project. The HHI foundry that delivered the chip reported some process issues, concerning the definition of the Bragg gratings and higher than usual losses at the transition point between active and passive regions. However, we expected to obtain useful results anyway.

Realized RAU, presented in Fig.1, utilizes a Coarse Wavelength Division Multiplexing (CWDM) multi/de-multiplexer (DEMUX) to provide six discrete spectral passbands: FTTH DL, FTTH UL, RoF DL, RoF UL, CTR (control signals) DL and CTR UL. In full operation all signals are processed simultaneously by specifically designed sub-circuits. Therefore, in order for the Remote Access Unit to be usable, the central wavelengths of transmitters and receivers have to match the AWG channels.



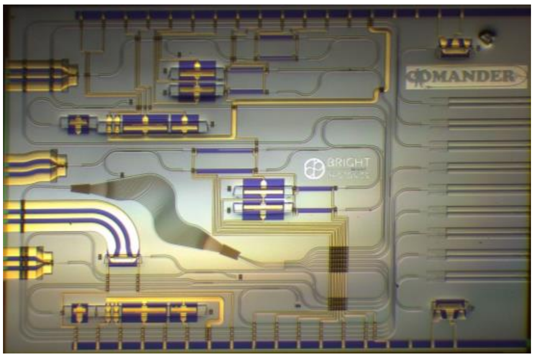
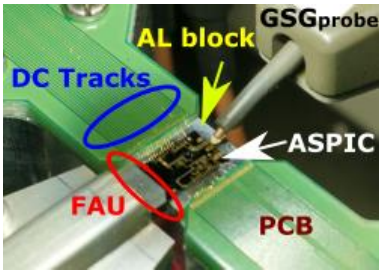


Fig. 1a. Mask layout of photonic integrated circuit. **Fig. 1b.** Photograph of the fabricated photonic chip. The size of a chip is 4 mm × 6 mm.

3 Experimental setup and results

The chip was mounted on an aluminum sub-carrier and electrical contacts were wire-bonded to DC tracks on a printed circuit board (PCB) providing with several feed lines as presented in Fig. 2a. For RF contacts, since all of them were accessible on one side of the chip, a Ground-Signal-Ground (GSG) RF probe was used. The temperature was stabilized at 19 ºC by water cooling of the metal sub-carrier. A fiber array unit (FAU) of single mode fibers was used to couple the signals into and from the chip.



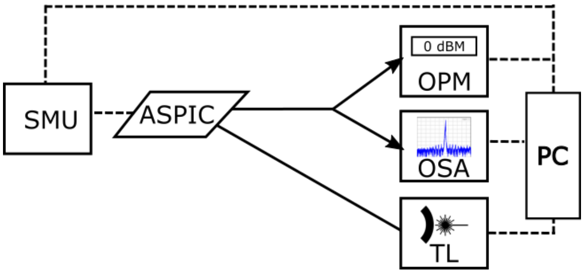
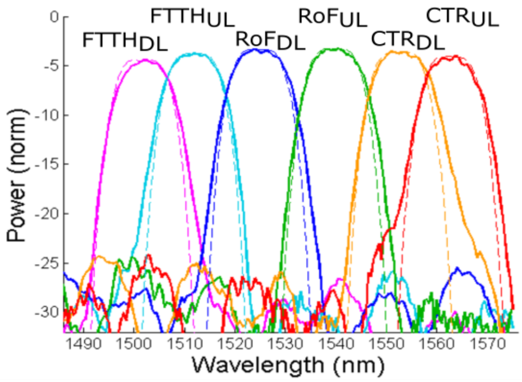


Fig.2a. PIC evaluation platform: application specific (AS) PIC; water cooled aluminum block (AL block) **Fig.2b.** Experimental setup: Source Meter Unit (SMU), Optical Power Meter (OPM), Optical Spectrum Analyzer (OSA), Tunable Laser (TL), Computer (PC) with dedicated software for measurement automation

