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Design and characterization of an integrated Remote Access Unit for wireless communication

K. Rylander*, S. Latkowski†, E. Bente†, R. Broeke‡, D. Tsiokos§, N. Pleros§, A. Sosa¶, T. Tekin¶ and A. Bakker*

*PhoeniX Software, Hengeloestraat 705, 7521 PA Enschede, Netherlands
Email: katrin.rylander@phoenixbv.com

†COBRA Research Institute, Eindhoven University of Technology, Den Dolech 2, 5612AZ Eindhoven, Netherlands

‡Bright Photonics, Burgemeester van den Helmlaan 67, 3604 CE Maarssen, Netherlands

§Center for Research and Technology Hellas, Aristotle University of Thessaloniki, P.O. Box 114, 54124 Thessaloniki, Greece

¶Research Center of Microperipheric Technologies, Technische Universität Berlin, Gustav-Meyer-Allee 25, 13355 Berlin, Germany

Abstract—We present the design and experimental evaluation 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. The Indium Phosphide chip was manufactured within Multi Project Wafer run and characterized in terms of DC and high speed transmission.

Keywords - Photonic Integrated Circuit, Multi Project Wafer Run, Fiber To The Home, Radio over Fiber

I. INTRODUCTION

Mobile data usage is projected to grow three times faster than IP traffic from fixed lines, while operators of wireless networks are already reaching the throughput limits of existing technologies [1]. One way to overcome this problem, as proposed by the COMANDER project [2] is to consider Passive Optical Network (PON) architectures, which provide broadband Fiber To The Home services, as an enabler for wireless systems [3]. The key component of a Next Generation Network (NGN) based on synergy of Fibre and Wireless, is a Remote Access Unit, see Fig. 1. Here we report on design and development of RAU and its performance.

II. CHIP DESIGN AND FABRICATION

Remote Access Unit was designed as a photonic integrated circuit (PIC) on an Indium Phosphide platform following the generic integration concept [4]. The advantage of a PIC compared to bulk optics is more compact and mechanically stable devices. Miniaturization also leads to a lower power consumption, making the final products more energy efficient. Moreover, high level of integration and shorter interconnects increase the reliability of the devices. The use of a Multi Project Wafer (MPW) runs simplifies the prototyping stages and allows low-cost access to the technology, as fabrication and design kit costs are shared between users.

The layout of RAU has been designed in OptoDesigner5, using foundry provided Photonic Design Kit (PDK) and an AWG IP Block. The chip was fabricated by Oclaro (main foundry) and HHI (back-up) in MPW runs accessed via PARADIGM project [5]. Since porting designs between foundries is supported by the software tools [6] it took 3 designers only 1 month to successfully complete 2 foundry specific layouts of the RAU chip. Using back-up foundry was beneficial as due to the difference in foundry schedules HHI delivered chips much earlier than Oclaro. Therefore work reported here concerns only HHI chip design and characterization.

Designed RAU utilizes a Coarse Wavelength Division Multiplexing (CWDM) multi/de-multiplexer (DEMUX) to provide six discrete spectral passbands, as presented on Fig. 2. In full

![Fig. 1: COMANDER Network in GPON.](image-url)

![Fig. 2: Schematic diagram of the RAU. CTR = Control signals, TF = Tuneable Filter, PD = Photo Diode, MOD = Modulator, TL = Tuneable Laser.](image-url)
operation all signals are processed simultaneously by specifically designed sub-circuits. Therefore, in order for the RAU to be operational, the central wavelengths of transmitters and receivers have to match the Arrayed Waveguide Grating (AWG) channels. Fig. 3 shows the mask layout submitted to the foundry along with the picture of the fabricated chip.

HHI foundry who delivered the chip reported some process issues, concerning the definition of Bragg gratings and increased losses at the transition point between active and passive regions. These were taken into account and allowed to explain measured response of the transmitters on the chip.

III. EXPERIMENTAL SETUPS

The chip was mounted on an aluminum sub-carrier and electrical contacts were wire-bonded to DC tracks on a printed circuit board providing with several feed lines. Since all RF (Radio Frequency) contacts were accessible on one side of the chip, a Ground-Signal-Ground RF probe was used for biasing. The chip temperature was stabilized at about 19°C by water cooling of the metal sub-carrier in case of DC and by Peltier element for high speed measurements. A fiber array unit of single mode fibers was used to couple the signals into and from the chip. Fig. 4 show the schematics of experimental setups used.

