InP-based Monolithic Integrated Colorless Reflective Transceiver

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A colorless monolithic integrated transceiver based on InP is presented. This transceiver consists of a wavelength duplexer, a reflective SOA (RSOA), and a short photodetector, suitable for the application at the user side to download and upload information carried by two different wavelengths spaced 200 GHz near 1.55 μm. The reflective SOA is 750 μm long, offers 5 dB fiber-to-fiber gain, and 1 Gbit/s dynamic operation at different wavelengths after wire bonding. The integrated 60 μm long photodetector shows 0.25 A/W external responsivity and up to 14 GHz 3 dB bandwidth after wire bonding.

Introduction

With the ever-increasing demands on the data rate at the user side to exchange information, fiber-to-the-home (FTTH) has been shown to be one of the most promising solutions. Currently the maximum widely available bitrate of installed optical network units (ONU) at the user side is 156 Mbit/s for upstream data carried by 1310 nm Fabry-Pérot laser, and 656 Mbit/s downstream data carried by 1550 nm in a TDM-BPON system in Japan [1]. This system uses wavelength-specific optical transceivers which will finally hinder the large-scale deployment of FTTH system due to cost and difficulty in maintenance. A colorless transceiver may be a more cost-effective and flexible alternative. A number of groups have demonstrated colorless upstream operation up to 1 Gbit/s with different methods, such as self-seeding, injection locking, spectral seeding or laser injected reflective SOA [2, 3, 4, 5]. However, most demonstrations were realized with discrete commercial components, which are costly and not practical in the user access network.

In this paper, a monolithic integrated colorless transceiver based on butt-joint active-passive regrowth on InP is presented, and it is one of the key devices developed for Broadband Photonics Architecture [6]. It consists of a wavelength duplexer, a reflective SOA, and a photodetector, Fig. 1. The device works as follows. Two wavelengths (λ_1 and λ_2) come from the network into the transceiver from the left side. They are spatially separated by the wavelength duplexer and guided to the photodetector (λ_1) and to the reflective SOA modulator (λ_2). The downstream data, carried by λ_1, is detected by the photodetector, while λ_2 is a continuous wave (CW) light and is guided to the RSOA where it is modulated, amplified and reflected back to the network.

The wavelength duplexer is a Mach-Zehnder (MZ) interferometer, composed of a 1×2 and a 2×2 3-dB MMI splitter/combiner, connected by two waveguides with different lengths. Due to the large 3-dB optical gain bandwidth of the SOA, it can be operated in a large wavelength range for a colorless operation by modulating the electrical current. A high reflectivity coating (HR) is applied at the SOA side of the chip, causing the light

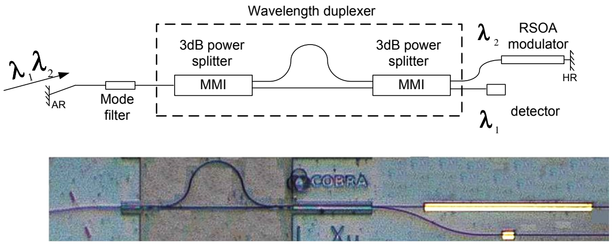

Figure 1: (Up) The layout of the integrated transceiver consisting of a wavelength duplexer, a reflective SOA modulator and a detector. (Below) The fabricated transceiver used for characterization.

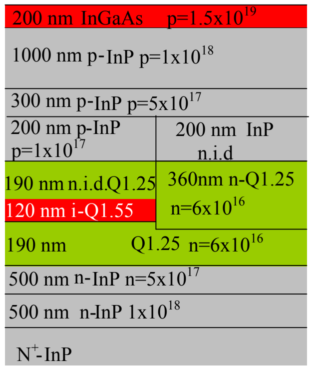

Figure 2: Active-passive butt-joint layerstack with specifications based on N-InP substrate.The unit for the doping level is cm^{-3}.

to be reflected back. The SOA is shallowly etched, 2 μm wide and 750 μm long. The photodetector is shallowly etched, 2 μm wide and 60 μm long. To avoid lasing and to reduce the coupling loss, the facet of the chip where the light is coupled into and out of the device, is provided with an anti-reflection coating (AR). To further reduce any residual reflections, the input waveguide is placed at an angle of 7° toward the chip facet [7], and a mode filter is inserted to suppress propagation of the first-order mode.

Fabrication

The device was fabricated in material grown on an N-type InP substrate by three-step low pressure metal-organic-vapor-phase epitaxy (MOVPE). The first epitaxy finished with a 120 nm thick SOA active InGaAsP layer (Q1.55, $\lambda_{gap} = 1.55\,\mu$m), embedded between two quaternary confinement layers (Q1.25) with different doping levels, covered by a 200 nm thick p-InP layer. Next, the active sections were defined by lithography and reactive ion etching (RIE) using a SiN_x layer as etching mask. In the second epitaxy step, a Q1.25 InGaAsP layer was selectively grown for the passive sections with the SiN_x mask protecting the active sections[8]. In the third epitaxy step, the p-doped InP cladding layers with graded doping level and the p-InGaAs contact layer were grown with a total thickness of 1300 nm, Fig. 2. All the waveguides were fabricated by reactive ion etching (RIE). Polyimide was spun for passivation and planarization. By etching back the polyimide, the p-InGaAs contact layer was exposed and Ti/Pt/Au metal layers were evaporated to form the electrodes on the top and the ground (n-InP) at the backside. To improve the conductivity, the device was annealed at 325°C for 30 seconds, and electro-plated with gold. The HR coated facet has about 90% reflectivity, and AR coated facet has about 0.1% reflectivity. The device was glued and wire bonded on a AlN RF submount with coplanar waveguide design, Fig. 3, to enable measurements with a GSG RF probe. The measured 3-dB bandwidth for such a RF submount is more than 20 GHz. The bonded wire has 20 μm radius, and is approximately 2 mm long. During the characterization, the chip was stabilized on a copper chuck and cooled by a Peltier element.