3.1 Multiplexer/Demultiplexer

The Arrayed Waveguide Grating (AWG) employed as a CDWM DEMUX was designed for a central wavelength of 1540 nm and a free spectral range of 100 nm. Additional requirements included flattened passbands and non-constant channel spacing. The spectral response of the AWG was measured for TE and TM polarizations and compared with the simulation data, see Fig.3. Results were normalized in order to eliminate the influence of the different coupling conditions between the channels as well as to compensate for a central wavelength shift. Note that noise levels of all measured passbands after calibration reached the same value, which supports the validity of our calibration method. Since the central wavelength offset reported in the previous MPW runs was + 7.2 nm, the central wavelength of AWG during the design stage was calibrated by this value. However, in this particular run the offset was much lower, of about 0.5 nm. As a result, central wavelength of AWG in the fabricated device got shifted by 7.7 nm towards shorter wavelengths. Normalized data shows a very good overlap between designed and obtained filter response when it comes to both channels distribution and the 3-dB bandwidths (BW). The passbands are slightly less flat as expected at the 1 dB bandwidth (1.6 nm) while as designed for 3-dB BW. Dependencies presented for TE results are valid also for the TM response. The measured offset between TE and TM central wavelength is about 1.2 nm compared to the expected value of 1.1 nm. Measured cross-talk is about 20 dB and typical for HHI platform.



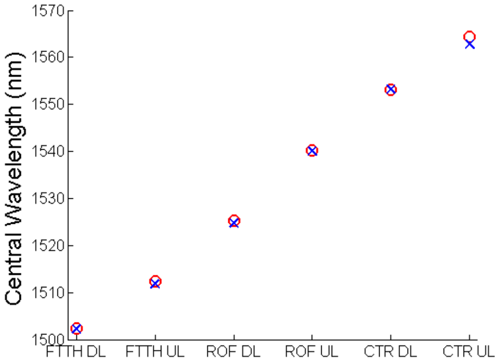
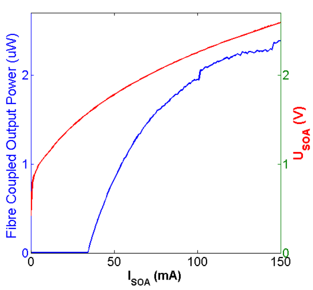
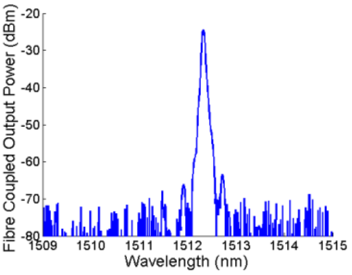


Fig.3a. Measured (solid line) versus simulated (dashed line) spectral responses of the AWG for TE polarization. The maximum power per channel was calibrated to match the peak values obtained from the simulations. **Fig.3b**. Measured vs simulated central wavelengths of each channel for TE polarization.

3.2 Tuneable Transmitters

The chip contains three transmitters: a Distributed Feedback (DFB) laser in the CTR UL sub-circuit and two tuneable Distributed Bragg Reflector (DBR) lasers inside FTTH UL and RoF UL transmitters. The lasers were designed for the central wavelengths of 1570 nm, 1522 nm and 1549 nm, respectively. The voltage across the gain sections, fiber coupled output power against the injected current characteristics and wavelength tuning curves for FTTH and CTR lasers are presented in Figure 4.





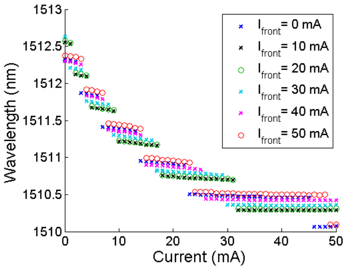
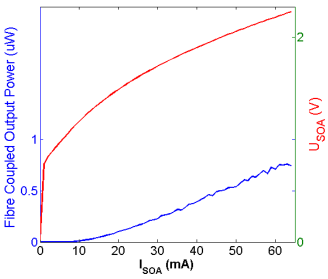
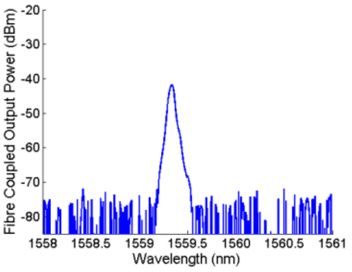


Fig.4a. FTTH UL laser: Optical power and gain section voltage against injected current characteristics. **Fig.4b.** Emission characteristics for gain section bias = 150 mA and booster bias = 40 mA, Full Width at Half Maximum (FWHM) = 0.05 nm. **Fig.4c.** Wavelength tuning with front and rear grating bias.