IV. RESULTS

A. Multiplexer/Demultiplexer

CWDM DEMUX was realized as an Arrayed Waveguide Grating with a central wavelength of 1540 nm, a free spectral range of 100 nm, flattened passbands and a non-constant channel spacing [7]. The spectral response of the AWG was measured for TE and TM polarizations and compared with the simulation data, as presented on Fig. 5. Results were normalized in order to match the peak values obtained from the simulations.
to eliminate the influence of different coupling conditions between the channels as well as to compensate for a central wavelength shift. After calibration, the noise levels of all measured passbands reached the same value, which supports the validity of our calibration method. The central wavelength offset reported in the previous MPW runs was +7.2 nm, therefore the central wavelength of AWG was calibrated by this value during the design stage. However, in this run the offset was of about -0.5 nm, leading to a 7.7 nm blue shift in central wavelength of the fabricated AWG. Normalized data show a satisfactory overlap between designed and obtained filter response when it comes to channels distribution and the 3-dB bandwidths (BW). Measured cross-talk is about 20 dB and typical for HHI platform, while measured offset between central wavelengths for TE and TM response is equal 1.2 nm.

B. Tuneable Transmitters: DC response

The chip contains three transmitters: two tuneable Distributed Bragg Reflector (DBR) lasers inside FTTH UL and RoF UL transmitters and a Distributed Feedback (DFB) laser in the CTR UL sub-circuit. The lasers were designed for central wavelengths of 1522 nm, 1549 nm and 1570 nm, respectively. Voltage measured across the gain sections and fiber coupled output power against the injected current characteristics along with wavelength tuning curves for FTTH and CTR lasers are presented in Fig. 6.

Measured threshold current is about 35 mA for the FTTH and about 8 mA for the CTR laser, which matches HHI specification. However, all lasers exhibit a blue shift in the central wavelength of nearly 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 drawback of gratings imperfections is the multi-mode behaviour of the DFB laser. Moreover, high transition losses result in lower than expected output power of all lasers. The side mode suppression ratio (SMSR) of the FTTH laser varies with the gain section bias from 25 to 45 dB. From Fig. 6c 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. The side mode suppression ratio (SMSR) of the CTR laser varies with the gain section bias from 10 to 33 dB. From Fig. 6f 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.
C. Tuneable Transmitters: RF response

High speed response was investigated for RoF UL and CTR UL lasers. Due to their low output power it was necessary to use an external amplifier - EDFA (see Fig. 4b). The central wavelength of FTTH UL transmitter lies outside the operating wavelength range of available EDFAs therefore it was not possible to characterize its high speed performance.

In the first stage a power-current-voltage test was performed for both transmitters to estimate their on/off optical extinction ratio (ER) and operating point. CTR UL laser was directly modulated while for RoF UL a short SOA (Semiconductor Optical Amplifier) switch in front of the DBR laser was used instead. As presented in Fig. 7a, 7b ER for the RoF UL transmitter equals 6 dB and 20 dB for the CTR UL. As a next step the spectral responses for ‘on’ and ‘off’ states were compared for each transmitter. Results indicate that the central wavelength increases and SMSR decreases in ‘on’ state as the side modes gain more power. In order to suppress these effects, an AWG was added behind EDFA to filter out the unwanted longitudinal modes. The BER was measured by transmitting a known pseudo-random binary sequence and comparing it with the received signal. The optical power before the receiver was varied with optical attenuator and corresponding BER was recorded. In these measurements, the decision threshold was optimized for each transmitter speed [8]. All measurements were performed in back-to-back configuration, formed by connecting a transmitter directly to a receiver. Eye diagrams obtained for RoF UL exhibit high noise level (Fig. 7c) originating mainly from SOA intrinsic noise. Another noise source can stem from the lack of impedance matched RF connector and using a DC wire instead. Presence of multiple levels that correspond to logic one significantly limits modulation speed to about 1 GHz. BER curve obtained for 1 GHz shows the noise floor of $10^{-5}$.

CTR UL transmitter, which was biased with a Ground-Signal-Ground RF probe connected to an impedance matched metal track exhibits much better high speed performance and offers modulation speeds up to 5 GHz.

D. Tuneable Receivers

Tuneable filters for FTTH DL and RoF DL receivers were designed as a cascade of an unbalanced Michelson and a...
Mach-Zehnder interferometers. It is worth noting that bragg gratings were added into both arms of the Michelson interferometer as a reflective element [9]. Obtained results show that it is possible to obtain a spectral response of 0.6 nm 3-dB BW and the extinction ratio of 4.6 dB. The filter is more selective than required 3-dB BW of 1 nm, however the extinction ratio is lower than calculated by nearly 5 dB. Fig. 8 shows measurement data obtained for different phase shifts, introduced by Michelson Interferometer with FSR of 1 nm, and overlaid with the simulation results. High noise level of the measured data, originating from high coupling losses and AWG insertion losses does not allow to make a more precise comparison.

CONCLUSIONS

DC characterization results show that majority of the sub-systems on fabricated RAU is operational. RF characterization results indicate that using a SOA section in front of a DBR laser for on-off keying cannot provide modulation speeds higher than 1 GHz. On the contrary, DFB lasers on HHI platform have a potential to provide modulation speeds of several GHz, which is sufficient for the COMANDER network. Finally, the new concept of a tunable filter based on a cascade of Michelson and MZI interferometers was proved to work.

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REFERENCES