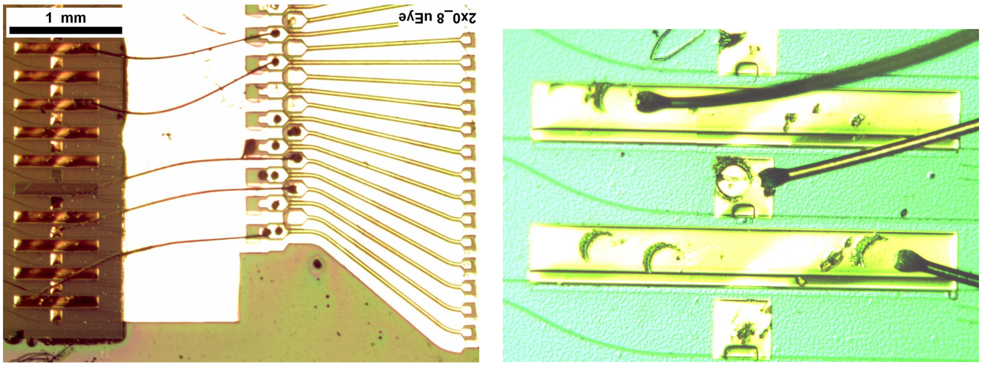

Figure 3: Bonded chip on a AlN RF submount (left) and bonded RSOA and the photodetector (right).

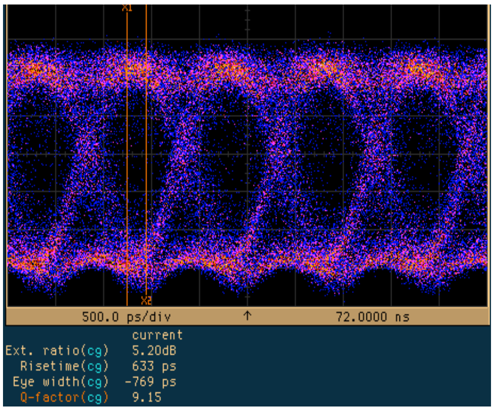

Figure 4: 1 Gbit/s eye diagram at $\lambda = 1541.9$ nm with input optical power $P_{in} = -11$ dBm, 80 mA injection current and 0.78 V modulation depth.

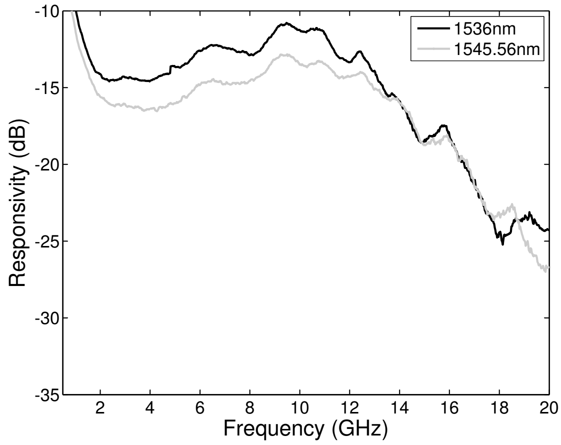

Figure 5: The measured frequency response of the wire bonded photodetector at -6 V when $P_{in} = -20$ dBm.

Characterisation

The reflective SOA is operated by modulating the electrical current. Because of residual reflections, the RSOA of the bonded device starts to lase at an injection current of 110 mA. The device gain peak is near 1530 nm, and the RSOA achieved about 5 dB fiber-to-fiber gain when injecting 100 mA. This fiber-to-fiber gain can be increased by reducing the fiber-chip coupling loss, which in our case is around 2×5 dB. To measure the bitrate of the SOA, we use a pulse pattern generator to produce 1 GHz PRBS code with $2^{31} - 1$ word length. The bias current was set at 80 mA, the modulation amplitude is 0.78 V over 50 Ω impedance. The input optical power is -11 dBm, and the recorded eye-diagram is presented in Fig. 4, showing a quality factor of 9, and an extinction ratio of 5.2 dB. The measurement has been done on four different upstream wavelengths from 1532.3 nm to 1541.9 nm, and the results are similar.

The photodetector was characterized by performing on-wafer S-parameter measurements in the range of 130 MHz to 20 GHz with a lightwave component analyzer HP8703A and a 50 GHz RF-probe. The photodetector was biased at -6 V through a 65 GHz bias tee, and the injected wavelengths are 1536 nm and 1545.56 nm with −20 dBm optical power before fiber chip coupling. The measured small signal frequency response is given in Fig. 5. The measured 3 dB frequency response is 14 GHz for a 60 μm long wire bonded photodetector, and the external responsivity shown in Fig. 5 includes the extra loss from the polarization controller and two fiber connectors. The measured static photoresponsivity is up to 0.25 A/W over a large wavelength range, which corresponds to about 64% on chip quantum efficiency (including the loss of the wavelength duplexer) when the chip fiber coupling loss is taken as −5 dB.

Conclusion

We presented a monolithic integrated transceiver that operates up to 1 Gbit/s for upstream data (modulated RSOA) and around 14 Gbit/s for downstream data (reversely biased photodetector). The reflective SOA offers up to 5 dB fiber-to-fiber gain for 100 mA bias current at 1532.3 nm, which is mostly limited by the fiber-chip coupling efficiency. The bonded photodetector has a high external responsivity up to 0.25 A/W within large wavelength range.

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