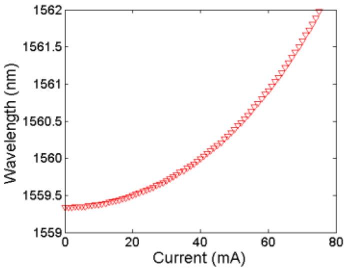


Fig.4d. CTR UL laser: Optical power and gain section voltage against injected current characteristics. **Fig.4e.** Emission characteristics for gain section bias = 18 mA and heater bias = 0 mA, FWHM = 0.05 nm. **Fig.4f.** Wavelength tuning with heater bias.

Measured threshold current is about 35 mA for the FTTH and about 8 mA for the CTR laser, which matches the values specified by the HHI foundry. However, due to the earlier mentioned issues all lasers exhibit a blue shift of the central wavelength of about 10 nm with respect to the specified values. This offset in central wavelength matches well the AWG response shift and allows operability of all transmitters. The unwanted drawback of gratings imperfections is the multi-mode behaviour of the DFB laser. Moreover, because of the high transition losses the output power of all lasers is 30 dB lower than expected. The side mode suppression ratio (SMSR) of the FTTH laser varies with the gain section bias from 25 to 45 dB. From Fig.4c it can be observed that the maximum possible blue shift of the central wavelength, obtained by biasing front and rear gratings, is 2.57 nm. The free spectral range (FSR) is equal 0.4 nm and corresponds well to the cavity length of 770 um. Observed multi-mode behaviour stems from the processing difficulties during the MPW run reported by the foundry. The side mode suppression ratio (SMSR) of the CTR laser varies with the gain section bias from 10 to 33 dB. From Fig.4f it can be observed that the maximum possible red shift of the central wavelength, obtained by biasing the built-in heater, is 2.75 nm. The FSR equals 4 nm which corresponds to the cavity length of 82 um.

3.3 Tuneable Receivers

A cascade of unbalanced Michelson and Mach Zehnder interferometers [3] was realized as a tuneable filter for FTTH DL receiver. The results so far show that it is possible to obtain the spectral response of 0.6 nm 3 - dB BW and the extinction ratio (ER) of 4.6 dB. The filter is more selective than required 3-dB BW of 1 nm, however the ER is lower than calculated by nearly 10 dB, which requires further investigation. Further test include as well the bandwidth tunability.

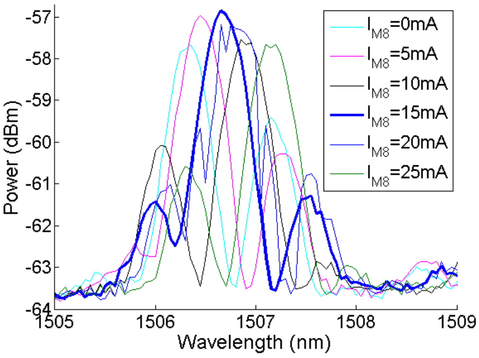


Fig.5. Change in filter response with Michelson's response shift

4 Summary and Acknowledgments

DC characterization results show that majority of the subsystems on fabricated RAU is operational. Therefore, the performance of the chip will be further investigated in terms of filters tunability and high speed modulation and reported in upcoming publications.

The research leading to these results has received funding from EU FP7-PEOPLE-2013-IAPP under grant agreement 612257 COMANDER and EU FP7/2007-2013 under grant agreement ICT 257210 PARADIGM.

References

[1] http://fp7-semafour.eu/media/cms_page_media/9/SEMAFOUR_2014_RAScluster%20White%20paper.pdf

[2] http://mc-comander.eu/

[3] K. Welikow, A. Sosa, R.Broeke, D. Tsiokos, N. Pleros, A. Bakker and T. Tekin "An integrated photonic Remote Access Unit for 60 GHz wireless connections," Proceedings of the 19th Annual Symposium of the IEEE Photonics Benelux Chapter, 91-94, 2014.